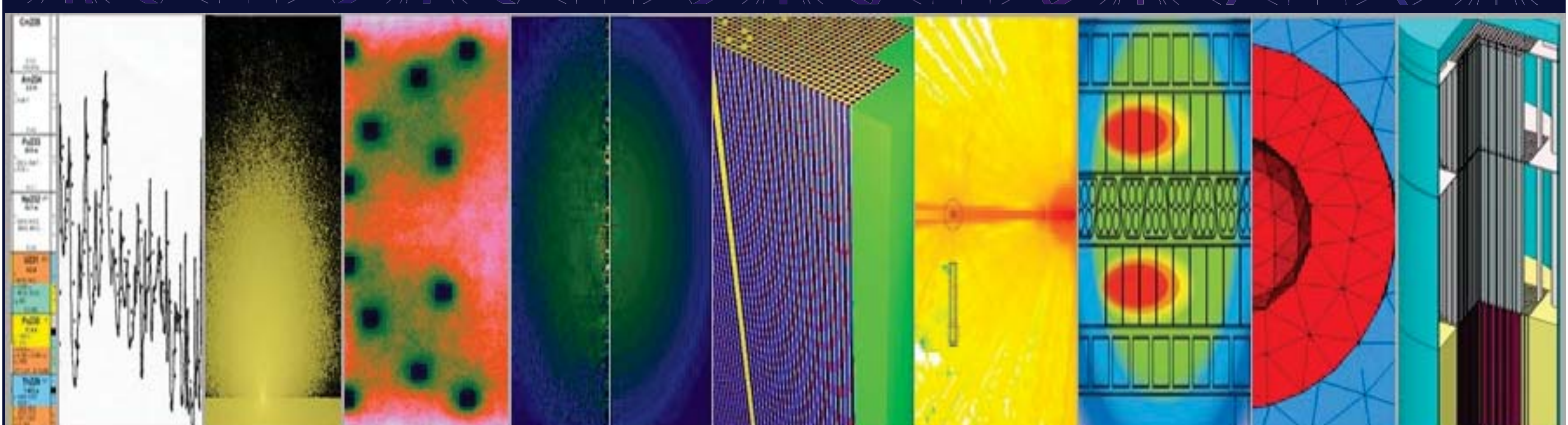
LA-UR-17-29981

MCNP®



User's Manual
Code Version 6.2

MCNP® USER'S MANUAL

Code Version 6.2

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Edited by: Christopher J Werner[1]

Contributors:

Jerawan Armstrong[1]
Forrest B. Brown[1]
Jeffrey S. Bull[1]
Laura Casswell[1]
Lawrence J. Cox[1]
David Dixon[1]
R. Arthur Forster[1]
John T. Goorley[1]
H. Grady Hughes[1]
Jeffrey Favorite[1]
Roger Martz[1]
Stepan G. Mashnik[1]
Michael E. Rising[1]
Clell(CJ) Solomon[1]
Avneet Sood[1]
Jeremy E. Sweezy[1]
Christopher J.Werner[1]
Anthony Zukaitis[1]
Casey Anderson[2]
Jay S. Elson[2]
Joe W. Durkee[2]
Russell C. Johns[2]
Gregg W. McKinney[2]
Garrett E. McMath[2]
John S. Hendricks[3]
Denise B. Pelowitz[3]
Richard E. Prael[4]
Thomas E. Booth[4]
Michael R. James[5]
Michael L. Fensin[6]
Trevor A. Wilcox[7]
Brian C. Kiedrowski[8]

[1] XCP-3 Monte Carlo Methods, Codes, and Applications, Los Alamos National Laboratory
[2] NEN-5 Systems Design and Analysis, Los Alamos National Laboratory
[3] NEN-5 Systems Design and Analysis, Los Alamos National Laboratory, Guest Scientist
[4] XCP-3 Monte Carlo Methods, Codes, and Applications, Los Alamos National Laboratory, contractor
[5] C-NR Nuclear & Radiochemistry, Los Alamos National Laboratory
[6] W-13 Advanced Engineering Analysis, Los Alamos National Laboratory
[7] XTD –SS Safety & Surety, Los Alamos National Laboratory
[8] XCP-3 Monte Carlo Methods, Codes, and Applications, Los Alamos National Laboratory, Guest Scientist

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1 MCNP INTRODUCTION AND PRIMER

1.1 INTRODUCTION

MCNP® is a general-purpose, continuous-energy, generalized-geometry, time-dependent, Monte Carlo radiation-transport code designed to track many particle types over broad ranges of energies. This MCNP Version 6.2 is a follow-on to the MCNP6.1.1 beta production version and has been released in order to provide the radiation transport community with the latest feature developments and bug fixes in the code.

MCNP6.2 has taken input from a group of people, residing in the Los Alamos National Laboratory's (LANL) X Computational Physics Division, Monte Carlo Methods, Codes, and Applications Group (XCP-3), and Nuclear Engineering and Nonproliferation Division, Systems Design and Analysis Group (NEN-5). This release of MCNP (v. 6.2) contains 31 new features. These new features are listed below.

1.1.1 New MCNP6.2 Features and Capabilities

Below is a listing of major MCNP6 features that have been implemented since the release of version 6.1.1 beta. For more information on each feature or enhancement, please refer to the appropriate manual section or the references provided with the distribution.

Physics:

- Improved correlated prompt secondary particle production (CGM)
- Exact line emission treatment for delayed gamma production
- Decay emission treatment
- Charged particle delta-ray production
- Correlated prompt fission neutron and gamma-ray emission models (CGMF & FREYA)

Sources:

- New ACT card keywords for user control of spontaneous decay sources
- Addition of spontaneous positrons decay sources
- Improved cosmic-ray source:
    - Inclusion of heavy ions
    - Updated solar modulation data
- Improved background source:
    - Updated cosmic and terrestrial background data file
    - Automatic elevation and data scaling

Data:

- Revised nuclear data for hydrogen
- SiO_2 $S(\alpha,\beta)$ thermal scattering data updated
- Zr-Hydride $S(a,\beta)$ thermal scattering data updated at 1200K
- New electron-photon relaxation library(EPRDATA14) added
- Improved decay library data file, increasing radionuclides from 979 to 3475

Tallies:

- Built-in physics-based neutron and photon response functions (FT PHL and DF cards)
- Improved first-fission special tally option
- Improved collision based cell-flag tally option
- Surface flux tally improvements

Unstructured Mesh:

- Improved tracking of all charged particles on unstructured mesh.
- Selection of overlap model by part.
- Ability to specify flux multipliers on the UM edits.
- Ability to handle multiple UM's in separate mesh universes.

Code Enhancements:

- Filenames used by MCNP may now be up to 256 characters in length
- Permit line lengths up to 128 chars in MCNP input files and xsdir files
- Extend command line length to permit up to 4096 characters
- Creation of installation log file recording each step in the installation
- Ability to run analytic criticality benchmarks using continuous energy physics treatment
- Remove limit on boundary-list entries for cell descriptions
- The number of point detectors allowed increased from 100 to 1000

1.1.2 MCNP6 Versatility

Application areas for the code among the thousands of MCNP users worldwide are quite broad and constantly developing. Examples include the following:

- Reactor design
- Nuclear criticality safety
- Nuclear safeguards
- Medical physics, especially proton and neutron therapy
- Design of accelerator spallation targets, particularly for neutron scattering facilities
- Investigations for accelerator isotope production and destruction programs, including the transmutation of nuclear waste
- Research into accelerator-driven energy sources
- Accelerator based imaging technology such as neutron and proton radiography

- Detection technology using charged particles via active interrogation
- Design of shielding in accelerator facilities
- Activation of accelerator components and surrounding groundwater and air
- High-energy dosimetry and neutron detection
- Investigations of cosmic-ray radiation backgrounds and shielding for high altitude aircraft and spacecraft
- Single-event upset in semiconductors from cosmic rays in spacecraft or from the neutron component on the earth's surface
- Analysis of cosmo-chemistry experiments, such as Mars Odyssey
- Charged-particle propulsion concepts for spaceflight
- Investigation of fully coupled neutron and charged-particle transport for lower-energy applications
- Transmutation, activation, and burnup in reactor and other systems
- Nuclear material detection
- Design of neutrino experiments

1.1.3 User's Manual Organization

MCNP6 documentation includes two primary volumes: the MCNP5 Theory Manual (Volume 1)[X-503a] and the MCNP6 User's Manual (Volume 2). Volume 1 contains an overview of the Monte Carlo method; a history of MCNP development; a discussion of program flow; details regarding the cross-section data, interaction physics, tally methodology, precision methods, variance-reduction techniques, and criticality computations that are available in MCNP6 (see the "Users Manual" section at `http://mcnp.lanl.gov`). The document you are reading is Volume 2, the comprehensive MCNP6 User's Manual for MCNP6. This volume includes installation instructions, input card descriptions, geometry specifications, and tally plotting details.

There are certain limitations in code usage that the user must be made aware of. These items are listed in Section 1.5.5. Section 1 presents an overview of MCNP6 and provides a basic primer for new users. A general description of the MCNP6 input structure can be found in Chapter 2, while Chapter 3 provides detailed descriptions of each of the available input parameters. Numerous examples, both simple and complex, are presented in Chapter 4. Chapter 5 contains basic geometry, cross-section, and tally plotting instructions. Several appendices provide greater detail regarding various code aspects. For example, Appendix A discusses code installation and includes general notes on software management. Appendix B contains a summary of all MCNP6 options. Supplemental information for the user can be found in Appendices C through F.

In addition to this manual, classes on MCNP6 are also held on a regular basis (see `http://mcnp.lanl.gov`)

1.2 MCNP6 PRIMER: GETTING STARTED

The user sets up simulations in MCNP6 by creating a text file that is read by MCNP6. This file contains information about the problem such as:

- the geometry specification,
- the description of problem materials and selection of cross-section evaluations,
- the location and characteristics of the particle source,
- the type of answers or tallies desired, and
- any variance reduction techniques used to improve efficiency.

Each area will be discussed in the primer by use of a sample problem. Remember the five "rules" listed below when running a Monte Carlo calculation. These rules will become more meaningful as you read this manual and gain experience with MCNP6, but no matter how sophisticated a user you may become, never forget the following five points:

1. Define and sample the geometry and source well.
2. You cannot recover lost information.
3. Question the convergence of the results.
4. Be conservative and cautious with variance reduction biasing.
5. The number of histories run is not indicative of the quality of the answer.

1.3 MCNP6 INPUT FOR SAMPLE PROBLEM

The main input file for the user is the INP (the default name) file that contains the information to describe the problem. We present here only the subset of cards required to run the simple fixed source demonstration problem. All input cards are discussed in Section 3 and summarized in Table 3-150.

The basic constants used in MCNP6 are printed in an optional `print table 98` in the output file. The MCNP6 units used in the sample problem that follows are length in centimeters (cm), energy in MeV, mass density in grams per cubic centimeter (g/cm^3), and atomic density in atoms/barn-cm. Additional standard MCNP6 units are provided in Section 2.

The simple sample problem is illustrated in Figure 1-1. A 0.5-cm-radius sphere of oxygen (Cell 1) and a 0.5-cm-radius sphere of iron (Cell 2) embedded in a carbon cube (Cell 3) with a side dimension of 10 cm. Cell 4 represents the “outside world”.The “outside world” is represented by Cell 4 and is referred to as such throughout the remainder of this section. We wish to start 14-MeV neutrons isotropically as a point source in the center of the small sphere of oxygen that is embedded in a cube of carbon. A small sphere of iron is also embedded in the carbon. The carbon is a cube 10 cm on each side; the spheres have a 0.5-cm radius and are centered between the front and back faces of the cube. We wish to calculate the total and energy-dependent flux in increments of 1 MeV from 1 to 14 MeV, where bin 1 will be the tally from 0 to 1 MeV

1. on the surface of the iron sphere, and
2. averaged in the iron sphere volume.

As depicted in Figure 1-1, this geometry has four cells and eight surfaces—six planes and two spheres. Circled numbers indicates cell numbers and surface numbers are written next to the appropriate surfaces. Surface 5 comes out from the page in the *+x* direction and surface 6 goes back into the page in the *–x* direction.

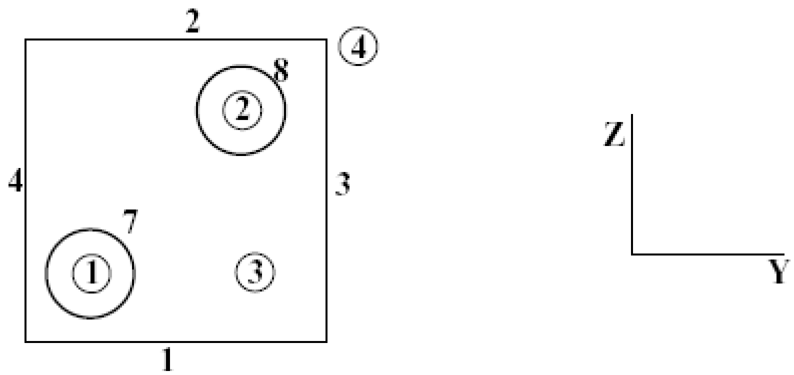


Figure 1-1. A 0.5-cm-radius sphere of oxygen (Cell 1) and a 0.5-cm-radius sphere of iron (Cell 2) embedded in a carbon cube (Cell 3) with a side dimension of 10 cm. Cell 4 represents the "outside world".

Assume we have knowledge of the cell-card format, the sense of a surface, and the union and intersection operators (see Section 1.3.2), then we can set up the cell cards for the geometry of our example problem. To simplify this step, assume the cells are void, for now. The following cards describe cells 1 and 2:

```
1  0   –7
2  0   –8
```

where the first entry on each of these cell cards is the cell number; the second entry is the material number, with "0" indicating a void; and the third number (in this case) provides cell surface information. In this sample problem, the negative signs denote the regions inside (negative sense) surfaces 7 and 8. Cell 3 is everything in the universe above surface 1 intersected with everything below surface 2, intersected with everything to the left of surface 3, and so forth for the remaining three surfaces. The region in common to all six surfaces is the cube, but we also need to exclude the two spheres by intersecting everything outside surface 7 and outside surface 8. By using a space to denote the intersection of two regions of space, the card entries required to describe cell 3 are

```
3  0   1 –2 –3 4 –5 6 7 8
```

Cell 4 requires the use of the union operator, which is denoted by a colon (:). Cell 4 is the outside world and is defined as everything in the universe below surface 1, plus everything above surface 2, plus everything to the right of surface 3, and so forth. The cell card for cell 4 is

```
4  0   −1 : 2 : 3 : −4 : 5 : −6
```

Cell 4, the outside world, would usually have zero importance (not denoted here). You will learn more about cell importance in Section 1.3.4.2.

1.3.1 INP File

An MCNP6 input file has the following form:

Message Block	Optional
Blank Line Delimiter	Optional
One Line Problem Title Card	
Cell Cards	
.	
.	
.	
Blank Line Delimiter	
Surface Cards	
.	
.	
.	
Blank Line Delimiter	
Data Cards	
.	
.	
.	
Blank Line Terminator	*Optional, but recommended*
Anything Else	*Optional*

All input lines are limited to 128 columns(note: for MCNP6.2 this has been increased from previous versions where the limit is 80). Alphabetic characters can be upper, lower, or mixed case. Unprintable characters found in an input line are converted to blank spaces. A $ (dollar sign) terminates data entry on a line. Anything on the line that follows the $ is interpreted as a comment. Blank lines are used as delimiters and as an optional input terminator. Data entries are separated by one or more blanks.

Tab characters in the input file are converted to one or more blanks, such that the character following the tab will be positioned at the next tab stop. Tab stops are set every eight characters, i.e., 9, 17, 25, etc. The limit of input lines to 128 columns applies after tabs are expanded into blank spaces.

Comment cards can be used anywhere in the INP file after the problem title card and before the optional blank terminator card. Comment lines must have a `C` somewhere in columns 1–5 followed by at least one blank and can be a total of 128 columns long.

Cell, surface, and data cards must all begin within the first five columns. Entries are separated by one or more blanks. Numbers can be integer or floating point. MCNP6 makes the appropriate conversion. A few entries on some cards are allowed to be 8-byte integers, i.e., integers larger than 2.147 billion but less than ~1E19. These entries are noted in their respective card description in Section 3. A data entry item, e.g., `IMP:N` or `1.1e2`, must be completed on one line.

Blanks filling the first five columns indicate a continuation of the data from the last named card. An & (ampersand) ending a line indicates data will continue on the following card, where data on the continuation card can be in columns 1–128.

The optional message block, discussed in detail in Section 2.4, is used to change file names and specify running options such as a continue-run. On most systems these options and files may alternatively be specified with an execution line (see Section 1.4.1). If both an execution line and a message block are present and there is a conflict, the execution line entries supersede the message block entries. The blank line delimiter signals the end of the message block.

The first card in the file after the optional message block is the required problem title card. If there is no message block, this must be the first card in the INP file. It is limited to one 128-column line and is used as a title in various places in the MCNP6 output. It can contain any information you desire but usually contains information describing the particular problem.

MCNP6 makes extensive checks of the input file for user errors. A fatal error occurs if a basic constraint of the input specification is violated, and MCNP6 will terminate before running any particles. The first fatal error is real; subsequent error messages may or may not be real because of the nature of the first fatal message.

1.3.2 Cell Cards

When populating the cell cards, the cell number is the first entry and must begin in the first five columns. The next entry is the cell material number, which is arbitrarily assigned by the user. The material is described on a material card (`M`) that has the same material number (see Section 1.3.4.5). If the cell is a void, a zero is entered for the material number. The cell and material numbers cannot exceed eight digits each. Following the material number is the cell material density. A positive entry is interpreted as atom density in units of 10^{24} atoms/cm^3. A negative entry is interpreted as mass density in units of g/cm^3. No density is entered for a void cell. After the material density, a complete specification of the geometry of the cell follows. This specification includes a list of the signed surfaces bounding the cell where the sign denotes the sense of the regions defined by the surfaces. The regions are combined with the Boolean intersection and union operators. A space indicates an intersection and a colon indicates a union.

Optionally, after the geometry description, cell parameters can be entered. The form is `KEYWORD=`*`value`*. The following line illustrates the cell card format:

```
1  1 –0.0014   –7  IMP:N=1
```

Cell 1 contains material 1 with density 0.0014 g/cm^3, is bounded only by one surface 7, and has a neutron importance of 1. If cell 1 were a void, the cell card would be

```
   1  0           –7  IMP:N=1
```

The complete cell input for this problem (with two comment cards) is

```
c cell cards for sample problem
 1  1 –0.0014   –7
 2  2 –7.86     –8
 3  3 –1.60      1 –2 –3 4 –5 6 7 8
 4  0           –1:2:3:–4:5:–6
c end of cell cards for sample problem
 blank line delimiter
```

The blank line at the end of the card terminates the cell-card section of the INP file. A complete explanation of the cell card input is found in Section 3.2.1.

1.3.3 Surface Cards

When populating surface cards the surface number is the first entry. The surface number must begin in columns 1–5 and not exceed eight digits. The surface number is followed by an alphabetic mnemonic entry that indicates the surface type. The surface type is then, in turn, followed by the numerical coefficients of the equation of the surface, in their proper order. This simplified description enables us to proceed with the sample problem. For a full description of the surface card see Section 3.2.2.

Our problem uses planes normal to the *x*-, *y*-, and *z*-axes and two general spheres. The respective mnemonics are PX, PY, PZ, and S. Table 1-1 shows the equations that determine the sense of the surface for the cell cards and the entries required for the surface cards. A complete list of available surface equations is contained in Table 3-4.

Table 1-1. Surface Equations for Sample Problem

Mnemonic	Equation	Card Entries
PX	$x - D = 0$	D
PY	$y - D = 0$	D
PZ	$z - D = 0$	D
S	$(x-\bar{x})^2 + (y-\bar{y})^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{x}\ \bar{y}\ \bar{z}\ R$

For the planes, D is the point where the plane intersects the axis. If we place the origin in the center of the 10-cm cube shown in Figure 1-1, the planes will be at x=-5, x=5, etc. The two spheres are not centered at the origin or on an axis, so we must give the x, y, z of their center as well as their radii, R. The complete surface card input for this problem is shown below. A blank line terminates the surface card portion of the input.

```
C Beginning of surfaces for cube
  1  PZ  −5
  2  PZ   5
  3  PY   5
  4  PY  −5
  5  PX   5
  6  PX  −5
C End of cube surfaces
  7  S    0  -4  -2.5  0.5  $ oxygen sphere
  8  S    0   4   4    0.5  $ iron sphere
  blank line delimiter
```

1.3.4 Data Cards

The remaining data input for MCNP6 follows the second blank card delimiter—or third blank card if there is a message block. The card name is the first entry and must begin in the first five columns. The required entries follow, separated by one or more blanks.

Several of the data cards require a particle designator to distinguish among input data for the numerous particle types supported by MCNP6. The particle designator consists of the symbol `:` (colon) and the alphabetic particle symbol (see Table 2-2) immediately following the name of the card. For example, to enter neutron importance, use an `IMP:N` card; enter photon importance on an `IMP:P` card; enter positive pion importance on an `IMP:/` card, etc. No data card can be used more than once with the same mnemonic, that is, `M1` and `M2` are acceptable, but two `M1` cards are not allowed. Defaults have been set for cards in some categories. A card summary presented in Table 3-150 shows which cards are required, which are optional, and whether defaults exist and if so, what they are. The sample problem will use cards in the following categories:

1. physics (`MODE`)
2. cell and surface parameters (`IMP:N`)
3. source specification (`SDEF`)
4. tally specification (`F`, `E`)
5. material specification (`M`)
6. problem termination (`NPS`)

A complete description of the data cards can be found in Section 3.3.

1.3.4.1 MODE CARD

The `MODE` card consists of the mnemonic `MODE` followed by a list of particles (separated by spaces) to be transported. If the `MODE` card is omitted, `MODE  N` is assumed (i.e., neutron transport only).

By default, MODE N P does not account for photo-neutrons, but does account for neutron-induced photons. Photonuclear particle production can be turned on through an option on the PHYS:P card (see Section 3.3.3.2.2). Photon production cross sections do not exist for all nuclides. If they are not available for a MODE N P problem, MCNP6 will print out warning messages.

MODE P or MODE N P problems generate bremsstrahlung photons with a thick-target bremsstrahlung approximation. This approximation can be turned off with the PHYS:E card.

The sample problem is a neutron-only problem, so the MODE card can be omitted because MODE N is the default.

1.3.4.2 CELL AND SURFACE PARAMETER CARDS

Data related to individual cells can be entered either on the cell card or in the data card section of the input file, data related to individual surfaces can only be entered using the data card format. If entered on a card in the data block section, entries must be listed in the same order as the associated cell (or surface) cards that appear earlier in the INP file. The number of entries on a cell or surface data card must equal the number of cells or surfaces in the problem, otherwise MCNP6 prints out a warning or fatal error message. In the case of a warning, MCNP6 allows the problem to continue, but assumes that the value of the parameter for each cell or surface is zero. Cell parameters also can be defined on cell cards using the KEYWORD=*value* format. If a cell parameter is specified on *any* cell card, it must be specified *only* on cell cards and *not at all* in the data card section.

The only surface parameter card is AREA. A listing of available cell parameter cards appears in Table 3-2. Examples include importance cards (IMP:N, IMP:P) and weight-window cards (WWE:N, WWE:P, WWN*i*:N, WWN*i*:P), etc. Each problem requires some method of specifying relative cell importance, most of the other cell parameters are used to specify optional variance reduction techniques.

The IMP:N card is used to specify relative cell importance in the sample problem. There are four cells in the sample problem, so the IMP:N card will have four entries. The IMP:N card is used a) for terminating the particle's history if the importance is zero and b) for geometry splitting and Russian roulette to help particles move more easily to important regions of the geometry. An IMP:N card for the sample problem is

```
IMP:N   1 1 1 0
```

1.3.4.3 SOURCE SPECIFICATION CARDS

A source definition card SDEF is one of four available methods of defining starting particles. Section 3.3.4 has a complete discussion of source specification. The SDEF card defines the basic source parameters, some of which are

POS= *x y z* Default = 0 0 0
CEL= *starting cell number*

ERG= *starting energy*	Default = 14 MeV
WGT= *starting weight*	Default = 1
TME= *time*	Default = 0
PAR= *source particle type*	Symbol or number of the source particle type (N or 1 for neutron, P or 2 for photon, etc.)

MCNP6 will determine the starting cell number for a point isotropic source, so the CEL entry is not always required. The default starting direction for source particles is isotropic.

For the example problem, a fully specified source card is

```
SDEF   POS=0 –4 –2.5  CEL=1  ERG=14  WGT=1  TME=0  PAR=N
```

Neutron particles will start at the center of the oxygen sphere (0 –4 –2.5), in cell 1, with an energy of 14 MeV, and with weight of 1 at time 0. All these source parameters except the starting position are the default values, so the most concise source card is

```
SDEF   POS=0 –4 –2.5
```

If all the default conditions applied to the problem, only the mnemonic SDEF would be required.

1.3.4.4 TALLY SPECIFICATION CARDS

The tally cards are used to specify what you want to learn from the Monte Carlo calculation, perhaps current across a surface, flux at a point, etc. You request this information with one or more tally cards. Tally specification cards are not required, but if none is supplied, no tallies will be printed when the problem is run and a warning message is issued. Many of the tally specification cards describe tally "bins." A few examples are energy (E), time (T), and cosine (C) bin cards.

MCNP6 provides seven different standard tally types, all normalized to be per starting particle. Some tallies in criticality calculations are normalized differently. Chapter 2 of the MCNP5 Theory Manual[X-503a] discusses tallies more completely, and Section 3.3.5 of this manual lists all the tally cards and fully describes each one.

Tally Mnemonic	Description
F1:<*pl*>	Surface current
F2:<*pl*>	Surface flux
F4:<*pl*>	Track length estimate of cell flux
F5*a*:N or F5*a*:P	Flux at a point (point detector)
F6:<*pl*>	Track length estimate of energy deposition
F7:N	Track length estimate of fission energy deposition
F8:<*pl*>	Energy distribution of pulses created in a detector

The tallies are identified by tally type and particle type. Tallies are given the numbers 1, 2, 4, 5, 6, 7, 8, or increments of 10 thereof, and are given the particle designator :N for neutron, :\ for pion, etc. You may have as many of any basic tally as you need, each with different energy bins or flagging or anything else. The tally designations `F4:N`, `F14:N`, `F104:N`, and `F234:N` are all legitimate neutron cell flux tallies; they could all be for the same cell(s) but with different energy or multiplier bins, for example. Similarly `F5:P`, `F15:P`, and `F305:P` are all photon point detector tallies. Having both an `F1:N` card and an `F1:P` card in the same INP file is not allowed. The tally number may not exceed 9999.

For our sample problem we will use `F` cards (tally type) and `E` cards (tally energy).

Tally (F*n*) Cards: The sample problem has a surface flux tally and a track length cell flux tally. Thus, the tally cards for the sample problem shown in Figure 1-1 are

```
F2:N   8   $ flux across surface 8
F4:N   2   $ track length in cell 2
```

Printed out with each tally result is the uncertainty of the tally corresponding to one estimated standard deviation. Results are not reliable until they become stable as a function of the number of histories run. Much information is provided for a specified bin of each tally in the tally fluctuation charts at the end of the output file to help determine tally stability. The user is strongly encouraged to look at this information carefully.

Tally Energy (E*n*) Cards: We wish to calculate flux in increments of 1 MeV from 1 to 14 MeV. Another tally specification card in the sample input deck establishes these energy bins.

The entries on the E*n* card are the upper bounds in MeV of the energy bins for tally *n*. The entries must be given in order of increasing magnitude. If a particle has an energy greater than the last entry, it will not be tallied, and a warning is issued. MCNP6 automatically provides the total over all specified energy bins unless inhibited by putting the symbol `NT` as the last entry on the selected E*n* card.

The following cards will create energy bins for the sample problem:

```
E2   1 2 3 4 5 6 7 8 9 10 11 12 13 14
E4   1 12I 14
```

If no E*n* card exists for tally *n*, a single bin over all energy will be used. To change this default, an `E0` (zero) card can be used to set up a default energy bin structure for all tallies. A specific E*n* card will override the default structure for tally *n*. We could replace the `E2` and `E4` cards with one `E0` card for the sample problem, thus setting up identical bins for both tallies.

1.3.4.5 MATERIALS SPECIFICATION

The cards in this section specify both the isotopic composition of the materials and the cross-section evaluations to be used in the cells. For a comprehensive discussion of materials specification, see Section 3.3.2.

Material (`M`*m*) Card: The following card is used to specify a material for all cells containing material *m*, where *m* cannot exceed five digits:

M*m* ZAID$_1$ *fraction*$_1$ ZAID$_2$ *fraction*$_2$ ...

The *m* on a material card corresponds to the material number on the cell card (see Section 1.3.2). The consecutive pairs of entries on the material card consist of the identification number (ZAID) of the constituent element or nuclide followed by the atomic fraction (or weight fraction if entered as a negative number) of that element or nuclide, until all the elements and nuclides needed to define the material have been listed.

(1) Nuclide Identification Number (ZAID). This number is used to identify the element or nuclide desired. The form of the number is `ZZZAAA.`*abx*, where

- `ZZZ` is the atomic number of the element or nuclide;
- `AAA` is the mass number of the nuclide, ignored for photons and electrons;
- *ab* is the cross-section evaluation identifier; and
- *x* is the class of data. Commonly used classes are: `C` is continuous energy neutron cross sections, `P` is photon, `E` is electron, `U` is photonuclear, and `H` is proton.

For naturally occurring elements, `AAA=000`. Thus ZAID=`74182` represents the isotope $^{182}_{74}W$, and ZAID=`74000` represents the element tungsten.

If *.abx* is omitted the first entry from the xsdir corresponding to the proper library class will be used. This same approach will be used for all libraries not specified. For example in a `mode N P` problem, if 1001.70c is specified the .70c library will be used for neutrons and the first photon library in the xsdir file will be used.

(2) Nuclide Fraction. The nuclide fractions may be normalized to 1 or left un-normalized. For example, if the material is H_2O, the fractions can be entered as 0.667 and 0.333, or as 2 and 1 for H and O, respectively. If the fractions are entered with negative signs, they are weight fractions; otherwise they are atomic fractions. Weight fractions and atomic fractions cannot be mixed on the same `M`*m* card.

Appropriate material cards for the sample problem are

```
M1     8016  1    $ oxygen 16
M2    26000  1    $ natural iron
M3     6000  1    $ carbon
```

`VOID` Card: The `VOID` card removes all materials and cross sections in a problem and sets all non-zero importance to unity. It is very effective for finding errors in the geometry description because many particles can be run in a short time. Flooding the geometry with many particles increases the chance of particles going to most parts of the geometry—in particular, to an incorrectly specified part of the geometry—and getting lost. The history of a lost particle often helps locate the geometry error. The other actions of and uses for the VOID card are discussed in Section 3.3.2.10.

The sample input deck could have a VOID card while testing the geometry for errors. When you are satisfied that the geometry is error-free, remove the VOID card.

1.3.4.6 PROBLEM TERMINATION

Problem termination cards are used to specify parameters for some of the ways to terminate execution of MCNP6. The full list of available cards and a complete discussion of problem cutoffs is found in Section 3.3.7.1. For our problem we will use only the history cutoff (NPS) card. The mnemonic NPS is followed by an entry (*npp*) that specifies the number of histories to transport. MCNP6 will terminate after *npp* histories unless it has terminated earlier for some other reason.

1.3.5 Sample Problem Input File

The entire input deck for the sample problem follows. Recall that the input can be upper case, lower case, or mixed case.

```
Sample Problem Input Deck
c    cell cards for sample problem
1    1 -0.0014   -7
2    2 -7.86     -8
3    3 -1.60      1 -2 -3 4 -5 6 7 8
4    0           -1:2:3:-4:5:-6
c    End of cell cards for sample problem
      [blank line delimiter (required)]
C    Beginning of surfaces for cube
1    PZ -5
2    PZ  5
3    PY  5
4    PY -5
5    PX  5
6    PX -5
C    End of cube surfaces
7    S   0 -4 -2.5   0.5   $ oxygen sphere
8    S   0  4  4.5   0.5   $ iron sphere
      [blank line delimiter (required)]
IMP:N   1 1 1 0
SDEF    POS=0 -4 -2.5
F2:N    8    $ flux across surface 8
F4:N    2    $ track length in cell 2
E0      1  12I  14
M1    8016 1    $ oxygen 16
M2   26000 1    $ natural iron
```

```
M3    6000 1    $ carbon
NPS   100000
      [blank line delimiter (optional)]
```

1.3.6 Running the Sample Problem

To run the example problem, place the input file in your current directory. Let's assume the file is called `SAMPLE`. Type

```
mcnp6 N=SAMPLE
```

where `N` is an abbreviation for the keyword `NAME`. MCNP6 will produce an output file `SAMPLEo` that you can examine at your terminal, send to a printer, or both. To look at the geometry with the PLOT module using an interactive graphics terminal, type

```
mcnp6 IP N=SAMPLE
```

After the plot window appears, click anywhere in the picture to get the default plot. This plot will show an intersection of the surfaces of the problem by the plane x=0 with an extent in the x direction of 100 cm on either side of the origin. If you want to do more with PLOT, see the instructions in Section 5. Otherwise click "`end`" to terminate the session.

MCNP6 does extensive input checking but is not foolproof. A geometry should be checked by looking at several different views with the geometry plotting option. You should also surround the entire geometry with a sphere and flood the geometry with particles from a source that has an inward cosine distribution on the spherical surface, using a `VOID` card to remove all materials specified in the problem. If there are any incorrectly specified places in your geometry, this procedure will usually find them. Make sure the importance of the cell just inside the source sphere is not zero. Then run a short job and study the output to see if you are calculating what you think you are calculating.

1.4 EXECUTING MCNP6

This section assumes a basic knowledge of UNIX. Lines the user will type are shown in `lower case typewriter style` type. Press the ENTER key after each input line. The file `mcnp6` is the executable binary file and the file `xsdir_mcnp6.2` contains the cross-section directory for MCNP6, Version 2. If `xsdir_mcnp6.2` is not in your current directory, you may need to set the DATAPATH environmental variable. The c-shell (csh) syntax for this is

```
setenv DATAPATH /ab/cd
```

and the bash syntax is

```
export DATAPATH=/ab/cd
```

where */ab/cd* is the directory containing both the file `xsdir_mcnp6.2` and the data libraries.

1.4.1 Execution Line

The MCNP6 execution line has the following form:

`mcnp6 KEYWORD=`*`value`*` ... KEYWORD=`*`value execution_option`*`(`*`s`*`)` *`other_options`*

where each `KEYWORD` is an MCNP6 default file name to which the user may assign a specific *`value`* (i.e., file name or path); *`execution_options`* is a character or string of characters that informs MCNP6 which of five execution module(s) to run; and *`other_option`*`(`*`s`*`)` provides the user with additional execution control. The execute line message may be up to 240 characters long. The order of the entries on the MCNP6 execution line is irrelevant. If no changes are desired to the default names and options, no entries to the MCNP6 execution line are necessary.

The execution-line keywords (i.e., default file names), execution options, and other options are summarized in Table 1-2. Let us examine each of these execution-line inputs.

a) `KEYWORD=`*`value`* (where `KEYWORD` is any of a list of default MCNP6 file names)

MCNP6 uses several files for input and output. The file names can include full paths to the files (e.g., `/mydir/problem-x/jobs/problem_1a.inp`), but the path cannot be longer than 256 characters. In the simplest case, in which the MCNP6 execution command has no arguments, a file named INP must be present in the local directory; then, during problem execution, MCNP6 will create two output files: OUTP and RUNTPE.

The default name of any of the files in Table 1-2 can be changed on the MCNP6 execution line by entering

`KEYWORD=`*`newname`*

For example, if you have an input file called MCIN and want the output file to be MCOUT and the restart file to be MCRUNTPE, the appropriate execution line would read

```
mcnp6 INP=MCIN OUTP=MCOUT RUNTPE=MCRUNTPE
```

Only enough letters of the default name are required to identify it uniquely. For example,

```
mcnp6 I=MCIN O=MCOUT RU=MCRUNTPE
```

also works. If a file in your local file space has the same name as a file MCNP6 needs to create, the file is created with a different unique name by changing the last letter of the name of the new file to the next letter in the alphabet. For example, if you already have a file named OUTP in the directory, MCNP6 will create OUTQ. However, if the file includes an extension, such as "`.txt`" or "`.inp`", the last character before the extension will be checked and changed if necessary.

Sometimes it is useful for all files from one run to have similar names. If your input file is called JOB1, the following line

```
mcnp6 NAME=JOB1
```

will create an OUTP file called JOB1O and a RUNTPE file called JOB1R. If these files already exist, MCNP6 will *not* overwrite them or modify the last letter, but will issue a message that JOB1O already exists and then will terminate.

b) *execution_option*

MCNP6 consists of six distinct execution modules: IMCN, PLOT, XACT, MCRUN, MCPLOT, and PARTISN_INPUT. A description of these modules, including a one-letter mnemonic assigned to each, appears in Table 1-2.

Given no other instructions, MCNP6 will process the input (`I`), process the cross-section data (`X`), and then perform the particle transport (`R`). Thus, the default execution input is `IXR`. Entering the proper mnemonic on the execution line controls the execution of the modules. If more than one operation is desired, combine the single characters (in any order) to form a string. To look for input errors only, specify `I`; to debug a geometry by plotting, use `IP`; to plot cross-section data, enter `IXZ`; to plot tally results from the RUNTPE or MCTAL files, specify `Z`; and to create a LNK3DNT geometry file for use in PARTISN, specify `M` on the execution line as the *execution_option*.

After a job has been run, the print file OUTP can be examined with an editor on the computer and/or sent to a printer. Numerous messages about the problem execution and statistical quality of the results are displayed at the terminal. These are repeated in the OUTP file.

c) *other_options*

The "other" options add more flexibility when running MCNP6 and also are shown in Table 1-2.

MCNP6 may be compiled for MPI and then executed in the same fashion as other parallel programs on a given system. The parallel operation is a master-slave algorithm with one master process accumulating total statistics and a group of slave processes tracking particles. When shared memory processors are used, MCNP6 may also be compiled for OpenMP threading, either independently or in combination with MPI.

Generally, the MPI execution line will look like this example from a Linux system, using OpenMPI:

```
MPIRUN -NP <m> MCNP.MPI I=input ...
```

where <*m*> is the total number of MPI processes, including the master, and <*m*>-1 slave processes will track the particles. On other systems, or other MPI implementations, the syntax of the MPI command may differ. Note that the minimum number of slaves accepted by MCNP6 is two, so at least three MPI processes must be initiated. That is, <*m*> can equal 1 or be greater than or equal to 3.

If MCNP6 is compiled with OpenMP on a multiprocessor SMP machine, then it is possible to optionally thread each slave by setting the `TASKS` option

```
MPIRUN -NP <m> MCNP.MPI I=input TASKS <n>
```

making (m-1)×n processors available to track particles. The syntax required to allocate enough resources for the threading varies by system.

An MCNP6 executable built with combined MPI and OpenMP options can be utilized as follows: sequentially, all MPI, threads only, or hybrid. To perform the combined executable in sequential or threads-only mode (for example, in early testing of a problem or for plotting geometry), the system will likely require `MPIRUN -NP 1`.

The simplest parallel run would be to build one shared memory node and run OpenMP threading. Then, use build option "`OMP`" and execute with just the `TASKS` option on the command line:

```
mcnp6 I=input TASKS <n>
```

Table 1-2. MCNP6 Execution Line Input

File Name Assignment	
Keyword† (Default File Name)	**Value‡**
INP	**User-supplied input file name. This is the name of the file that contains the problem input specification and must be present as a local file.**
OUTP	**File name to which results are written. This file may be viewed and/or printed. Created by MCNP6 during problem execution.**
RUNTPE	**Name of file containing binary start/restart data. Created by MCNP6 during initial problem execution and added to by MCNP6 during continued problem execution.**
XSDIR	**Name of cross-section directory (XSDIR) file. Note: The default name for the XSDIR file in MCNP6 (Version 2) is `xsdir_mcnp6.2`.**
WWINP	**Name of weight-window generator input file containing either cell- or mesh-based lower weight-window bounds.**
WWOUT	**Name of weight-window generator output file containing either cell- or mesh-based lower weight-window bounds.**
WWONE	**Name of weight-window generator output file containing cell- or mesh-based time- and/or energy-integrated weight windows.**
PARTINP	**PARTISN input file for MCNP6 to output.**
LINKIN	**Name of LNK3DNT file to input.**
LINKOUT	**Name of LNK3DNT-format geometry file created by MCNP6.**
KSENTAL	**Name of ASCII results file KCODE for sensitivity profiles.**
HISTP	**History tape file. See Section 3.3.7.2.6.**
DUMN1 and DUMN2	**See Section 3.3.7.3.6, File creation card.**

File Name Assignment	
`COM`	File from which plot commands will be read.
`COMOUT`	File to which all plot requests are written.
`PLOTM`	Name of graphics metafile.
`MCTAL`	Tally results file (ASCII).
`MESHTAL`	`FMESH` tally output file (ASCII).
`MDATA`	`TMESH` mesh tally data (unformatted binary).
`PTRAC`	Name of output file containing user-filtered particle events.
`NAME`	User-supplied input file name. Will automatically generate OUTP, RUNTPE, and MDATA files with the same name as the supplied input file name appended with by "`O`", "`R`", and "`D`" respectively. If the `NAME` option is used on the execute line, the WWOUT and WWONE file names end in `E` and `1`, respectively.
`SRCTP`	Name of file containing fission source data for a KCODE calculation.
`WSSA`	Name of file to which surface and volume source particles are recorded.
`RSSA`	Name of file from which surface and volume source particles are read.

† Requires only enough letters of the default name to identify it uniquely.
‡ File names are limited to a maximum of 256 characters. File names may also include directory paths.

Execution Options	
Option††	Description
`-v`	Print build info to screen, if used all other command line input is disregarded. Input file is not needed for this option.
`I`	Execute module IMCN to process the input file.
`P`	Execute module PLOT to plot geometry.
`X`	Execute module XACT to process the cross-section data.
`R`	Execute module MCRUN to perform the particle transport.
`Z`	Execute module MCPLOT to plot tally results or cross-section data.
`M`	Execute module PARTISN_INPUT to create LNK3DNT-format geometry file.

†† DEFAULT: `IXR`

Other Options	
Option	Description
`C [`*m*`]`	Continue a previous run starting with the *m*th dump. If *m* is omitted, the last dump is used.
`CN [`*m*`]`	Continue a run, starting with the *m*th dump and writing the dumps immediately after the fixed part of the RUNTPE, rather than at the end.
`DBUG` *n*	Write debug information every *n* particles. Note: An 8-byte integer is allowed.

File Name Assignment	
DEV-TEST	**Delete time-dependent quantities from files for SQA testing. (See 3rd entry on the PRDMP card.)**
NOTEK	**Indicates that your terminal has no graphics capability. PLOT output is in PLOTM.PS. Equivalent to TERM=0.**
FATAL	**Transport particles and calculate volumes even if fatal errors are found.**
PRINT	**Create the full output file; equivalent to PRINT card in the input file.**
TASKS *n*	**Invokes OpenMP threading on shared memory systems. The parameter *n* is the number of threads to be used. This keyword may be used in conjunction with MPI on a hybrid system.**
BALANCE	**Provides load balancing when used with MPI. (Note: When using multiprocessing with KCODE runs, the option for load balancing is not available.)**
EOL	**Add after all other MCNP6 keywords to distinguish MCNP6 keywords from directives added by MPICH. Only needed if the MPICH implementation of MPI is used.**

1.4.2 Interrupts

For non-MPI versions, MCNP6 allows four types of interactive interrupts while it is running:

<ctrl-c><cr> — MCNP6 status (Default if no entry is provided)

<ctrl-c>s — MCNP6 status

The <ctrl-c>s interrupt causes MCNP6 to print the computer time used so far, the number of particles run so far, and the number of collisions. If the code is processing in the IMCN module, it prints the input line being processed and if in the XACT module, it prints the cross section being processed.

<ctrl-c>m — Invoke MCPLOT to create interactive plots of tallies or to further invoke PLOT, to plot the geometry

<ctrl-c>q — Quit MCNP6 gracefully after current history

The <ctrl-c>q interrupt has no effect until MCRUN, the particle transport section of the code, is executed. After particle transport simulation has commenced <ctrl-c>q causes the code to stop after the current particle history, to terminate gracefully, and to produce final output and RUNTPE files.

<ctrl-c>k — Kill MCNP6 immediately

The <ctrl-c>k interrupt kills MCNP6 immediately, without normal termination. If <ctrl-c>k fails, enter <ctrl-c> three or more times in a row.

Batch jobs, run in sequential or multiprocessing mode, may be interrupted and stopped with the creation of a file in the directory where the job was started. The name of the file must be "`STOP`*`inp`*" where *`inp`* is the name of the original input file that initiated the run. On a computer system that is case sensitive (e.g., Linux), the "`stop`" must be in lower case and "*`INP`*" must match the case of the input file name. The contents of this file are meaningless. Once this file is created, MCNP6 will terminate the job during the next output rendezvous (see 5th entry on `PRDMP` card, Section 3.3.7.2.3) as if a `<ctrl-c>q` interrupt had been issued.

Caution: If one uses the `<ctrl-c>q` interrupt during a KCODE multiple-processor MPI run in Linux, MCNP6 does not finish writing the OUTP file before the code exits. This failure appears to be an MPI error in the `MPI_FINALIZE` call, where the last processor kills all subtasks and the master. Also, the `<ctrl-c>` interrupt does not function properly when using the MPI executable on Windows systems.

On some computer systems (e.g., SGI), MPI versions, even when run sequentially, do not allow the interactive interrupts because the MPI daemon catches the signal and aborts the MCNP6 run.

1.5 TIPS FOR CORRECT AND EFFICIENT PROBLEMS

Provided in this section are checklists of helpful hints that apply to three phases of your calculation: defining and setting up the problem, preparing for the long computer runs that you may require, and making the runs that will give you results. A fourth checklist is provided for KCODE calculations. The list can serve as a springboard for further reading in preparation for tackling more difficult problems.

1.5.1 Problem Setup

1. Draw a picture of your geometry to help you with geometry setup.
2. Always plot the geometry to see if it is defined correctly and that it is what was intended.
3. Model the geometry and source distribution in enough detail as needed for accurate particle tracking.
4. Use simple cells.
5. Use the simplest surfaces, including macrobodies.
6. Avoid excessive use of the complement operator, #.
7. Do not set up all the geometry at one time.
8. Put commonly used cards in a separate file and add them to your input file via the `READ` card.
9. Know and compare calculated mass, cell volumes, and surface areas.
10. Use the `VOID` card when checking the geometry.
11. Look at `print tables 10`, `110`, and `170` to check the source.
12. Check your source with a mesh tally.
13. Be aware of physics approximations, problem cutoffs, and default cross sections.
14. Cross-section sets matter! Check the listing of datasets in the output file.
15. Use separate tallies for the fluctuation chart.

16. Use the most conservative variance-reduction techniques.
17. Do not use too many variance-reduction techniques.
18. Balance user time with computer time.
19. Study all warning messages.
20. Generate the best output (consider the `PRINT` card).
21. Recheck the INP file (materials, densities, masses, sources, etc.).
22. Remember that garbage into MCNP6 equals garbage out of MCNP6.

1.5.2 Preproduction

1. Do *not* use MCNP6 as a black box. Become familiar with the theory and methods.
2. Run some short jobs.
3. Examine the outputs carefully.
4. Study the summary tables.
5. Study the statistical checks on tally quality and the sources of variance.
6. Compare the figures of merit and variance of the variance.
7. Consider the collisions per source particle.
8. Examine the track populations by cell.
9. Scan the mean-free-path column.
10. Check detector diagnostic tables.
11. Understand large tally contributions (with event logs).
12. Strive to reduce the number of unimportant tracks.
13. Check secondary particle production.
14. Do a back-of-the-envelope check of the results.

1.5.3 Production

1. Save RUNTPE file for expanded output printing, continue-run, and tally plotting.
2. Limit the size of the RUNTPE file with the `PRDMP` card.
3. Look at figure of merit stability.
4. Make sure answers seem reasonable.
5. Examine and understand the 10 statistical checks provided by MCNP6.
6. Form valid confidence intervals.
7. Make continue-runs if necessary.
8. See if stable errors decrease by $1/\sqrt{N}$.
9. Remember, accuracy is only as good as the nuclear data, modeling, MCNP6 sampling approximations, etc.
10. Adequately sample all cells.

1.5.4 Criticality

1. Determine how many inactive cycles are needed by using the MCNP6 plotter to examine the behavior of k_{eff} and the Shannon entropy of the source distribution with cycle number.
2. Run a large number of histories per cycle. For production runs, at least 5000 or 10000 neutrons per cycle are recommended. More neutrons per cycle are better.

3. Examine the behavior of k_{eff} with cycle number and continue calculations if trends are noticed.
4. Use at least 100 cycles after source convergence.
5. After a production run, use the MCNP6 plotter again to examine the behavior of k_{eff} and the Shannon entropy of the source distribution with cycle number. Ensure that a sufficient number of inactive cycles were used so that k_{eff} and the source distribution are both properly converged.

1.5.5 Warnings and Limitations

All computer simulation codes must be validated for specific uses, and the needs of one project may not overlap completely with the needs of other projects. It is the responsibility of the user to ensure that his or her needs are adequately identified, and that benchmarking activities are performed to ascertain how accurately the code will perform. The benchmarking done by code developers for the MCNP6 sponsors may or may not be adequate for a user's particular requirements. We make our benchmarking efforts public as they are completed, but the user must also develop a rigorous benchmarking program for his/her own application. Such benchmarking efforts by the user also ensures that the user understands how to use MCNP6 for his/her application.

The following warnings and known bugs apply to the energies and particles beyond MCNP, version 4C [BRI00]:

1. Perturbation methods used in MCNP4C have not been extended yet to the non-tabular models present in MCNP6. MCNP6 gives a fatal error if it is run for problems that invoke the perturbation capabilities above the MCNP4C energy range or beyond the MCNP4C particle set.

2. KCODE criticality calculations work only with available actinide nuclear data libraries and have not been extended to the model energy regions of the code.

3. Charged-particle reaction products are not generated for some neutron reactions below 20 MeV in the LA150N library. In calculating total particle-production cross sections, the library processing routines include only those reactions for which complete angular and energy information is given for secondary products. Most 150-MeV evaluations are built "on top" of existing ENDF and JENDL evaluations which typically go to 20 MeV. Although the 150-MeV evaluations do include the detailed secondary information in the 20–150-MeV range, the <20-MeV data typically do not. Therefore secondary production is generally ignored when processing interactions in that energy range. Table 2-2 lists the actual secondary particle-production thresholds in LA150N. Fixing this situation is non-trivial, and involves a re-evaluation of the low-energy data. Improved libraries will be issued, but on an isotope-by-isotope basis.

4. Beware of the results of an `F6:P` tally in small cells when running a photon or photon/electron problem. Photon heating numbers include the energy deposited by electrons generated during photon collisions, but assume that the electron energy is deposited locally. In a cell where the majority of the electrons lose all of their energy

before exiting that cell, this is a good approximation. However, if the cell is thin and/or a large number of electrons are created near the cell boundary, these electrons could carry significant energy into the neighboring cell. For this situation, the `F6:P` tally for the cell in which the electrons were created would be too large. The user is encouraged to consider use of the `F6:E` tally instead, which provides an accurate tally of electron energy deposition within a cell.

5. The FLUKA [FAS94] physics module that was in MCNPX is not present in MCNP6. We recommend using the Los Alamos Quark-Gluon String Model (LAQGSM03.03) [GUD75, GUD83, GUD01, GUD06, MAS74, MAS01, MAS05, MAS05a, MAS05b, MAS06, MAS07, MAS07a, MAS08, MAS11, MAS11a, MAS11b, MAS12] for very high-energy calculations.
6. Specifying different densities for the same material produces a warning. MCNP6 performs a material density correction for charged-particle energy deposition that is not a strict linear function. MCNP6 searches through all cells, finds the first one with the material of interest, and uses the associated material density to determine the correction factor for all cells using that material. For MCNP4C applications the effect is typically small; therefore this is an adequate procedure. For MCNP6 applications that utilize more charged particles and a greatly expanded energy range, this formerly "small" correction becomes increasingly important, and the usual way of handling it is not sufficient. A suggested practice in such instances is to specify a unique material identifier for each density.
7. "Next-event estimators," i.e., point and ring detectors, DXTRAN, and radiography tallies, use an assumption of isotropic scatter for contributions from collisions within the model regime. These estimators require the angular distribution data for particles produced in an interaction to predict the "next event." Information on these distributions is available in tabular form in the libraries; however, this information is not available in the required form from physics models used to produce secondary particles above the tabular region.
8. A numerical problem occurs in the straggling routines with densities less than about 1E-9 g/cm^3 for heavier charged particles and with densities less than about 1E-15 g/cm^3 for electrons. Users should avoid such low densities.

2 DESCRIPTION OF MCNP6 INPUT

Input to MCNP6 consists of several files that are provided as part of the code package, generated by problem runs, or user-supplied. This section focuses on the user-supplied INP (the default name) file, which describes the problem to be run. The INP file contains information about the problem including the geometry specification, the description of materials and selection of cross-section evaluations, the location and characteristics of the source, the type of answers or tallies desired, and any variance-reduction techniques used to improve efficiency.

The word "card," as used throughout this manual, describes a single line of input up to 128 characters long. This terminology and the line length restriction are historical and refer to a time when all input was done with punched cards. Throughout the input file, alphabetic characters can be upper, lower, or mixed case. All input cards are summarized by card type in Section 3.4. The user will provide only a small subset of all available input cards in a given problem.

Table 2-1 summarizes some of the limitations that have to be considered when setting up a problem. It may be necessary to modify MCNP6 to change one or more of these restrictions for a particular problem. The user may increase the size of the dimensioned arrays associated with some of these parameters by altering the source code and recompiling.

Table 2-1. Storage Limitations

Permitted Values for Card Labels	
Allowed cell numbers	**1–99,999,999**
Allowed surface numbers	**1–99,999,999**
Allowed material numbers	**0–99,999,999**
Allowed universe numbers	**0–99,999,999**
Allowed surface numbers for transformations	**1–999**
Allowed cell numbers for transformations	**1–999**
Allowed tally numbers	**1–99,999,999**
Allowed perturbation numbers	**1–99,999,999**
Allowed source distribution numbers	**1–999**
Allowed "card numbers"	**1–99,999,999**
Maximum Number of Code Options	
Maximum quantity of TMESH tallies	**20**
Maximum quantity of transformations	**999**
Maximum levels for nested geometry	**20**
Maximum length of the list for any single cell*	**9,999**

Maximum length of file names	**256 characters**
Maximum file name path length, including file name	**256 characters**
Maximum quantity of different tallies	**9,999**
Maximum quantity of detector tallies	**1,000**
Quantity of DXTRAN spheres per particle type	**10**
Quantity of `URAN` universes	**unlimited**
Entries on `IDUM` and `RDUM` cards	**2,000**

* MCNP6 allocates a generous amount of array space to store the surfaces bounding the cells. Occasionally, the use of macrobodies, surface unions, and complement operators can cause a cell specification to overflow the array. If not enough storage is allocated, MCNP6 will output a fatal error message instructing the user how to increase the array to the proper size.

Total storage requirements can be significantly reduced by turning off model physics for neutron problems (see `PHYS:N` card, Section 3.3.3.2.1)

All features of MCNP6 should be used with caution and knowledge. This is especially true of detectors and variance-reduction schemes. Read and understand the relevant sections of the manual before using them.

The units of measurement used throughout MCNP6 are the following:

- length in centimeters,
- energy in MeV,
- time in shakes (10^{-8} sec),
- temperature in MeV (*kT*),
- atomic density in atoms/barn-cm,
- mass density in g/cm^3,
- cross sections in barns (10^{-24} cm^2),
- heating numbers in MeV/collision, and
- atomic weight ratio based on a neutron mass of 1.008664967 amu. In these units, Avogadro's number is $0.59703109 \times 10^{24}$ per amu.

The INP file can have two forms, initiate-run and continue-run. Either form can contain an optional message block that replaces or supplements the MCNP6 execution-line information.

2.1 Initiate-Run

This form is used to set up a Monte Carlo problem (describe geometry, materials, tallies, etc.) and to run it using information from either the message block or the execution line. The initiate-run file has the following form:

Message Block *Blank Line Delimiter*	} Optional
Problem Title Card	
Cell Card Block . . .	
Blank Line Delimiter	
Surface Card Block . . .	
Blank Line Delimiter	
Data Card Block . . .	
Blank Line Terminator	Optional, but recommended
Anything else	Optional

In an MCNP6 initiate-run input file, an optional message block with its blank line delimiter is followed by a required title card. After the title card appears, three card blocks follow, each separated by a blank line. These three blocks provide 1) cell descriptions, 2) surface descriptions, and 3) data about everything else in the problem (materials, source, tallies, etc.). MCNP6 interprets a blank line as the end of the preceding information block. A final (optional) blank line at the end of the data block signals the end of the input file. With a valid set of cards, MCNP6 will run with or without the blank line terminator. However, when MCNP6 encounters the blank line terminator, MCNP6 will stop reading the input file even if additional lines exist in the file. This region following the blank line terminator can be used by the user for problem documentation or to retain cards not used in the current run.

2.2 CONTINUE-RUN

The continue-run form allows the user to restart a previously terminated job where it left off. For example, a job run for two hours may be continued for an additional amount of time. Continue-run can also be used to reconstruct the output of a previous run. The MCNP6 execution line (or message-block execution information) of a continue-run must contain `C` or `CN` to indicate a continue-run. The continue-run will start with the last dump on the specified restart file or, alternatively, with the m^{th} dump if either `C` *m* or `CN` *m* is specified.

When the `C` option is specified on the MCNP6 execution line, the dumps produced during the continue-run are appended after the dump from which the continue-run started. However, by specifying the `CN` option instead of the `C` option, the dumps produced during the continue-run are written immediately after the fixed data portion of the RUNTPE file. These new dumps overwrite the old dumps, providing a way for the user to prevent unmanageable growth of RUNTPE files. RUNTPE growth also can be controlled by the *ndmp* entry on the `PRDMP` card.

In addition to the C or CN option on the MCNP6 execution line, two files can be important for this procedure: the binary restart file (default name RUNTPE) and an optional continue-run input file (default name INP). Note that RUNTPE files **are not** compatible from one version of MCNP6 to the next. Therefore, a continue-run should use the same code version as that which created the RUNTPE file.

The binary restart file (RUNTPE), generated by MCNP6 in the initiate-run sequence, contains the geometry, cross sections, problem parameters, tallies, and all other information necessary to restart the job. In addition, the problem results at various stages of the run are recorded in a series of dumps. See the PRDMP card (Section 3.3.7.2.3) for a discussion of the selection of the dump frequency. As discussed below, the run may be restarted from any of the dumps saved to and retained on the RUNTPE file. Generally, for a RUNTPE file to be usable as a restart file, its closure must have been complete and graceful. RUNTPE files are generally compatible only with the version of MCNP6 used to create them (older or newer versions of MCNP6 will usually give a fatal error when reading incompatible RUNTPE files).

The optional continue-run input file must have the word CONTINUE as the first entry on the first line (title card), or after the optional message block and its blank line delimiter. This file has the following form:

Message Block *Blank Line Delimiter*	} Optional
CONTINUE	
Data Card Block . . .	
Blank Line Terminator	Optional, but recommended
Anything else	Optional

The data cards allowed in the continue-run input file are a subset of the data cards available for an initiate-run file. The allowed continue-run data cards include FQ, DD, NPS, CTME, IDUM, RDUM, PRDMP, LOST, DBCN, PRINT, KCODE, MPLOT, MESH, TALNP, ZA, ZB, ZC, FMESH, RAND, STOP, ZD, and EMBED. Additionally, the number of threads specified on the execution line (TASKS *n*) may be changed between runs.

If none of the above items is to be changed the continue-run input file is not required; only the restart file (RUNTPE) and the C option on the MCNP6 execution line are necessary. For example, the command line sequence MCNP6 C or MCNP6 CN will pick up the job where it stopped and continue until another time limit or particle cutoff is reached or until you stop it interactively. This example assumes that a properly closed restart file from the initial run with the default name "RUNTPE" is in your current directory.

The complete continue-run execution line option is C *m* or CN *m*, where *m* specifies from which dump in the restart file to reinitiate the run. If *m* is not specified, the last dump is taken by default.

If the initial run producing the restart file was stopped because of particle cutoff (`NPS` card, Section 3.3.7.1.1), the value of *`npp`* on the `NPS` card must be increased for a continue-run via a continue-run file. The parameter *`npp`* represents the cumulative histories to be run, including preceding continue-runs and the initial run. On the other hand, the *`tme`* parameter on the `CTME` card in a continue-run is the number of minutes *more* to run, not cumulative total time. To run more KCODE cycles, only the fourth entry on the `KCODE` card, *`kct`*, must be changed. Like *`npp`*, *`kct`* refers to total cycles to be run, including previous ones.

In a continue-run, a negative number entered for *`npp`* on the `NPS` card produces a print output file at the time of the requested dump. No more histories will be run. This can be useful when the printed output has been lost or you want to alter the content of the output with the `PRINT` or `FQ` cards.

Continue-runs do not produce identical results to initial-runs for delayed particle calculations (see the `ACT` card, Section 3.3.3.3).

Be cautious if you use a `FILES` card in the initial run. See Section 3.3.7.3.6.

2.3 CARD FORMAT

Most input is entered in horizontal format; however, a vertical input format is allowed for data cards. Comment cards (Section 2.6) can be inserted throughout the input file. Additionally, a comment can be added to any input card: a `$` (dollar sign) terminates data entry on a card and anything that follows the `$` is interpreted as a comment. (One exception is that you cannot use a $ within a `TMESH` tally block. See Section 3.3.5.24.) Blank lines are used as delimiters between input blocks and as a terminator after the data block to indicate the end of the input file. Individual data entries are separated by one or more blanks.

If the first five columns of a card are blank, the entries on the card are interpreted as a continuation of the data from the last named card. The user also can continue data on the following card by ending the line with an `&` (ampersand) preceded by at least one blank space. In this case, the data on the continuation card can reside in columns 1–128. Remember that completely blank cards are reserved as delimiters between major sections of the input file.

2.4 MESSAGE BLOCK

In computer environments where there are no execution line messages, the optional message block is the only means for providing MCNP6 with execution information. Optionally, it is a convenient way to avoid retyping an often-repeated message. Both initiate-run and continue-run input files can contain a message block that **replaces** or **supplements** the MCNP6 execution line information. If used, the message block is located before the problem title card in the INP file. The message block starts with the string, `MESSAGE:` and is limited to columns 1–128. The message block ends with a blank line delimiter before the title card. All cards before the blank line delimiter are continuation cards. The `$` symbol (which indicates an end-of-line comment follows) and the `&` symbol (which indicates that the information continues on the next line) are permitted in message blocks and act as end-of-line markers. The syntax and components of the message are the same as for the regular execution line message. Any file name substitution, program module execution option, or keyword entry on the execution line takes precedence over conflicting information in the message block. Renaming of the input file default file name, `INP=`*`filename`*, is *not* a legitimate entry in the message block. The name `INP` can be changed on the execution line only.

For example, assume the MCNP6 execution line required to run the input file, `sphere.i`, and to assign user-designated names to the output files is

```
mcnp6 i=sphere.i o=sphere.o r=sphere.r mctal=sphere.m   .
```

The following simplified execution line

```
mcnp6 i=sphere.i
```

can provide the same file name assignments through the message block feature:

```
message: o=sphere.o r= sphere.r mctal= sphere.m

Title: bare uranium sphere   .
```

The three lines above show the message block and the input-file title card separated by a blank line delimiter.

2.5 PROBLEM TITLE CARD

The first card in the file after the optional message block is the required problem title card. If there is no message block, this must be the first card in the INP file. It is limited to one 128-column line and is used as a title in various places in the MCNP6 output. It can contain any information the user desires (or can even be blank) and often contains information describing the particular problem. Note that a blank card elsewhere is used as a delimiter or as a terminator.

2.6 COMMENT CARDS

General comment cards can be used anywhere in the INP file after the problem title card and before the last blank terminator card. (The `TMESH` tally format is an exception. See Section 3.3.5.24.) These cards must have a `C` anywhere in columns 1–5 followed by at least one blank. Comments can be up to a total of128 columns long. General comment cards are printed only with the input file listing and not anywhere else in the MCNP6 output file.

Additionally, specific comment cards are provided for tallies (the `FC`*`n`* card, Section 3.3.5.2) and for sources (the `SC`*`n`* card, Section 3.3.4.6). User-provided text on these cards are printed in the output as a tally title and as a heading for a source probability distribution, *`n`*, respectively.

2.7 AUXILIARY INPUT FILE CAPABILITY

Subsections of the input file may be inserted using the `READ` card (Section 3.1). The text of these insertions will be expanded in the output file unless disabled by the `READ NOECHO` keyword.

2.8 CELL, SURFACE, AND DATA CARDS

Detailed specifications for the cell, surface, and data cards are provided in Chapter 3. A general description of these card types is provided in this section to orient the user.

The first entry on any cell card is the user-assigned cell number, which must begin in the first five columns of the card. The second entry is a cell material number that corresponds to a material card number (*m* on the `M`*m* card) in the data card input block. If the cell is void, a zero is entered for the material number. For a cell with a non-zero material number, the material density follows the material number. The next entries include a list of signed surfaces that provide a complete specification of the geometry of the cell. Optionally, after the geometry description, cell parameters can be entered.

Similarly, the first entry on any surface card is the user-assigned surface number, which must begin in the first five columns of the card. The second entry is typically an alphabetic mnemonic indicating the surface type. Following the surface mnemonic are the numerical coefficients of the equation of the surface in the proper order.

The remaining data input for MCNP6 follows the second blank card delimiter (or third blank card if there is a message block). Although a horizontal input format for data cards is most commonly used, a vertical format option permitted by MCNP6 is particularly useful for some cell parameters and source distributions. Both formats are described in the sections that follow.

2.8.1 Data Card Horizontal Input Format

Like cell and surface cards, data cards all must begin within the first five columns. The card name or number and particle designator are followed by data entries separated by one or more blanks. An individual entry cannot be split between two lines. There can be only one card of any given type for a given particle designation. (See Section 2.9.) Integers must be entered where integer input is required. Other numerical data can be entered as integer or floating point and will be read properly by MCNP6. (In fact, non-integer numerical data can be entered in any form acceptable to a Fortran E-edit descriptor.)

MCNP6 allows five shortcuts to facilitate data input:

1. *n*`R` means *repeat* the immediately preceding entry on the card *n* times. For example, `2 4R` is the same as `2 2 2 2 2`.
2. *n*`I` means *insert n* linear interpolates between the entries immediately preceding and following this feature. For example, `1.5 2I 3.0` on a card is the same as

`1.5 2.0 2.5 3.0`. In the construct `X` *n*`I Y`, if `X` and `Y` are integers, and if `Y-X` is an exact multiple of *n*`+1`, then correct integer interpolates will be created. Otherwise, only real interpolates will be created, but `Y` will be stored directly in all cases. In the above example, the `2.0` value may not be exact, but in the example `1 4I 6`, all interpolates are exact and the entry is equivalent to `1 2 3 4 5 6`.

3. *x*`M` means *multiply* the previous entry on the card by the value *x*. For example, `1 1 2M 2M 2M 2M 4M 2M 2M` is equivalent to `1 1 2 4 8 16 64 128 256`.
4. *n*`J` means *jump* over the entry and take the default value. As an example, the following two cards are identical in their effect:

```
DD   0.1   1000
DD     J   1000
```

   `J J J` is also equivalent to `3J`. Also using this shortcut, you can jump to a particular entry on a card without having to specify explicitly previous items on the card. This feature is convenient if you know you want to use a default value but cannot remember it. Another example of this capability is `DBCN  2J 10 15`.

5. *n*`LOG` or, equivalently, *n*`ILOG` means insert *n* (base-10) logarithmic interpolates between the entries immediately preceding and following this feature. For example, `0.01 2ILOG 10` is equivalent to `0.01 0.1 1 10`. In the construct `X` *n*`ILOG Y`, `X` and `Y` must be non-zero and have the same sign—otherwise a fatal error is produced.

These features apply to both integer and floating-point quantities. If *n* (an integer) is omitted in the constructs *n*`R`, *n*`I`, *n*`LOG`, *n*`ILOG`, and *n*`J`, then *n* is assumed to be `1`. If *x* (integer or floating point) is omitted in *x*`M`, it is a fatal error. The rules for dealing with adjacent special input items are as follows:

1. *n*`R` must be preceded by a number or by an item created by `R` or `M`.
2. *n*`I`, *n*`LOG`, and *n*`ILOG` must be preceded by a number or by an item created by `R` or `M`, and must be followed by a number. The preceding number cannot be `0.0` for *n*`LOG` or *n*`ILOG`.
3. *x*`M` must be preceded by a number or by an item created by `R` or `M`.
4. *n*`J` may be preceded by anything except `I` and may begin the card input list.

Several examples follow:

`1 3M 2R`	is equivalent to	`1 3 3 3`
`1 3M I 4`	is equivalent to	`1 3 3.5 4`
`1 3M 3M`	is equivalent to	`1 3 9`
`1 2R 2I 2.5`	is equivalent to	`1 1 1 1.5 2.0 2.5`
`1 R 2M`	is equivalent to	`1 1 2`
`1 R R`	is equivalent to	`1 1 1`

`1 2I 4 3M`	is equivalent to	`1 2 3 4 12`
`1 2I 4 2I 10`	is equivalent to	`1 2 3 4 6 8 10`
`3J 4R`	is illegal	
`1 4I 3M`	is illegal	
`1 4I J`	is illegal	

2.8.2 Data Card Vertical Input Format

Column input is particularly useful for cell parameters and source distributions. Cell importance or volumes strung out on horizontal input lines are not very readable and often lead to errors when users add or delete cells. In vertical format, all the cell parameters for one cell can be on a single line, labeled with the name of the cell. If a cell is deleted, the user deletes just one line of cell parameters instead of hunting for the data item that belongs to the cell in each of several multi-line cell-parameter cards. For source distributions, corresponding SI, SP, and SB values are side by side. Source options, other than defaults, are on the next line and must all be entered explicitly. The & continuation symbol is not needed and is ignored if it is present.

In column format, card names are put side by side on one input line and the data values are listed in columns under the card names. To indicate that vertical input format is being used, a # is put somewhere in columns 1–5 on the line with the card names. The card names must be all cell parameters, all surface parameters, or all something else. If a card name appears on a # card, there must not be a regular horizontal card by that name in the same input file. If there are more entries on data value lines than card names on the # line, the first data entry is assumed to be a cell or surface number. If any cell names are entered, all must be entered. If cell names are entered, the cells do not have to be in the same order as they are in the cell cards block. If cell names are omitted, the default order is the order of the cells in the cell card block. The same rules apply to surface parameters, but because we presently have only one surface parameter (AREA), column input of surface parameters is less useful.

There can be more than one block of column data in an input file. Typically, there would be one block for cell parameters and one for each source distribution. If a lot of cell parameter options are being used, additional blocks of column data would be needed.

We strongly suggest keeping columns reasonably neat for user readability. The column format is intended for input data that naturally fit into columns of equal length, but less tidy data are not prohibited. If a longer column is to the right of a shorter column, the shorter column must be filled with enough J entries to eliminate any ambiguity about which columns the data items are in.

Special syntax items (R, M, I, LOG, ILOG, and J) are not as appropriate in column format as they are on horizontal lines, but they are not prohibited. They are, of course, interpreted vertically instead of horizontally. Multiple special syntax items, such as 9R, are not allowed if cell or surface names are present.

The form of a column input block is

```
#     S1     S2     ...    Sm
k1    d11    d12    ...    d1m
k2    d21    d22    ...    d2m
.     .      .      ...    .
.     .      .      ...    .
.     .      .      ...    .
kN    dN1    dN2    ...    dNm
```

1. The # is somewhere in columns 1–5.
2. Each line can be only 128 columns wide.
3. Each column, S_i through d_{li}, where l may be less than N, represents a regular input card.
4. The S_i must be valid MCNP6 card names. They must be all cell parameters, all surface parameters, or all something else.
5. d_{1i} through d_{Ni} must be valid entries for an S_i card, except that $d_{l+1,i}$ through d_{Ni} may be some Js possibly followed by some blanks.
6. If d_{ji} is non-blank, $d_{j,i-1}$ must also be non-blank. A J may be used if necessary to make $d_{j,i-1}$ non-blank.
7. The S_i must not appear anywhere else in the input file.
8. The k_j are optional integers. If any are non-blank, all must be non-blank.
9. If the S_i are cell parameter card names, the k_j, if present, must be valid cell names. The same is true with surface parameters.
10. If the k_j is present, the d_{ji} must not be multiple special syntax items, such as 9R or 9M.

2.9 PARTICLE DESIGNATORS

Numerous input cards require a particle designator to distinguish between input data for tracked particles. Refer to the pertinent card information for instructions. The particle designator consists of a colon (:) followed by the particle symbol(s) immediately after the name of the card. These particle designations are presented in Table 2-2. At least one blank must follow the particle designator. For example, IMP:N signifies neutron importance values follow while IMP:P signifies photon importance values follow. To specify the same value for more than one kind of particle, a single card can be used instead of several. For example, if the designation IMP:E,P,N 1 1 0 appears on a cell card, the electron importance for that cell is 1, the photon importance is 1, and the neutron importance is 0. With a tally card, the particle designator follows the card name including tally number. For example, *F5:N indicates a neutron point-detector energy tally. In the heating tally case, two particle designators may appear. The syntax F6:N,P indicates the combined heating tally for both neutrons and photons.

Table 2-2. MCNP6 Particles

IPT*	Name of Particle	Symbol	Mass[1] (MeV)	Low Kinetic Energy Cutoff / Default Cutoff (MeV)	Mean Lifetime[1] (seconds)	
					As treated by MCNP6	Actual (if different)
1	neutron (n)	N	939.56563	0.0 / 0.0	no decay	887.0
2	photon (γ)	P	0.0	1.e-6 / 1.e-3	1×1029	
3	electron (e)	E	0.511008	1.e-5 / 1.e-3	1×1029	
4	negative muon (μ)	|	105.658389	1.e-3 / 0.11261	2.19703×10-6	
5	anti neutron ( )	Q	939.56563	0.0 / 0.0	no decay	887.0
6	electron neutrino (νe)	U	0.0	0.0 / 0.0	1×1029	
7	muon neutrino (νm)	V	0.0	0.0 / 0.0	no decay	
8	positron (e^+) (See Note 1)	F	0.511008	1.e-3 / 1.e-3	1×10^{29}	
9	proton (p+)	H	938.27231	1.e-3 / 1.0	1×1029	
10	lambda baryon (Λ0)	L	1115.684	1.e-3 / 1.0	DOP†	2.632×10-10
11	positive sigma baryon (Σ+)	+	1189.37	1.e-3 / 1.26760	DOP†	7.99×10-11
12	negative sigma baryon(Σ)	-	1197.436	1.e-3 / 1.26760	DOP†	1.479×10-10
13	cascade; xi baryon (Ξ0)	X	1314.9	1.e-3 / 1.0	DOP†	2.9×10-10
14	negative cascade; negative xi baryon (Ξ)	Y	1321.32	1.e-3 / 1.40820	DOP†	1.639×10-10
15	omega baryon (Ω)	O	1672.45	1e-3 / 1.78250	DOP†	8.22×10-11
16	positive muon (μ^+)	!	105.658389	1.e-3 / 0.11261	2.19703×10^{-6}	
17	anti electron neutrino ($\bar{\nu}_e$)	<	0.0	0.0 / 0.0	1×10^{29}	
18	anti muon neutrino ($\bar{\nu}_m$)	>	0.0	0.0 / 0.0	no decay	
19	anti proton ($\bar{p}$)	G	938.27231	1.e-3 / 1.0	1×10^{29}	

[1] Particle Data Group (PDG), *Particle Physics Booklet*, July 2002, extracted from K. Hagiwara et al., "Review of Particle Physics," *Physical Review* **D 66**, 010001 (2002).

IPT*	Name of Particle	Symbol	Mass[1] (MeV)	Low Kinetic Energy Cutoff / Default Cutoff (MeV)	Mean Lifetime[1] (seconds)	
					As treated by MCNP6	Actual (if different)
20	positive pion (π+)	/	139.56995	1.e-3 / 0.14875	2.603×10-8	
21	neutral pion (π0)	Z	134.9764	0.0 / 0.0	8.4×10-17	
22	positive kaon (K+)	K	493.677	1.e-3 / 0.52614	1.2371×10-8	
23	kaon, short (K0S)	%	497.672	0.0 / 0.0	0.8926×10-10	
24	kaon, long (K0L)	^	497.672	0.0 / 0.0	5.17×10-8	
25	anti lambda baryon ($\overline{\Lambda}^0$)	B	1115.684	1.e-3 / 1.0	DOP†	2.632×10^{-10}
26	anti positive sigma baryon ($\overline{\Sigma}^+$)	_	1189.37	1.e-3 / 1.26760	DOP†	7.99×10^{-11}
27	anti negative sigma baryon ($\overline{\Sigma}^-$)	~	1197.436	1.e-3 / 1.26760	DOP†	1.479×10^{-10}
28	anti cascade; anti neutral xi baryon ($\overline{\Xi}^0$)	C	1314.9	1.e-3 / 1.0	DOP†	2.9×10^{-10}
29	positive cascade; positive xi baryon (Ξ^+)	W	1321.32	1.e-3 / 1.40820	DOP†	1.639×10^{-10}
30	anti omega ($\overline{\Omega}^-$)	@	1672.45	1e-3 / 1.78250	DOP†	8.22×10^{-11}
31	deuteron (d)	D	1875.627	1.e-3 / 2.0	1×1029	
32	triton (t)	T	2808.951	1.e-3 / 3.0	12.3 years	
33	helion (3He)	S	2808.421	1.e-3 / 3.0	1×1029	
34	alpha particle (α)	A	3727.418	1.e-3 / 4.0	1×1029	
35	negative pion (π^-)	*	139.56995	1.e-3 / 0.14875	2.603×10^{-8}	
36	negative kaon (K^-)	?	493.677	1.e-3 / 0.52614	1.2371×10^{-8}	
37	heavy ions‡	#	varies	1.e-3 / 5.0	1×10^{29}	

† DOP=Decayed on production

‡ The “#” symbol represents all possible heavy-ion types—in other words, any ion that is not one of the four light ions available in MCNP6.

** A list of heavy ions available for transport is provided in Appendix G.

Note 1: Positrons are treated identical to electrons in transport (outside magnetic field effects), and need to be used with the electron transport option (particle e) enabled. Please refer to the MODE section (3.3.3.1) to see the exceptions for positron labels.

2.10 DEFAULT VALUES

Many MCNP6 input parameters have default values that are summarized in Section 3.4. Therefore, you do not always have to specify explicitly every input parameter every time if the defaults match your needs. If an input card is left out, the default values for all parameters on the card are used. However, if you want to change a particular default parameter on a card where others precede that parameter, you have to specify the others or use the `nJ` jump feature to jump over the parameters for which you still want the defaults. For example, the input `CUT:P 3J -0.10` is a convenient way to use the defaults for the first three parameters on the photon cutoff card but change the fourth.

2.11 INPUT ERROR MESSAGES

MCNP6 makes over 800 checks of the input file for user errors. If the user violates a basic constraint of the input specification, a fatal error message is printed, both at the terminal and in the OUTP file. If a fatal input error is detected, MCNP6 will terminate before running any particles. The first fatal error is real; subsequent error messages may or may not be real because of the nature of the first fatal message. The `FATAL` option on the MCNP6 execution line instructs MCNP6 to ignore fatal errors and run particles, but the user should be extremely cautious when doing this.

Most MCNP6 error messages are either warnings or comments that are not fatal. Warnings are intended to inform the user about unconventional input parameters or running conditions and may need further attention. Comments relay useful additional information to the user. The user should not ignore these messages but should understand their significance before making important calculations.

In addition to fatal, warning, and comment messages, MCNP6 issues `BAD TROUBLE` messages immediately before any impending catastrophe, such as a divide by zero, which would otherwise cause the program to "crash." MCNP6 terminates as soon as the `BAD TROUBLE` message is issued. User input errors in the INP file are the most common reason for issuing a `BAD TROUBLE` message. These error messages indicate what corrective action is required.

2.12 GEOMETRY ERRORS

There is one important kind of input error that MCNP6 will not detect while processing data from the INP file. MCNP6 cannot detect overlapping cells or gaps between cells until a particle track actually gets lost. Even then the precise nature of the error may remain unclear. However, there is much that you can and should do to check your geometry before starting a long computer run.

Use the geometry-plotting feature of MCNP6 to look at the system from several directions and at various scales. Be sure that what you see is what you intend. Any gaps or overlaps in the geometry will probably show up as dashed lines. The intersection of a surface with the plot plane is drawn as a dashed line if there is not exactly one cell on each side of the surface at each point. Dashed lines can also appear if the plot plane happens to coincide with a plane of the problem, there are any cookie-cutter cells in the source, or there are DXTRAN spheres in the problem.

One way to check your geometry is to set up and run a short problem in which your system is flooded with particle tracks from an external source. The changes required in the INP file to perform this test follow:

1. Add a `VOID` card to override some of the other specifications in the problem and make all the cells voids, turn heating tallies into flux tallies, and turn off any tally multiplication (`FM`) cards.
2. Add another cell and a large spherical surface to the problem such that the surface surrounds the system and the old outside world cell is split by the new surface into two cells: the space between the system and the new surface, which is the new cell, and the space outside the new surface, which is now the outside world cell. Be sure that the new cell has non-zero importance. Actually, it is best to make all non-zero importance equal. If the system is infinite in one or two dimensions, use one or more planes instead of a sphere.
3. Replace the source specifications by an inward directed surface source to flood the geometry with particles. To do this, you can use the command

   `SDEF     SUR=`*m*`   NRM=-1` ,

   where *m* is the number of the new spherical surface added in Step 2. If the new surface is a plane, you must specify the portion to be used by means of `POS` and `RAD` or possibly `X`, `Y`, and `Z` source distributions.

Because there are no collisions, a short run will generate a great many tracks through your system. If there are any geometry errors, they should cause some of the particles to get lost.

When a particle first gets lost, whether in a special run with the `VOID` card or in a regular production run, the history is rerun to produce some special output on the OUTP file. Event-log printing is turned on during the rerun. The event log will show all surface crossings and will tell you the path the particle took to the bad spot in the geometry. When the particle again gets lost, a description of the situation at that point is printed. You can usually deduce the cause of the lost particle from this output. It is not possible to rerun lost particles in a multitasking run.

If the cause of the lost particle is still obscure, try plotting the geometry with the origin of the plot at the point where the particle got lost and with the horizontal axis of the plot plane along the direction the particle was moving. You might also consider turning `COLOR OFF` using the interactive geometry plotter. A wire drawing then appears, reducing the complexity of the visual representation caused by the color. The cause of the trouble is likely to appear as a dashed line somewhere in the plot or as some discrepancy between the plot and your idea of what it should look like.

3 INPUT CARDS

MCNP6 input cards other than those that define cells (Section 3.2.1) and surfaces (Section 3.2.2) typically are entered after the blank card delimiter following the cell-card and surface-card blocks. The mnemonic that specifies the type of data card must begin within the first five columns of the input file.

No data card can be used more than once with the same number or particle type designations. For example, `M1` and `M2` are acceptable, as are `CUT:N` and `CUT:P`, but two `M1` cards or two `CUT:N` cards are disallowed.

Note that when *values* are assigned to keywords, the equals sign (=) is optional.

3.1 AUXILIARY INPUT FILE AND ENCRYPTION (READ)

The MCNP6 `READ` card enables (1) the reading of parts of the input file from other (auxiliary) files, (2) the suppression of the printing of the auxiliary input files to shorten output files and protect proprietary information, and (3) the encryption of auxiliary input files to protect proprietary information. Unlike most MCNP6 input cards, there may be as many `READ` cards and auxiliary input files as desired. The `READ` card may appear anywhere after the title card of an MCNP6 input file but not in the middle of a card continuation. `READ` cards may appear in auxiliary files, allowing the nesting of `READ` cards to multiple levels. The encryption capability may be applied to any or all of the `READ` levels. There is no limit to the number of nested levels.

The encryption capability can be used to protect proprietary designs of tools and other systems modeled with MCNP6. The encryption capability is localized in subroutine ENCRYPT. The MCNP6 scheme is very simple; therefore, it protects nothing. To protect input, the subroutine should be modified to a more sophisticated scheme known only to those producing the data and only executable MCNP6 versions should be provided to users of the encrypted files.

Form: `READ KEYWORD=`*`value(s)`* `...`

Table 3-1. Auxiliary Input and Encryption (READ)

Keyword	Value
FILE=*filename*	**Causes input from the file *filename* to be inserted after the READ card in the MCNP6 input deck.**
NOECHO	**Suppresses printing in the output file of the input cards that follow the READ card.**

Keyword	Value
ECHO	**Resumes echoing in the output file of the input after a NOECHO keyword was given in a previous READ card. Echoing also will resume when the next READ card is encountered without the NOECHO keyword. (DEFAULT)**
DECODE=*password*	**Allows reading of an encrypted file. When DECODE is invoked, the encrypted input file is not echoed, and many default print tables are turned off (and cannot be turned back on) to protect the data in the encrypted file.**
ENCODE=*password*	**Allows the writing of an encrypted file.**

Example 1:

READ FILE=*filename* NOECHO

Because the echoing of the input cards also is resumed when an "end of file" is encountered, the above example causes the input from the auxiliary file, *filename*, to be suppressed. After the file *filename* is read, input transfers back to the input file that contains the READ card and printing is no longer suppressed.

Example 2:

READ DECODE *password* FILE=*filename*

This example causes the reading of the encrypted file, *filename*.

Example 3:

READ ENCODE *password* FILE=*filename*

This example causes an encrypted file, *filename*, to be written.

3.2 GEOMETRY SPECIFICATION

The geometry of MCNP6 treats an arbitrary three-dimensional configuration of user-defined materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori. (See Table 3-4.) The cells are defined by the intersections, unions, and complements of the regions bounded by the surfaces. Surfaces are defined by supplying coefficients to the analytic surface equations or, for certain types of surfaces, known points on the surfaces. MCNP6 also provides a "macrobody" capability, where basic shapes such as spheres, boxes, cylinders, etc., may be combined using Boolean operators.

Each surface divides all space into two regions, one with positive sense with respect to the surface and the other with negative sense. Define $S=f(x,y,z)=0$ as the equation of a surface in the problem. For any set of points (x,y,z) if $S=0$, the points are on the surface; if S is negative, the points are said to have a negative sense with respect to that surface, and if S is positive, the points have a positive sense. The expression for a surface is the left side of the equation for the surface in Table 3-4. For the sphere, cylinder, cone, and torus, this definition is identical to defining the sense to be positive outside the figure. With planes normal to axes (PX, PY, or PZ), the definition gives positive sense for points with *x*, *y*, or *z* values exceeding the intercept of the plane. For the P, SQ and GQ surfaces, the user supplies all of the coefficients for the expression and thus can determine the sense of the surface at will. This is different from the other cases where the sense, though arbitrary, is uniquely determined by the form of the expression. Therefore, in a surface transformation (see the TR*n* card in Section 3.3.1.3) a PX, PY, or PZ surface will sometimes be replaced by a P surface just to prevent the sense of the surface from getting reversed.

The geometry of each cell is described on a cell card by a list of operators and signed surfaces that bound the cell. (If the sense is positive, the + sign can be omitted.) This geometry description defines the cell to be the intersection, union, and/or complement of the listed regions. The intersection operator in MCNP6 is implicit; it is simply the blank space between two signed surface numbers on the cell card. The union operator, signified by a colon (:), allows concave corners in cells and also cells that are completely disjoint. Because the intersection and union operators are binary Boolean operators, their use follows Boolean algebra methodology; unions and intersections can be used in combination in any cell description. Spaces on either side of the union operator are irrelevant, but a space without the colon signifies an intersection.

The complement operator, signified by the # symbol[1], provides no new capability over the intersection and union operators. It is just a shorthand cell-specifying method that implicitly uses the intersection and union operators. The complement operator can be thought of as standing for *not in*. The notation #*n*, where *n* is a previously defined cell number, means that the description of the current cell is the complement of the description of cell *n*. In other words, a number immediately after a complement operator, without parentheses, is interpreted as a cell number and is shorthand for the geometry specification of that cell number. The notation #(...), where (...) is usually a list of surfaces describing another cell, means to complement the portion of the cell description in parentheses.

The default order of operations is complement first, intersection second, and unions third. There is no right-to-left ordering. Parentheses can be used to clarify operations and in some cases are required to force a certain order of operations. Innermost parentheses are cleared first. Spaces are optional on either side of a parenthesis. A parenthesis is equivalent to a space and signifies an intersection. Parentheses and operator symbols also function as delimiters; where they are present, blank delimiters are not necessary.

[1] The symbol "#" is also used to denote heavy ions. The meaning of the symbol in the input file should be obvious from context.

3.2.1 Cell Cards

Preparing Cell Cards

Recommended precautions when creating cell definitions include the following:

1. Avoid excessively complicated cells. A problem geometry constructed of numerous simple cells runs faster than the same problem described using fewer, more complicated cells.

2. Avoid ineffective use of the complement operator, which can cause unneeded surfaces to be added to the geometry description of a cell. Extra surfaces make the problem run more slowly and may destroy the necessary conditions for volume and area calculations. See Section 4.1.1, Example 14.

3. Always use the geometry-plotting feature of MCNP6 to check the geometry of a problem. See Section 5.2.

4. Flood the system with particles from an outside source to find errors in the geometry. See Section 2.12.

5. If you add or remove cells, remember to change all the cell parameter cards accordingly. The difficulty of this can be reduced if the vertical format is used to specify values on the cell parameter cards. (See Section 2.8.2.) Alternatively, define cell parameter values directly on cell cards and eliminate cell parameter cards entirely.

Form 1: `j m d geom params`

Form 2: `j LIKE n BUT list` (See Note 1 after the cell-card table.)

Table 3-2. Cell Cards

Input Parameter	Description
J	**Cell number assigned by the user.** **Restriction: 1≤*j*≤99,999,999** **Restriction: If the cell is affected by a TRCL transformation, 1≤*j*≤999. (See Section 3.3.1.4.)**
M	**Material number if the cell is not a void.** **If *m*>0, the cell contains material *m*, which is specified on the M*m* card located in the data card section of the INP file.** **If *m*=0, the cell is a void.** **Restriction: 1≤*m*≤99,999,999**
D	**Cell material density.** **If *d*>0, interpret the value as the atomic density in units of 10^{24} atoms/cm^3 (i.e., atoms/b-cm).** **If *d*<0, interpret the value as the mass density in units of g/cm^3.** **This parameter is absent if the cell is a void.**

Input Parameter	Description
Geom	**Specification of the geometry of the cell. This specification consists of signed surface numbers and Boolean operators that specify how the regions bounded by the surfaces are to be combined. Boolean operators include the following:** **"<space>" indicates intersection,** **":" indicates union; and** **"#" indicates complement.**
Params	**Optional specification of cell parameters by entries in the KEYWORD=*value* form. Allowed keywords include IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, TMP, U, TRCL, LAT, FILL, ELPT, COSY, BFLCL, and UNC. (See Notes 2 and 3.)**
N	**Number of another cell.** **Restriction: Cell card for cell *n* must appear in the INP file before the cell card for cell *j*.**
List	**Set of KEYWORD=*value* specifications that define the attributes that differ between cells *n* and *j*. Allowed keywords include MAT (material number) and RHO (density) as well as the cell parameter keywords IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, TMP, U, TRCL, LAT, FILL, ELPT, COSY, BFLCL, and UNC.**

Note 1: The LIKE *n* BUT feature is very useful in problems with a lot of repeated structures. Cell *j* inherits from cell *n* the values of all attributes that are not specified in the list. The cell card for cell *n* must be before the cell card for cell *j* in the INP file. The LIKE *n* BUT feature uses keywords for the cell material number and density. The mnemonics are MAT and RHO, respectively. These two keywords are only allowed following the LIKE *n* BUT construct, and may not appear in a normal cell description. Any other keyword name that appears after the BUT is a cell parameter and, therefore, must appear on cell cards only, not on any cards in the data block of the INP file.

Note 2: Cell parameters may be defined on cell cards instead of in the data card section of the INP file. If a cell parameter is entered on any cell card, a cell-parameter card with that name cannot be present, nor can the mnemonic appear on any vertical-format input card. It is permitted for some cell parameters to be specified on cell cards, while other subsets are specified in the data section. The format for cell parameters defined on cell cards is KEYWORD=*value(s)*, where the allowed keywords are IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, TMP, U, TRCL, LAT, FILL, ELPT, COSY, BFLCL, and UNC, with particle designators where necessary. Similarly, the cell-parameter cards associated with the repeated structures capability, U, LAT, and FILL, may be placed either on the cell cards or in the data card section of the INP file.

Note 3: TMP and WWN data can be entered on cell cards in two ways. The KEYWORD=*value* form (TMP1=*value* TMP2=*value* ...) can be used or a special syntax is available where the single keyword TMP is followed by all the temperatures of the cell in an order corresponding to the times on the THTME card. The form for the WWN card is analogous: WWN1:*n*=*value* or WWN:*n* followed by all the lower weight bounds for the energy intervals of the cell.

Example 1:

```
3  0    -1    2   -4          $ definition of cell 3
5  0    #3                    $ equivalent to each of the next 2 lines
```
or
```
5  0   #(-1  2  -4)
```
or
```
5  0   (+1 : -2 : +4)
```

Cell 3 is defined as the region in space with negative sense with respect to surface 1, positive sense with respect to surface 2, and negative sense with respect to surface 4. Cell 5 is the region of space not including cell 3. In the second and third lines of the example, it is specified using the complement operator; in the fourth line, the same region is specified using the union operator.

Example 2:

```
2   3  -3.7     -1   IMP:N=2   IMP:P=4
3   LIKE 2 BUT       IMP:N=10  TRCL=1
```

This second example says that cell 3 is the same as cell 2 in every respect except that cell 3 has a different location (TRCL=1) and a different neutron importance. The material in cell 3, the density, and the definition are the same as cell 2 and the photon importance is the same.

Example 3:

```
10  16  -4.2   1   -2    3   IMP:N=4  IMP:P=8  EXT:N=-0.4X
```

This says that cell 10 is to be filled with material 16 at a density of 4.2 g/cm^3. The cell consists of the intersections of the regions on the positive side of surface 1, the negative side of surface 2, and the positive side of surface 3. The neutron importance in cell 10 is 4 and the photon importance is 8. Neutrons in cell 10 are subject to an exponential transform in the minus X direction with stretching parameter 0.4.

3.2.2 Surface Cards

Surfaces can be defined by equations (Section 3.2.2.1), points (Sections 3.2.2.2 and 3.2.2.3), or macrobodies (Section 3.2.2.4). Each of these methods is discussed in the sections that follow.

INDEX OF SURFACE SPECIFICATION INFORMATION		
Mnemonic	**Description**	**Section**
	Surface Defined by Equations	3.2.2.1
P	Plane (General)	
PX, PY, PZ	Plane (Normal to *x*-, *y*-, *z*-axis)	
SO	Sphere (Centered at origin)	
S	Sphere (General)	
SX, SY, SZ	Sphere (Centered on *x*-, *y*-, *z*-axis)	
C/X, C/Y, C/Z	Cylinder (Parallel to *x*-, *y*-, *z*-axis)	
CX, CY, CZ	Cylinder (On *x*-, *y*-, *z*-axis)	
K/X, K/Y, K/Z	Cone (Parallel to *x*-, *y*-, *z*-axis)	
KX, KY, KZ	Cone(On *x*-, *y*-, *z*-axis)	
SQ	Ellipsoid, Hyperboloid, Paraboloid (Axes parallel to *x*-, *y*-, or *z*-axis)	
GQ	Cylinder, Cone, Ellipsoid, Hyperboloid, Paraboloid (Axes not parallel to *x*-, *y*-, or *z*-axis)	
TX, TY, TZ	Elliptical or Circular Torus (Axis parallel to *x*-, *y*-, or *z*-axis)	
X, Y, Z	Axisymmetric Surfaces Defined by Points	3.2.2.2
P	General Plane Defined by Three Points	3.2.2.3
	Surfaces Defined by Macrobodies	
BOX	Arbitrarily Oriented Orthogonal Box	3.2.2.4.1
RPP	Rectangular Parallelepiped	3.2.2.4.2
SPH	Sphere	3-16
RCC	Right Circular Cylinder	3.2.2.4.4
RHP or HEX	Right Hexagonal Prism	3-17
REC	Right Elliptical Cylinder	3.2.2.4.6
TRC	Truncated Right-Angle Cone	3-18
ELL	Ellipsoid	3.2.2.4.8
WED	Wedge	3.2.2.4.9
ARB	Arbitrary Polyhedron	3.2.2.4.10

3.2.2.1 SURFACES DEFINED BY EQUATIONS

The available surface types, equations, mnemonics, and the order of the card entries are given in Table 3-4. To specify a surface by this method, find the surface in Table 3-4 and determine the coefficients for the equation. The information is entered on the surface card according to the following format:

Form: *j* *n* A *list*

Table 3-3. Surfaces Defined by Equations

Input Parameter	Description
`j`	**Surface number assigned by the user.** **Restriction:** `1≤j≤99,999,999` **Restriction: If surface is affected by a `TR` transformation, `1≤j≤999`. See Sections 3.3.1.3 and 3.3.1.4.**
`*j`	**Reflecting surface number. A particle track that hits a reflecting surface is reflected specularly. (See Note 1.)**
`+j`	**White boundary surface number. A particle hitting a white boundary is reflected with a cosine distribution relative to the surface normal. (See Note 1.)**
`n`	**If `n>0`, the value specifies a transformation number `n` of a `TRn` card.** **If `n<0`, the value specifies that surface `j` is periodic with surface `n`. (See Note 2.)** **If `n` is absent then no coordinate transformation is specified.**
`A`	**Equation mnemonic from Table 3-4 that specifies the type of surface.**
`list`	**One to ten numerical entries, as required to define the selected surface.**

Table 3-4. MCNP6 Surface Cards

Mnemonic	Type	Description	Equation	Card Entries
`P`	Plane	General	$Ax + By + Cz - D = 0$	A B C D
`PX`		Normal to *x*-axis	$x - D = 0$	D
`PY`		Normal to *y*-axis	$y - D = 0$	D
`PZ`		Normal to *z*-axis	$z - D = 0$	D
`SO`	Sphere	Centered at Origin	$x^2 + y^2 + z^2 - R^2 = 0$	R
`S`		General	$(x-\bar{x})^2 + (y-\bar{y})^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ R
`SX`		Centered on *x*-axis	$(x-\bar{x})^2 + y^2 + z^2 - R^2 = 0$	$\bar{x}$ R
`SY`		Centered on *y*-axis	$x^2 + (y-\bar{y})^2 + z^2 - R^2 = 0$	$\bar{y}$ R
`SZ`		Centered on *z*-axis	$x^2 + y^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{z}$ R
`C/X`	Cylinder	Parallel to *x*-axis	$(y-\bar{y})^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{y}$ $\bar{z}$ R
`C/Y`		Parallel to *y*-axis	$(x-\bar{x})^2 + (z-\bar{z})^2 - R^2 = 0$	$\bar{x}$ $\bar{z}$ R
`C/Z`		Parallel to *z*-axis	$(x-\bar{x})^2 + (y-\bar{y})^2 - R^2 = 0$	$\bar{x}$ $\bar{y}$ R
`CX`		On *x*-axis	$y^2 + z^2 - R^2 = 0$	R
`CY`		On *y*-axis	$x^2 + z^2 - R^2 = 0$	R
`CZ`		On *z*-axis	$x^2 + y^2 - R^2 = 0$	R

Mnemonic	Type	Description	Equation	Card Entries
K/X	**Cone (See Note 3.)**	**Parallel to *x*-axis**	$\sqrt{(y-\bar{y})^2+(z-\bar{z})^2}-t(x-\bar{x})=0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ t^2 ± 1
K/Y		**Parallel to *y*-axis**	$\sqrt{(x-\bar{x})^2+(z-\bar{z})^2}-t(y-\bar{y})=0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ t^2 ± 1
K/Z		**Parallel to *z*-axis**	$\sqrt{(x-\bar{x})^2+(y-\bar{y})^2}-t(z-\bar{z})=0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ t^2 ± 1
KX		**On *x*-axis**	$\sqrt{y^2+z^2}-t(x-\bar{x})=0$	$\bar{x}$ t^2 ± 1
KY		**On *y*-axis**	$\sqrt{x^2+z^2}-t(y-\bar{y})=0$	$\bar{y}$ t^2 ± 1
KZ		**On *z*-axis**	$\sqrt{x^2+y^2}-t(z-\bar{z})=0$	$\bar{z}$ t^2 ± 1
				± 1 **used only for 1 sheet cone**
SQ	**Ellipsoid Hyperboloid Paraboloid**	**Axes parallel to *x*-, *y*-, or *z*-axis**	$A(x-\bar{x})^2+B(y-\bar{y})^2+C(z-\bar{z})^2 +2D(x-\bar{x})+2E(y-\bar{y})+2F(z-\bar{z}) +G=0$	**A B C D E F G** $\bar{x}$ $\bar{y}$ $\bar{z}$
GQ	**Cylinder Cone Ellipsoid Hyperboloid Paraboloid**	**Axes not parallel to *x*-, *y*-, or *z*-axis**	$Ax^2+By^2+Cz^2+Dxy+Eyz+Fzx +Gx+Hy+Jz+K=0$	**A B C D E F G H J K**
TX	**Elliptical or Circular Torus (See Note 4.)**	**Axis is parallel to *x*-,*y*-, or *z*- axis**	$(x-\bar{x})^2/B^2+\left(\sqrt{(y-\bar{y})^2+(z-\bar{z})^2}-A\right)^2/C^2-1=0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ A B C
TY			$(y-\bar{y})^2/B^2+\left(\sqrt{(x-\bar{x})^2+(z-\bar{z})^2}-A\right)^2/C^2-1=0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ A B C
TZ			$(z-\bar{z})^2/B^2+\left(\sqrt{(x-\bar{x})^2+(y-\bar{y})^2}-A\right)^2/C^2-1=0$	$\bar{x}$ $\bar{y}$ $\bar{z}$ A B C
X Y Z P	**Surfaces defined by points (See Sections 3.2.2.2 and 3.2.2.3)**			
BOX RPP SPH RCC RHP or HEX REC TRC ELL WED ARB	**Surfaces defined by macrobodies (See Section 3.2.2.4)**			

Note 1: Detectors and DXTRAN (next-event estimators) usually should not be used in problems that have reflecting surfaces or white boundaries. Also, tallies in problems with reflecting surfaces will need to be normalized differently as discussed in the MCNP6 Theory Manual[X-503a], Sections 2.6.3 and 5.5.4.2.

Note 2: If periodic boundaries are specified (i.e., `n<0`) such that surface `j` is periodic with surface `n`, the following restrictions apply:

1. Surfaces `j` and `n` must be planes.
2. No surface transformation is allowed for the periodic planes.
3. The periodic cell(s) can be infinite or bounded by planes on the top and bottom that can be reflecting or white, but cannot be periodic.
4. Periodic planes can bound only other periodic planes or top and bottom planes.
5. A single zero-importance cell must be on one side of each periodic plane.
6. All periodic planes must have a common rotational vector normal to the geometry top and bottom.
7. Next-event estimators such as detectors and DXTRAN should not be used.

Note 3: The quadratic equation for a cone describes a cone of two sheets—one sheet is a cone of positive slope, and the other has a negative slope. MCNP6 provides the option to select either of the two sheets. The `+1` or the `-1` entry on the cone surface card causes the one sheet cone treatment to be used. If the sign of the entry is positive, the specified sheet is the one that extends to infinity in the positive direction of the coordinate axis to which the cone axis is parallel. The converse is true for a negative entry. A cell whose description contains a two-sheeted cone may require an additional surface specification to help distinguish between the two sheets. This ambiguity surface helps to eliminate any ambiguities as to which region of space is included in the cell.

Note 4: The TX, TY, and TZ input cards represent elliptical tori (fourth degree surfaces) rotationally symmetric about axes parallel to the *x*-, *y*-, and *z*-axes, respectively. A TY torus is illustrated in Figure 3-1a. Note that the input parameters $\bar{x}$ $\bar{y}$ $\bar{z}$ a b c specify the ellipse

$$\frac{s^2}{b^2}+\frac{(r-a)^2}{c^2}=1$$

rotated about the *s*–axis in the (*r*,*s*) cylindrical coordinate system (Figure 3-1b) whose origin is at in the *x*, *y*, *z* system. In the case of a TY torus,

$$s=(y-\bar{y})$$

and $$r=\sqrt{(x-\bar{x})^2+(z-\bar{z})^2}$$

A torus is degenerate if $|a|<c$ where $0<a<c$ produces the outer surface (Figure 3-1c), and $-c<a<0$ produces the inner surface (Figure 3-1d).

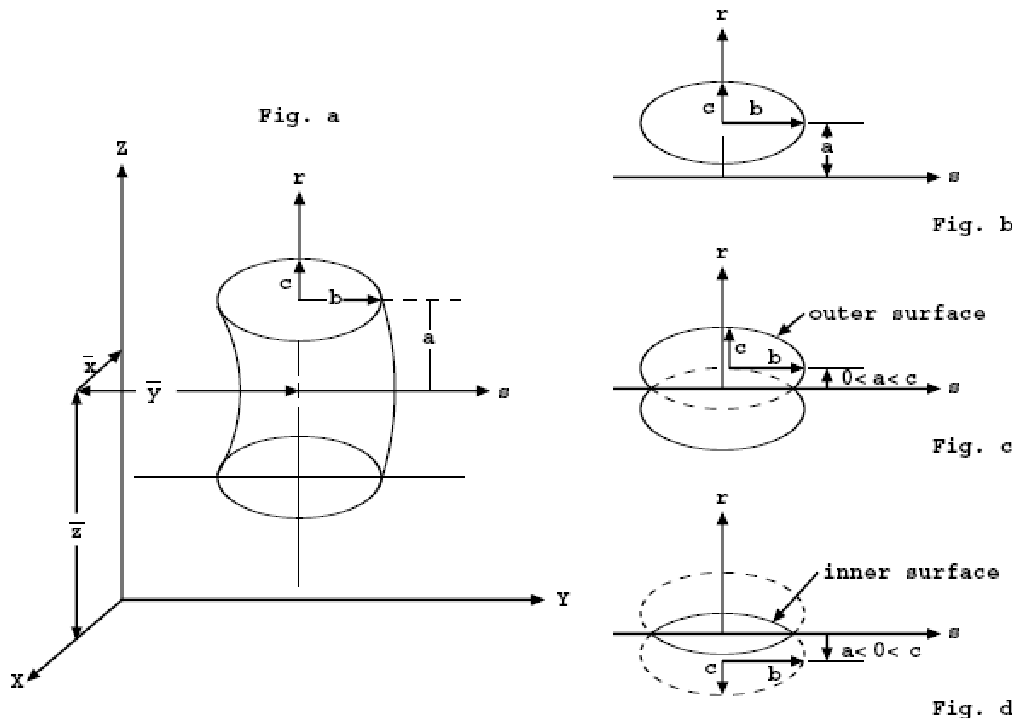


Figure 3-1. Torus

Coordinate transformations for tori are limited to those in which each axis of the auxiliary coordinate system is parallel to an axis of the main system.

Warning: MCNP6 may incorrectly compute the internal volume of tori that exhibit a large ratio of major to minor axes. A warning message is printed when the ratio of the major to minor axes exceeds 2000.

Example 1:

```
1      PY  3
```

Surface `1` describes a plane normal to the *y*-axis at y=`3` with positive sense for all points with y>`3`.

Example 2:

```
3      K/Y  0   0   2   0.25   1
```

Surface `3` is a cone whose vertex is at (x,y,z)=(`0`,`0`,`2`) and whose axis is parallel to the *y*-axis. The tangent t of the opening angle of the cone is 0.5 (note that t^2 is entered) and only the positive (right hand) sheet of the cone is used. Points outside the cone have a positive sense.

Example 3:

```
11     GQ  1  0.25  0.75   0   –0.866
              0  –12   –2   3.464   39
```

This is a cylinder of radius 1 cm whose axis is in a plane normal to the *x*-axis at *x*=6, displaced 2 cm from the *x*-axis and rotated 30 degrees about the *x*-axis off the *y*-axis toward the *z*-axis. The sense is positive for points outside the cylinder. Such a cylinder would be much easier to specify by first defining it in an auxiliary coordinate system where it is symmetric about a coordinate axis and then using the TR*n* card (see Section 3.3.1.3) to define the relationship between the basic and auxiliary coordinate systems. The input would then be

```
11  7  CX  1
*TR7    6  1  –1.732   0  30  60
```

3.2.2.2 AXISYMMETRIC SURFACES DEFINED BY POINTS

Surface cards of the type X, Y, and Z can be used to describe surfaces by coordinate points rather than by equation coefficients as in the previous section. The surfaces described by these cards must be symmetric about the *x*-, *y*-, or *z*-axis, respectively, and, if the surface consists of more than one sheet, the specified coordinate points must all be on the same sheet.

Each of the coordinate pairs defines a geometrical point on the surface. On the Y card, for example, the entries may be

j Y y_1 r_1 y_2 r_2

where $r_i = \sqrt{\left(x_i^2 + z_i^2\right)}$ and y_i is the coordinate of point *i*. If one coordinate pair is used, a plane (PX, PY, or PZ) is defined. If two coordinate pairs are used, a linear surface (PX, PY, PZ, CX, CY, CZ, KX, KY, or KZ) is defined. If three coordinate pairs are used, a quadratic surface (PX, PY, PZ, SO, SX, SY, SZ, CX, CY, CZ, KX, KY, KZ, or SQ) is defined.

When a cone is specified by two points, a cone of only one sheet is generated.

The senses of these surfaces (except SQ) are determined by the code to be identical to the senses one would obtain by specifying the surface by equations. For SQ, the sense is defined so that points sufficiently far from the axis of symmetry have positive sense. Note that this is different from the equation-defined SQ, where the user could choose the sense freely.

Form: *j n* A *list*

Table 3-5. Axisymmetric Surfaces

Input Parameter	Description
`j`	**Surface number assigned by user.** **Restriction:** `1≤j≤99,999,999` **Restriction:** `1≤j≤999` **if** `j` **is the surface number of a repeated structure or if surface** `j` **defines a surface transformed with** `TR`**. See Section 3.3.1.4.**
`n`	**Transformation number on** `TRn` **card.** **If** `n` **is absent, then no coordinate transformation is specified.**
`a`	**The letter** `X`**,** `Y`**, or** `Z`**.**
`list`	**One to three coordinate pairs.**

Example 1:

```
12   X   7  5   3  2   4  3
```

This input describes a surface symmetric about the *x*–axis, which passes through the three (*x*,*r*) points (7,5), (3,2), and (4,3). This surface is a hyperboloid of two sheets, converted in MCNP6 to its equivalent

```
12   SQ   −0.083333333 1 1 0 0 0 68.52083 −26.5 0 0.
```

Example 2:

```
12   Y   1  2   1  3   3  4
```

These data describe two parallel planes at *y*=1 and *y*=3 and is a fatal error because the requirement that all points be on the same sheet is not met.

Example 3:

```
12   Y   3  0   4  1   5  0
```

This input describes a 1-cm-radius sphere with center at (*x*,*y*,*z*)=(0,4,0).

Example 4:

```
12   Z   1  0   2  1   3  4
```

This surface is rejected because the points are on two different sheets of the hyperboloid

$$x^2 + y^2 - 7z^2 + 20z - 13 = 0 \quad .$$

However, the surface

```
12   Z   2  1   3  4   5  9.380832   ,
```

which has the same surface equation as above is accepted because all coordinates lie on a single surface, the right sheet of the hyperboloid.

Example 5:

```
1  0     1  −2  3         $ cell 1

1   Y     −3  2   2  1           $ surface 1
2   Y      2  3   3  3   4  2    $ surface 2
3   Y      2  1   3  1   4  2    $ surface 3
```

This final example defines a cell bounded by a cone, hyperboloid, and an ellipsoid. The three surfaces define the donut-like cell that is symmetric about the *y*-axis. A cross section of this cell is seen in Figure 3-2. To plot this view, type `PX=0 EX=5`. One surface goes through the points (-3,2) and (2,1). The second surface goes through (2,3), (3,3), and (4,2). The last surface is defined by the points (2,1), (3,1), and (4,2). These coordinate points are in the form (*y*,*r*). Using these cards, MCNP6 indicates that surface 1 is a cone of one sheet, surface 2 is an ellipsoid, and surface 3 is a hyperboloid of one sheet. The equation coefficients for the standard surface equations are printed out for the various surfaces when the `PRINT` input card or execution option is used. For example, an `SQ` card defining surface 3 is

```
3   SQ    1  -1.5  1  0  0  0  −0.625  0  2.5  0
```

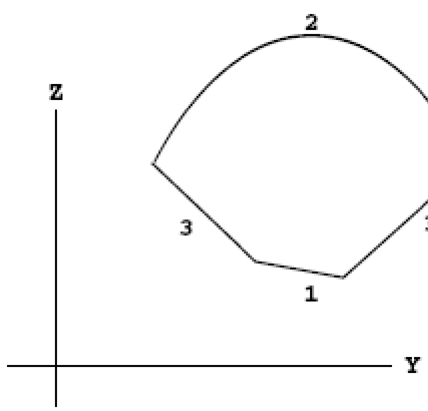


Figure 3-2. A geometry plot of Cell 1 of Example 5.

3.2.2.3 GENERAL PLANE DEFINED BY THREE POINTS

If there are four entries on a `P` card, they are assumed to be the general plane equation coefficients as in Table 3-4. If there are more than four entries, they give the coordinates of three points lying in the desired plane. The code uses the coordinate points to determine the required surface coefficients to produce the plane

$$Ax + By + Cz - D = 0 \quad .$$

The sense of the plane is determined by requiring the origin to have negative sense. If the plane passes through the origin (D=0), the point (0,0,∞) has positive sense. If this fails (D=C=0), the point (0,∞,0) has positive sense. If this fails (D=C=B=0), the point (∞,0,0) has positive sense. If this fails, the three points lie in a line and a fatal error is issued.

Form: *j* *n* P x_1 y_1 z_1 x_2 y_2 z_2 x_3 y_3 z_3

Table 3-6. General Plane Defined by Three Points

Input Parameter	Description
j	**Surface number assigned by the user.** **Restriction: 1≤*j*≤99,999,999** **Restriction: 1≤*j*≤999 if *j* is the surface number of a repeated structure or if surface *j* defines a surface transformed with TR. See Section 3.3.1.4.**
n	**If *n*>0, specifies transformation number *n* of a TR*n* card.** **If *n*<0, specifies surface *j* is periodic with surface *n*.** **If *n* is absent, then no coordinate transformation is specified.**
P	**Mnemonic that indicates this is a planar surface. (See Table 3-4.)**
x_i, y_i, z_i	**Coordinates of three points that define the plane.**

3.2.2.4 SURFACES DEFINED BY MACROBODIES

Using a combinatorial-geometry-like macrobody capability is an alternative method of defining cells and surfaces. The combinatorial geometry bodies available are similar to those in the Integrated Tiger Series (ITS) [HAL92] codes. The macrobodies can be mixed with the standard cells and surfaces. The macrobody surface is decomposed internally by MCNP6 into surface equations and the facets are assigned individual numbers according to a predetermined sequence. The assigned numbers are the number selected by the user followed by a decimal point and 1, 2, … .The facets can be used for tallying, tally segmentation, other cell definitions, SDEF sources, etc. They cannot be used on the surface source read and write cards (SSR/SSW), the surface flagging card (SF), PTRAC, or MCTAL files.

The space inside a macrobody has a negative sense with respect to the macrobody surface and all its facets. The space outside a body has a positive sense. The sense of a facet is the sense assigned to it by the macrobody "master" cell and the facet retains that assigned sense if it appears in other cell descriptions and must be properly annotated. More information regarding facets is provided in Section 3.2.2.4.11.

3.2.2.4.1 BOX—ARBITRARILY ORIENTED ORTHOGONAL BOX

Form: BOX v_x v_y v_z $a1_x$ $a1_y$ $a1_z$ $a2_x$ $a2_y$ $a2_z$ $a3_x$ $a3_y$ $a3_z$

Table 3-7. Macrobody Box (BOX)

Input Parameter	Description
v_x v_y v_z	**The x,y,z coordinates of a corner of the box.**
$a1_x$ $a1_y$ $a1_z$	**Vector of 1st side from the specified corner coordinates.**
$a2_x$ $a2_y$ $a2_z$	**Vector of 2nd side from the specified corner coordinates.**
$a3_x$ $a3_y$ $a3_z$	**Vector of 3rd side from the specified corner coordinates.**

Note: All corner angles are 90˚.

Example:

```
BOX    -1  -1  -1   2  0  0   0  2  0   0  0  2
```

This input represents a cube centered at the origin, 2 cm on a side, with sides parallel to the major axes.

3.2.2.4.2 RPP—RECTANGULAR PARALLELEPIPED

Form: RPP x_{min} x_{max} y_{min} y_{max} z_{min} z_{max}

Table 3-8. Macrobody Rectangular Parallelepiped (RPP)

Input Parameter	Description
x_{min} x_{max}	**Termini of box sides normal to the *x*-axis.**
y_{min} y_{max}	**Termini of box sides normal to the *y*-axis.**
z_{min} z_{max}	**Termini of box sides normal to the *z*-axis.**

Note: RPP surfaces will only be normal to the *x*-, *y*-, and *z*-axes; *x*,*y*,*z* values are relative to the origin.

Example:

```
RPP    -1  1  -1  1  -1  1
```

This specification is equivalent to the BOX example above. The rectangular parallelepiped is centered at the origin. Each side is 2 cm long and parallel to one of the major axes.

3.2.2.4.3 SPH—SPHERE

Form: SPH v_x v_y v_z r

Table 3-9. Macrobody Sphere (SPH)

Input Parameter	Description
v_x v_y v_z	The x,y,z coordinates of the center of the sphere.
r	Radius of sphere.

3.2.2.4.4 RCC—RIGHT CIRCULAR CYLINDER

Form: `RCC` v_x v_y v_z h_x h_y h_z r

Table 3-10. Macrobody Right Circular Cylinder (RCC)

Input Parameter	Description
v_x v_y v_z	**The x,y,z coordinates at the center of the base for the right circular cylinder.**
h_x h_y h_z	**Right circular cylinder axis vector, which provides both the orientation and the height of the cylinder.**
r	**Radius of right circular cylinder.**

Example:

```
RCC    0 -5 0   0 10 0   4
```

This input specification represents a 10-cm-high can about the *y*-axis with its base plane at *y*=-5 and having a radius of 4 cm.

3.2.2.4.5 RHP OR HEX—RIGHT HEXAGONAL PRISM

Form: `RHP` v_1 v_2 v_3 h_1 h_2 h_3 r_1 r_2 r_3 s_1 s_2 s_3 t_1 t_2 t_3

Table 3-11. Macrobody Right Hexagonal Prism (HEX or RHP)

Input Parameter	Description
v_1 v_2 v_3	**The *x,y,z* coordinates of the bottom of the hexagonal prism.**
h_1 h_2 h_3	**Vector from the bottom to the top of the hexagonal prism. For a z-hex with height h, h_1, h_2, and h_3= `0 0` h .**
r_1 r_2 r_3	**Vector from the axis to the center of the 1st facet. For a pitch 2p facet normal to *y*-axis, r_1, r_2, and r_3= `0` p `0` .**
s_1 s_2 s_3	**Vector to center of the 2nd facet.**
t_1 t_2 t_3	**Vector to center of the 3rd facet.**

Note: Differs from ITS-ACCEPT [HAL92] format.

Example:

```
RHP    0 0 -4  0 0 8  0 2 0
```

This input specification represents a hexagonal prism about the *z*-axis whose base plane is at *z*=-4 with a height of 8 cm and whose first facet is normal to the *y*-axis at *y*=2.

3.2.2.4.6 REC—RIGHT ELLIPTICAL CYLINDER

Form: REC $v_x\ v_y\ v_z\quad h_x\ h_y\ h_z\quad v1_x\ v1_y\ v1_z\quad v2_x\ v2_y\ v2_z$

Table 3-12. Macrobody Right Elliptical Cylinder (REC)

Input Parameter	Description
$v_x\ v_y\ v_z$	**The x,y,z coordinates of the cylinder bottom.**
$h_x\ h_y\ h_z$	**Cylinder axis height vector.**
$v1_x\ v1_y\ v1_z$	**Ellipse major axis vector (normal to $h_x\ h_y\ h_z$).**
$v2_x\ v2_y\ v2_z$	**Ellipse minor axis vector (orthogonal to vectors $\vec{h}$ and $\overrightarrow{v1}$).**

Note: If there are 10 entries instead of 12, the 10th entry is the minor axis radius, where the direction is determined from the cross product of $\vec{h}$ and $\overrightarrow{v1}$.

Example:

```
REC    0 -5 0  0 10 0  4 0 0  2
```

This input specification represents a 10-cm-high elliptical cylinder about the *y*-axis with the center of the base at *x*,*y*,*z*=0,-5,0 and with major radius 4 cm in the *x* direction and minor radius 2 cm in the *z* direction.

3.2.2.4.7 TRC—TRUNCATED RIGHT-ANGLE CONE

Form: TRC $v_x\ v_y\ v_z\quad h_x\ h_y\ h_z\quad r_1\quad r_2$

Table 3-13. Macrobody Truncated Right-Angle Cone (TRC)

Input Parameter	Description
$v_x\ v_y\ v_z$	**The x,y,z coordinates of the cone bottom.**
$h_x\ h_y\ h_z$	**Cone axis height vector.**
r_1	**Radius of lower cone base.**
r_2	**Radius of upper cone base, where $r_1>r_2$.**

Example:

```
TRC    -5 0 0  10 0 0  4  2
```

This input specification represents a 10-cm-high truncated cone about the *x*-axis with the center of the 4-cm radius base at *x*,*y*,*z*=`-5,0,0` and with the 2-cm radius top at *x*,*y*,*z*=`5,0,0`.

3.2.2.4.8 ELL—ELLIPSOID

Form: `ELL` $v1_x$ $v1_y$ $v1_z$ $v2_x$ $v2_y$ $v2_z$ *rm*

Table 3-14. Macrobody Ellipsoid (ELL)

Input Parameter	Description
$v1_x$ $v1_y$ $v1_z$	**If *rm*>0, the coordinates of the 1st focus.** **If *rm*<0, the coordinates of the center of the ellipsoid.**
$v2_x$ $v2_y$ $v2_z$	**If *rm*>0, the coordinates of the 2nd focus.** **If *rm*<0, major axis vector (vector from the center of the ellipsoid through a focus to the vertex; length = major radius).**
rm	**If *rm*>0, major radius length.** **If *rm*<0, minor radius length.**

Examples:

```
ELL    0. 0. -2.236068   0. 0. 2.236068    3.
ELL    0. 0.  0.         0. 0. 3.         -2
```

These input specifications represent an ellipsoid centered at the origin with major axis of length 6 cm in the *z* direction and minor axis of length 4 cm normal to the *z* axis. Note that the major and minor radii are half the lengths of the major and minor axes, respectively. Also note that the ellipsoid macrobody is a surface of revolution about the major axis, but the major radius may be smaller than the minor radius.

3.2.2.4.9 WED—WEDGE

Form: `WED` v_x v_y v_z $v1_x$ $v1_y$ $v1_z$ $v2_x$ $v2_y$ $v2_z$ $v3_x$ $v3_y$ $v3_z$

Table 3-15. Macrobody Wedge (WED)

Input Parameter	Description
v_x v_y v_z	**The x,y,z coordinates of wedge vertex.**
$v1_x$ $v1_y$ $v1_z$	**Vector of 1st side of triangular base.**
$v2_x$ $v2_y$ $v2_z$	**Vector of 2nd side of triangular base.**
$v3_x$ $v3_y$ $v3_z$	**Height vector.**

Note: A right-angle wedge has a right triangle for a base defined by $\vec{v1}$ and $\vec{v2}$ and a height $\vec{v3}$. The vectors $\vec{v1}$, $\vec{v2}$, and $\vec{v3}$ are orthogonal to each other.

Example:

```
WED    0 0 -6  4 0 0  0 3 0  0 0 12
```

This input specification represents a 12-cm-high wedge with vertex at x,y,z=`0,0,-6`. The triangular base and top are a right triangle with sides of length 4 cm in the x direction and 3 cm in the y direction and hypotenuse of length 5 cm.

3.2.2.4.10 ARB—ARBITRARY POLYHEDRON

Specification of an Arbitrary Polyhedron

There must be eight triplets of entries input for the ARB to describe the (x,y,z) of the corners, although some may not be used (just use triplets of zeros). These are followed by six more entries, n_i, which follow a prescribed convention: each entry is a four-digit integer that defines a side of the ARB in terms of the corners for the side. For example, the entry 1278 would define this plane surface to be bounded by the first, second, seventh, and eighth triplets (or equivalently, corners). Since three points are sufficient to determine the plane, only the first, second, and seventh corners would be used in this example to determine the plane. The distance from the plane to the fourth corner (corner 8 in the example) is determined by MCNP6. If the absolute value of this distance is greater than 1.0E-6, an error message is given and the distance is printed in the OUTP file along with the (x,y,z) that would lie on the plane. If the fourth digit is zero, the fourth point is ignored. For a four-sided ARB, four non-zero four-digit integers (last digit is zero for four-sided since there are only three corners for each side) are required to define the sides. For a five-sided ARB, five non-zero four-digit integers are required, and six non-zero four-digit integers are required for a six-sided ARB. Since there must be 30 entries altogether for an ARB (or MCNP6 gives an error message), the last two integers are zero for the four-sided ARB and the last integer is zero for a five-sided ARB.

Form: ARB $a_x\ a_y\ a_z\quad b_x\ b_y\ b_z\ \ldots\ h_x\ h_y\ h_z\quad n_1\ n_2\ n_3\ n_4\ n_5\ n_6$

Table 3-16. Macrobody Arbitrary Polyhedron (ARB)

Input Parameter	Description
$a_x\ a_y\ a_z$ $b_x\ b_y\ b_z$ $c_x\ c_y\ c_z$ $d_x\ d_y\ d_z$ $e_x\ e_y\ e_z$ $f_x\ f_y\ f_z$ $g_x\ g_y\ g_z$ $h_x\ h_y\ h_z$	**The x-, y-, z-coordinates of the 1st through 8th corners of the polyhedron. There must be eight x,y,z triplets to describe the eight corners of the polyhedron.**
$n_1\ \ldots\ n_6$	**Four-digit numbers describing a side of the polyhedron in terms of its corresponding corners. [E.g., n_1=1278 is a plane/side bounded by corners 1, 2, 7, and 8 (a, b, g, and h)].**

Example:

```
ARB    -5 -10 -5   -5 -10 5   5 -10 -5   5 -10 5   &
        0 12 0      0 0 0     0 0 0      0 0 0    &
       1234  1250  1350  2450  3450  0
```

This input specification represents a five-sided polyhedron with corners at x, y, z = (-5,-10,-5) (-5,-10,5) (5,-10,-5) (5,-10,5) (0,12,0), and planar facets constructed from corners 1234, etc. (Note the zero entry for the 6th facet.)

3.2.2.4.11 MACROBODY FACETS

The facets of the macrobodies are numbered sequentially and can be used on other MCNP6 cards. BOX and RPP can be infinite in a dimension, in which case those two facets are skipped and the numbers of the remaining facets are decreased by two. RHP can be infinite in the axial dimension in which case facets 7 and 8 do not exist. Facet numbering can be displayed graphically with MBODY=OFF in the geometry plotter. The order of the facet numbering presented by macrobody type, is provided in the table below.

MACROBODY FACET DESCRIPTIONS		
Macrobody Type	**Facet Number**	**Facet Description**
BOX	1 2 3 4 5 6	Plane normal to end of $a1_x$ $a1_y$ $a1_z$ Plane normal to beginning of $a1_x$ $a1_y$ $a1_z$ Plane normal to end of $a2_x$ $a2_y$ $a2_z$ Plane normal to beginning of $a2_x$ $a2_y$ $a2_z$ Plane normal to end of $a3_x$ $a3_y$ $a3_z$ Plane normal to beginning of $a3_x$ $a3_y$ $a3_z$
RPP	1 2 3 4 5 6	Plane x_{max} Plane x_{min} Plane y_{max} Plane y_{min} Plane z_{max} Plane z_{min}
SPH		Treated as a regular surface so no facet
RCC	1 2 3	Cylindrical surface of radius r Plane normal to end of h_x h_y h_z Plane normal to beginning of h_x h_y h_z
RHP or HEX	1 2 3 4 5 6 7 8	Plane normal to end of r_1 r_2 r_3 Plane opposite facet 1 Plane normal to end of s_1 s_2 s_3 Plane opposite facet 3 Plane normal to end of t_1 t_2 t_3 Plane opposite facet 5 Plane normal to end of h_1 h_2 h_3 Plane normal to beginning of h_1 h_2 h_3

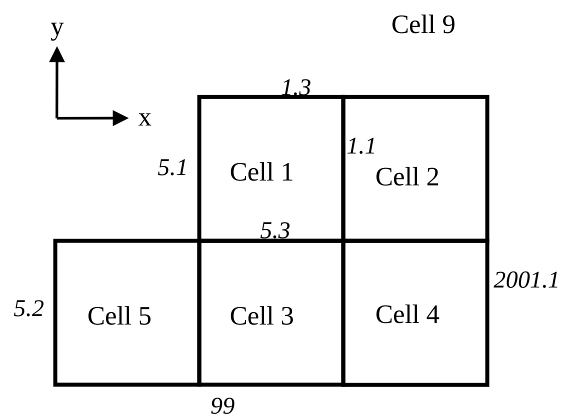
MACROBODY FACET DESCRIPTIONS		
Macrobody Type	**Facet Number**	**Facet Description**
REC	1 2 3	Elliptical cylinder Plane normal to end of h_x h_y h_z Plane normal to beginning of h_x h_y h_z
TRC	1 2 3	Conical surface Plane normal to end of h_x h_y h_z Plane normal to beginning of h_x h_y h_z
ELL		Treated as regular surface, so no facet
WED	1 2 3 4 5	Slant plane including top and bottom hypotenuses Plane including vectors ***v2*** and ***v3*** Plane including vectors ***v1*** and ***v3*** Plane including vectors ***v1*** and ***v2*** at end of ***v3*** (top triangle) Plane including vectors ***v1*** and ***v2*** at beginning of ***v3*** (bottom triangle, including vertex point)
ARB	1 2 3 4 5 6	Plane defined by corners *n*1 Plane defined by corners *n*2 Plane defined by corners *n*3 Plane defined by corners *n*4 Plane defined by corners *n*5 Plane defined by corners *n*6

Example:

The following input file describes five cells and illustrates a combination of the various body and cell/surface descriptions. In the figure, surface numbers are in italics alongside the planes they define. Note that the cell and surface numbers do not have to start with 1 or be consecutive.

```
3  0 –1.2    –1.1  1.4 –1.5 –1.6 99
4  0  1.1 –2001.1 –5.3 –5.5 –5.6 –5.4
5  0  –5
1  0  –1
2  like 1 but trcl = (2 0 0)
9  0 (–5.1:1.3:2001.1:–99:5.5:5.6) #5

5  rpp  –2 0 –2 0 –1 1
1  rpp   0 2  0 2 –1 1
99  py  –2
```



Alternative descriptions for cell 3:

```
3  0  5.1 –1.1 –5.3 –5.5 –5.6 99
3  0  5.1 –1.1  1.4 –5.5 –5.6 –5.4
3  0 –1.2 –1.1 –5.3 –5.5 –5.6 –5.4
```

3.3 DATA CARDS

All MCNP6 input cards other than those for cells and surfaces are entered after the blank card delimiter following the surface card block. The mnemonic must begin within the first five columns.

Only the cards listed in Section 2.2 are allowed in a continue-run input file. No data card can be used more than once with the same number or particle type designations. For example, `M1` and `M2` are acceptable, as are `CUT:N` and `CUT:P`, but two `M1` cards or two `CUT:N` cards are disallowed.

DATA CARD CATEGORIES	
Description	**Section**
Geometry Data Cards	3.3.1
Material Data Cards	3.3.2
Physics Data Cards	3.3.3
Source Specification Data Cards	3.3.4
Tally Specification Data Cards	3.3.5
Variance Reduction Data Cards	3.3.6
Problem Termination, Output Control, and Peripheral Data Cards	3.3.7

3.3.1 Data Cards Related to Geometry

INDEX OF DATA RELATED TO GEOMETRY		
Mnemonic	**Description**	**Section**
VOL	Cell Volume	3.3.1.1
AREA	Surface Area	3.3.1.2
TR	Coordinate Transformation	3.3.1.3
TRCL	Cell Transformation	3.3.1.4
U	Universe	3.3.1.5.1
LAT	Lattice	3.3.1.5.2
FILL	Fill	3.3.1.5.3
URAN	Stochastic Geometry for HTGRs	3.3.1.5.4
DAWWG	Deterministic Automated Weight-Window Generator	3.3.1.6.1
DM	ZAID Aliases for Deterministic Materials	3.3.1.6.1
EMBED, EMBEE, EMBEB, EMBEM, EMBTB, EMBTM	Embedded Geometry	3.3.1.6.2

3.3.1.1 VOL CELL VOLUME

Volumes or masses of cells are required for some tallies. MCNP6 calculates the volumes of all cells that are rotationally symmetric (generated by surfaces of revolution) about any axis, even a skew axis. It will also calculate the volumes of polyhedral cells. As a by-product of the volume calculation, areas and masses are also calculated. These volumes, areas, and masses can be printed in the OUTP file by using the `PRINT` card. The user can enter values on the `VOL` card for the volume of any cell and these values, instead of the calculated values, will be used for tally purposes. If a cell volume required for a tally cannot be calculated and is not entered on the `VOL` or `SD`*n* cards, a fatal error message is printed.

Form 1 (cell card entry): `VOL=`*x*

Form 2 (data card): `VOL [NO]` x_1 x_2 ... x_j

Table 3-17. Cell Volume Card/Keyword (VOL)

Input Parameter	Description
x	**Volume of cell.**
x_j	**Volume of cell *j* where *j*= 1, 2, ..., and the number of entries is equal to the number of cells in the problem. (See Note 1)**
`NO`	**No volumes or areas are calculated. (See Note 2.)**

Default: Use MCNP6-calculated volumes. MCNP6 attempts to calculate the volume of all cells unless the keyword "`NO`" appears on the `VOL` card.

Use: Use if required cell volumes are not properly calculated. Provides an alternative way to enter volumes required by tallies. Normally the `SD`*n* (Section 3.3.5.15) card is used. The `VOL` card can be used only for cell volumes; the `SD`*n* card can be used for cell and segment volumes or masses.

Note 1: If the number of entries does not equal the number of cells in the problem, it is a fatal error. Use the jump (*n*`J`) feature to skip over cells for which you do not want to enter values.

Note 2: When the `NO` entry appears on the `VOL` card, MCNP6 bypasses the volume calculation altogether. The x_j entries following `NO` are optional. If present, x_j entries are the volume values the code will use. If no value is entered for a cell on the `VOL` card, the calculated volume is used.

Stochastic Volume and Area Calculation

MCNP6 cannot calculate the volumes and areas of asymmetric, non-polyhedral, or infinite cells. Also, in very rare cases, the volume and area calculation can fail because of round-off errors. For these cases, when neither MCNP6 nor the user can calculate the volume or area, a stochastic estimation is possible by ray tracing. The procedure follows:

1. Void out all materials in the problem by inserting a `VOID` card into the data card portion of the input.
2. Set all nonzero importance to one and all positive weight windows to zero.
3. Use a planar source with a source weight equal to the surface area to flood the geometry with particles. This setup will cause the particle flux throughout the geometry to statistically approach unity. Perhaps the best way to do a stochastic volume estimation is to use an inward-directed, biased cosine source on a spherical surface with weight equal to πr^2 [CAS53].
4. Use the cell flux tally (`F4`) to tabulate volumes and the surface flux tally (`F2`) to tabulate areas. The cell flux tally is inversely proportional to cell volume. Thus in cells whose volumes are known, the unit flux will result in a tally of unity and, in cells whose volumes are uncalculated, the unit flux will result in a tally of volumes. Similarly, the surface flux tally is inversely proportional to area so that the unit flux will result in a tally of unity wherever the area is known and a tally of area wherever it is unknown.
5. For any tally volume or area that MCNP6 cannot calculate, use the `AREA`, `VOL`, or `SD` card to assign a value of 1.0 to the area(s) and/or volume(s) of the surface(s) or cell(s) of interest.

3.3.1.2 AREA SURFACE AREA

MCNP6 calculates the area of surfaces as a by-product of the volume calculation. If the volume of all cells on either side of the surface can be calculated, the area of the surface will be calculated. Otherwise, the area calculation will fail.

Form (data card only): `AREA` x_1 x_2 ... x_j ...

where x_j is the area of surface j where j= 1, 2, ..., and the number of entries equals the total number of surfaces in the problem. (See Notes 1 and 2.)

Default: MCNP6 attempts to calculate the area of all surfaces.

Use: Use if required surface areas for `F2` tallies are not properly calculated. Provides an alternative way to enter areas required by tallies. Normally the `SD`*n* (Section 3.3.5.15) card is used. The `AREA` card can be used only for areas of whole surfaces; the `SD`*n* card can be used for area of surface segments as well as whole surfaces.

Note 1: If the number of entries does not equal the number of surfaces in the problem, it is a fatal error. Use the jump (*n*`J`) feature to skip over surfaces for which you do not want to enter values.

Note 2: If no value is entered for a surface on the AREA card, the calculated area, if any, is used. A fatal error occurs if an area is required for tallying purposes and is not available either from the MCNP6 calculation or from and AREA or SD*n* card.

3.3.1.3 TR COORDINATE TRANSFORMATION

Coordinate transformations in MCNP6 can be used to simplify the geometrical description of surfaces. They also may be used to relate the coordinate system of a surface source problem to the coordinate system of the problem that wrote the surface source file and to position universes within container cells. (See the surface source SSR card in Section 3.3.4.8 or the discussion of universes in Section 3.3.1.5.1.) Periodic boundary surfaces cannot have surface transformations.

To use a transformation to simplify the description of a surface, choose an auxiliary coordinate system in which the description of the surface is easy, include a transformation number *n* on the surface card, and specify the transformation on a TR*n* card. See Section 4.1.2 for an example showing how much easier it is to specify a skewed cylinder this way than as a GQ surface. Often a whole cluster of cells will have a common natural coordinate system. All of their surfaces can be described in that system and then translated and/or rotated to a new system by a single TR*n* card.

Form (data card):

TR*n* o_1 o_2 o_3 *xx′ yx′ zx′ xy′ yy′ zy′ xz′ yz′ zz′ m*

Table 3-18. Surface Coordinate Transformation Card (TR)

Input Parameter	Description
n	**Number assigned to the transformation.** **Restriction: 1 ≤ *n* ≤ 999 for surface transformations, no limit for cell transformations using TRCL=n**
o_1 o_2 o_3	**Displacement vector of the transformation. (DEFAULT: 0 0 0)**
xx′ yx′ zx′ *xy′ yy′ zy′* *xz′ yz′ zz′*	**Rotation matrix of the transformation. (DEFAULT: 1 0 0 0 1 0 0 0 1) (See Notes 1, 2, and 3.)**
m	**If *m*=1, then the displacement vector is the location of the origin of the auxiliary coordinate system, defined in the main system. (DEFAULT)** **If *m*=-1, then the displacement vector is the location of the origin of the main coordinate system, defined in the auxiliary system.**

Default: TR*n* 0 0 0 1 0 0 0 1 0 0 0 1 1

Use: Optional. Convenient for many geometries. TR cards used in a surface definition must have numbers 1 <= n <= 999. TR card used for cell transformations via TRCL=n can have any number.

Reminder: When a transformation is applied to a cell, MCNP6 generates a set of new unique surface numbers based on the original surface numbers. The number of the generated surface is equal to the number of original surface plus 1000 times the number of the cell. This formula creates generated surface numbers that are predictable and can be used on other cell cards and on tally cards. This method, however, limits cell numbers to no more than 6 digits and the original surface numbers to no more than 3 digits.

Note 1: If the symbol `*TR` is used, the rotation matrix entries are angles in degrees instead of cosines of the angles.

Note 2: The rotation matrix entries specify the relationship between the directions of the axes of the two coordinate systems. For example, the value of `xx'` is the cosine of the angle (or, if the optional asterisk is used, the angle in degrees ranging from 0° to 180°) between the *x*-axis of the main coordinate system and the *x*′-axis of the auxiliary coordinate system. Similarly, `yx'` is the cosine of the angle between the *y*-axis of the main coordinate system and the *x*′-axis of the auxiliary system.

The meaning of the rotation matrix entries do not depend on the value of *m*. It is usually not necessary to enter all of the elements of the matrix. The following patterns are acceptable:

1. All nine elements. (Required if one of the systems is right-handed and the other is left-handed.)
2. Two of the three vectors either way in the matrix (6 values). MCNP6 will create the third vector by cross product.
3. One vector each way in the matrix (5 values). The component in common must be less than 1. MCNP6 will fill out the matrix by the Eulerian angles scheme.
4. One vector (3 values). MCNP6 will create the other two vectors in some arbitrary way. (Appropriate when the auxiliary coordinate system is being used to describe a set of surfaces that are all surfaces of rotation about a common skew axis.)
5. None. MCNP6 will create the identity matrix. (Appropriate when the transformation is a pure translation.)

A vector consists of the three elements in either a row or a column in the matrix. In all cases, MCNP6 cleans up any small non-orthogonality and normalizes the matrix. In this process, exact vectors like (1,0,0) are left unchanged. A warning message is issued if the non-orthogonality is more than about 0.001 radian.

Note 3: A cone of one sheet can be rotated only from being on or parallel to one coordinate axis to being on or parallel to another coordinate axis (multiples of 90°). A cone of one sheet can have any origin displacement vector appropriate to the problem. A cone of two sheets can be transformed anywhere. A cone of two sheets with an ambiguity surface in the cell description to cut the two-sheet cone in half (so that the cell appears as one sheet) can be transformed. The ambiguity surface must have the same transformation number as the cone of two sheets. Ambiguity surfaces are described in Section 2.6.2 of the MCNP5 Theory Manual[X-503a].

Example 1:

```
  17  4  RCC   0 0 0   0 12 0   5
*TR4           20 0 0  45 -45 90  135 45 90  90 90 0
```

In this example, surface `17` is transformed via transformation `4` causing it to be displaced to x,y,z=`20,0,0` and rotated 45° counter-clockwise with respect to x and y. If the rotational matrix is left incomplete, MCNP6 will calculate what it should be, but completeness is the only way to be sure you get what you want and get error messages if you are wrong.

Example 2:

```
11 4 PX    5
TR4           7 0.9 1.3  0 –1 0  0 0 1  –1 0 0
```

Surface 11 is set up in an auxiliary coordinate system that is related to the main coordinate system by transformation number 4. MCNP6 will produce coefficients in the main coordinate system as if surface 11 had been entered as

```
11 P      0  -1.0  4.1
```

It will not produce

```
11 PY     4.1 .
```

This surface, represented by `PY` as shown in the line above, has the wrong sense. More examples of the transformation capability appear in Section 4.1.2.

3.3.1.4 TRCL CELL COORDINATE TRANSFORMATION

A cell transformation (`TRCL` cell parameter) may be applied to a cell using either of two formats. The first `TRCL` entry form is an integer that is interpreted as the number of a `TR`*n* card that contains transformation information for all of the surfaces defining the cell. The associated `TR`*n* card is located in the data card section of the INP file. An alternate entry form for `TRCL` allows the actual transformation to be entered on the cell card following the `TRCL` mnemonic, enclosed by parentheses. If the actual transformation is entered, all the rules applying to the `TR` card (Section 3.3.1.3) are valid.

Although a cell transformation can be applied to a standard cell, the utility of the `TRCL` parameter becomes most evident when applied to repeated structures. (See Section 3.3.1.5.) Assume your analysis model contains several cells identical in size and shape but located at multiple places in the geometry. You can describe the surfaces that describe these cells once and then use the `TRCL` keyword to position the identical cells in various locations and/or orientations. The `TRCL` feature is especially valuable when these cells are filled with the same universe. If the surfaces of these filled cells and the surfaces of the cells belonging to the universe that fills them are all described in the same auxiliary coordinate system, then a single transformation will completely define the interior of all these filled cells. That is, the cells of the universe will inherit the transformation of the cells they fill.

Form 1 (cell card entry): `TRCL=`*n*

Form 2 (cell card entry):

`TRCL=(`o_1 o_2 o_3 *xx′ yx′ zx′ xy′ yy′ zy′ xz′ yz′ zz′ m*`)`

Table 3-19. Cell Transformation Keyword (TRCL)

Input Parameter	Description
n	**Number of the transformation corresponding to a `TR`*n* card in the data section of the input file. (DEFAULT: *n*=`0`)**
o_1 o_2 o_3	**Displacement vector of the transformation. (DEFAULT: `0 0 0`)**
xx′ yx′ zx′ *xy′ yy′ zy′* *xz′ yz′ zz′*	**Rotation matrix of the transformation. (DEFAULT: `1 0 0 0 1 0 0 0 1`) (See the description of the rotation matrix in Note 2 of Section 3.3.1.3.) (See Note 1.)**
m	**If *m*=`1`, then the displacement vector is the location of the origin of the auxiliary coordinate system, defined in the main system. (DEFAULT)** **If *m*=`-1`, then the displacement vector is the location of the origin of the main coordinate system, defined in the auxiliary system.**

Default: No transformation if `TRCL` card is absent. This is equivalent to

`TRCL=0` or

`TRCL 0 0 0 1 0 0 0 1 0 0 0 1 1`

Use: Optional. Convenient for many geometries. Use with the `LIKE BUT` cell description. To transform a standard cell description it is recommended that the `TR` parameter associated with the surface cards be used.

Reminder: Coordinate transformations using `TRCL` can be applied only to cells with surface numbers <1000. When a transformation is applied to a cell, MCNP6 generates a set of new unique surface numbers based on the original surface numbers. The number of the generated surface is equal to the number of the original surface plus 1000 times the number of the cell. This formula creates generated surface numbers that are predictable and can be used on other cell cards and on tally cards. This method, however, limits cell numbers to 6 digits and original surface numbers to no more than three digits. These generated surfaces are only the bounding surfaces of the transformed cell, not the surfaces of any universe that fills it. MCNP6 requires only one full description of each universe, no matter how many times that universe is referenced in the problem

Note 1: If the symbol `*TRCL` is used, the rotation matrix entries are angles in degrees instead of cosines of the angles.

Example:

```
1    0     -17        $ rcc can
21   like 1 but *trcl=(20 0 0  45 -45 90  135 45 90  90 90 0)
```

Cell 21 is like cell 1 but is translated to *x*,*y*,*z*=20,0,0 and rotated 45° counter-clockwise with respect to *x* and *y*. If the rotational matrix is left incomplete, MCNP6 will calculate what it should be, but completeness is the only way to be sure you get what you want and get error messages if you are wrong.

3.3.1.5 REPEATED STRUCTURES

The primary goal of the repeated-structures capability is to make it possible to describe only once the cells and surfaces of any structure that appears more than once in a geometry. Obvious examples of geometry models constructed from repeated structures include a reactor core with dozens of nearly identical fuel modules or a room containing complicated, nearly identical objects arranged in an irregular order. Although the repeated-structures feature reduces input and memory use, problems will not run any faster than with any other description. Examples of the use of repeated structures cards appear in Section 4.1.3.

The repeated structures capability extends the concept of an MCNP6 cell. Four input cards are used exclusively to define repeated-structure features of a geometry: universe (U); fill (FILL); lattice (LAT); and, for stochastic geometries, URAN. Additionally, the cell transformation keyword (TRCL) is a supportive companion to the repeated-structures capability and the LIKE *n* BUT cell-description construct provides a convenient way to create multiple cells with similar attributes.

The user can specify that a cell is to be filled with something called a universe. The U card identifies the universe, if any, to which a cell belongs, and the FILL card specifies with which universe a cell is to be filled. A universe is either a lattice (LAT card) or a user-specified collection of cells. A single universe, described only once, can be designated to fill each of any number of cells in the geometry. Some or all of the cells in a universe may themselves be filled with universes. To use the repeated-structures capability effectively, keep in mind the following information:

- Cell parameters (IMP, VOL, PWT, EXT, FCL, WWN, DXC, NONU, PD, TMP, U, TRCL, LAT, FILL, ELPT, COSY, BFLCL, and UNC) can be defined on cell cards.
- "LIKE *n* BUT" is a shorthand method to describe easily one cell as equivalent to another except for a limited list of attributes. See Section 3.2.1.
- The universe (U) card specifies to what universe a cell belongs.
- The fill (FILL) card specifies with which universe a cell is to be filled.
- The cell transformation (TRCL) keyword allows the user to define only once the surfaces that bound several cells identical in size and shape but located at different places in the geometry. The TRCL keyword follows the transformation rules established for the surface transformation (TR) card. See Section 3.3.1.3.

- The lattice (LAT) card defines an infinite array of hexahedra or hexagonal prisms. Lattice cell indexing is determined by the user-specified order of the surfaces that describe the (0,0,0) lattice cell.
- A general source description can be defined in a repeated structures part of the geometry. Surface source surfaces must be regular MCNP6 surfaces, not surfaces associated with a repeated structures part of the geometry. ***No check is made that this requirement is met.***
- An importance assigned to a cell that is in a universe is interpreted as a multiplier of the importance of the filled cell. Weight-window lower bounds are not multipliers. Mesh-based weight windows (MESH card) automatically address this issue.

3.3.1.5.1 U UNIVERSE

Think of a universe as either a lattice cell or a collection of ordinary cells that you want to treat in a common manner. For example, perhaps this collection of cells appears multiple times in your model, but in varying orientations. You can use the repeated structures capability to simplify the setup of your model.

By assigning a non-zero universe number to one or more cells, the user creates a geometry unit that can be manipulated or referenced as a group. This assignment is accomplished by using the universe (U) card or, equivalently, the U cell-parameter keyword. If a cell lacks a universe assignment or is assigned to universe zero (U=0), then the cell does not belong to any universe and is a member of the real world. By using the FILL card (Section 3.3.1.5.3), a cell can be filled with a collection of cells that are assigned to the same universe. Note that the cells of a universe may be geometrically finite or infinite, but they must fill all of the space inside any cell that the universe is specified to fill.

One way to think about the connection between a filled cell and the filling universe is that the filled cell is a "window" that looks into a second level, like a window in a wall provides a view of the outdoors. Cells in the second level can be infinite because they will be (virtually) truncated when they bump into or intersect the surfaces of the window. The second level can have its own origin, in a primed coordinate system, unrelated to the upper level origin. However, if the filled cell and filling universe have all their surfaces in the same coordinate system, one TRCL card (Section 3.3.1.4) defines the coordinate system of both filled and filling cells.

A cell in a universe can be filled by another universe, in which case a third level is introduced. Up to 20 levels are permitted, more than most problems will need. The nomenclature chosen to address these hierarchical levels uses the following convention: the highest to lowest level is in inverse order to the associated numerical value. That is, the highest level is level zero (also known as the real world), lower is level one, lower still is level two, etc.

Every cell in the problem is either part of the real world (universe level 0) or part of some universe, but the surfaces of a problem are less restricted. A single planar surface can be used to describe cells in more than one universe. Coincident surfaces cannot be reflecting or periodic, source surfaces, or tally surfaces. Materials are normally put into the cells of the lowest level universe, not in the higher level, but there is an exception in the case of a lattice.

Form 1 (cell card entry): `U=`*n*

Form 2 (data card): `U` n_1 n_2 ... n_j ...

Table 3-20. Universe Card/Keyword (U)

Input Parameter	Description
n	**Arbitrary universe number (integer) to which cell is assigned. (DEFAULT: `U=0`, the "real world" universe) (See Note 1.)** **Restriction: $0 \le n \le$ 99,999,999**
n_j	**Universe numbers assigned to each cell of the problem in the same order as the cells appear in the cell card section.** **Note: When provided in the form of a data card, there must be an entry (which can be `0`) for each cell in the problem. The jump feature (*n*`J`) can be used for cells not assigned a universe number.** **Restriction: $0 \le n_j \le$ 99,999,999**

Default: Lack of a `U` card or a zero entry means that the cell does not belong to any universe. Instead the cell is part of what is termed the "real world."

Use: Required for repeated structures.

Note 1: A problem will run faster by preceding the `U` card entry with a minus sign for any cell that is not truncated by the boundary of any higher-level cell. (The minus sign indicates that calculating distances to boundary in higher-level cells can be omitted.) Use this capability with EXTREME CAUTION; MCNP6 cannot detect errors in this feature because the logic that enables detection is omitted by the presence of the negative universe. Extremely wrong answers can be quietly calculated. Plot several views of the geometry or run with the VOID card to check for errors.

Example:

```
1    0     1 -2 -3  4 -5  6         fill=1
2    0    -7  1 -3  8         u=1   fill=2  lat=1
3    0   -11                  u=-2
4    0    11                  u=2
5    0    -1:2:3:-4:5:-6

1    px     0
2    px    50
3    py    10
4    py   -10
5    pz     5
```

```
 6    pz    -5
 7    px    10
 8    py     0
10    py    10
11    s      5  5  0  4
```

Planar surfaces of a filled cell and those in a filling universe can be coincident. In other words, the cells of a universe can fit exactly into the filled cell. This example illustrates this feature. Represented is a 50×20×10-cm box filled with a lattice of 10×10×10-cm cubes, each of which is filled with a sphere. Cell `1` is filled with cell `2`, which is designated universe `1`. Cell `2` is filled with cells `3` and `4` (universe `2`). It is also a square lattice cell (to be discussed in Section 3.3.1.5.2). Cell `3` is designated universe `-2` indicating it is fully enclosed by surface `11`.

The minus universe number of cell `3` indicates that calculating distances to boundary in higher level cells can be omitted. Cell `3` is a finite cell and is not truncated by any other cell. Cell `4` cannot have a negative universe number because it is an infinite region that is truncated by cell `2`. This negative notation can increase computational efficiency.

The above example can be described with macrobodies as follows:

```
 1    0   -20           fill=1
 2    0   -30     u=1   fill=2   lat=1
 3    0   -11     u=-2
 4    0    11     u=2
 5    0    20

20    rpp   0   50  -10   10   -5    5
30    rpp   0   10    0   10
11    s     5    5    0    4
```

3.3.1.5.2 LAT LATTICE

Two different lattice-element shapes can be specified in MCNP6: hexahedra (`LAT=1`), solids with six faces, and hexagonal prisms (`LAT=2`), solids with eight faces. A non-zero entry on the `LAT` card indicates that the corresponding cell is the (`0`,`0`,`0`) element of a lattice. The hexahedra need not be rectangular and the hexagonal prisms need not be regular, but the lattices made out of them must fill space exactly. In other words, opposite sides have to be identical and parallel. A hexahedral lattice cell may be infinite in one or two of its dimensions. A hexagonal prism lattice cell may be infinite in the direction along the length of the prism. The cross section of a lattice element must be convex (no butterflies). It does not matter whether the lattice is left-handed or right-handed. A lattice must be the only thing in its universe. The real world (universe level 0) itself can be a lattice. If a particle leaves the last cell of a real-world, limited-extent lattice (see the `FILL` card for how the extent of a lattice can be limited), the particle escapes and is killed.

The cell description of a lattice cell not only provides the standard MCNP6 cell description for the base lattice element, but, through the order of the surface specification for the lattice cell, it identifies which lattice element lies beyond each surface. The first two surfaces listed on the cell card define the direction of the first lattice index; the third and fourth surfaces listed in the cell description define the direction of the second lattice element, etc. This concept is further explained in the following discussion.

After designing your lattice, decide which element you want to be the (`0`,`0`,`0`) element and in which directions you want the three lattice indices to increase. In the case of a hexagonal prism lattice you have two constraints: the first and second indices must increase across adjacent surfaces and the third index must increase in one or the other direction along the length of the prism. Enter the bounding surfaces of the (`0`,`0`,`0`) element on the cell card in the appropriate order, in accordance with the following conventions. For a hexahedral lattice cell, beyond the first surface listed is the (`1`,`0`,`0`) element, beyond the second surface listed is the (`-1`,`0`,`0`) element. Similarly, the (`0`,`1`,`0`), (`0`,`-1`,`0`), (`0`,`0`,`1`), and (`0`,`0`,`-1`) lattice elements are beyond the 3rd, 4th, 5th, and 6th surfaces in that order. This method provides the order of arrangement of the lattice to the code so that when you specify element (`7`,`9`,`3`), the code knows to which element you are referring.

For a hexagonal prism lattice cell, on the opposite side of the first surface listed is element (`1`,`0`,`0`), opposite the second listed surface is (`-1`,`0`,`0`), followed by the lattice elements (`0`,`1`,`0`), (`0`,`-1`,`0`), (`-1`,`1`,`0`), (`1`,`-1`,`0`), (`0`,`0`,`1`), and (`0`,`0`,`-1`), which are opposite the 3rd through 8th surfaces defining the hexagonal prism (`0`,`0`,`0`) lattice cell. These last two surfaces must be the base surfaces of the prism. You can use the MCNP6 geometry plotter to label the lattice cells with their indices. This provides an easy way to verify the lattice index arrangement. Example 7 in Section 4.1.3 illustrates a hexagonal prism lattice cell.

Each cell containing a lattice, whether specified using a `LAT` keyword or a `LAT` data card, must have an associated `FILL` keyword.

Form 1 (cell card entry): `LAT=`*n*

Form 2 (data card): `LAT` n_1 n_2 `...` n_j `...`

Table 3-21. Lattice Card/Keyword (LAT)

Input Parameter	Description
N	**If n=1, the cell describes a rectangular (square) lattice comprised of hexahedra with six faces.** **If n=2, the cell describes a hexagonal (triangular) lattice comprised of hexagonal prisms with eight faces.**
n_j	**Lattice type assigned to each cell of the problem in the same order as the cells appear in the cell card section** **If n_j=1, the cell describes a rectangular (square) lattice comprised of hexahedra with six faces.** **If n_j=2, the cell describes a hexagonal (triangular) lattice comprised of hexagonal prisms with eight faces.** **Note: When provided in the form of a data card, there must be an entry for each of the cells in the problem. Use jump feature to pass over cells that are not lattice cells.**

Use: Used to define an infinite array of hexahedra or hexagonal prisms. A non-zero entry on the `LAT` card means that the corresponding cell is the (0,0,0) element of a lattice. The order of specification of the surfaces of a lattice cell identifies which lattice element lies beyond each surface. Required for lattices.

Example:

```
 1     0     -20          fill=1
 2     0     -30   u=1    fill=2   lat=1
 3     0     -11   u=-2
 4     0      11   u=2
 5     0      20

20     rpp     0   50  -10   10   -5    5
30     rpp     0   10    0   10
11     s       5    5    0    4
```

Cell `2` is the base (`0`,`0`,`0`) element of a square lattice described by surface `30`, a right parallelepiped with x_{min}=0, x_{max}=10, y_{min}=0, y_{max}=10, and infinite in the z direction. It is filled with Universe `2` (cells `3` & `4`) and it is assigned to universe `1`, which fills and is bounded by cell `1` (an `RPP` with x_{min}=0, x_{max}=50, y_{min}=-10, y_{max}=10, z_{min}=-5 and z_{max}=5. In this case the lattice elements (i,j,k) would be `0:4`, `-1:0`, and `0:0`.

3.3.1.5.3 FILL FILL

A nonzero entry on the `FILL` card indicates the number of the universe that fills the corresponding cell. The same number on the `U` card identifies the cells making up the filling universe. If the filled cell is a lattice, the `FILL` specification can be either a single entry or an array. If it is a single entry, every cell of the lattice is filled by the same universe. If it is an array, the portion of the lattice covered by the array is filled and the rest of the lattice does not exist. It is possible to fill various elements of the lattice with different universes.

Lattice Indexing

The array specification for a cell filled by a lattice has three-dimension array declarations followed by the array values themselves. The dimension declarations define the ranges of the three lattice indices. They are in the same form as in Fortran, but both lower and upper bounds must be explicitly stated with positive, negative, or zero integers, separated by a colon. The indices identify each lattice element's location with respect to the (`0,0,0`) element. The `LAT` card (Section 3.3.1.5.2) describes how the specified order of the surfaces of the lattice-element cell (`0,0,0`) determines the ordering of the lattice elements. The numerical range of the indices depends on where in the lattice the (`0,0,0`) element is located. For example, −5:5, 0:10, and −10:0 all define a range of 11 elements.

The array values follow the dimension declarations. Each element in the array corresponds to an element in the lattice. Only those elements of the lattice that correspond to elements in the array actually exist. The value of each array element is the number of the universe that is to fill the corresponding lattice element. A real world (level zero) lattice, by default, is universe zero and can only be universe zero.

Form 1 (cell card entry):

`FILL=`*n* `[(`*m*`)]`

`FILL=`*n* `[(`o_1 o_2 o_3 *xx′ yx′ zx′ xy′ yy′ zy′ xz′ yz′ zz′* *m*`)]`

Form 2 [fully specified fill cell card entry (See Note 1)]:

`FILL=`i_1:i_2 j_1:j_2 k_1:k_2 n_{111} n_{211} ... $n_{i_1 j_1 k_1}$ ... $n_{i_2 j_2 k_2}$

Form 3 (data card):

`FILL` n_1 n_2 ... n_j ...

Table 3-22. Fill Card/Keyword (FILL)

Input Parameter	Description
n	**Arbitrary number (integer) of the universe with which cell is to be filled. If the filled cell is a lattice, every cell of the lattice is filled by the same universe. (DEFAULT: `FILL=0`)**
m	**Optional transformation number of a `TR`*m* surface transformation card, enclosed in parentheses.**
o_1 o_2 o_3 *xx′ yx′ zx′* *xy′ yy′ zy′* *xz′ yz′ zz′* *m*	**Optional displacement vector, rotation matrix of the transformation, and coordinate system indicator, enclosed in parentheses. See Section 3.3.1.3. (See Note 2.)**
i_1:i_2 j_1:j_2 k_1:k_2	**Lattice element parameters for the upper and lower bounds in the *i*, *j*, and *k* directions (for fully specified fill).**

Input Parameter	Description
n_{ijk}	**Number of the universe with which to fill each existing lattice element (for fully specified fill). Each element in the array corresponds to an element in the lattice. The portion of the lattice covered by the array is filled and the rest of the lattice does not exist. (See Note 3.)**
n_j	**Number of the universe with which each cell is to be filled in the same order as the cells appear in the cell card section. (See Note 3.)** **Note: When provided in the form of a data card, there must be an entry for each of the cells in the problem. The jump feature can be used for cells not assigned a universe number.**

Default: `FILL=0`

Use: Required for repeated structures.

Note 1: As with a single entry `FILL` specification, any `FILL` entry for a fully specified fill card optionally may be followed by, in parentheses, either a transformation number or the transformation itself. This transformation is between the coordinate systems of the filled cell and the filling universe, with the universe considered to be in the auxiliary coordinate system. If no transformation is specified, the universe inherits the transformation, if any, of the filled cell.

Note 2: A `*FILL` may be used if the rotation matrix entries are angles in degrees rather than cosines. In the data card section of the INP file you cannot have both a `FILL` and a `*FILL` entry. If you want to enter some angles by degrees and some angles by cosines, all `FILL` and `*FILL` data must be placed on the cell cards of the INP file.

Note 3: There are two n_j values that can be used in the lattice array that have special meanings. A zero in the level-zero (real world) lattice means that the lattice element does not exist, making it possible, in effect, to specify a non-rectangular array. If the array value is the same as the number of the universe of the lattice, that element is not filled with any universe but with the material specified on the cell card for the lattice cell. Therefore, using the universe number of a real world lattice as an n_j value to fill that element with the cell material is not possible.

Example:

```
FILL=0:2 1:2 0:1    4 4 2   $ i=0,1,2 for j=1 & k=0
                    0 4 0   $ i=0,1,2 for j=2 & k=0
                    0 3 3   $ i=0,1,2 for j=1 & k=1
                    4 4 0   $ i=0,1,2 for j=2 & k=1
```

Only eight elements of this lattice exist. Elements (0,1,0), (1,1,0), (1,2,0), (0,2,1) and (1,2,1) are filled with universe 4. Element (2,1,0) is filled with universe 2. Elements (1,1,1) and (2,1,1) are filled with universe 3.

3.3.1.5.4 URAN STOCHASTIC GEOMETRY FOR HTGRS

Randomization of HTGR Fuel-Kernel Geometry

The URAN card provides a limited means of modeling stochastic geometry in MCNP6 for both fixed-source and eigenvalue problems. It is primarily intended for modeling the randomly located fuel kernels in high-temperature gas-cooled reactor (HTGR) geometries. (Although this feature may have other possible applications, users should proceed carefully and perform their own verification calculations to ensure that the feature adequately represents the physical problem they are modeling.)

MCNP6 has been used frequently to model HTGRs with explicit geometric representation of fuel compacts or pebbles, including the microscopic fuel kernels within them. [(BRO05) (BRO04)] Each fuel kernel typically has a spherical (~0.5-mm-diameter) uranium oxycarbide region surrounded by layers of graphite, pyrolytic graphite, and silicon carbide. Modular HTGRs contain cylindrical fuel compacts filled with randomly located fuel kernels in a graphite matrix. Pebble bed HTGRs contain spherical fuel pebbles filled with randomly located fuel kernels in a graphite matrix.

Modeling these geometries in multigroup deterministic codes requires the implementation of shielding factors to account for double heterogeneities (i.e., fuel kernels and fuel particles). Monte Carlo codes that permit hierarchical geometry models, such as MCNP6 with its embedded lattices and universes, can explicitly model the pebble bed double heterogeneities. The random locations of fuel kernels within each fuel compact or pebble are typically modeled in MCNP6 using a regular lattice arrangement, ignoring any randomness.

To provide a limited form of randomness to the locations of fuel kernels in HTGR models, the URAN card may be used to flag selected universes in a lattice as stochastic. This feature provides an additional, random transformation to the geometry each time a neutron enters the lattice element. That is, when a neutron enters a lattice element containing an embedded universe flagged as stochastic, the universe coordinates are transformed randomly according to

$$x = x + (2\xi_1 - 1)\cdot\delta_x$$
$$y = y + (2\xi_2 - 1)\cdot\delta_y$$
$$z = z + (2\xi_3 - 1)\cdot\delta_z$$

where ξ_1, ξ_2, ξ_3 are random numbers uniformly distributed on (0,1), and δ_x, δ_y, δ_z are user-defined parameters supplied on the URAN card. Different translation parameters can be declared for different levels of the geometry, and the random translations are performed only when entering lattice elements containing universes that the user declares as stochastic on the URAN card. To preserve mass and packing fractions, the translation parameters should be chosen such that fuel kernels or other objects are not displaced beyond the edges of the enclosing cell or lattice element.

In addition to the random translation applied to a neutron entering a stochastic universe, special treatment is needed to save the fission sites in an eigenvalue calculation. When a fission occurs and the site parameters are saved in the fission bank, the current values of the random translation parameters must be saved along with the normal fission-site data. In the next cycle of the calculation, these saved translation parameters are used for the neutron starting at that fission site. This ensures that the flight continues from the same stochastic realization in effect when the site was saved.

This stochastic geometry treatment has been verified for several realistic HTGR problems. [(BRO05) (BRO04)]

Form (data card):

URAN n_1 dx_1 dy_1 dz_1 … n_j dx_j dy_j dz_j

Table 3-23. Stochastic Geometry Card (URAN)

Input Parameter	Description
n_i	**Universe number to which to apply stochastic transformation. (Only applied when used to fill a lattice element.)**
dx_i	**Maximum translation in the ±*x* direction for stochastic transformation applied to universe n_i.**
dy_i	**Maximum translation in the ±*y* direction for stochastic transformation applied to universe n_i.**
dz_i	**Maximum translation in the ±*z* direction for stochastic transformation applied to universe n_i.**

Default: None.

Use: To model random nature of HTGR or similar geometries.

Caution: There is no stochastic geometry plotting capability associated with the URAN card. Users should be extremely cautious in supplying information using the URAN card because MCNP6 has no means of checking whether the supplied parameters properly represent the physical model being simulated.

3.3.1.6 HYBRID GEOMETRIES: STRUCTURED AND UNSTRUCTURED MESHES

A geometry mesh from an external file can be embedded into a MCNP6 constructive solid geometry model using the "universe" construct from the repeated structures capability. The embedded geometry mesh may be structured or unstructured.[1]

A structured mesh, such as that defined by the geometry/materials block of the PARTISN discrete ordinates (SN) code [ALC08], can be embedded into an MCNP6 geometry. The resultant hybrid geometry can then be used for Monte Carlo calculations. It is also possible to convert a standard MCNP6 geometry to a PARTISN-style mesh. The only structured-mesh geometry file format accommodated at this time is LNK3DNT, used by the LANL discrete-ordinates deterministic-transport code PARTISN. With this capability, Monte Carlo vs. discrete-ordinates comparisons can be accomplished directly, thus separating geometry, cross-section data, and methodology effects. This initial capability takes MCNP6's constructive solid geometry, creates a homogenized regular mesh of materials in 1D (*r*), 2D (*rz*), or 3D (*xyz* or $rz\theta$), and writes a PARTISN-style geometry file in the LNK3DNT file format. MCNP6 can also import a geometry description from an existing LNK3DNT geometry file for continuous-energy neutron transport.

Unstructured meshes, such as those created by the finite-element code Abaqus/CAE [DES09], also can be embedded in a hybrid arrangement. Only the format output by Abaqus is recognized at this time. However, many other computer-aided engineering (CAE) tools have the ability to generate a mesh from a solid model that can be converted easily to the Abaqus format. Meshes consisting of four-, five-, or six-sided finite elements, with linear, bi-linear, or quadratic faces are allowed.

Before creating or incorporating structured or unstructured meshes, it is highly recommended that the interested user become familiar with external references, as appropriate. [MAR12a, MAR12b, MAR12c, MAR17, COX11] This section is not meant to provide information regarding PARTISN or Abaqus file formats nor provide a primer on how to run or interact with these codes.

3.3.1.6.1 CREATION OF A STRUCTURED DISCRETE-ORDINATES-STYLE GEOMETRY FILE

LNK3DNT-format files, used by the LANL PARTISN code, can be created from a standard MCNP6 input deck. [COX11] Two cards are required to accomplish this task: the `MESH` card (discussed in Section 3.3.6.4.4) and the `DAWWG` card.

`MESH`: ***Superimposed Importance Mesh for Mesh-Based Weight-Window Generator***

The `MESH` card (see Section 3.3.6.4.4) specifies the layout and orientation of the geometry to be generated with respect to the cell-based coordinate system. For this application, the supported coordinate-system options include `XYZ` (3D Cartesian), `CYL` [in either 2D (*rz*) or 3D ($rz\theta$)], and `SPH` (1D spherical). The optional `ORG`, `AXS`, and `VEC` keywords of the `MESH` card can be used to

[1] Currently, the file of a structured mesh to be embedded in MCNP6 must be in PARTISN-style format and that of a unstructured mesh must be in Abaqus-style format.

align the mesh with the MCNP6 geometry from which the discrete-ordinates geometry will be generated.

Note that the geometry orientation is *not* transferred to the resultant LNK3DNT file. Regarding the MESH orientation parameters, the generated homogenized geometry will have a geometrical center at (0,0,0) and will be aligned with the standard MCNP6 Cartesian coordinate system. For cylindrical geometries, the defaults are that the cylinder axis is aligned with the positive z-axis and the azimuthal plane (θ=0) is aligned with the positive x-axis.

DM *ZAID Aliases for Deterministic Materials*

Form: DM*n* $zaid_1$ $zaid_2$ $zaid_3$ ...

(See external documentation [COX11]).

DAWWG *Deterministic Adjoint Weight-Window Generator*

Note: The DAWWG card must appear after the MESH card in the input file's data section.

The DAWWG card specifies the number of points to sample in each element of the mesh. This sampling is used to estimate the volume fraction of different materials within each element. From this information a homogenized material definition with its associated density can be generated for each element. DAWWG may also be used to pass information directly to PARTISN.

Form: DAWWG KEYWORD=*value*(*s*) ...

Table 3-24. Deterministic Adjoint Weight-Window Generator Card (DAWWG)

Keyword	Value
POINTS=*n*	**Randomly sample the material within each element of the defined mesh using *n* sample points in each coordinate direction for each mesh element, where *n* is an integer. This sampling is used to estimate material volume fractions and thereby estimate the composition of each geometry element. (DEFAULT: POINTS=1) (See Note 1.) (Required)**
XSEC=<*name*>	**Declares that cross-section library <*name*> will be passed to the discrete-ordinates code for weight-window generation. This information is not explicitly used in the generation of the mesh. (Required)†**
TALLY=*i*	**(Optional)†**

Keyword	Value
`BLOCK=`*`k`* `KEYWORD=`*`value`*` ...`	**Passes values from MCNP6 to PARTISN input file. (Optional)** **If `BLOCK=1`, pass values of the listed keywords to the dimension and controls block of the PARTISN input file.** **If `BLOCK=3`, pass values of the listed keywords to the nuclear data type and options block of the PARTISN input file.** **If `BLOCK=5`, pass values of the listed keywords to the solver input block of the PARTISN input file.** **If `BLOCK=6`, pass values of the listed keywords to the edit controls block of the PARTISN input file.** **Multiple `BLOCK` entries are permitted. The allowed keywords for each BLOCK are provided in Table 3-25.**

† This keyword is to be implemented at a later date.

Note 1: If *`n`*`=10`, then 10^3=1000 points will be sampled in each geometry mesh element.

Table 3-25. PARTISN Blocks—Keyword/Value Types and Defaults Suitable for the DAWWG Card

Block 1: Dimension and Controls			
Block Keyword	**Type**	**Default**	**Description**
`NGROUP`	**Integer**	**30**	**Number of energy groups**
`ISN`	**Integer**	**8**	**Sn order**
`NISO`	**Integer**	**0**	**Number of isotopes**
`MT`	**Integer**	**1**	**Number of materials**
`IQUAD`	**Integer**	**6**	**Quadrature: {1–9}**
`FMMIX`	**Integer**	**1**	**1 = read composition from LNK3DNT file**
`NOSOLV`	**Integer**	**0**	**1 = suppress solver module**
`NOEDIT`	**Integer**	**0**	**1 = suppress edit module**
`NOGEOD`	**Integer**	**0**	**1 = suppress writing GEODST file**
`NOMIX`	**Integer**	**0**	**1 = suppress writing mixing files**
`NOASG`	**Integer**	**0**	**1 = suppress writing ASGMAT file**
`NOMACR`	**Integer**	**0**	**1 = suppress writing MACRXS file**
`NOSLNP`	**Integer**	**0**	**1 = suppress writing SOLINP file**
`NOEDTT`	**Integer**	**0**	**1 = suppress writing EDITIT file**
`NOADJM`	**Integer**	**0**	**1 = suppress writing ADJMAC file**

Block 3: Nuclear Data Type and Options			
Block Keyword	**Type**	**Default**	**Description**
`LIB`	Text	ndilib	Name/Form of the cross-section data file
`LIBNAME`	Text	mendf5	Cross-section file name
`FISSNEUT`	Integer	0	Fission neutron flag
`LNG`	Integer	0	Number of the last neutron group
`BALXS`	Integer	0	Cross-section balance control (-1,0,1)
`NTICHI`	Integer	0	MENDF fission fraction to use

Block 5: Solver Input			
Block Keyword	**Type**	**Default**	**Description**
`IEVT`	Integer	1	Calculation type (0–4)
`ISCT`	Integer	3	Legendre order
`ITH`	Integer	0	Direct (0) or adjoint (1) calculation
`TRCOR`	Text	diag	
`IBL`	Integer	0	Left boundary condition
`IBR`	Integer	0	Right boundary condition
`IBT`	Integer	0	Top boundary condition
`IBB`	Integer	0	Bottom boundary condition
`IBFRNT`	Integer	0	Front boundary condition
`IBBACK`	Integer	0	Back boundary condition
`EPSI`	Real	0.0001	Convergence precision
`OITM`	Integer	20	Maximum outer iteration count
`NOSIGF`	Integer	0	1=inhibit fission multiplication
`SRCACC`	Text	dsa	Transport accelerations (DSA,TSA,NO)
`DIFFSOL`	Text	mg	Diffusion operator solver
`TSASN`	Integer	0	Sn order for low order TSA sweeps
`TSAEPSI`	Real	0.0	Convergence criteria for TSA sweeps
`TSAITS`	Integer	0	Maximum TSA iteration count
`TSABETA`	Real	0.0	Scattering cross-section reduction for TSA
`PTCONV`	Integer	0	1=Special criticality convergence scheme
`NORM`	Real	1.0	
`XSECTP`	Integer	0	Cross-section print flag (0,1,2)
`FISSRP`	Integer	1	1=Print fission source rate
`SOURCP`	Integer	0	Source print flag (0,1,2,3)

ANGP	Integer	0	1=Print angular flux
BALP	Integer	0	1=Print coarse-mesh balance tables
RAFLUX	Integer	0	1=Prepare angular flux file
RMFLUX	Integer	0	1=Prepare flux moments file
AVATAR	Integer	0	1=Prepare special XMFLUXA file
ASLEFT	Integer	0	i=Right-going flux at plane i
ASRITE	Integer	0	i=Left-going flux at plane i
ASBOTT	Integer	0	j=Top-going flux at plane j
ASTOP	Integer	0	j=Bottom-going flux at plane j
ASFRNT	Integer	0	k=Back-going flux at plane k
ASBACK	Integer	0	k=Front-going flux at plane k
Block 6: Edit Controls			
Block Keyword	**Type**	**Default**	**Description**
MASSED	Integer	1	1=Mass edits
PTED	Integer	0	1=Edits by fine mesh
ZNED	Integer	0	1=Edits by (edit) zone
RZFLUX	Integer	0	1=Write a-flux file
RZMFLUX	Integer	0	1=Write b-flux file
EDOUTF	Integer	3	ASCII output files control [-3:3]
BYVOLP	Integer	0	1=Printed point reaction rates scaled by mesh volume
AJED	Integer	0	Regular (0) and Adjoint (1) edit
FLUXONE	Integer	0	1=Flux override

Example 1:

```
Converts MCNP cube geometry to LNK3DNT format
1   1  -18.7     -1    imp:n=1
2   0             1    imp:n=0

1  rpp    -10 10  -10 10  -10 10

kcode     5000  1.0  50  250
ksrc      0.0 0.0 0.0
m1        92235.69c   1.0
dm1 92235 92235.50
prdmp    j    275
mesh  geom  xyz
      ref      0.0    -0.0    -0.0
      origin -10.000 -10.000 -10.000
```

```
      imesh  10
      iints   2
      jmesh  10
      jints   2
      kmesh  10
      kints   2
f4:n 1
dawwg points=10
      block=1 ngroup=16 isn=16 iquad=4
      block=3 libname=mendf5 lib=ndilib
      block=5 trcor=diag srcacc=dsa diffsol=mg isct=2
      block=6 massed=1 edoutf=3
```

This MCNP6 input file creates a LNK3DNT-format mesh file of a solid, one-material cube with density 18.7 g/cm^3. Each edge of the cube is 20 cm long. The mesh is Cartesian with 10 coarse meshes in each direction (i.e., every 2 cm) and 2 fine mesh segments within each coarse mesh (i.e., every 1 cm). In each element of the mesh, 1000 points will be randomly sampled to estimate the material composition in each element. The `DAWWG` card is used to pass additional options directly to the PARTISN discrete ordinates code. These additional options are not used by MCNP6.

Creation of Structured Mesh File

After an MCNP6 input file has been created to generate the structured mesh file, execute MCNP6 using the `M` execution option:

```
mcnp6 M I=MYINP LINKOUT=MYLNK ...
```

The LNK3DNT file created by MCNP6 is named LINKOUT by default but can be changed via file name assignment on the MCNP6 execution line. If a file with the name "LINKOUT" already exists, MCNP6 will adhere to the usual rules for selecting a file name. In the example, the MCNP6 input file is MYINP and the LNK3DNT output file is MYLNK. When invoked in this manner, MCNP6 will process the input file, generate the LINKOUT file, and exit.

3.3.1.6.2 MESH IMPORTATION AND SPECIFICATION OF AN EMBEDDED GEOMETRY

Structured and/or unstructured mesh geometries may be embedded into MCNP6 by using the repeated-structure's universe (`U`) and fill (`FILL`) constructs. When used in MCNP6, an embedded geometry must be assigned to an MCNP6 universe. To ensure that this universe will completely fill the cell in which it is placed, a background cell that represents the infinite region surrounding the embedded geometry must also be assigned to the same universe. The embedded mesh geometry must not be clipped by the fill cell into which it is placed and no other universe or cell may be contained within it. This combination of the mesh geometry that is to be embedded and its surrounding infinite cell is called a "mesh universe." Similar to other repeated structures, a mesh universe may be placed in multiple locations within an MCNP6 geometry; also, more than one unique mesh universe may be embedded into an MCNP6 geometry.

In MCNP6, space is defined by a collection of cells using surfaces, lattices, universes, fills, etc. Building on this cell-geometry concept, incorporation of an embedded geometry into MCNP6 requires defining cells to represent the embedded geometry and its composition. There are three special MCNP6 cell categories for specifying the use of an embedded geometry: geometry cells, background cells, and fill cells. Geometry cells and background cells are instances of a special cell-type category called *pseudo*-cells, meaning cell-like. The treatment of these cells differs depending on the type of embedded mesh; this concept is explained in great detail below. Each embedded mesh universe consists of one or more pseudo-cell geometry cells and a single pseudo-cell background cell.

Pseudo-cells are defined in the MCNP6 cell block by a null surface—with a surface number of "`0`." These pseudo-cells are used to communicate normal MCNP6 cell properties from the external mesh to the MCNP6 code. The cell-card format for pseudo-cells exhibits the following properties that differ from those of regular MCNP6 cells:

- Pseudo-cells have a single null-surface entry (i.e., "`0`") instead of a list of signed surfaces.
- Pseudo-cells are assigned to a universe (e.g., `U=10` or `U=e10 where the "e" prefix to the universe is optional and signifies a mesh universe`).
- The universe number of the pseudo-cell must match the *n* specified on its associated `EMBED`*n* card.
- Pseudo-cells cannot be filled by another universe or lattice (i.e., a pseudo-cell cannot have a `FILL` or `LAT` entry).

Pseudo cells cards may contain material, density, importance, and other cell properties. All cell-card fields that typically are required by regular MCNP6 cells also are required by pseudo cells. How the user should think about these cells differs slightly depending on the type of embedded mesh.

For the PARTISN mesh, a pseudo-cell geometry cell must exist for each material defined in an embedded geometry mesh input file. If void elements exist, a separate pseudo-cell is required to represent them. Pure elements, i.e., those that contain only one material or void, belong to only one pseudo-cell. Multi-material elements, however, belong to each pseudo-cell that is associated with a material contained in the element. As will be seen in the next section, the geometry cells are connected to an embedded geometry through the `MATCELL` entries on the associated `EMBED` card.

Material information (i.e., density, composition) is assigned to each mesh element within the external mesh geometry file. The materials within the LNK3DNT geometry file must be numbered consecutively, starting with 1. The material information in the external mesh file is transferred to MCNP6 through the pseudo-cells and the MCNP6 `EMBED` card; each unique material in the external mesh file must have an associated pseudo-cell.

For the Abaqus unstructured mesh, the unstructured mesh library that handles all of the details of unstructured meshes for MCNP6 establishes pseudo-cells (unique combinations of materials and element sets) from the information contained in the Abaqus input file. The user is referred to "The MCNP6 Book on Unstructured Mesh Geometry: User's Guide" [MAR17] for details on this topic. A pseudo-cell cross-reference table is printed to the MCNP6 outp file. Among other things, this table lists the known pseudo-cells and the associated material assignments that are expected. For each pseudo-cell entry in this table, there must be a pair of values for the `MATCELL` parameter on the `EMBED` card. This association connects the MCNP6 pseudo-cell with the unstructured mesh pseudo-cell. This association is essential to establish the material properties for the unstructured mesh pseudo-cells because the only required material property in the mesh file is the material numbers. It is up to the user to ensure that this information is input correctly through the `MATCELL` entries on the associated `EMBED` card. For large and complex geometries, this can be a tedious process. To help with this input setup, users should take advantage of the unstructured mesh pre-processor program, um_pre_op. For details, see "The MCNP6 Book on Unstructured Mesh Geometry: User's Guide" [MAR17].

Mesh element assignment to each MCNP6 pseudo-cell is determined by the data as it appears in the external geometry mesh file. For a given geometry mesh, if the element sets of the mesh are built in a different order, then the mapping to the associated MCNP6 pseudo-cells will also be different. The user is directed to the previous list of references to decipher the cross-reference mapping data provided in the external geometry mesh file.

To make a mesh universe infinite in extent, it must have a background pseudo-cell that consists of all space outside the associated embedded geometry. The background cell is connected to the mesh universe through the `BACKGROUND` entry on the `EMBED` card.

The third cell type required to embed a mesh geometry into a MCNP6 input is the fill cell. The fill cell is a regular MCNP6 cell into which the mesh universe is placed. (Note: Mesh surfaces should not be coincident with fill-cell surfaces, else lost particles may result.) The cell card for a cell filled with a mesh universe has the following properties that differ from those of other MCNP6 fill cells:

- A mesh universe cannot be an pseudo-cell.
- Mesh universe fill cells have a fill entry of the form `FILL=E`*n* or `FILL=`*n*, where *n* is the MCNP6 universe number of the mesh universe. This universe number, *n*, also appears as the *n* on the `EMBED`*n* card. The `FILL` entry may have a transformation (`TR`) to permit realignment of the embedded geometry within the fill cell. Recall that LNK3DNT geometries are always defined relative to the MCNP6 origin.
- Mesh universe fill cells cannot have a lattice entry.

Eight MCNP6 data cards are available to support mesh importation. The `EMBED` card is required for both structured and unstructured mesh importation. Seven additional cards (`EMBEE`, `EMBEB`, `EMBEM`, `EMBTB`, `EMBTM`, `EMBDE`, and `EMBDF`) are optional and only valid for unstructured meshes. These seven cards provide for elemental edits, i.e., results accumulated on the unstructured mesh. These mesh results, along with a generic description of the unstructured mesh model, can be output to a special file, EEOUT [MAR17]. (See the EMBEE card.) Not all tally features are duplicated with the unstructured mesh elemental edit capability, hence the name *edit* instead of *tally*. If traditional MCNP6 statistical analysis is desired for the results, the user must set up a tally for the appropriate pseudo-cell(s).

Please be aware that there are additional limitations when using an unstructured mesh in an MCNP6 geometry. Consult "The MCNP6 Book on Unstructured Mesh Geometry: User's Guide" [MAR17] for an up-to-date list and more detailed guidance on using the UM feature.

EMBED Embedded Geometry Specification

One card, EMBED, is required for embedding a mesh geometry into MCNP6 input. For each unique embedded geometry used in an MCNP6 input deck, there must exist an associated EMBED card.

Form: EMBED*n* KEYWORD=*value*(*s*) ...

Table 3-26. Embedded Geometry Specification (EMBED)

Input Parameter	Description
N	**The universe number assigned to the embedded mesh. (See Note 1.)**
Keyword	**Value**
BACKGROUND=c_b	**Cell number of the background pseudo-cell. (Required)**
MATCELL=m_1 c_1 m_2 c_2 ...	**Integer pairs. (Required)** **For the structured mesh, there is one pair for each material (including void), where m_i values are the embedded mesh material numbers (sequential, beginning with 1) and c_i is the pseudo-cell number associated with m_i. If the material is void, m_i=0. (See Notes 2 and 3.)** **For the unstructured mesh there is one pair associating each pseudo-cell in the unstructured mesh (m_i) with one pseudo-cell in the MCNP6 cell block (c_i). Pseudo-cells in the unstructured mesh are numbered sequentially, beginning with 1. See the pseudo-cell cross-reference table in the OUTP file for the expected pairings or use the um_pre_op utility program to assist with problem setup**
MESHGEO=<*format*>	**Format specification of the embedded mesh input file.** **If MESHGEO=LNK3DNT, the embedded (structured) geometry file is in LNK3DNT format.** **If MESHGEO=ABAQUS, the embedded (unstructured) geometry file is in Abaqus format.** **If MESHGEO=MCNPUM, the Abaqus format has been converted to the MCNP internal format.** **(No other options are supported at this time; Required)**
MGEOIN=<*filename*>	**Name of the input file containing the mesh description. (Required)**
MEEOUT=<*filename*>	**Name assigned to EEOUT, the elemental edit output file.** **(Unstructured mesh only; Recommended)**

MEEIN=<*filename*>	**Name of the EEOUT results file to read. (Required for an unstructured mesh continue-run)**
CALC_VOLS	**If CALC_VOLS=YES, calculate the inferred geometry cell volumes and masses. If CALC_VOLS=NO do not calculate the inferred geometry cell volumes and masses. (Structured mesh only; Optional)**
DEBUG	**If DEBUG=ECHOMESH, write the embedded geometry parameters to the OUTP file. (No other values are supported at this time; Structured mesh only; Optional)**
FILETYPE=[ASCII|BINARY]	**File type for the elemental edit output file. If FILETYPE=ASCII, then write the elemental edit output file in ASCII format. (DEFAULT) If FILETYPE=BINARY, then write the elemental edit output file as a binary file. (Unstructured mesh only; Optional)**
GMVFILE=<*filename*>	**Name of the GMV output file.* (Unstructured mesh only; Optional)**
LENGTH=f_L	**A multiplicative conversion factor to centimeters for all mesh dimensions in the input and output files (DEFAULT: f_L=1) (Unstructured mesh only; Optional)**
MCNPUMFILE=<*filename*>	**Name of the MCNPUM output file.**
OVERLAP=<*key value*>	**Model to treat overlapping parts. First entry should be one of the following: EXIT (default when OVERLAP is not provided), ENTRY, AVERAGE. Treatments for individual pseudo-cells can be specified by following the initial entry with a second parameter and a list of valid pseudo-cell numbers (from the MATCELL entry). All 3 parameters may be used if the format is correct.**

* General Mesh View (GMV) is an external program written to support mesh geometry visualization. [ORT95]

Note 1: This universe number must match those specified on the related inferred-cell cards.

Note2: The MATCELL keyword entries must have one m_i/c_i pair for each structured material or unstuctued mesh pseudo-cell in the embedded mesh. A unique pseudo-cell must exist in the MCNP cell block for each unique structured mesh material or unstructured mesh pseudo-cell. If there are void elements in the embedded structured mesh geometry, there must also be a MATCELL entry pair for material 0 and an associated pseudo-cell. The assigned background cell must be a unique pseudo-cell. A warning is issued if there are pseudo-cells that are not listed on the background or MATCELL entries. It is a fatal error if a structured mesh material or unstructured mesh pseudo-cell appears in the external mesh file that is not mapped to a pseudo-cell.

Note 3: In the case of a structured mesh, while pseudo-cells associated with non-void embedded geometry mesh elements must have a specified density, MCNP6 uses the element-specific densities stored in the external mesh file for transport (e.g., cross-section lookup) and plotting. The density for the pseudo-cell on the cell card should be considered a reference density.

EMBEE Embedded Elemental Edits Control

If no EMBEE card is present, a total flux edit is created for each particle on the MODE card.

Form: EMBEE*n*:<*pl*> KEYWORD=*value*(*s*) ...

Table 3-27. Embedded Elemental Edits Control (EMBEE)

Input Parameter	Description
N	Elemental edit number ending in 4, 6, or 7. These values follow the F4, F6, and F7 tally convention.
<*pl*>	Particle designator. Restriction: Only N or P or charged particles allowed.
Keyword	**Value**
EMBED=*m*	Embedded mesh universe number. Must correspond to a valid EMBED card or mesh universe number. (Required)
ENERGY=f_E	Multiplicative conversion factor from MeV/g for all energy-related output. (DEFAULT: ENERGY=1) (Optional)
TIME=f_T	Multiplicative conversion factor from shakes for all time-related output. (DEFAULT: TIME=1) (Optional)
ATOM	Flag to multiply by atom density; NO (default) / YES.
FACTOR	Multiplicative constant; default: 1.0; equivalent in concept to |C| on the FM card.
LIST	Reaction list where this is the sum and/or product of ENDF or special reaction numbers. Limited to 1 reaction list as with FMESH tallies. Parentheses can be used but are ignored by the code.
MAT	Material number identified on an Mn card. Can be a dummy material or 0 (default). If the value is 0, use the cell material.

<table>
<tr><td>MTYPE</td><td>
Multiplier type. Acceptable character input values follow:
<table>
<tr><td>flux</td><td>Normal volume flux calculations. Same interpretation as FMESH tally type = flux. (default)</td></tr>
<tr><td>isotopic</td><td>Isotopic calculation. UM equivalent to the FMESH isotopic mesh tallies that require an +FM card.</td></tr>
<tr><td>population</td><td>Population calculation. Same as an F4 tally with an FM card where k = -2 in the multiplier set.</td></tr>
<tr><td>reaction</td><td>Reaction calculation that requires the LIST parameter. This mtype with the LIST parameters is equivalent to an FMESH tally with a single multiplier set specified and its accompanying FM card.</td></tr>
<tr><td>source</td><td>Accumulate source point locations. Same interpretation as FMESH tally type = source.</td></tr>
<tr><td>tracks</td><td>Tracks calculation. Same as an F4 tally with an FM card where k = -1 in the multiplier set.</td></tr>
</table>
</td></tr>
</table>

EMBEB Embedded Elemental Edit Energy Bin Boundaries

Form: EMBEB*n* e_1 e_2 e_3 . . . e_k

Table 3-28. Embedded Elemental Edit Energy Bin Boundaries (EMBEB)

Input Parameter	Description
N	**The universe number from EMBEE card; *n*=0 is not valid**
e_i	**Upper energy of the *i*th bin. List must be monotonically increasing. (DEFAULT: One energy bin with boundary set to the maximum energy limit for the particle type.)**

EMBEM Embedded Elemental Edit Energy Bin Multipliers

Form: EMBEM*n* m_1 m_2 m_3 . . . m_k

Table 3-29. Embedded Elemental Edit Energy Bin Multipliers (EMBEM)

Input Parameter	Description
N	**The universe number from the EMBEE card; *n*=0 is not valid**
m_i	**Multiplier for the *i*th energy bin. (DEFAULT: m_i=1)**

EMBTB Embedded Elemental Edit Time Bin Boundaries

Form: `EMBTB`*n* t_1 t_2 t_3 ... t_k

Table 3-30. Embedded Elemental Edit Time Bin Boundaries (EMBTB)

Input Parameter	Description
n	**The universe number from `EMBEE` card; *n*=0 is not valid**
t_i	**Upper time for the *i*th time bin. List must be monotonically increasing. (Unit is shakes, where 1 shake=10^{-8} s) (DEFAULT: One time bin with boundary set to the maximum time limit for the particle type.)**

EMBTM Embedded Elemental Edits Time Bin Multipliers

Form: `EMBTM`*n* m_1 m_2 m_3 ... m_k

Table 3-31. Embedded Elemental Edits Time Bin Multipliers (EMBTM)

Input Parameter	Description
n	**The universe number from the `EMBEE` card; *n*=0 is not valid**
m_i	**Multiplier for the *i*th time bin. (DEFAULT: m_i=1)**

EMBDE Embedded Elemental Edit Dose Energy Bin Boundaries

Form: `EMBDE`*n* e_1 e_2 e_3 ... e_k

Table 3-31a. Embedded Elemental Edit Dose Energy Bin Boundaries (EMBDE)

Input Parameter	Description
N	**The universe number from `EMBEE` card; *n*=0 is not valid**
e_i	**Upper energy for the *i*th energy bin. List must be monotonically increasing. (Unit is MeV) (DEFAULT: One energy bin with boundary set to the maximum energy limit for the particle type.)**

EMBDF Embedded Elemental Edits Dose Function Bin Multipliers

Form: `EMBDF`*n* m_1 m_2 m_3 ... m_k

Table 3-31b. Embedded Elemental Edits Dose Function Bin Multipliers (EMBDF)

Input Parameter	Description
N	**The universe number from the `EMBEE` card; *n*=0 is not valid**
m_i	**Multiplier for the i^{th} energy bin. (DEFAULT: m_i=1)**

Example 1:

```
Test of Cube with hole; lnk3dnt file being imported
11   1 -18.0    0     u=e10 imp:n=1   $ inferred geometry cell
12   0          0     u=e10 imp:n=1   $ inferred background cell
20   2 -0.001  -2  fill=e10 imp:n=1   $ fill cell
c
21         0    2           imp:n=0   $ outside world

2  so 17.4

kcode     1000     1.0  10   100
ksrc -5.0  0.0  0.0   5.0  0.0  0.0
      0.0 -5.0  0.0   0.0  5.0  0.0
      0.0  0.0 -5.0   0.0  0.0  5.0
totnu no
m1        92235.69c   1.0
m2         1001.60c   1.0
prdmp    j    275
embed10 meshgeo=lnk3dnt mgeoin=CUBE01.linkout debug=echomesh
        background=12
        matcell= 1 11
        calc_vols=yes
```

Example 2:

```
C Cell Cards
10  1 -2.03    0    u=2   $ inferred geometry cell
11  1 -2.03    0    u=2   $ inferred geometry cell
12  1 -2.03    0    u=2   $ inferred geometry cell
13  1 -2.03    0    u=2   $ inferred geometry cell
14  1 -2.03    0    u=2   $ inferred geometry cell
15  1 -2.03    0    u=2   $ inferred geometry cell
21  0          0    u=2   $ inferred background cell
30  0        -99 fill=2   $ fill cell
40  0         99
```

```
C Surface Cards
99 sph    0. 0. 3.  10.

c Data Cards
m1   1001 -0.02  8016 -0.60  14000 -0.38
c
embed2   meshgeo= abaqus
         meeout= sample01.eeout
         gmvfile= sample01.gmv
         filetype= binary
         background= 21
         matcell= 1 10  2 11  3 12  4 13  5 14  6 15
c
embee4:n embed=2
embtb4   1  2  3  4  5  1e+39
embeb4   0.1  1.0  1e+10
```

The EMBED card is allowed in a continue-run for an embedded unstructured mesh problem. This allows for the previous elemental edit output file to be read in as the elemental edit input file and for a new name to be assigned to the newly created elemental edit output file, as shown below.

```
continue
c
embed2   meshgeo= abaqus
         meein= sample01.eeout
         meeout= sample01.cont.eeout
         background= 21
         matcell= 1 10  2 11  3 12  4 13  5 14  6 15
```

3.3.2 Data Cards Related to Materials

The data provided in this section specify the isotopic composition of the materials in the cells and the cross-section evaluations to be used.

INDEX OF MATERIAL INPUT INFORMATION		
Mnemonic	**Description**	**Section**
M	Material Specification	3.3.2.1
MT	$S(\alpha,\beta)$ Thermal Neutron Scattering	3.3.2.2
MX	Material Card Nuclide Replacement	3.3.2.3
MPN	Photonuclear Nuclide Selector	3.3.2.4
OTFDB	On-The-Fly Doppler Broadening	3.3.2.5
TOTNU	Total Fission	3.3.2.6

INDEX OF MATERIAL INPUT INFORMATION		
Mnemonic	**Description**	**Section**
NONU	Fission Turnoff	3.3.2.7
AWTAB	Atomic Weight	3.3.2.8
XS	Cross-Section File	3.3.2.9
VOID	Material Void	3.3.2.10
MGOPT	Multigroup Adjoint Transport Option	3.3.2.11
DRXS	Discrete-Reaction Cross Section	3.3.2.12

3.3.2.1 M MATERIAL SPECIFICATION

Transport Table Selection

Each material must be defined as a set of components with their corresponding material fraction. A component consists of a nuclide identifier (ZZZAAA) and an optional library identifier (*abx*). Nuclide is the generic term for either a "generic" element or an isotope. This is usually specified as an integer value ZZZAAA where ZZZ is the atomic number and AAA is the atomic mass number. If AAA=000, a natural element is selected. When discussing nuclear data (e.g., in selecting neutron, proton, dosimetry, or photonuclear transport tables), nuclides should be given as isotope descriptions. This reflects the isotopic nature of nuclear data.

It should be noted that some older nuclear data sets contain "natural" elemental nuclear data that combines data for all the naturally occurring isotopes in an element into one data set. When discussing atomic data (e.g., in selecting electron or photoatomic transport tables), nuclides should be given as elemental descriptions; i.e., use AAA=000. *Always* specify a material with the most descriptive nuclides possible. If a material is best described using isotopic nuclide identifiers, the appropriate atomic data automatically will be selected by using ZZZ000 obtained from the specified ZZZAAA value.

The optional library identifier (*abx*) may be specified in one of two ways. If a component is specified using the full ZAID identifier, the requested table will always be chosen. For example, a component specified as 74184.60c will always choose the ENDF60 ^{184}W transport table for neutron interactions. Similarly, a component given as 74184.24u will always choose the LA150 ^{184}W table for photonuclear interactions. As a convenience to the user, a component given as 74184.02p will always choose the MCPLIB02 W (74000.02p) table for photoatomic interactions because AAA=184 will be changed internally to AAA=000 for elemental atomic data. As implied by these examples, only one unique table (i.e., fully specified ZAID) can be prescribed for each material component. Other tables for that component will be chosen according to the *x*LIB keyword option or as the first table in the XSDIR file matching the nuclide identifier and containing the appropriate transport data. The NLIB, PLIB, PNLIB, ELIB, and HLIB options allow the user to specify the default *abx* for neutron, photoatomic, photonuclear, electron, and proton tables, respectively; however, a component with a fully specified ZAID of the appropriate class of data will always take precedence over the `xLIB` specified default library.

Form: `Mm zaid₁ fraction₁ zaid₂ fraction₂ ... [KEYWORD=value(s) ...]`

Table 3-32. Material Card (M)

Input Parameter	Description
M	**Arbitrary material number; same as material number, *m*, on cell card. (Section 3.2.1)** **When *m*=0, keyword entries on that card are applied to all other M cards. See Note 1 below.** **Restriction: 0≤*m*≤99,999,999.**
zaid$_i$	**Either a full ZZZAAA.*abx* or partial ZZZAAA element or nuclide identifier for each constituent *i*, where** **a) ZZZ represents the atomic number;** **b) if AAA>0, then AAA represents the atomic mass number; and if AAA=000, then AAA indicates a naturally occurring element. See Note 2.** **c) *ab* is the alphanumeric library identifier; and** **d) *x* is the class of data.** **To represent a metastable isotope, adjust the AAA value using the following convention: AAA'=(AAA+300)+(*m* × 100), where m is the metastable level and *m*=1, 2, 3, or 4.**
fraction$_i$	**Fraction of the *i*th constituent in the material, where** **if *fraction*>0, then the value is interpreted as an atomic fraction and** **if *fraction*<0, then the value is interpreted as the weight fraction.** **See Notes 3 and 4.** **Atomic and weight fractions may not both appear on a single M card.**
Keyword*	**Value**
GAS	**Flag for density-effect correction to electron stopping power.** **If GAS=0, code calculates a density-effect correction appropriate for material in the condensed (solid or liquid) state (DEFAULT), or** **If GAS=1, code calculates a density-effect correction appropriate for material in the gaseous state.**
ESTEP=*n1*	**Causes the number of electron sub-steps per energy step to be increased to *n1* for the material. If *n1* is smaller than the built-in default found for this material, the entry is ignored. Both the default value and the ESTEP value actually used are printed in Table 85 of the output file. (DEFAULT: internally set)**
HSTEP=*n2*	**Causes the number of proton or other charged-particle sub-steps (exclusive of electrons, but including heavy ions) per energy step to be increased to *n2* for the material. If ESTEP is specified and HSTEP is not, then the ESTEP value is used for HSTEP. Both the default value and the HSTEP value actually used are printed in Table 85 of the output file. (DEFAULT: internally set)**

Input Parameter	Description
`NLIB=`***abx***	**Changes the default neutron table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`PLIB=`***abx***	**Changes the default photoatomic table identifier to the string *abx*. (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`PNLIB=`***abx***	**Changes the default photonuclear table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`ELIB=`***abx***	**Changes the default electron table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`HLIB=`***abx***	**Changes the default proton table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`ALIB=`***abx***	**Changes the default alpha table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`SLIB=`***abx***	**Changes the default helion table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`TLIB=`***abx***	**Changes the default triton table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`DLIB=`***abx***	**Changes the default deuteron table identifier to the string *abx* (DEFAULT: blank string, which selects the first matching entry in the XSDIR file)**
`COND`	**Sets conduction state of a material only for the EL03 electron-transport evaluation.** **If `COND<0`, material is a non-conductor.** **If `COND=0`, material is a non-conductor if there is at least one non-conducting component; otherwise it is a conductor (DEFAULT)** **If `COND>0`, material is a conductor if there is at least one conducting component.**
`REFI=A`	**Constant refractive index**
`REFC = A B C D`	**Cauchy coefficients for refractive index** $n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \frac{D}{\lambda^6}$
`REFS =` B_1 C_1 B_2 C_2 B_3 C_3	**Sellmeier coefficients for refractive index** $n^2(\lambda) = 1 + \frac{B_1\lambda^2}{\lambda^2 - C_1} + \frac{B_2\lambda^2}{\lambda^2 - C_2} + \frac{B_3\lambda^2}{\lambda^2 - C_3}$

* `M` card keywords may appear anywhere among the *`zaid-fraction`* pairs, but must not separate a pair.

Use: Required if you want materials in cells. Recall that an equals sign (=) following a keyword, such as the *x*LIB keywords, is optional. Inclusion of the decimal point in the library *abx* designation (e.g., .70c) is permitted, but not required.

Note 1: An M0 card may be specified to select default cross-section library identifiers via the library keywords NLIB, HLIB, PLIB, PNLIB, and ELIB, for all materials specified in the input file. Default cross-section library identifiers also may be specified for an individual material M*m*. (*m*≠0). Fully specified ZAIDs on an M*m* card override the default structure library selections for material *m*..

Note 2: For naturally occurring elements, AAA=000. Very few natural-element libraries exist within the isotopic data libraries (i.e., neutron, proton, and photonuclear); examine the XSDIR library directory file to determine availability. Natural elements not available from among those listed in the XSDIR file must be constructed on an M card by adding together the individual isotopes if they are available. The value of AAA for photons and electrons is always 000, providing no distinction between isotope and element.

Note 3: The nuclide fractions can be normalized to 1.0 or left un-normalized, in which case the code will perform the normalization.

Note 4: The code uses the atomic weight ratio values from the transport table to convert mass fractions to atom fractions. To avoid this conversion and therefore ensure the most accurate material representation, it is recommended that atom fractions be specified.

Example 1:

```
M1   6012.50c 1   8016.01p 2   NLIB=60c  PNLIB=24u  PLIB=02p
```

This material definition will cause the data tables 6012.50c and 8016.60c to be used for neutron transport. The component 6012.50c is a fully specified neutron transport table that takes precedence over the NLIB default *abx* specifier. The 02p portion of the component 8016.02p is ignored because it specifies the wrong class of table; therefore the NLIB default 60c is used to choose the 8016.60c neutron transport table.

Similarly, the material definition will invoke the photoatomic transport tables 6000.02p and 8000.01p by ignoring the mass number (AAA) and using the PLIB specified *abx* 02p for carbon and the component specified 01p for oxygen. Because neither component *abx* is appropriate for specification of photonuclear tables, the data tables 6012.24u and 8016.24u will be chosen based on the PNLIB default *abx* 24u. Because no *abx* is specified for electron or proton tables via the component description or by the ELIB or HLIB options, the first matching entries in the XSDIR file will determine the selection of electron and proton tables.

Example 2:

```
M1    NLIB=50D    1001  2    8016.50C  1   6012  1
```

This material consists of three isotopes. Hydrogen (`1001`) and carbon (`6012`) are not fully specified and will use the default neutron table that has been defined by the `NLIB` entry to be `50D`, the discrete-reaction library. Oxygen (`8016.50C`) is fully specified and will use the continuous-energy library. The same default override hierarchy applies to proton, photonuclear, photon, and electron specifications.

Example 3:

To represent the ZZZAAA of the 1st metastable state of ^{110m}Ag, add 300 to the atomic mass number (110+300=410) and to this result add 1×100=100. The adjusted atomic mass number becomes 510. The ZZZAAA for the 1st metastable state of ^{110m}Ag is therefore `47510`.

Example 4:

```
M1  1001 2   8016 1  REFI=1.3199
```

Water with a constant Ref. Index=1.3199

Example 5:

```
M1 1001 2 8016 1 REFC=1.3119 6.878e-2 1.132e-3 1.11e-4
```

Water with Ref Index specified by coefficients for 4th order CAUCHY expression. The coefficients are in units of micrometers.

Example 6:

```
M1 14028 1 8016 2
     REFS = 1.0396 6e-3 0.2318 2.0018e-2 1.0104 1.0356e2
```

Borosilicate crown glass with Ref Index specified by coefficients for Sellmeier equation. Note that Sellmeier coefficients are applied directly, they are not squared.

3.3.2.2 MT $S(\alpha,\beta)$ THERMAL NEUTRON SCATTERING

Thermal Neutron Scattering Treatment

For any material defined on an `M` card, a particular isotope or isotopes of that material [represented by ZAID number(s)] can be treated in the thermal regime as a molecular compound through an `MT` card with an $S(\alpha,\beta)$ data set if that data set exists. The $S(\alpha,\beta)$ data are used in every cell in which that material is specified. In transport, the free-gas treatment is used down to the energy where $S(\alpha,\beta)$ data are available. At that point, the $S(\alpha,\beta)$ treatment automatically overrides the free-gas treatment (that is, there is no mixing of the two treatments for the same isotope in the same material at a given energy). Typically the free-gas model is used for each isotope of a material down to a few electron volts and then the $S(\alpha,\beta)$ treatment takes over for the isotope(s) comprising the substance specified on the `MT` card. In general, $S(\alpha,\beta)$ effects are most significant below 2 eV. The appearance of an `MT` card will cause the loading of the corresponding $S(\alpha,\beta)$ data from the thermal data file. Multiple $S(\alpha,\beta)$ libraries can be specified on one `MT` card, but only if the libraries treat different isotopes—otherwise, the first $S(\alpha,\beta)$ treatment is used.

Form: `MTm` x_1 x_2 ...

Table 3-33. $S(\alpha,\beta)$ Card (MT)

Input Parameter	Description
m	**Material identifier, same as *m* on the corresponding material (M*m*) card.**
x_i	**$S(\alpha,\beta)$ identifier corresponding to a particular component on the M*m* card. See Note 1.**

Default: None.

Use: Essential for problems with thermal neutron scattering.

Note 1: $S(\alpha,\beta)$ contributions to detectors of DXTRAN spheres are approximate.

Example 1:

```
M1     1001  2    8016  1  $ light water
MT1    LWTR.02T
```

Example 2:

```
M8     6012  1             $ graphite
MT8    GRPH.06T
```

Example 3:

When a particle is within the energy regime at which the $S(\alpha,\beta)$ treatment applies, the specification

```
M1   1001 2  8016 1  4009 1e-3  $ light water w/ small amt of Be
MT1  LWTR.01t BE.01t
```

will substitute the light-water $S(\alpha,\beta)$ library for the hydrogen (`1001`) and the beryllium metal library for the beryllium (`4009`).

However, the specification

```
M1   4009 2  8016 1       $ Be oxide
MT1  BE.60T BEO.60T
```

will not work as desired because both libraries will try to substitute for the beryllium (`4009`) in the problem. Only the first $S(\alpha,\beta)$ specification (for `be.60t`) will be used.

3.3.2.3 MX MATERIAL CARD NUCLIDE SUBSTITUTION

Mixing of Nuclide Physics Models and Data Tables

The MCNP6 nuclide substitution capability [HEN03] enables mixing of physics models and data tables for individual isotopes. Different nuclides can be substituted for different particle types. For example, natural carbon and calcium can be used for neutrons, whereas ^{12}C and ^{40}Ca can be used for protons and photonuclear reactions.

Above tabular data limits, models are automatically called in MCNP6. The model to be used depends on values set on the `LCA` card (Section 3.3.3.7.2). The sole exception is photonuclear interactions, for which CEM03.03 [MAS12, MAS08, MAS05b, MAS05a,GUD83] is always used regardless of whether CEM03.03 is used for other particles (see the `LCA` card). Using the term "`MODEL`" on an `MX` card will substitute model physics for the entire energy range of a particle—no tabular data will be used. This option should be carefully considered before use. The parameter '`0`' on an `MX` card eliminates all interaction physics, whether model or table-based. This makes sense in the case of photonuclear interactions on hydrogen, which do not exist in nature, but should be avoided for other cases.

Form: `MX`*`m`*`:`*`<pl>`*   *`zaid`*$_1$ *`zaid`*$_2$ `...`

Table 3-34. Nuclide Substitution (MX)

Input Parameter	Description
m	**Material number of an associated M*m* material card. See Note 1.**
<pl>	**Particle designator (see Table 2-2); allowed values are neutron (N), photonuclear (P), proton (H), deuteron (D), triton (T), hellion (S), and alpha (A).**
zaid$_i$	**If *zaid*$_i$ is set to the full library identifier, ZZZAAA.*abx*, substitute the specified library for the *i*th nuclide identifier on the M card.** **If *zaid*$_i$ is set to, ZZZAAA, replace the *i*th nuclide on the M card with the nuclide ZZZAAA.** **If *zaid*$_i$=MODEL, substitute model physics for the *i*th nuclide on the M card. A mixture of models and tabular data may be specified for nuclides on a single M card.** **If *zaid*$_i$=0 on a photonuclear substitution card (MX*m*:P), then omit photonuclear reactions for *zaid*$_i$. This option is only available for photonuclear particles.** **No substitutions are allowed for photoatomic (P) and electron (E) data because these data depend only on Z and are not isotope-specific.**

Use: The `MXm` card enables nuclide substitution for different particle types. The nuclide replacement capability is particularly useful for photonuclear and proton calculations when few data tables are available. Libraries are used when available and models are used otherwise.

Note 1: The `MXm` card must appear after its associated (`Mm`) material card.

Example 1:

```
MODE      n  h  p
M3        1002 1  1003.6 1  6012 1  20040.70c 1  NLIB .24c
MX3:N     j       MODEL     6000    20000
MX3:H     MODEL   1001      j       j
MX3:P     6012    0         j       j
```

In this example, note that models will be used for neutrons on tritium and protons on deuterium. Natural libraries will be used for neutron interactions on carbon and calcium. A model will be used for proton interactions for deuterium, and protons on tritium will substitute the hydrogen cross section. For photonuclear, ^{12}C substitutes for deuterium and the cross section for tritium interactions will be set to 0.0.

Example 2:

```
m1         8016   1.0
          82206  10.0
           nlib=.60c
           hlib=.24h
          pnlib=.24u
mx1:h   j  26056.70h
mx1:n   j  88223.70c
mx1:p   j  94239.70u
```

For ^{16}O of material 1, MCNP6 will use the neutron, proton, and photonuclear cross-section data files, 8016.60c, 8016.24h and 8016.24u, respectively. For ^{206}Pb of material 1, the `MX` cards specify that data file 88223.70c will be substituted for 82206.60c, 26056.70h for 82206.24h, and 94239.70u for 82206.24u.

3.3.2.4 MPN PHOTONUCLEAR NUCLIDE SELECTOR

This feature has been replaced by the material card nuclide substitution (`MX`) capability. The `MPN` card remains available to support backward compatibility. To control the selection of photonuclear nuclide data, use the `MX` card.

3.3.2.5 OTFDB ON-THE-FLY-DOPPLER BROADENING

MCNP6 has a capability for on-the-fly (OTF) Doppler broadening of neutron cross sections. Background, theory and methodology, and implementation details are provided in several references [MAR12d, MAR12e, BRO12a, BRO12b], including the collection of references distributed with MCNP6.

To use the OTF Doppler broadening, data tables with temperature-fitting coefficients must first be prepared using the *fit_otf* code. This code is included in the MCNP6 distribution in the `MCNP_CODE/Utilities/FIT_OTF` directory. Input specifications and example scripts for running *fit_otf* are also available in that directory. Running the *fit_otf* code will produce a file of OTF coefficients in either a binary or a text file format. These files have names of the form

Binary:	`otf_92235.70c.binary`	`otf_8016.70c.binary`	etc.
Test:	`otf.92235.70c.txt`	`otf_8016.70c..txt`	etc.

The ZAID (with suffix) that is part of the file name refers to the original ZAID for the base dataset used as input to *fit_otf* (not necessarily to the ZAIDs use in an MCNP6 input file). The files generated by *fit_otf* for various nuclides should be placed in the DATAPATH directory. Alternatively, symbolic links to the files could be placed in the DATAPATH directory, with the actual files located elsewhere.

The `OTFDB` card is used to provide MCNP6 with the list of OTF data files that should be used in a calculation. The ZAID portion of the file names should be supplied, including the ZAID suffix.

Form: `OTFDB` $zaid_1$ $zaid_2$ `...`

where $zaid_i$ are the `ZZZAAA.`*`abx`* identifiers for OTF Doppler broadening data tables.

In the MCNP6 input processing, ZAIDs specified on the material input (`M`) cards are matched with available ZAIDs from the `OTFDB` card. In doing so, the ZAID suffixes used in the material specification and the `OTFDB` list are ignored; only the ZZZAAA portions of the data identifiers are compared. For all nuclides where the ZZZAAA portion of the identifier matches an `OTFDB` entry, the OTF data is used during calculations to adjust the cross-section Doppler broadening to the temperature for the current cell (i.e., the `TMP` value for a cell is used for OTF Doppler broadening adjustment).

Example 1:

```
OTFDB     92235.70c   8016.70c
```

3.3.2.6 TOTNU TOTAL FISSION

Caution: Former MCNP5 users need to be aware that the default behavior of this card has changed to total $\bar{\nu}$.

Form: `TOTNU` `[NO]`

Default: If the `TOTNU` card is absent or if a `TOTNU` card is present but has no entry after it, total $\bar{\nu}$, which samples both prompt and delayed fission neutrons, is used for all fissionable nuclides for which prompt and delayed values are available. Thus, the TOTNU card is not needed unless only prompt $\bar{\nu}$ is desired.

Use: Needed to specify use of only prompt $\bar{\nu}$. A TOTNU card with NO as the entry causes prompt $\bar{\nu}$ to be used for all fissionable nuclides for which prompt values are available.

3.3.2.7 NONU FISSION TURNOFF

Fission Turnoff

The NONU card provides the ability to turn off fission in a cell. The fission is then treated as simple capture and is accounted for on the loss side of the problem summary as the "Loss to fission" entry. The NONU card is not allowed in a continue-run.

Form 1 (cell card entry): NONU=*a*

Form 2 (data card): NONU [a_1 a_2 ...]

Table 3-35. Fission Turnoff Card/Keyword (NONU)

Input Parameter	Description
a	**If *a*=0, then fission in cell treated as capture; gammas produced. If *a*=1, then fission in cell treated as real; gammas produced. If *a*=2, then fission in cell treated as capture; gammas not produced. See Note 1. If no entry (i.e., blank), then fission in the cells is treated like capture; gammas produced (i.e., *a*=0).**
a_j	**If a_j=0, then fission in cell *j* treated as capture; gammas produced. If a_j=1, then fission in cell *j* treated as real; gammas produced. If a_j=2, then fission in cell *j* treated as capture; gammas not produced. See Note 1. Number of entries equals the number of cells unless no entry appears. If no entry (i.e., blank), then fission in all cells is treated like capture with gamma production included (i.e., a_j=0).**

Default: If the NONU card is absent, fission is treated as real fission (a_j=1). If card present but without entries, fission is treated as capture with gammas produced (a_j=0).

Use: Needed with SSR for fissioning neutron problems only. When fission is already modeled in the source, such as SSR, it should not be duplicated in transport and should be turned off with NONU. Use a_j value of 2.

Note 1: An a_j value of 2 treats fission as capture and, in addition, no fission gamma rays are produced. This option should be used with KCODE fission source problems written to surface source files. Suppressing the creation of new fission neutrons and photons is necessary because they are already accounted for in the source. Consider a problem with a fixed source in a multiplying medium. For example, an operating reactor power distribution could be specified as a function of position in the core either by an `SDEF` source description or by writing the fission source from a KCODE calculation to a WSSA file with a `CEL` option on an `SSW` card. Without the ability to turn off fission, the non-KCODE calculation would be impossible to run because of the criticality of the system and because fission neutrons have already been accounted for. Using the `NONU` card in the non-KCODE mode allows this problem to run correctly by treating fission as simple capture.

3.3.2.8 AWTAB ATOMIC WEIGHT

Specifying Atomic Weights

Entries on this card override the existing atomic weight ratios as contained in both the cross-section directory (XSDIR) file and the cross-section tables. The `AWTAB` card is needed when atomic weights are not available in an XSDIR file.

Form: `AWTAB` *zaid*$_1$ *aw*$_1$ *zaid*$_2$ *aw*$_2$ ...

Table 3-36. Atomic Weight (AWTAB)

Input Parameter	Description
zaid$_i$	**Nuclide or element identifier used on the *Mm* material card excluding the *x* for class of data specification. (See Table 3-32.)**
aw$_i$	**Atomic weight ratios. See Note 1.**

Default: If the `AWTAB` card is absent, the atomic weight ratios from the cross-section directory (XSDIR) file and cross-section tables are used.

Use: Discouraged. Occasionally useful when `XS` card introduces rare isotopes.

Warning: Using atomic weight ratios different from the ones in the cross-section tables in a neutron problem can lead to negative neutron energies that will cause the problem to terminate prematurely.

Note 1: For fission products, *zaid*=50120.35, the atomic weight of tin ($^{120}_{50}\mathrm{Sn}$) will be used, so the following `AWTAB` card is needed:

```
AWTAB   50120.35   116.490609
```

3.3.2.9 XS CROSS-SECTION FILE

The XS*n* card can be used to load cross-section evaluations not listed in the cross-section directory (XSDIR) file. The XS*n* cards can be used in addition to the XSDIR file. Each XS*n* card describes one cross-section table. The entries for the XS*n* card are identical to those that appear in the default cross-section directory file (`xsdir_mcnp6.2`) provided with MCNP6, Version 2, except that the "+" is not used for continuation..

Form: XS*n* *zaid*$_i$ *aw*$_i$ ...

Table 3-37. Cross-Section File (XS)

Input Parameter	Description
n	**Arbitrary cross-section identification number.** **Restriction: 1≤*n*≤99,999,999**
zaid$_i$	**Nuclide identifier (ZZZAAA.*abx*) used on the M material card.**
aw$_i$	**Atomic weight ratio associated with nuclide *i*.**
...	**Remaining XSDIR file entries for the user-provided cross-section table.**

Use: Add an XSDIR entry for nuclides not represented in the XSDIR file.

3.3.2.10 VOID MATERIAL VOID

Form: VOID [c_1 c_2 ...] See Notes 1 and 2.

where the c_j values form a list of cells to treat as void.

Default: Use problem materials.

Use: Debugging geometry and calculating volumes stochastically.

Note 1: When the VOID card is blank, the material number and density is set to zero for all cells, FM cards are turned off, heating tallies are turned into flux tallies, and, if there is no NPS card, the effect of an NPS 100000 card is created. If there is a TALLYX subroutine, it may need to be changed, too.

Note 2: Entries on the VOID card selectively set the material number and density to zero for the specified cells. Can be used to check whether the presence of some object in your geometry makes a significant difference in the results.

3.3.2.11 MGOPT MULTIGROUP ADJOINT TRANSPORT OPTION

Form: MGOPT *mcal igm iplt isb icw fnw rim*

Table 3-38. Multigroup Adjoint Transport Option (See Note 1.)

Input Parameter†	Description
mcal††	**If *mcal*=F, specifies a forward problem.** **If *mcal*=A, specifies an adjoint problem. (See Note 2.)**
igm††	**The total number of energy groups for all kinds of particles in the problem. A negative total indicates a special electron-photon problem. (See Note 3.)**

Input Parameter†	Description
iplt	**Indicator of how weight windows are to be used.** **If *iplt*=0, IMP values set cell importance. Weight windows, if any, are ignored for cell importance splitting and Russian roulette. (DEFAULT)** **If *iplt*=1, weight windows must be provided and are transformed into energy-dependent cell importance. A zero weight-window lower bound produces an importance equal to the lowest non-zero importance for that energy group.** **If *iplt*=2, weight windows do what they normally do.**
isb	**Controls adjoint biasing for adjoint problems; valid only for *mcal*=A.** **If *isb*=0, collisions are biased by infinite-medium fluxes. (DEFAULT)** **If *isb*=1, collisions are biased by functions derived from weight windows, which must be supplied.** **If *isb*=2, collisions are not biased.**
icw	**Name of the reference cell for generated weight windows.** **If *icw*=0, weight windows are not generated. (DEFAULT)** **If *icw*≠0, volumes must be supplied or calculated for all cells of non-zero importance.**
fnw	**Normalization value for generated weight windows. The value of the weight-window lower bound in the most important energy group in cell *icw* is set to *fnw*. (DEFAULT: *fnw*=1)**
rim	**Compression limit for generated weight windows. Before generated weight windows are printed out, the weight windows in each group separately are checked to see that the ratio of the highest to the lowest is less than *rim*.** **If not, they are compressed. (DEFAULT: *rim*=1000)**

† "J" is not an acceptable value for any of the parameters.

†† Note: *mcal* and *igm* must be specified.

Use: Required for neutron multigroup calculations.

Note 1: Presently, the standard MCNP6 multigroup neutron cross sections are given in 30 groups and photons are given in 12 groups. Thus, an existing continuous-energy input file can be converted to a multigroup input file simply by adding one of the following cards:

```
MGOPT   F  30    $MODE N
MGOPT   F  42    $MODE N P
MGOPT   F  12    $MODE P
```

Note 2: An input file for an adjoint problem can have both an IMP card and weight-window cards (*iplt*=0 and *isb*=1). The entries on the weight-window cards are not weight windows in the normal sense but biasing functions. If *iplt*=1, the values on a weight-window card become energy-dependent cell importance.

Note 3: A negative *igm* value allows a single cross-section table to include data for more than one sort of particle. This feature applies currently to electron/photon multigroup calculations only. A problem with 50 electron groups followed by 30 photon groups in one table would have *igm*=-80. Also, all tables must have the same group structure. A negative *igm* value will use the energy variable on the source or tally card as groups index unless it is associated with a distribution. For an energy distribution on the source card, there should be *igm* increasing integer entries for each group on the SI card. On a tally energy card, if there are fewer than *igm* entries, they will be taken as energies in MeV; otherwise, the bins will be according to group index. The particles can be separated in tallies by using the PTT keyword on the FT*n* tally special treatment card.

3.3.2.12 DRXS DISCRETE-REACTION CROSS SECTION

Discrete Energy Treatment

If the necessary discrete data are available, nuclides listed on the optional DRXS card are given a discrete energy treatment instead of the regular fully continuous-energy cross-section treatment.

All discrete reaction libraries are based on a 262-energy-group structure. Groups below 1 eV make the discrete treatment appropriate for thermal neutron problems near room temperature. All discrete reaction libraries have photon production data given in expanded format.

Form: DRXS [$zaid_1$ $zaid_2$ ... $zaid_i$...] See Note 1.

where $zaid_i$ is an identifying number of the form ZZZAAA.*ab*, where ZZZ is the atomic number, AAA the atomic mass number, and *ab* the neutron library identifier.

Default: Continuous-energy cross-section treatment if DRXS is absent. If the DRXS card is present but has no entries after the mnemonic, discrete cross sections will be used for every nuclide, if available.

Use: Discouraged. Applies only to neutron cross sections. It is not recommended that this card be used unless you are transporting neutrons in an energy region where resonances and hence self-shielding are of little importance. If the problem under consideration meets this criterion, using the DRXS card can reduce computer storage requirements and enhance timesharing.

Note 1: Use of these discrete cross sections will not result in the calculation being what is commonly referred to as a multigroup Monte Carlo calculation because the only change is that the cross sections are represented in a histogram form rather than a continuous-energy form. The angular treatment used for scattering, energy sampling after scattering, etc., is performed using identical procedures and data as in the continuous-energy treatment. The user wanting to make a truly multigroup Monte Carlo calculation should use the MGOPT card multigroup capability.

3.3.3 Data Cards Related to Physics

The data provided in this section describe the physics options that can be selected.

INDEX OF PHYSICS INPUT INFORMATION		
Mnemonic	**Description**	**Section**
MODE	Problem Type	3.3.3.1
PHYS	Particle Physics Options	3.3.3.2
ACT	Section Activation Control	3.3.3.3
CUT	Time, Energy, and Weight Cutoffs	3.3.3.4.1
ELPT	Cell-by-Cell Energy Cutoff	3.3.3.4.2
TMP	Free-Gas Thermal Temperature	3.3.3.5
THTME	Thermal Times	3.3.3.6
MPHYS	Model Physics Control	3.3.3.7.1
LCA, LCB, LCC, LEA, LEB	Physics Models	3.3.3.7.2-6
FMULT	Multiplicity Constants	3.3.3.8
TROPT	Transport Options	3.3.3.9
UNC	Uncollided Secondaries	3.3.3.10
COSP/COSY	Magnetic Field Tracking: Transfer Maps	3.3.3.11.1
BFLD/BFLCL	Magnetic Field Tracking: Ray Tracing	3.3.3.11.2
FIELD	Gravitational Field	3.3.3.12

3.3.3.1 MODE PROBLEM TYPE

The MODE card can take any argument listed in the "Symbol" column of Table 2-2 except for positrons (f), in any order. It must list all particles that will be transported in space-delimited format. In addition to the particle designators in Table 2-2, anti-particles may be designated placing a "-" in front of the particle. For example, `MODE H –H`, `MODE H G`, and `MODE G -G` are ways to specify both proton (H) and anti-proton (G) .

Form: MODE *<pl>*$_1$ ... *<pl>*$_i$

where *<pl>*$_i$ is a particle designator. See Notes 1 and 2.

Default: If the MODE card is omitted, `MODE N` is assumed.

Use: Required; else `MODE N` is assumed.

Note 1: The symbol "#" represents all possible heavy ion types and, although the "#" is generic to all heavy ions, the identities of different heavy ions are tracked by their appropriate ZZZ (charge) and AAA (mass number). The user cannot choose to transport any *particular* heavy ion, however, the user may specify individual ions as source particles and may request tallies for specific ions.

Note 2: If heavy ions (#) are specified on the `MODE` card, any residuals produced from any model physics will be transported even if the source particle is not a heavy ion.

3.3.3.2 PHYS PARTICLE PHYSICS OPTIONS

3.3.3.2.1 NEUTRONS (PHYS:N)

Caution: The `PHYS:N` data card entries are different for MCNP6 than they were for MCNP5 or MCNPX. In particular, the MCNPX `PHYS:N` 5th entry (*`tabl`*) has been replaced with the MCNP6 8th entry (*`cutn`*); the fission multiplicity setting on the `PHYS:N` card (*`fism`* for MCNPX and *`fisnu`* for MCNP5) has been moved to the `FMULT` card.

Form: `PHYS:N` *`emax emcnf iunr`* `J J J` *`coilf cutn ngam`* `J`
`J` *`i_int_model i_els_model`*

Table 3-39. Neutron Physics Options (PHYS:N)

Input Parameter	Description
emax	Upper limit for neutron energy and memory reduction control. (DEFAULT: *emax*=100 MeV) See Notes 1, 2, and 3. Note: If *emax*<*cutn*, all model physics is eliminated, thus reducing memory requirements.
emcnf	Analog energy limit. (DEFAULT: *emcnf*=0 MeV) If E is the energy of the neutron and E>*emcnf*, perform implicit capture. If E is the energy of the neutron and E<*emcnf*, perform analog capture.
iunr	Controls unresolved resonance range probability table treatment when data tables are available. If *iunr*=0, treatment is on. (DEFAULT) If *iunr*=1, treatment is off.
J	Unused.[1]
J	Unused; fatal error if a value appears. (*Warning*: In the MCNPX codes, the 5th parameter of the PHYS:N card, *tabl*, has been moved to the 8th entry, *cutn*.)
J	Unused; fatal error if a value appears. (*Warning*: The function of MCNP5's 5th entry on the PHYS:N card (*fisnu*) and MCNPX's 6th entry on the PHYS:N card (*fism*) has been moved to the FMULT card.

[1] The *dnb* parameter for delayed neutron biasing, which previously held this position, has been deprecated. The user is directed to use the `ACT` card described in Section 3.3.3.3 to set delayed neutron parameters.

Input Parameter	Description
coilf=n.m	**Light-ion and heavy-ion recoil and NCIA control. (See discussion after the table.)** **In this format, *n* is an integer and *m* is a specified fractional value.** **If 0<*m*≤1 and *n*=0,1,2,or 4, then *m* is the number of light ions (protons, deuterons, tritons, ^{3}He, and alphas) per incident neutron to be created at each neutron elastic scatter event with light nuclei H, D, T, ^{3}He, and ^{4}He. Heavy ions are also created if they are specified on the MODE card.** **If *n*=3 or *n*=5, then *m*=0 and light-ion recoil is turned off.** **For *n*=2 or *n*=3, NCIA is active only when the production of NCIA ions (see table below) is not modeled with the nuclear data tables.** **For *n*=4 or *n*=5, NCIA is active and the nuclear data tables for production of NCIA ions are not used.** **Using the above set of criteria, we obtain the following description for valid *coilf* entries:** **If *coilf* = 0 — then light-ion recoil is off; NCIA is off. (DEFAULT)** **If .001 < *coilf* < 1.001 — then light–ion recoil makes *coilf* ions from elastic scatter.** **If 1.001 < *coilf* < 2.001 — then light-ion recoil makes *coilf*-1 ions from elastic scatter; NCIA ions from neutron capture.*** **If *coilf* = 3 — then light-ion recoil is off; NCIA ions from neutron capture.*** **If 3.001 < *coilf* < 4.001 — then light-ion recoil makes *coilf*-3 ions from elastic scatter; NCIA ions from neutron capture.†** **If *coilf* = 5 — then light-ion recoil is off; NCIA ions from neutron capture.†** *** Table data ion production will be used if possible** **† NCIA will be used even if table data are available.**
Cutn	**Controls table-based physics cutoff and memory reduction.** **For *cutn*≥0, use physics models for energies (E) above *cutn* and data tables for those energies below *cutn*, if available (otherwise use models).** **For *cutn*=-1, then mix and match. When tables are available, use them up to their upper limit for each nuclide, then use the physics models above that limit. (DEFAULT) Also see MX card in Section 3.3.2.3.** **For *cutn*>*emax*, save memory by eliminating all model physics arrays.**
Ngam	**Controls secondary photon production. (See Note 5.)** **For *ngam=0* no photons are produced.** **For *ngam=1* photons are produced using ACE. (DEFAULT)** **For ngam=2 photons are produced using CGM.**
J J	**Unused placeholders. (Be sure to put the Js in the keyword string.)**

Input Parameter	Description
i_int_model	**Controls treatment of nuclear interactions.** **If *i_int_model*=-1, no interactions. (Equivalent to setting the inelastic cross section to zero.).** **If *i_int_model*=0, process all interactions. (DEFAULT)** **If *i_int_model*=1, no secondaries, inelastic collisions treated as weight reduction.** **If *i_int_model*=2, no secondaries, inelastic collisions treated as removal.**
i_els_model	**Controls treatment of nuclear elastic scattering. (See Note 4.)** **If *i_els_model*=-1, no elastic scattering (i.e., treat as pseudo collision)** **If *i_els_model*=0,elastic scattering by Prael/Liu/Striganov model. (DEFAULT)**

Default: `PHYS:N 100 0 0 J J J 0 -1 J J J 0 0`

Use: Encouraged. Also see FMULT card, Section 3.3.3.8. Continue-runs are not supported for delayed-neutron calculations that use model physics.

Note 1: Memory allocation can be reduced significantly for MODE N P E problems that do not invoke the photonuclear option. By setting the neutron table/model cutoff energy, *cutn*, greater than the maximum neutron energy, *emax*, physics models are disabled, storage requirements for secondary particles are greatly reduced, and, consequently, the amount of memory that must be allocated to several MCNP6 arrays is decreased. The reduction of memory usage is helpful particularly for burnup problems. Use of this memory reduction option (i.e., setting *emax*<*cutn*) is confirmed by the following OUTP file message: "memory reduction option specified, models disabled".

Note 2: The parameter *emax* must be higher than the highest energy in the problem or the physics *is wrong*. For problems with energies above 100 MeV, *emax* should be chosen carefully; the default is appropriate for problems with energies below 100 MeV.

Note 3: Neutron data above *emax* are expunged, as are neutron data below *e*, the lower energy cutoff, which is entered via the second entry on the CUT:N card (Section 3.3.3.4.1).

Note 4: Elastic scattering will be ignored if nuclear interactions are turned off.

Note 5: Correlated neutron and gamma emission is provided by CGM (unlike use of the ACE libraries) [WIL13], although execution times will increase. CGM/CGMF currently treats neutron interactions with targets of Z>9, except elastic scatter which continues to be treated by ACE libraries.

Discussion: Light Ion Recoil Physics and the Neutron Capture Ion Algorithm (NCIA)

Light ion recoil physics accounts for the ionization potential and uses the proper two-body kinematics (with neutron free-gas thermal treatment if appropriate) to bank recoil particles with the proper energy and angle. The input card `MODE N H D T S A ...` is required to produce light ions `H`, `D`, `T`, `S`, and `A`. Heavy-ion recoils are produced if `#` is on the `MODE` card. The card `CUT:<pl>  J 0` for particles `H`, `D`, `T`, `S`, and `A` is recommended so that the low-energy recoil ions produced are not killed by energy cutoff.

If activated by the 7th entry on the `PHYS:N` card, the optional neutron capture ion algorithm (NCIA) performs neutron capture in ^{3}He, ^{6}Li, and ^{10}B to produce protons, tritons, deuterons, and/or alphas according to the following table:

Isotope	Reactions
^{3}He	^{3}He(n,h)t n(^{3}He,d)d
^{6}Li	n(^{6}Li,t)α
^{10}B	n(^{10}B,α)^{7}Li

The diagnostic indicating that NCIA has been used appears in `print table 100`.

The energies of light ions are often very low, especially for thermal neutron captures. To enable transport of these secondaries, use the `CUT:<pl>` card to reduce the low-energy cutoff.

Unlike most secondary particle production in the table physics region, NCIA particles are coupled. However, if `.001<coilf≤3`, then one light ion is created by the data library and the other by NCIA, the correlation between the two particles is lost. If both particles are produced by the library, no correlation exists, either. Thus, `3.001<coilf≤5` is recommended so that when NCIA data are available, table data are not used.

When performing heating calculations, the user must exercise caution. Because neutron energy deposition is physically mediated in most cases by the secondary particle emission, NCIA may be inconsistent for heating calculations. Neutron heating is done with kerma factors (heating numbers), whereas heating from the charged secondaries is done at collisions. For `+F6` tallies and type 3 `TMESH` mesh tallies, the charged ion heating is subtracted from the neutron heating and thus is counted only once. For `F6:N` and `F6:H`, `D`, `T`, `A` tallies, the heating is counted once for each particle type. If heating tallies are done in cells where charged ions are produced, energy may be double-counted in `F6:<pl>` tallies.

Example: 1

```
PHYS:N    800  10  0  J  J  J  3  1
```

3.3.3.2.2 PHOTONS (PHYS:P)

Caution: Former MCNPX users need to be aware that the default behavior of the `PHYS:P` *nodop* parameter has changed. Photon Doppler broadening is now on by default (*nodop*=`0`).

Form: `PHYS:P` *emcpf ides nocoh ispn nodop* `J` *fism*

Table 3-40. Photon Physics Options (PHYS:P)

Input Parameter	Description
emcpf	**Upper energy limit for detailed photon physics treatment; photons with energy greater than *emcpf* will be tracked using the simple physics treatment. (See Note 1.) (DEFAULT: *emcpf*=100 MeV)**
ides	**Controls generation of electrons by photons in MODE E problems or, in photon-only problems, controls generation of bremsstrahlung photons with the thick-target bremsstrahlung model. (See Note 2.)** **If *ides*=0, then generation is on. (DEFAULT)** **If *ides*=1, then generation is off.**
nocoh	**Controls coherent (Thomson) scattering.** **If *nocoh*=0, then coherent scattering is turned on. (DEFAULT)** **If *nocoh*=1, then coherent scattering is turned off. (See Note 3.)**
ispn	**Controls photonuclear particle production. (See Note 4.)** **If *ispn*=-1, then photonuclear particle production is analog. One photon interaction per collision is sampled.** **If *ispn*=0, then photonuclear particle production is turned off. (DEFAULT)** **If *ispn*=1, then photonuclear particle production is biased. The bias causes a photonuclear event at each photoatomic event.**
nodop	**Controls photon Doppler energy broadening. (See Note 5.)** **If *nodop*=0, then Doppler energy broadening is turned on. (DEFAULT)** **If *nodop*=1, then Doppler energy broadening is turned off.**
J	**Unused.[1]**
fism	**Controls selection of photofission method. (See Note 6.)** **If *fism*=0, sample photofission from ACE libraries (no photofission prompt gammas). (DEFAULT)** **If *fism*=1, sample photofission from the LLNL fission model [VER14]. Requires photonuclear physics (*ispn*≠0). See note below.**

Default: `PHYS:P 100 0 0 0 0 J 0`

Use: Optional. Continue-runs are not supported for delayed-gamma calculations.

[1] The *dgb* parameter for delayed photon biasing, which previously held this position, has been deprecated. The user is directed to use the `ACT` card described in Section 3.3.3.3 to set delayed gamma parameters.

Note 1: If *emax* on the `PHYS:E` card is less than *emcpf* on the `PHYS:P` card, MCNP6 will internally reset *empcf* to be equal to *emax*.

If wc_1=0 on the `CUT:P` card, analog capture is used in the energy region above *emcpf*. Otherwise capture is simulated by weight reduction with Russian roulette on weight cutoff. Photons with energy less than *emcpf* will be treated with the more detailed physics that always includes analog capture. For a detailed discussion of the simple and detailed photon physics treatments, see the MCNP5 Theory Manual[X-503a], Section 4.4.

The simple physics treatment, intended primarily for higher energy photons, considers the following physical processes: photoelectric effect without fluorescence, Compton scattering, and pair production. The highly forward peaked coherent Thomson scattering is ignored. In the detailed physics treatment, photoelectric absorption can result in fluorescent emission, the Thomson and Klein-Nishina differential cross sections are modified by appropriate form factors [HEN11] and Compton profiles taking electron binding effects into account, and coherent scattering is included.

Note 2: To turn off the production of secondary electrons generated by photons, the switch *ides* can be set, either on the `PHYS:P` or on the `PHYS:E` card. If either of these cards sets *ides*=1, photons will *not* produce electrons, even if *ides*=0 is set on the other. In a photon-only problem, turning off secondary electrons causes the thick-target bremsstrahlung model to be bypassed. This option should be exercised only with great care because it alters the physics of the electron-photon cascade and will give erroneously low photon results when bremsstrahlung and electron transport are significant.

Note 3: When *nocoh*=1, the cross section for coherent scattering will be set to zero. This approximation can be useful in problems with bad point detector variances.

Note 4: Photonuclear physics models enable (γ,n) and other photonuclear reactions when photonuclear data tables are unavailable. When some photonuclear data tables are available, MCNP6 will mix and match, using tables when available and physics models when no tables are available. Consider using an `MX:P` card to override this default behavior.

Note 5: When photon Doppler broadening is turned on (*nodop*=0), there is no effect unless photon Doppler broadening momentum profile data are available in the photon library. These data are available in the MCPLIB03 and later photon libraries.

Note 6: When *fism*=1, photofission secondaries are sampled only when a photofission event occurs (unlike *fism*=0). This enables coincidence counting of photofission secondaries. The LLNL fission model for photofission is the only way to produce prompt photofission gammas; these gammas are correlated with the photofission neutrons with appropriate multiplicities. When *fism*=1 on the `PHYS:P` card, photonuclear physics must be turned on (*ispn*≠0) and the LLNL fission model should be used also for neutrons (`METHOD=5` on the `FMULT` card).

3.3.3.2.3 ELECTRONS (PHYS:E)

Form:

PHYS:E *emax ides iphot ibad istrg bnum xnum rnok enum numb i_mcs_model* J J *efac electron_method_boundary ckvnum*

Table 3-41. Electron Physics Options (PHYS:E)

Input Parameter	Description
emax	**Upper limit for electron energy. (See Note 1.) (DEFAULT: *emax* on PHYS:N card or 100 MeV if no PHYS:N card)**
ides	**Controls production of electrons by photons in MODE E problems or, in photon-only problems, controls generation of bremsstrahlung photons with the thick-target bremsstrahlung model.** **If *ides*=0, then electron production by photons is turned on. (DEFAULT)** **If *ides*=1, then electron production by photons is turned off.**
iphot	**Controls production of photons by electrons.** **If *iphot*=0, then photon production by electrons is turned on. (DEFAULT)** **If *iphot*=1, then photon production by electrons is turn off.**
ibad	**Controls bremsstrahlung angular distribution method.** **If *ibad*=0, perform full bremsstrahlung tabular angular distribution. (DEFAULT)** **If *ibad*=1, perform simple bremsstrahlung angular distribution approximation. (See Note 2.)**
istrg	**Controls electron continuous-energy slowing down ("straggling") treatment.** **If *istrg*=0, use sampled value straggling method to compute electron energy loss at each collision. (DEFAULT)** **If *istrg*=1, use expected-value straggling method to compute electron energy loss at each collision.**
bnum	**Controls production of bremsstrahlung photons created along electron sub steps.** **If *bnum*=0, bremsstrahlung photons will not be produced.** **If *bnum*>0, produce *bnum* times the analog number of bremsstrahlung photons. Radiative energy loss uses the bremsstrahlung energy of the first sampled photon. (DEFAULT: *bnum*=1)** **The specification *bnum*<0 is only applicable is using the EL03 electron-transport cross section library. Produce |*bnum*| times the number of analog photons. Radiative energy loss uses the average energy of all the bremsstrahlung photons sampled.**
xnum	**Controls sampling of electron-induced x-rays produced along electron sub steps.** **If *xnum*>0, produce *xnum* times the analog number of electron-induced x-rays. (DEFAULT: *xnum*=1)** **If *xnum*=0, x-ray photons will not be produced by electrons.**

Input Parameter	Description
Rnok	**Controls creation of knock-on electrons produced in electron interactions.** **If *rnok*>0, produce *rnok* times the analog number of knock-on electrons. (DEFAULT: *rnok*=1)** **If *rnok*=0, knock-on electrons will not be produced.**
Enum	**Controls generation of photon-induced secondary electrons. (See Note 3.)** **If *enum*>0, produce *enum* times the analog number of photon-induced secondary electrons. (DEFAULT: *enum*=1)** **If *enum*=0, photon-induced secondary electrons will not be produced.**
Numb	**Controls bremsstrahlung production on each electron sub step. (See Note 4.)** **If *numb*>0, produce bremsstrahlung on each sub step.** **If *numb*=0, analog bremsstrahlung production. (DEFAULT)**
i_mcs_model	**Controls the choice of Coulomb scattering model.** **If *i_mcs_model*=-1, turn off angular deflection.** **If *i_mcs_model*=0, select the standard Goudsmit-Sunderson angular deflection method. (DEFAULT)**
J J	**Unused placeholders. (Be sure to put the Js in the keyword string.)**
Efac	**Controls stopping power energy spacing (DEFAULT: *efac*=0.917) (See Note 5.)** **Restriction: 0.8≤*efac*≤0.99**
electron_method_ boundary	**Controls the start of single-event transport. (See Notes 6 and 7.)** ***electon_method_boundary* is the energy (in MeV) above which MCNP6 transports electrons by the condensed-history algorithms and below which the single-event method is used. (DEFAULT: *electron_method_boundary*=1.0e-3)**
Ckvnum	***ckvnum* (allowed values 0<= n < 1) can be used to scale Cerenkov photon emission from a particular particle by a fractional amount with the photons emitted at higher weight. Values of 1e-3 to 1e-2 are recommended.** **DEFAULT: 0** ***ckvnum*=0 turns off Cerenkov emission.**

Default: PHYS:E 100 0 0 0 0 1 1 1 1 0 0 J J 0.917 0.001 0

Use: Optional.

Caution: The use of the switches (or of zero values for the biasing parameters) to turn off various processes goes beyond biasing and actually changes the physics of the simulation. Therefore such actions should be taken with extreme care. These options are provided primarily for purposes of debugging, code development, and special-purpose studies of the cascade transport process.

Note 1: The parameter *emax* should be set to the highest electron energy encountered in your problem.

Note 2: Point detectors and DXTRAN spheres use the simple bremsstrahlung angular distribution approximation. Always use(ibad=1).

Note 3: The specification *enum*=0 differs from *ides*=1. If *enum*=0, pair production is totally turned off. If *ides*=1, the pair production-produced annihilation photons are still produced.

Note 4: Only a real event, i.e., one that has been sampled to have a bremsstrahlung interaction, causes energy loss. The weights of the bremsstrahlung photons are multiplied by the probability of interaction in a substep. If two or more photons are produced in a real event, the weight of the second or more photons is the unadjusted value because there is no Poisson sampling, except for real events.

Note 5: When *efac* is specified, the energy spacing for multiple-scattering tables (stopping power, range, etc.) is determined by

$$E_{n+1} = E_n * F$$

where E_1 is the highest energy and

$$F = (1/2) ** (1/D)$$

with

$$D=real(nint(ln(1/2) / ln(efac)))$$

This means that on average, the energy of the particle will decrease by a factor of two in D energy steps and that a larger value of *efac* results in more points in the multiple-scattering tables. The default value, 0.917, leads to the traditional choice of eight energy steps for a factor-of-two energy loss.

Note 6: To invoke the single-event electron-transport method, the problem must have access to photon data, even if the user is not interested in the photon transport. Therefore, the MODE card must included the specification for both photons (P) and electrons (E). Access to the EPRDATA14 library data is required to transport electrons below 1 keV. This library, which is denoted by the cross-section identifier ".14p", is not the default in the xsdir_mcnp6.2 cross-section directory file provided with the MCNP6 (Version 2) distribution; therefore the EPRDATA14 library may need to be requested on the material cards explicitly. This low-energy (<1 keV) data are only for zero-temperature atomic targets, so temperature, condensed state, and molecular effects are not yet treated for electrons in this regime.

Note 7 The energy boundary that defines the switch to single-event transport should never be lower than 1 keV, because condensed-history methods rapidly collapse below this traditional lower limit.

Example 1:

```
PHYS:E   100.  13J  0.01
```

This setting causes the energy-boundary switch to the single-event electron-transport method to occur at 10 keV.

3.3.3.2.4 PROTONS (PHYS:H)

Form: `PHYS:H` *`emax ean tabl`* `J` *`istrg`* `J` *`recl`* `J J J` *`i_mcs_model i_int_model i_els_model efac`* `J` *`ckvnum drp`*

Table 3-42. Proton Physics Options (PHYS:H)

Input Parameter	Description
Emax	**Upper proton energy limit. (See Note 1.) (DEFAULT: *emax* on `PHYS:N` card or 100 MeV if no `PHYS:N` card)**
Ean	**Analog energy limit. (DEFAULT: *ean*=`0` MeV)** **If E is the energy of the proton and E>*ean*, perform implicit capture.** **If E is the energy of the proton and E<*ean*, perform analog capture.**
Tabl	**Table-based physics cutoff.** **For *tabl*≥`0`, use physics models for energies (E) above *tabl* and data tables for those below *tabl*, if available (otherwise use models).** **For *tabl*=`-1`, then mix and match. When tables are available, use them up to their upper limit for each nuclide, then use the physics models above this limit. (DEFAULT)**
`J`	**Unused placeholder. (Be sure to put the `J` in the keyword string.)**
Istrg	**Controls charged-particle straggling.** **If *istrg*=`0`, then use Vavilov model for charged-particle straggling. (DEFAULT)** **If *istrg*=`1`, use continuous slowing-down approximation for charged-particle straggling.**
`J`	**Unused placeholder. (Be sure to put the `J` in the keyword string.)**
Recl	**Light ion recoil control. (See Note 2.)** **If *recl*=`0`, then no light ion recoil. (DEFAULT)** **For `0`<*recl*≤1, *recl* is the number of light ions (protons, deuterons, tritons, ^{3}He, and alphas) to be created at each proton elastic scatter event with light nuclei H, D, T, ^{3}He, and ^{4}He.**
`J J J`	**Unused placeholders. (Be sure to put the `J`s in the keyword string.)**

Input Parameter	Description
i_mcs_model	**Controls the choice of Coulomb scattering model.** **If *i_mcs_model*=-1, turn off angular deflection.** **If *i_mcs_model*=0, use FermiLab angular deflection model with Vavilov straggling. (DEFAULT)** **If *i_mcs_model*=1, use Gaussian angular deflection model with Vavilov straggling..** **If *i_mcs_model*=2, use FermiLab coupled energy/angle MCS model..**
i_int_model	**Controls treatment of nuclear interactions.** **If *i_int_model*=-1, no interactions. (Equivalent to setting the inelastic cross section to zero.).** **If *i_int_model*=0, process all interactions. (DEFAULT)** **If *i_int_model*=1, no secondaries, inelastic collisions treated as weight reduction.** **If *i_int_model*=2, no secondaries, inelastic collisions treated as removal.**
i_els_model	**Controls treatment of nuclear elastic scattering.(See Note 3.)** **If *i_els_model*=-1, no elastic scattering (i.e., treat as pseudo collision)** **If *i_els_model*=0, elastic scattering by Prael/Liu/Striganov model. (DEFAULT)**
efac	**Controls stopping power energy spacing (DEFAULT: *efac*=0.917) (See Note 4.)** **Restriction:** 0.8≤***efac***≤0.99
J	**Unused placeholder. (Be sure to put the J in the keyword string.)**
ckvnum	***ckvnum* (allowed values 0<= n < 1) can be used to scale Cerenkov photon emission from a particular particle by a fractional amount with the photons emitted at higher weight. Values of 1e-3 to 1e-2 are recommended.** **DEFAULT: 0** ***ckvnum*=0 turns off Cerenkov emission.**
drp	**Lower energy delta-ray cutoff. (See Note 5.)** **If *drp*=0, turn off delta-ray production (DEFAULT)** **If *drp*=-1, turn on delta-ray production and use the default energy cutoff (0.020 MeV)** **If *drp*>0, turn on delta-ray production and set the cutoff to *drp* MeV, valid for charged particles only**

Default: PHYS:H 100 0 -1 J 0 J 0 J J J 0 0 0 0.917 0 0

Use: Optional

Note 1: If *emax* on the PHYS:E card is less than *emax* on the PHYS:H card, MCNP6 will internally set the PHYS:H *emax* to the PHYS:E *emax*.

The parameter *emax* must be higher than the highest energy in the problem or the physics *is wrong*. For problems with energies above 100 MeV, *emax* should be chosen carefully; the default is appropriate for problems with energies below 100 MeV.

Note 2: Light ion recoil physics accounts for the ionization potential and uses the proper two-body kinematics (with neutron free-gas thermal treatment if appropriate) to bank recoil particles with the proper energy and angle. The input card `MODE N H D T S A ...` is required to produce light ions `H`, `D`, `T`, `S`, and `A`. The card `CUT:<pl> J 0` for particles `H`, `D`, `T`, `S`, and `A` is recommended so that the low-energy recoil ions produced are not killed by energy cutoff. Note that protons colliding with hydrogen to produce more protons can produce an overwhelming number of protons. Therefore, caution is required, and *recl*<1 may be needed. This capability is the same for incident neutrons as controlled by the *recl* keyword on the `PHYS:N` card.

Note 3: Elastic scattering will be ignored if nuclear interactions are turned off.

Note 4: When *efac* is specified, the energy spacing for multiple-scattering tables (stopping power, range, etc.) is determined by

$$E_{n+1} = E_n * F$$

where E_1 is the highest energy and

$$F = (1/2) ** (1/D)$$

with

$$D=real(nint(ln(1/2) / ln(efac)))$$

This means that on average, the energy of the particle will decrease by a factor of two in `D` energy steps and that a larger value of *efac* results in more points in the multiple-scattering tables. The default value, 0.917, leads to the traditional choice of eight energy steps for a factor-of-two energy loss.

Note 5: Delta-ray production is according to the formulation by B. Rossi, as found in ICRU Report 37. The $1/E^2$ differential spectrum is truncated by the drp parameter, which should be greater than 1 keV, with a default value of 20 keV and a maximum of 1,022 keV. To increase execution speed, this parameter should be set as large as possible, while retaining important effects to tallies of interest.

Example:

```
PHYS:H    800  10  150  J  0  J  2
```

3.3.3.2.5 OTHER PARTICLES (PHYS:<*PL*>)

Form: `PHYS:<pl>` *emax* J J J *istrg* J *xmunum* *xmugam* J J *i_mcs_model* *i_int_model* *i_els_model* *efac* J *ckvnum* *drp*

Table 3-43. Other Particles Physics Options (PHYS:<*pl*>)

Input Parameter	Description
<pl>	Particles designators other than N, P, E, and H. (See Note 1.)
emax	Upper energy limit. (See Note 2.) (DEFAULT: *emax* on PHYS:N card or 100 MeV if no PHYS:N card)
J J J	Unused placeholders. (Be sure to put the Js in the keyword string.)
istrg	Controls charged-particle straggling. If *istrg*=0, use Vavilov model with an energy correction addressing stopping powers. (DEFAULT) If *istrg*=1, use continuous slowing-down ionization model.
J	Unused placeholders. (Be sure to put the Js in the keyword string.)
xmunum	Controls the selection of muonic x-ray data: If *xmunum*=-1, use only x-ray literature data. If *xmunum*=1, emit all x-rays including data from literature and from the MUON/RURP code package. (DEFAULT) Restriction: Only valid for muons (PHYS: |) . This PHYS card 7th entry has other meanings for *<pl>*=N, P, E, and H and is ignored for other particles.
xmugam	Probability for emitting k-shell photon. (DEFAULT: *xmugam* =0.65) Restriction: Only valid for muons (PHYS:| card) . This PHYS card 8th entry has other meanings for *<pl>*=N, P, E, and H and is ignored for other particles;.
J J	Unused placeholders. (Be sure to put the Js in the keyword string.)
i_mcs_model	Controls the choice of Coulomb scattering model. If *i_mcs_model*=-1, turn off angular deflection. If *i_mcs_model*=0, use FermiLab angular deflection model with Vavilov straggling. (DEFAULT) If *i_mcs_model*=1, use Gaussian angular deflection model with Vavilov straggling.. If *i_mcs_model*=2, use FermiLab coupled energy/angle MCS model. Restriction: Valid for charged particles only.
i_int_model	Controls treatment of nuclear interactions. If *i_int_model*=-1, no interactions. (Equivalent to setting the inelastic cross section to zero.). If *i_int_model*=0, process all interactions. (DEFAULT) If *i_int_model*=1, no secondaries, inelastic collisions treated as weight reduction. If *i_int_model*=2, no secondaries, inelastic collisions treated as removal.

Input Parameter	Description
i_els_model	**Controls treatment of nuclear elastic scattering.(See Note 3.)** **If *i_els_model*=-1, no elastic scattering (i.e., treat as pseudo collision)** **If *i_els_model*=0, elastic scattering by Prael/Liu/Striganov model. (DEFAULT)**
Efac	**Controls stopping power energy spacing (DEFAULT: *efac*=0.917) (See Note 4.)** **Restriction: 0.8≤*efac*≤0.99; valid for charged particles only**
J	**Unused placeholder. (Be sure to put the J in the keyword string.)**
Ckvnum	***ckvnum* (allowed values 0<= n < 1) can be used to scale Cerenkov photon emission from a particular particle by a fractional amount with the photons emitted at higher weight. Values of 1e-3 to 1e-2 are recommended.** **DEFAULT: 0** ***ckvnum*=0 turns off Cerenkov emission.**
Drp	**Lower energy delta-ray cutoff. (See Note 5)** **If *drp*=0, turn off delta-ray production (DEFAULT)** **If *drp*=-1, turn on delta-ray production and use the default energy cutoff (0.020 MeV)** **If *drp*>0, turn on delta-ray production and set the cutoff to *drp* MeV, valid for charged particles only**

Default
```
PHYS:<pl>  100  3J  0  5J                 0  0  0 0.917 J 0 0
PHYS:|     100  3J  0   J  1  0.65  2J  0  0  0 0.917 J 0 0
```

Use: Optional.

Note 1: If *emax* on the PHYS:E card is less than *emax* on the PHYS:<pl> card, MCNP6 will internally set the PHYS:<pl> *emax* to the PHYS:E *emax.*

Although heavy ions (#) may be designated, there is no heavy ion recoil for proton elastic scattering events.

Note 2: The parameter *emax* must be higher than the highest energy in the problem or the physics *is wrong*. For problems with energies above 100 MeV, *emax* should be chosen carefully; the default is appropriate for problems with energies below 100 MeV.

Note 3: Elastic scattering will be ignored if nuclear interactions are turned off.

Note 4: When *efac* is specified, the energy spacing for multiple-scattering tables (stopping power, range, etc.) is determined by

$$E_{n+1} = E_n * F$$

where E_1 is the highest energy and

```
F = (1/2) ** (1/D)
```

with

```
D=real(nint(ln(1/2) / ln(efac)))
```

This means that on average, the energy of the particle will decrease by a factor of two in `D` energy steps and that a larger value of *efac* results in more points in the multiple-scattering tables. The default value, 0.917, leads to the traditional choice of eight energy steps for a factor-of-two energy loss.

Note 5: Delta-ray production is according to the formulation by B. Rossi, as found in ICRU Report 37. The $1/E^2$ differential spectrum is truncated by the drp parameter, which should be greater than 1 keV, with a default value of 20 keV and a maximum of 1,022 keV. To increase execution speed, this parameter should be set as large as possible, while retaining important effects to tallies of interest.

Example:

```
PHYS:D    800   3J   1
```

3.3.3.3 ACT ACTIVATION CONTROL CARD

Available delayed particles are: neutrons, gammas, betas, alphas, and positrons. Delayed-neutron emission can be calculated using library (`DN=LIBRARY`) or model (`DN=MODEL`) treatments. The library treatment uses ACE data and produces delayed neutrons only for fission. The model treatment uses data from the DELAY_LIBRARY_V5.dat library and produces delayed neutrons for fission and, if requested, activation. Delayed-gamma emission is calculated by line emission data (`DG=LINES`), from ENDF/B-VII.1 data contained in CINDERGL.dat and augmented by model data contained in DELAY_LIBRARY_V5.dat, or only model data (`DG=MG`). Delayed betas, alphas, and positrons are sampled solely from DELAY_LIBRARY_V5.dat data.

The DELAY_LIBRARY_V5.dat delayed-particle library provides unique delayed neutron, gamma, beta, alpha, and positron spectra to be sampled for each radionuclide. Delayed neutron spectra are sampled from 750 bins ranging from 0-7.5 MeV for 298 nuclides. Delayed gamma spectra are sampled from 500 bins ranging from 0-10 MeV for 1865 nuclides, (see Note 3 & 4). Delayed beta spectra are sampled from 100 bins ranging from 0-10 MeV for 1891 nuclides. Delayed positron spectra are sampled from 100 bins ranging from 0-10 MeV for 531 nuclides. Delayed alpha spectra are sampled from 100 bins ranging from 0-10 MeV for 248 nuclides. A warning is issued when no delayed particle data is available and a nuclide with a non-zero delayed-particle probability is sampled.

Delayed-gamma emission is limited to fixed source (`SDEF`) problems.

Form: `ACT KEYWORD=value(s) ...`

Table 3-44 Activation Options (ACT)

Keyword	Value
FISSION=[NONE|N,P,E,F,A|ALL]	Type of delayed particle(s) to be produced from residuals created by fission: If FISSION=NONE, create no delayed particles from fission events. If FISSION=N,P,E,F,A create delayed neutrons (N), delayed gammas (P), delayed beta particles (E), delayed positron particles (F), and/or delayed alphas (A) from fission events. Only those listed will be created. (DEFAULT: FISSION=N) If FISSION=ALL, create all delayed particles from fission events.
NONFISS=[NONE|N,P,E,F,A|ALL]	Type of delayed particle(s) to be produced by simple multi-particle reaction (SMR) activation (i.e., non-fission) events: If NONFISS=NONE, create no delayed particles from non-fission events. (DEFAULT) If NONFISS=N,P,E,F,A create delayed neutrons (N), delayed gammas (P), delayed beta particles (E), delayed positron particles (F), and/or delayed alphas (A) from non-fission events. Only those listed will be created. If NONFISS=ALL, create all delayed particles from non-fission events.
DN=[MODEL|LIBRARY|BOTH|PROMPT]	Delayed neutron data source: If DN=MODEL, production of delayed neutrons uses models only. See Note 1. If DN=LIBRARY, production of delayed neutrons uses libraries only. (DEFAULT) If DN=BOTH, production of delayed neutrons uses models when libraries are missing. If DN=PROMPT, treat prompt and delayed neutrons as prompt.
DG=[LINES|MG|NONE]	Delayed gamma data source: See Note 2. If DG=LINES, sample delayed gammas using models based on line-emission data contained in cindergl.dat, augmented by data in the latest delay_library_v[n].dat. If DG=MG, sample delayed gammas using models based on 25-group emission data. See Note 3. If DG=NONE, do not create delayed gammas. (DEFAULT)
THRESH=*f*	The fraction of highest-amplitude discrete delayed-gamma lines, *f*, that will be retained. See Note 4. (DEFAULT: THRESH=0.95)
DNBIAS=*n*	Produce up to *n* delayed neutrons per interaction. (DEFAULT: analog calculation) Restriction: $1 \le n \le 10$; DNBIAS is disallowed in KCODE calculations
NAP=*m*	The integer number *m* of activation products for which cumulative distribution functions will be calculated once and stored for reuse. (The *m* most frequently accessed distribution functions are dynamically updated during execution.) The NAP keyword is applicable to ACT NONFISS problems using line data only. (DEFAULT: NAP=10)

Keyword	Value
DNEB=w_1,e_1,w_2,e_2, ... w_n,e_n	Delayed neutron energy biasing: Used to bias delayed neutron energy w_m = weight for the m^{th} energy bin e_m = upper energy for the m^{th} energy bin (initial lower bin bound of 0 assumed) Energies within a bin are sampled evenly; probability of sampling from within a bin is based upon w_m. See Note 5.
DGEB=w_1,e_1,w_2,e_2, ... w_n,e_n	Delayed photon energy biasing: Used to bias delayed photon energy w_m = weight for the m^{th} energy bin e_m = upper energy for the m^{th} energy bin (initial lower bin bound of 0 assumed) Energies within a bin are sampled evenly; probability of sampling from within a bin is based upon w_m. See Note 5.
PECUT=*e*	Delayed-gamma energy cutoff (MeV). Gamma lines below PECUT will be expunged. (Default: PECUT=0)
HLCUT=*t*	Spontaneous-decay half-life threshold (seconds). Decay chains are truncated when a daughter half-life exceeds HLCUT. Delayed-particle production from this and subsequent daughters is omitted. (Default: HLCUT=0, i.e., no truncation of decay chains).
SAMPLE=[CORRELATE|NONFISS_COR]	Flag for correlated or uncorrelated

Note 1: Delayed-particle emission is currently integrated over 10^{10} seconds with 99 time steps; however, the user should consider increasing the stability half-life parameter (10^{th} entry on the DBCN card) when emission from long-lived radionuclides is important. Increasing this parameter results in an increase in the time integration to 10^{19} seconds with 234 time steps.

Note 2: The FISSION keyword enables delayed-particle emission from the decay of radioactive fission products created by neutron- or photon-induced fission treated by ACE libraries or any fission event treated by model physics. The NONFISS keyword enables delayed-particle emission from the decay of radioactive residuals created by neutron and photon interactions treated by ACE libraries or any nuclear interaction treated by model physics. Most neutron ACE libraries contain the necessary secondary-production cross sections needed to determine radioactive residuals (1), however very few ACE photonuclear libraries currently contain this data. Thus users should consider the use of photonuclear model physics (see the MX card) or obtain updated ACE photonuclear libraries in which secondary reactions are not lumped into MT=5. Proton ACE library interactions also suffer from this issue.

Note 3: Bin-wise emission (DG=MG) is preferred when individual line-amplitude detail is not important. This option is significantly faster and the emission spectra will converge more quickly than line emission mode (i.e., DG=LINES). Line emission augmented with bin-wise emission (DG=LINES) is useful for studies that require high fidelity, detailed-amplitude emission spectra. This option is significantly slower and can require the execution of large numbers of histories to suitably converge low probability delayed-gamma emission lines.

Note 4: Set `THRESH=1.0` to retain all lines in the CINDERGL.dat file. *Caution*: For some problems (e.g., fission), the calculation with `THRESH=1.0` will either run slowly or exceed memory limits and fail.

Note 5: A weight of "0" should not be set for any of the energy bins with DGEB/DNEB. Instead, a small value (0.001) is recommended. More information on the Delayed Neutron and Photon Energy Biasing is available in "Delayed Neutron and Photon Energy Biasing in MCNP6" LA-UR-13-23368.

3.3.3.4 PHYSICS CUTOFFS

3.3.3.4.1 CUT:<*PL*> TIME, ENERGY, AND WEIGHT CUTOFFS

Form: `CUT:<pl>` *t* *e* wc_1 wc_2 *swtm*

Table 3-45. Time, Energy, and Weight Cutoff Card (CUT:<*pl*>)

Input Parameter	Description
<*pl*>	**Particle designator.**
t	**Time cutoff in shakes, 1 shake=10^{-8} second. (See Notes 1 and 2.)**
e	**Lower energy cutoff in MeV. (See Note 1.)**
wc_1, wc_2	**Weight cutoffs. If weight goes below wc_2 roulette is played to restore weight to wc_1. Setting wc_1=wc_2=0 invokes analog capture. (See Notes 3, 4, and 5.)**
swtm	**Minimum source weight. (See Note 6.)**

Neutron default: *t*=very large, *e*=`0.0` MeV, wc_1=`-0.50`, wc_2=`-0.25`, *swtm*=minimum source weight if the general source is used

Photon default: *t*=neutron cutoff, *e*=`0.001` MeV, wc_1=`-0.50`, wc_2=`-0.25`, *swtm*= minimum source weight if the general source is used; if there are pulse-height tallies, wc_1=wc_2=`0`, unless forced collisions are also used; if pulse-height tallies exist with forced collisions, the default values are wc_1=`-0.50` and wc_2=`-0.25`

Electron default: *t*=neutron cutoff, *e*=`0.001` MeV, wc_1=`0`, wc_2=`0`, *swtm*=minimum source weight if the general source is used; if there are pulse-height tallies, wc_1=wc_2=`0`, unless forced collisions are also used; if pulse-height tallies exist with forced collisions, the default values are wc_1=`-0.50` and wc_2=`-0.25`

With the exception of photon energy and electron/positron energy (see "*Additional Photon Cutoff Notes*" and "*Additional Electron/Positron Cutoff Notes*" below), the default energy cutoff values for all particles appear in Table 2-2. All other particle time and weight default cutoffs are the same as for electrons.

Use: Optional, as needed. Analog capture is highly recommended when using weight windows and for many other applications.

Note 1: If a particle's time becomes greater than *t* as specified for that particle, its transport is stopped and the particle is killed. Although MCNP6 is time dependent, particle decay is not considered. Any particle with energy lower than the *e* specified for that particle is killed.

Note 2: The default (and maximum) emission time for delayed particle emission is 10^{10} s. By using the CUT card(s), the maximum emission time becomes 1) the particle's time cutoff if time cutoff is specified or 2) the minimum of time cutoff if multiple time cutoffs are provided.

Note 3: For non-analog capture, if a particle's weight WGT falls below wc_2 times the ratio **R** of the source cell importance to the current cell importance, then with probability WGT/(wc_1*$\mathbf{R}$), the particle survives and is assigned WGT=wc_1*$\mathbf{R}$. If negative values are entered for the weight cutoffs, the values $|wc_1|*W_s$ and $|wc_2|*W_s$ will be used for wc_1 and wc_2, respectively, where W_s is the minimum starting weight assigned to a source particle from an MCNP6 general source. These negative entries are recommended over positive entries for most problems. If only wc_1 is specified, then wc_2=0.5*wc_1.

Note 4: If wc_1 is set to zero, capture is treated explicitly by analog rather than implicitly by reducing the particles' weight according to the capture probability. If *ean or emcnf =emax* on the PHYS:<*pl*> card (i.e., applies to neutrons or protons), analog capture is used regardless of the value of wc_1 except for particles leaving a DXTRAN sphere.

Note 5: To generate delayed particles from non-fissioning isotopes, wc_1 must be set to zero on both the photon and neutron CUT:<*pl*> cards so that analog capture is invoked.

Note 6: The parameter *swtm* can be used to make the weight cutoffs relative to the minimum starting weight of a source particle for a user source, as is done automatically for the general source. The entry will in general be the minimum starting weight of all source particles, including the effects of energy and direction biasing. The entry is also effective for the general source. Then *swtm* is multiplied by the WGT entry on the SDEF card, but is unaffected by any directional or energy biasing. This entry is ignored for a KCODE calculation.

Additional Photon Cutoff Notes

The `CUT:P` weight cutoffs are analogous to those on the `CUT:N` card except that they are used only for energies above the *emcpf* entry on the `PHYS:P` card. If wc_1=0, analog capture is specified for photons of energy greater than *emcpf*. For energies below *emcpf*, analog capture is the only choice with one exception: photons leaving a DXTRAN sphere. Their weight is always checked against the `CUT:P` weight cutoff upon exiting. If only wc_1 is specified, then wc_2=0.5*wc_1.

In a coupled neutron/photon problem, the photon weight cutoffs are the same as the neutron weight cutoffs unless overridden by a `CUT:P` card.

In a coupled neutron/photon problem, photons are generated before the neutron weight cutoff game is played.

Although the default photon energy cutoff is 1 keV, a user may explicitly specify a lower cutoff down to 1 eV. The required photoatomic cross sections from ENDF/B-VI, release 8, are included in the new data library EPRDATA14 (Electron-Photon-Relaxation DATA). The tables in this library are presented in a newly developed ACE format specifically designed for use with MCNP6. (They cannot be used correctly with the earlier codes MCNP5 or MCNPX.) The proper tables can be requested on material cards using the cross-section identifier ".14p". Users are cautioned that at very low energies, molecular and other effects become important for scattering and absorption, and these more complex effects are not yet included in the photon transport methods. Also, note that although electron transport has been extended down to 10 eV, electron energies have not been extended as low as photon energies.

MCNP6 allows only analog capture below 0.001 MeV. Because the photoelectric cross section is virtually 100% of the total cross section below that energy for all isotopes, tracks will be quickly captured and terminated.

Additional Electron/Positron Cutoff Notes

Positron physics in MCNP6 is identical to electron physics, except for tracking directions in magnetic fields and consideration of positron annihilation. Whereas electrons below the energy cutoff are terminated, positrons below the energy cutoff produce annihilation photons. The positrons have a positive charge and may be tallied using the `FT` card `ELC` option (Section 3.3.5.18). Electron transport, which has a default cutoff of 1 keV, may be explicitly specified down to 10 eV.

To transport electrons at energies below 1 keV, the EPRDATA14 library is required. As with low-energy photon transport, the proper tables can be requested with the cross-section identifier ".14p". Also as with photons, the same cautions regarding temperature, molecular, solid-state, and other low-energy phenomena apply to low-energy electrons.

For very low-energy electrons, a physics-based practical difficulty can arise: the lack of energy-loss-inducing processes. Although bremsstrahlung is still present, it is completely dominated by electron elastic scattering, which results in no energy loss. Electro-ionization, an important energy-loss channel, vanishes below the binding energy of the least-bound shell given in the data. Whether that event occurs above or below 10 eV is element-dependent. Excitation, another energy-loss process, also can vanish at some energy above 10 eV, depending on the element. Consequently, there can be a small energy range just above 10 eV in which the electron can no longer lose energy and only experiences a large number of elastic scatterings. Coupled with the very short step sizes that characterize electron transport at low energies, the effect is that the transport suddenly grinds nearly to a halt because an electron has become trapped, taking a huge number of small steps with little or no opportunity to lose energy. Such an electron is very close to the energy cutoff, but cannot get there because it is spending all its time in elastic scatter. Preliminary practical experience indicates that setting the electron cutoff no lower than about 12 eV may be sufficient to avoid this occasional effect. Again note that the low-energy cross-section data are only for cold atomic targets, and that potential future treatments of molecular and other low-energy physics will significantly alter this discussion.

Example 1:

```
CUT:N    1.0D16  J  0  0
CUT:P    1.5D15  J  0  0
```

These specifications will cause delayed-neutron and delayed-gamma emission to be calculated for a time maximum of 1.5×10^{7} s, the lesser of 1.0×10^{16} and 1.5×10^{15} shakes.

Example 2:

```
CUT:P    J  1.0e-5
CUT:E    J  2.0e-5
```

These specifications will define transport of photons down to 10 eV and transport of electrons down to 20 eV. Without these `CUT` cards, the code sets the cutoffs to the default value of 1 keV.

3.3.3.4.2 ELPT CELL-BY-CELL ENERGY CUTOFF

Form 1 (cell card entry): `ELPT:<pl>` *x*

Form 2 (data card): `ELPT:<pl>` x_1 x_2 ... x_j ...

Table 3-46. Cell-by-Cell Energy Cutoff Card (ELPT:<*pl*>)

Input Parameter	Description
<pl>	**Particle designator.**
x	**Lower energy cutoff of cell.**
x_j	**Lower energy cutoff of cell *j*. Number of entries equals number of cells in problem. (See Note 1.)**

Default: Cutoff parameters from `CUT:`<*pl*>

Use: Optional. For cell-dependent energy cutoff.

Note 1: A separate lower energy cutoff can be specified for each cell in the problem. The higher of either the value on the `ELPT:`<*pl*> card or the global value *e* on the `CUT:`<*pl*> card applies.

3.3.3.5 TMP FREE-GAS THERMAL TEMPERATURE

Thermal Temperature

The `TMP` cards provide MCNP6 with the time-dependent thermal cell temperatures that are necessary for the free-gas thermal treatment of low-energy neutron transport. This treatment becomes important when the neutron energy is less than about four times the temperature of heavy nuclei or less than about 400 times the temperature of light nuclei. Thus the `TMP` cards should be used when parts of the problem are not at room temperature and neutrons are transported with energies within a factor of 400 from the thermal temperature.

Cell temperatures impact elastic scattering cross sections and collision kinematics. It should be noted, however, that the temperatures given on the `TMP` card affect only elastic scattering cross sections and have no effect on, for example, absorption cross sections or thermal scattering kernels. Furthermore, while the temperature effect on smoothly varying scattering cross sections (such as free-gas thermal scattering) is treated correctly, resonances in scattering cross sections are not broadened accurately. However, because the default value for free-gas thermal scattering is room temperature, values do need to be given on `TMP` cards whenever cells are at other temperatures.

Form 1 (cell card entry): `TMP`*n*=*t*

Form 2 (data card): `TMP`*n* t_1^n t_2^n ... t_j^n ...

or `TMP` t_1 t_2 ... t_j ...

Table 3-47. Free-Gas Thermal Temperature Card/Keyword (TMP)

Input Parameter	Description
N	**Index of time on the thermal time (`THTME`) card.** **Restriction:** $n \leq 99$
T	**Temperature of cell at time index *n*, in MeV. (See Notes 1 and 2.)**
t_j	**Temperature of cell *j* at all times, in MeV. Number of entries equals number of cells in the problem. (No `THTME` is card is present.) (See Note 2.)**
t_j^n	**Temperature of j^{th} cell at time index *n*, in MeV. Number of entries equals number of cells in the problem. (See Notes 1 and 2.)**

Default: t_j^n =2.53×10^{-8} MeV, room temperature, for all cells of the problem.

Use: Optional. Required when `THTME` card is used. Needed for low-energy neutron transport at other than room temperature. A fatal error occurs if a zero temperature is specified for a non-void cell.

Note 1: Cell thermal temperatures at times between two entries are determined by linear interpolation. Times before the first time value or after the last time value use the thermal temperature(s) at the nearest time entry.

Note 2: The thermal temperature of a cell is denoted by *kT* in units of MeV. The following conversion formulas may be used:

***kT* (MeV)**	**Unit of *T***
$8.617 \times 10^{-11}\ T$	**degrees K**
$8.617 \times 10^{-11}\ (T+273.15)$	**degrees C**
$4.787 \times 10^{-11}\ T$	**degrees R**
$4.787 \times 10^{-11}\ (T+459.67)$	**degrees F**

3.3.3.6 THTME THERMAL TIMES

The `THTME` card specifies the times at which the thermal temperatures on the `TMP`*n* cards are provided. For example, the temperatures on the `TMP1` card are at t_1 on the THTME card; the temperatures on the `TMP2` card are at time t_2 on the THTME card, etc. The times must be monotonically increasing. For each entry on the `THTME` card, there must be a `TMP`*n* card.

Form: `THTME` t_1 t_2 ... t_i ...

Table 3-48. Thermal Times (THTME)

Input Parameter	Description
t_i	**Time in shakes (10^{-8} s) at which thermal temperatures are specified on the `TMP`*i* card(s). Number of entries is equal to the total number of thermal times specified.** **Restriction: $i \leq 99$**

Default: Zero; temperature is not time dependent.

Use: Optional. Use with `TMP` card(s).

3.3.3.7 MODEL PHYSICS

3.3.3.7.1 MPHYS MODEL PHYSICS CONTROL

The use of physics models is controlled with the MPHYS card.

Form: MPHYS [ON/OFF]

Default: All MODE N P E problems (and subsets) run with physics models off (MPHYS OFF) by default. Any particle on the MODE card other than N, P, or E will automatically activate the use of physics models (MPHYS ON).

Use: To disable the use of physics models, set MPHYS OFF. To enable the use of physics models, set MPHYS ON or include the MPHYS card with no entries.

Note: When isotopes that are missing cross-section libraries in a problem or when reactions exceed a libraries' maximum energy, MCNP6's behavior can change whether models are being used or not.

Physics Models Options:

Five cards (LCA, LCB, LCC, LEA, and LEB) control physics parameters for the Bertini [BER63a, BER69], ISABEL [YAR79, YAR81], CEM03.03 and LAQGSM03.03 [GUD75, GUD83, GUD01, GUD06, MAS74, MAS01, MAS05, MAS05a, MAS05b, MAS06, MAS07, MAS07a, MAS08, MAS11, MAS11a, MAS11b, MAS12], and INCL4 [BOU02] with ABLA [GAI91, JUN98] options. All of the input values on the five cards have defaults, which will be taken in the absence of the cards, or with the use of the J input option.

These MCNP6 input cards provide the user control of physics options. A summary of the cards follows. The options controlling the Bertini and ISABEL physics modules are taken from the User Guide to LCS™ [PRA89]. The user is referred to that document for further information.

The table that follows shows how different combinations of physics models are possible using the third and ninth entries on the LCA card, *iexisa* and *icem*, and the seventh entry on the LEA card, *ievap*.

Caution: Combinations of options for the physics models should be chosen with careful consideration. Although many combinations are allowed, inappropriate choices can lead to incorrect results.

	LCA(3)	LCA(9)	LEA(7)
Bertini/Dresner	1	0	0
ISABEL/Dresner	2	0	0
Bertini/ABLA	1	0	2

	LCA(3)	LCA(9)	LEA(7)
ISABEL/ABLA	2	0	2
CEM03.03	---	1	---
INCL4/Dresner	0	2	0
INCL4/ABLA	0	2	2

3.3.3.7.2 LCA

LCA is used to select the Bertini, ISABEL, CEM03.03, or INCL4 model, as well as to set certain parameters used in Bertini and ISABEL. CEM03.03 is a self-contained package with no user-adjustable options presently defined.

Form: LCA *ielas ipreq iexisa ichoic*

jcoul nexite npidk noact icem ilaq nevtype

Table 3-49. LCA Input Description (LCA)

Input Parameter	Description
ielas	**Controls elastic scattering.** **If *ielas*=0, then no nucleon elastic scattering.** **If *ielas*=1, then elastic scattering for neutrons only.** **If *ielas*=2, elastic scattering for neutrons and protons. (DEFAULT)**
ipreq	**Controls pre-equilibrium model [PRA88} for Bertini and ISABEL. (See Note 1.)** **If *ipreq*=0, no pre-equilibrium model will be used.** **If *ipreq*=1, use pre-equilibrium model after intranuclear cascade. (DEFAULT)** **If *ipreq*=2 and if *iexisa*=0, select *ipreq*=1 and *ipreq*=3 randomly, with an energy-dependent probability that goes to *ipreq*=3 at low energies and to *ipreq*=1 at high incident energies. If *iexisa*≠0, defaults to *ipreq*=1.** **If *ipreq*=3 and if *iexisa*=0, use pre-equilibrium model instead of the intranuclear cascade. If *iexisa*≠0, defaults to *ipreq*=1.**
iexisa	**Controls model choice.† (See Note 2.)** **If *iexisa*=0, do not use ISABEL intranuclear cascade (INC) model for any particle. (DEFAULT if *icem*=2, which specifies the INCL4 model)** **If *iexisa*=1, use Bertini model for nucleons and pions and ISABEL model for other particle types. (DEFAULT)** **If *iexisa*=2, use ISABEL model for all incident particle types.**

Input Parameter	Description
Ichoic	**Four integers (*ijkl*) that control ISABEL intranuclear cascade model. (DEFAULT: *ichoic*=0023)** **If *i*=0, use partial Pauli blocking. (DEFAULT)** **If *i*=1, use total Pauli blocking.** **If *i*=-2, do not use Pauli blocking. (Not recommended)** **If *j*=0, no interaction between particles already excited above the Fermi sea. (DEFAULT)** **If *j*>0, *j* is the number of time steps to elapse between such "CAS-CAS" interactions.** **If *k*=0, use Meyer's density prescription with 8 steps.** **If *k*=1, use original (isobar) density prescription with 8 steps.** **If *k*=2, use Krappe's folded-Yukawa prescription for radial density in 16 steps, with a local density approximation to the Thomas-Fermi distribution for the (sharp cutoff) momentum distribution. (DEFAULT)** **If *k*=3, the choice is the same as *k*=0 but using the larger nuclear radius of the Bertini model.** **If *k*=4, the choice is the same as *k*=1 but using the larger nuclear radius of the Bertini model.** **If *k*=5, the choice is the same as *k*=2 but using the larger nuclear radius of the Bertini model.** **If *l*=1, perform reflection and refraction at the nuclear surface, but no escape cutoff for isobars.** **If *l*=2, perform reflection and refraction at the nuclear surface, with escape cutoff for isobars.** **If *l*=3, perform no reflection or refraction, with escape cutoff for isobars. (DEFAULT)** **If *l*=4, the choice is the same as *l*=1 but using a 25-MeV potential well for pions.** **If *l*=5, the choice is the same as *l*=2 but using a 25-MeV potential well for pions.** **If *l*=6, the choice is the same as *l*=3 but using a 25-MeV potential well for pions.**
Jcoul	**Controls Coulomb barrier for incident charged particles.** **If *jcoul*=1, the Coulomb barrier is on. (DEFAULT)** **If *jcoul*=0, the Coulomb barrier is off.**
Nexite	**Subtract nuclear recoil energy to get excitation energy.** **If *nexite*=1, this feature is on. (DEFAULT)** **If *nexite*=0, this feature is off.**
Npidk	**If *npidk*=0, force π^- to interact by nuclear capture (INC) when cutoff is reached. (DEFAULT)** **If *npidk*=1, force π^- to terminate by decay at the pion cutoff energy.‡**

Input Parameter	Description
noact	**Particle transport options.** **If *noact*=-2, source particles immediately collide; all progeny escape. In other words, all secondary particles produced are transported with no interactions and no decay. Used to compute and tally double-differential cross sections and residual nuclei with an F1 or F8 tally in conjunction with the FT RES option. (See Note 3.)** **If *noact*=-1, nuclear interactions of source particles only—transport and slowing down are off.** **If *noact*=0, turn off all non-elastic reactions.** **If *noact*=1, perform normal transport. (DEFAULT)** **If *noact*=2, attenuation mode—transport primary source particles without non-elastic reactions.**
icem	**Choose alternative physics model.** **If *icem*=0, use the Bertini or ISABEL model determined by the *iexisa* parameter.** **If *icem*=1, use the CEM03.03 model. (DEFAULT) (See Note 4.)** **If *icem*=2, use INCL4 model (Default evaporation model is ABLA; see *ievap* on LEA card.) (See Note 5.)**
ilaq	**Choose light ion and nucleon physics modules. (See Note 5.)** **If *ilaq*=0, use LAQGSM03.03 to handle all heavy ion interactions as well as all light ion interactions above 940 MeV/nucleon. ISABEL will handle light ion interactions below this energy. Use LAQGSM03.03 for proton and neutron interactions above the energy cutoff specified by parameters *flenb1* and *flenb2* on the LCB card. (DEFAULT)** **If *ilaq*=1, use LAQGSM03.03 to handle all heavy ion interactions as well as all light ion interactions.**
nevtype	**Choose number of evaporation particles modeled by GEM2 (DEFAULT=66) .** **If *nevtype*=N, evaporation modeling is limited to the lightest *N* particles. *nevtype* has a minimum value of "6" (n, p, d, t, ^{3}He, and ^{4}He). Values below this will be raised to "6" (See Note 6.)**

† The ISABEL INC model requires a much greater execution time. In addition, incident particle energies must be less than 1 GeV per nucleon for light ions (at higher energies, the LAQGSM03.03 model is automatically invoked).

‡ The capture probability for any isotope in a material is proportional to the product of the number fraction and the charge of the isotope. However, capture on ^{1}H leads to decay rather than interaction.

Use: CEM03.03 and LAQGSM03.03 are highly recommended (`LCA 8J 1 1`); `NOACT` is very useful for examining single reactions, i.e., interactions with nuclei without transport.

Note 1: CEM03.03 and LAQGSM03.03 use their own pre-equilibrium model [GUD75, MAS74, MAS12] all the time. INCL uses no pre-equilibrium model.

Note 2: The antinucleons and kaons are unaffected by the choice of physics models. They always choose ISABEL below the *flenb5* (see LCB card) and LAQGSM03.03 above the *flenb6*. At energies intermediate to these two, a weighted random choice is made between the two models.

Note 3: If *noact*=-2 on the LCA card, table physics will be used whenever possible to get the differential data actually used in a given problem. To get the differential data with models only, table data can be turned off by setting the *cutn* parameter on the PHYS:N card and the *tabl* parameter on the PHYS:H card.

Note 4: CEM03.03 allows neutrons, protons, pions, and photons to initiate nuclear reactions. We recommend when possible using CEM03.03 for target-nuclei energies up to about 5 GeV for reactions induced by nucleons and pions on heavy nuclei-targets, up to about 1.2 GeV for photonuclear reactions, and up to about 1 GeV for reactions on light nuclei-targets. Although results from CEM03.03 are expected to be more reliable in these energy regions, CEM03.03 is expected also to work quite reliably for all target-nuclei at energies up to about 5 GeV. CEM03.03 consists of an IntraNuclear Cascade (INC) model [BAR72, BAR73, MAS12], followed by its own pre-equilibrium model [GUD75, MAS74, MAS12] and an evaporation model (see details in reference MAS12 and references therein). Possible fission events are initiated in the equilibrium stage for compound nuclei with a charge number greater than 65. The evaporation/fission is handled by a modification of the Generalized Evaporation/Fission Model (GEM2) [FUR00]. Fission fragments undergo an evaporation stage that depends on their excitation energy. When the mass number of excited nuclei produced after INC, as well as after and during the preequilibrium and evaporation/fission stages of reactions, is below 13 (i.e., A<13), CEM03.03 uses the Fermi break-up model to calculate the following de-excitation, instead of using the preequilibrium and/or the evaporation/fission models. After the last stage of a reaction calculated by CEM03.03 (usually, the evaporation), a de-excitation of the residual nucleus follows in MCNP6 (but not in CEM03.03 when used as a stand-alone code [MAS12]), generating gammas with the PHT code adopted from LAHET [PRA89].

Note 5: By default, light ions (d, t, ^{3}He, alpha) are handled by ISABEL below 940 MeV/nucleon and LAQGSM03.03 above 940 MeV/nucleon. Specifying *ilaq*=1 will send them to LAQGSM03.03 at all energies. Specifying *icem*=2 will instead send them to INCL for all energies.

Note 6: By default, GEM2 models the evaporation of 66 types of particles (up to ^{28}Mg). As heavier nuclei often have negligible fission/evaporation probabilities, specifying *nevtype*=*N*, limits evaporation modeling to the lightest *N* particles. A minimum number of 6 particle types (n, p, d, t, ^{3}He, and ^{4}He) is needed, and will default to “6” when *nevtype<6*. It is recommended that users of CEM03.03 and LAQGSM03.01 use a *nevtype* value of “66” only when evaporation of fragments heavier than ^{4}He are desired; otherwise the value of “6” is recommended to save computational performance.

3.3.3.7.3 LCB

LCB controls which physics module is used for particle interactions depending on the kinetic energy of the particle.

Form: `LCB` *`flenb1 flenb2 flenb3 flenb4 flenb5 flenb6 ctofe flim0`*

Table 3-50. LCB Input Description (LCB)

Input Parameter	Description
flenb1	**Kinetic energy. (DEFAULT: *flenb1*=3500 MeV)** **For nucleons, the CEM/Bertini/INCL INC model will be used below this value. See the LCA *icem* parameter for choice of INC model. (See Note 1.)**
flenb2†	**Kinetic energy. (DEFAULT: *flenb2*=3500 MeV)** **For nucleons, the LAQGSM03.03 high-energy generator will be used above this value. See the LCA *ilaq* parameter for choice of high-energy model. (See Note 2.)**
flenb3	**Kinetic energy. (DEFAULT: *flenb3*=2500 MeV)** **For pions, the CEM/Bertini/INCL INC model will be used below this value. See the LCA *icem* parameter for choice of INC model.**
flenb4	**Kinetic energy. (DEFAULT: *flenb4*=2500 MeV)** **For pions, the LAQGSM03.03 high-energy generator will be used above this value. See the LCA *ilaq* parameter for choice of high-energy model. (See Note 2.)**
flenb5	**Kinetic energy. (DEFAULT: *flenb5*=800 MeV)** **For nucleons, the ISABEL INC model will be used below this value.**
flenb6	**Kinetic energy (DEFAULT: *flenb6*=800 MeV)** **For nucleons, an appropriate model will be used above this value.** **For *iexisa*=2 *flenb6* applies to all particle types.** **For *iexisa*=1 *flenb6* applies to all particles except nucleons and pions.** **For *iexisa*=0 *flenb6* is immaterial.** **See the example following this table for further explanation.**
ctofe	**The cutoff kinetic energy (MeV) for particle escape during the INC when using the Bertini model. The cutoff energy prevents low-energy nucleons from escaping the nucleus during the INC; for protons, the actual cutoff is the maximum of *ctofe* and a Coulomb barrier.** **If *ctofe*≥0, *ctofe* will be used as the cutoff energy.** **If *ctofe*<0, a random cutoff energy, uniformly distributed from zero to twice the mean binding energy of a nucleon will be sampled for each projectile-target interaction and separately for neutrons and protons. In this case the Coulomb barrier for protons is also randomized. (DEFAULT: *ctofe*=-1.0)** **For the ISABEL INC, the randomized cutoff energy is always used.**

Input Parameter	Description
flim0	**The maximum correction allowed for mass-energy balancing in the cascade stage, used with NOBAL=1 and NOBAL=3.** **If *flim0*>0, kinetic energies of secondary particles will be reduced by no more than a fraction of *flim0* in attempting to obtain a non-negative excitation of the residual nucleus and a consistent mass-energy balance. A cascade will be resampled if the correction exceeds *flim0*.** **If *flim0*=0, no correction will be attempted and a cascade will be resampled if a negative excitation is produced.** **If *flim0*<0, the maximum correction is 0.02 for incident energy above 250 MeV, 0.05 for incident energy below 100 MeV, and is set equal to 5/(incident energy) between those limits. (DEFAULT: *flim0*=-1.0)**

† The probability for selecting the interaction model is interpolated linearly between *flenb*1 and *flenb2*.

Note 1: For nucleons, the Bertini model switches to a scaling procedure above 3.495 GeV, wherein results are scaled from an interaction at 3.495 GeV. Although both models will execute to arbitrarily high energies, a plausible upper limit for the Bertini scaling law is 10 GeV.

Example 1:

```
LCB   3000  3000  2000  2000  1000  1000
```

For *iexisa*=1 (see the LCA card), the default, nucleons will switch to the Bertini model from the LAQGSM03.03 model below 3 GeV, and pions would switch below 2 GeV. Kaons and anti-nucleons would switch to the ISABEL model from the LAQGSM03.03 model below 1 GeV. (Muons have no nuclear interactions.)

For *iexisa*=2 (see the LCA card), nucleons and pions would also switch to the ISABEL model below 1 GeV. Note that the upper energy threshold in the ISABEL version used by MCNP6 is 1 GeV/nucleon. No interactions are allowed at energies greater than this value.

3.3.3.7.4 LCC

The LCC card specifies control parameters for the INCL4 model and the ABLA fission-evaporation model. INCL4 is invoked by setting the ninth LCA card entry, *icem*, to 2, and ABLA is invoked by setting the seventh LEA card entry, *ievap*, to 2.

Form: LCC *stincl v0incl xfoisaincl npaulincl*

nosurfincl J J ecutincl ebankincl ebankabla

Table 3-51. Input Description for INCL4 Options (LCC)

Input Parameter	Description
stincl	**Rescaling factor of the cascade duration. (DEFAULT: *stincl*=1.0)**
v0incl	**Potential depth. (DEFAULT: *v0incl*=45 MeV)**
xfoisaincl	**Controls the maximum impact parameter for Pauli blocking: *rmaxws=r0 + xfoisainc*a,* where *r0* is the radius of the nucleus and *a* is the diffuseness (DEFAULT: *xfoisaincl=8.0*)**
npaulincl	**Controls the Pauli blocking parameter If *npaulincl=1*, use Pauli strict blocking If *npaulincl=0*, use Pauli statistic blocking (DEFAULT) If *npaulincl=-1*, no Pauli blocking**
nosurfincl	**Controls the diffuse nuclear surface based on Wood-Saxon density. If *nosurfincl=-2*, use Wood-Saxon density and INCL4 stopping time (DEFAULT) If *nosurfincl=-1,* use Wood-Saxon density and stopping time with impact dependence If *nosurfincl=0,* use Wood-Saxon density and stopping time without impact dependence If *nosurfincl=1,* use sharp surface**
J J	**Unused placeholders (Be sure to put the Js in the keyword string)**
ecutincl	**Use Bertini model below this energy (DEFAULT:*ecutincl*=0)**
ebankincl	**Write no INCL bank particles below this energy (DEFAULT: *ebankincl* =0)**
ebankabla	**Write no ABLA bank particles below this energy (DEFAULT: *ebankaba* =0)**

3.3.3.7.5 LEA

LEA controls evaporation, Fermi-breakup, level-density parameters, and fission models. These are external to the particular intranuclear cascade/pre-equilibrium model chosen (Bertini, ISABEL, or INCL), and may be used with any of these choices (except CEM03.03 and LAQGSM03.03).

Form: LEA *ipht icc nobalc nobale ifbrk ilvden ievap nofis*

Table 3-52. LEA Input Description (LEA)

Input Parameters	Description
Ipht	**Control generation of de-excitation photons.** **If *iphtm*=0, generation of de-excitation photons is off.** **If *ipht*=1, generation of de-excitation photons is on. (DEFAULT)**
Icc	**Defines the level of physics to be applied for the PHT physics.** **If *icc*=0, use the continuum model.** **If *icc*=1, use the Troubetzkoy (E1) model.** **If *icc*=2, use the intermediate model (hybrid between *icc*=1 and *icc*=2).** **If *icc*=3, use the spin-dependent model.** **If *icc*=4, use the full model with experimental branching ratios. (DEFAULT)**
Nobalc	**Controls mass-energy balancing in cascade.†** **If *nobalc*=0, use mass-energy balancing in the cascade phase.** **If *nobalc*=1, turn off mass-energy balancing in the cascade phase. (DEFAULT)**
Nobale	**Controls mass-energy balancing in evaporation.** **If *nobale*=0, use mass-energy balancing in the evaporation stage. (DEFAULT)** **If *nobale*=1, turn off mass-energy balancing in the evaporation stage.**
Ifbrk	**Controls Fermi-breakup model nuclide range.** **If *ifbrk*=1, use Fermi-breakup model for atomic mass number (A)≤13 and for 14≤A≤20 with excitation below 44 MeV. (DEFAULT)** **If *ifbrk*=0, use Fermi-breakup model only for atomic mass number (A)≤5.**
Ilvden	**Controls level-density model.** **If *ilvden*=-1, use original HETC level-density formulation. See the LEB card for details on parameter inputs.** **If *ilvden*=0, use Gilbert-Cameron-Cook-Ignatyuk level-density model [PRA88]. (DEFAULT)** **If *ilvden*=1, use the Julich level-density parameterization as a function of mass number [CLO83].**
Ievap	**Controls evaporation and fission models. (See Note 1.)** **If *ievap*=0, use the RAL fission model [ATC80].** **If *ievap*=-1, use the ABLA evaporation model with its built-in fission model when *icem=2*, and use the RAL RAL fission model [ATC80] for all other cases (see iecm on the LCA card) (DEFAULT)** **If *ievap*=1, use the ORNL fission model [BAR81].‡** **If *ievap*=2, use the ABLA evaporation model with its built-in fission model.**
Nofis	**Controls fission.** **If *nofis*=1, allow fission. (DEFAULT)** **If *nofis*=0, suppress fission.**

† A forced energy balance may distort the intent of any intranuclear cascade model. Energy balancing for the INC is controlled by the input parameter *flim0*.

‡ The ORNL model allows fission only for isotopes with atomic number (Z)≥91.

Note 1: Bertini and ISABEL invoke the Dresner evaporation model with Rutherford Appleton Laboratory (RAL) fission by default. The fission model can be switched to the ORNL model using the `ievap` option on the `LEA` card. The evaporation model can be switched from Dresner to ABLA (with its built-in fission model) by setting `ievap=2`.

3.3.3.7.6 LEB

This card controls level-density input options for the original HETC implementation. (`ilvden=-1` on the `LEA` card)

Form: `LEB` *`yzere`* *`bzere`* *`yzero`* *`bzero`*

Table 3-53. LEB Input Descriptions (LEB)

Input Parameter	Description
yzere	**The Y0 parameter in the level-density formula for atomic number (Z)≤70. (DEFAULT: *yzere*=1.5. Zero or negative is an error condition.)** **For target nuclei with Z≤70, the *bzere* and *yzere* parameters are used to compute level densities. The default values are those used in LAHET before installation of the ORNL fission model.** **For target nuclei with Z≥71, the *bzero* and *yzero* parameters are used to compute level densities for the target nucleus and fission fragments.**
bzere	**The B0 parameter level-density formula for atomic number (Z)≤70. (DEFAULT: *bzere*=8.0. Zero or negative is an error condition.) (See *yzere* above.)**
yzero	**The Y0 parameter in the level-density formula for atomic number (Z)≥71 and all fission fragments. (DEFAULT: *yzero*=1.5. Zero or negative is an error condition.) (See *yzere* above.)**
bzero	**The B0 parameter in the level-density formula for atomic number (Z)≥71 and all fission fragments. (DEFAULT: *bzero*=10.0 for *ievap*=0 and for *ievap*=1. Zero and negative is an error condition.) (See *yzere* above.)**

3.3.3.8 FMULT MULTIPLICITY CONSTANTS

For induced fission, the average value of $\bar{\nu}$ generally comes from the nuclear data library and is a function of the incident neutron energy. For spontaneous fission sources, the fission multiplicity is sampled from a cumulative distribution when available or sampled from a Gaussian distribution when unavailable. The values of the FWHM and spontaneous fission $\bar{\nu}$ may be overridden using the `FMULT` card.

Form: `FMULT` *`zaid`* `[KEYWORD=value(s) ...]`

Table 3-54. Multiplicity Constants (FMULT)

Input Parameter	Description
`zaid`	`zaid`=nuclide for which data are entered. (See Note 1.)
Keyword	**Value**
`SFNU=nu` or `SFNU=x1 x2 ...`	The value *nu* is the $\bar{\nu}$ for sampling spontaneous fission multiplicity from a Gaussian distribution with width *w*. The values x_1, x_2, . . . provide the cumulative probability distribution of spontaneous fission multiplicity. (See Note 2.)
`WIDTH=w`	Gaussian width for sampling $\bar{\nu}$ for both spontaneous and induced fission. This value is ignored for spontaneous fission when `SFNU` is specified as a cumulative probability distribution. (See Note 3.)
`SFYIELD=y`	Spontaneous fission yield (n/s-g). Used for selecting the spontaneous fission nuclide when more than one is present in a material. (See Note 3.)
`WATT=a b`	Watt energy spectrum parameters *a* and *b* for spontaneous fission neutron energy sampling. (See Notes 2 and 3.)
`METHOD=m`	Use to select the Gaussian sampling algorithm method: If `METHOD=0`, use the MCNP5 sine/cosine sampling method. (DEFAULT*) If `METHOD=1`, use the Lestone method [LES05] (fits moments); this is MCNPX polar sampling with a factor or 0.5 added to the result. If `METHOD=3`, use the Ensslin/Santi/Beddingfield/Mayo method (1998–2004); this is MCNP polar sampling with a random number between 0 and 1 added to the result. If `METHOD=5`, use the LLNL fission model for neutron-induced, spontaneous, and photonuclear (if `fism=1` on the `PHYS:P` card) fission [VER14]. See Notes 4 and 5. Restriction: `METHOD=5` cannot be used with delayed neutron biasing (`DNBIAS` on `ACT` card). If `METHOD=6`, use the FREYA fission model for neutron-induced and spontaneous fission [VER16]. See Notes 4, 5 and 6. Restriction: `METHOD=6` cannot be used with delayed neutron biasing (`DNBIAS` on `ACT` card). If `METHOD=7`, use the CGMF fission model for neutron-induced and spontaneous fission [TAL16]. See Notes 4, 5 and 6. Restriction: `METHOD=7` cannot be used with delayed neutron biasing (`DNBIAS` on `ACT` card). Note: `METHOD=2` and `METHOD=4` are unused.
`DATA=d`	If `DATA=0`, use bounded integer fission sampling. (DEFAULT*) If `DATA=1`, use Lestone re-evaluated Gaussian width by isotope for multiplicities. If `DATA=2`, use original Terell Gaussian widths by isotope for multiplicities. If `DATA=3`, use Ensslin/Santi/Beddingfield/Mayo.

SHIFT=*s*	**Designate method to decrease ν to preserve $\bar{\nu}$:** **If SHIFT=0, use the MCNP5 treatment, which assumes an integer number of neutrons per fission.** For example, if $\bar{\nu}$ **=2.7, then the number of neutrons will be two 30% of the time and three 70% of the time. (DEFAULT*)** **If SHIFT>0, sample $\bar{\nu}$ from an isotope-dependent Gaussian distribution. The full-width at half-maximum (FWHM) values are displayed in print table 38. The following values are allowed:** **If SHIFT=1, correct the sampled $\bar{\nu}$ to preserve the average multiplicity (MCNPX-style adjustment). This method uses a reevaluated Gaussian width to sample fission neutron multiplicities for all fissionable isotopes.** **If SHIFT=2, preserve the multiplicity by increasing the $\bar{\nu}$ threshold.** **If SHIFT=3, sample the Gaussian distribution without correction. (This will over predict ν.)** **If SHIFT=4, use MCNP4C integer sampling method in the presence of spontaneous fission.**

* Default if no METHOD, DATA, or SHIFT keywords are specified. If any of these keywords appear, the code will automatically assign values for the unspecified keywords. The default assignments are METHOD=3, DATA=3, and SHIFT=1.

Use: Enables users to override or add additional fission multiplicity data.

Table 3-55. Mapping from MCNP5 and MCNPX PHYS:N Settings to New FMULT Settings*

MCNPX: PHYS:N 6th entry (*fism*)	FMULT Keyword: METHOD	FMULT Keyword: DATA	FMULT Keyword: SHIFT
0 (sample fission neutron multiplicity using bounded integers)	0	0	0
-1, 1 (correct the sampled $\bar{\nu}$ to preserve the average multiplicity)	3	3	1
2 (preserve the multiplicity by increasing the $\bar{\nu}$ threshold)	3	3	2
3 (sample the Gaussian distribution without correction)	3	3	3
4 (use the bounded integer method in the presence of spontaneous fission)	3	3	4
5 (use the LLNL fission model for neutron-induced, spontaneous, and photonuclear fission)	5	unused	unused

MCNPX: **PHYS:N 6th entry (*fism*)**	**FMULT Keyword: METHOD**	**FMULT Keyword: DATA**	**FMULT Keyword: SHIFT**
MCNP5: **PHYS:N 5th entry (*fisnu*)**	**FMULT Keyword: METHOD**	**FMULT Keyword: DATA**	**FMULT Keyword: SHIFT**
0 (sample fission neutron multiplicity using bounded integers)	0	0	0
1 (use reevaluated Gaussian width by isotope for multiplicities	0	1	0
2 (use original Terrell Gaussian widths by isotope for multiplicities	0	2	0

* The specific METHOD, SHIFT, and DATA parameter combinations listed in this table are the only ones assured to work correctly. Other combinations are possible but have not been tested.

Note 1: When it is desired to override the default values for the SFNU, WIDTH, SFYIELD or WATT keywords, the zaid parameter must be specified. Without zaid parameter specified only the least common fissioning nuclei, which are missing default (zero values in print table 38), will inherit the specified keyword values. Defaults exist only for the most common fission nuclei; these defaults are provided in `print table 38` of the MCNP6 output [HEN04a, SAN04, HOL84, ENS98, ZUC83, HOL85, HIC56, CRA56, BOL85, DIV56]. METHOD, SHIFT, and DATA keywords are not isotope (zaid) specific while the rest of the FMULT keywords are isotope (zaid) specific, therefore the zaid parameter need not be specified.

While the METHOD, SHIFT, and DATA keywords may be specified on multiple FMULT cards in the input deck, only the last instance of each keyword determines the algorithms and data used for multiplicity sampling.

Note 2: The keywords `SFNU` and `WATT` are used for spontaneous fission only; for induced fission, $\bar{\nu}$ and/or the spectrum parameters (a and b) are taken from the nuclear data library at the energy of the incident neutron.

Note 3: Fission widths, Watt fission spectra parameters, and fission yields are not available for the following nuclides, which have no transport cross sections: ^{246}Cf, ^{254}Cf, ^{257}Fm, and ^{252}No. Neither are they available for ^{246}Pu, ^{246}Cm, ^{248}Cm, and ^{250}Cf. To have a spontaneous fission source for these nuclides, a `FMULT` data card is required. For example,

```
FMULT 96246  WIDTH = 1.1  WATT = .2 4  SFYIELD 1
```

Because the multiplicities are provided as a table with 10 bins, the width is ignored for the spontaneous fission source; however, a value is still required for induced fission. For spontaneous fission, the energy distribution is sampled from the two Watt-fission spectra parameters; for induced fission, the energy spectra is chosen from parameters in the nuclear data tables of the transport cross sections. Finally, the spontaneous fission yield must be specified if more than one spontaneous fission source nuclide occurs. The yield is used to determine the relative sampling among spontaneous fission source nuclides. These parameters have no default values; if the FMULT card is missing, a fatal error message is issued.

Note 4: The LLNL fission model (METHOD=5), the FREYA fission model (METHOD=6), and the CGMF fission model (METHOD=7) are the only ways in MCNP6 to produce prompt fission photons at low energies. (At high energies, use of event generators followed by the PHT code produces photons from fission fragments.) Both fission neutrons and photons are correlated to the fission event and have multiplicities. When photofission is also turned on (*ispn*≠0 and *fism*=1 on the PHYS:P card), prompt photofission gammas are generated using the LLNL fission model with appropriate photofission neutron correlation and multiplicities. Use of the fission models is confirmed by the following example OUTP file message: "Using LLNL Fission Multiplicity Model". Delayed fission gammas are independent of the fission model and are controlled by the ACT card.

When any one of the fission models is selected (METHOD=5,6,7), the prompt fission photons are correlated with the fission event. Furthermore, for PAR=SF, the fission models are the only MCNP6 method emitting spontaneous fission prompt gamma rays. These are neglected in the MCNP6 default FMULT spontaneous fission source.

Note 5: If the LLNL, FREYA, or CGMF fission model is used, then only the spontaneous fission yield (SFYIELD) is used for nuclides in the respective model. For fissioning nuclides not in the LLNL model, the FMULT parameters are used.

Note 6: If either the FREYA or CGMF fission model is used, and the fission nuclide is unavailable, the LLNL fission model is used to emit correlated neutrons and photons.

Multiplicity Parameters Default Values

The data that follow are the default values [SAN04] of the multiplicity parameters in MCNP6; these can be modified with the FMULT card. The spontaneous fission multiplicity table values are displayed in print table 38 to three-digits, but are accurate to seven digits in MCNP6.

```
1fission multiplicity data.                                         print table 38

    zaid  width    watt1    watt2     yield   sfnu

   90232  1.079  .800000  4.00000  6.00E-08  2.140
   92232  1.079  .892204  3.72278  1.30E+00  1.710
   92233  1.041  .854803  4.03210  8.60E-04  1.760
   92234  1.079  .771241  4.92449  5.02E-03  1.810
   92235  1.072  .774713  4.85231  2.99E-04  1.860
   92236  1.079  .735166  5.35746  5.49E-03  1.910
```

92238	1.230	.648318	6.81057	1.36E-02	0.048	.297	.722	.950	.993	1.00	1.00	1.00	1.00	1.
93237	1.079	.833438	4.24147	1.14E-04	2.050									
94236	0.000	.000000	0.00000	0.00E+00	0.080	.293	.670	.905	.980	1.00	1.00	1.00	1.00	1.
94238	1.115	.847833	4.16933	2.59E+03	0.056	.267	.647	.869	.974	1.00	1.00	1.00	1.00	1.
94239	1.140	.885247	3.80269	2.18E-02	2.160									
94240	1.109	.794930	4.68927	1.02E+03	0.063	.295	.628	.881	.980	.998	1.00	1.00	1.00	1.
94241	1.079	.842472	4.15150	5.00E-02	2.250									
94242	1.069	.819150	4.36668	1.72E+03	0.068	.297	.631	.879	.979	.997	1.00	1.00	1.00	1.
95241	1.079	.933020	3.46195	1.18E+00	3.220									
* 96242	1.053	.887353	3.89176	2.10E+07	0.021	.168	.495	.822	.959	.996	.999	1.00	1.00	1.
96244	1.036	.902523	3.72033	1.08E+07	0.015	.131	.431	.764	.948	.991	1.00	1.00	1.00	1.
96246	0.000	.000000	0.00000	0.00E+00	0.015	.091	.354	.699	.917	.993	1.00	1.00	1.00	1.
96248	0.000	.000000	0.00000	0.00E+00	0.007	.066	.287	.638	.892	.982	.998	1.00	1.00	1.
97249	1.079	.891281	3.79405	1.00E+05	3.400									
98246	0.000	.000000	0.00000	0.00E+00	0.001	.114	.349	.623	.844	.970	1.00	1.00	1.00	1.
98250	0.000	.000000	0.00000	0.00E+00	0.004	.040	.208	.502	.801	.946	.993	.997	1.00	1.
98252	1.207	1.180000	1.03419	2.34E+12	0.002	.028	.153	.427	.733	.918	.984	.998	1.00	1.
98254	0.000	.000000	0.00000	0.00E+00	0.000	.019	.132	.396	.714	.908	.983	.998	1.00	1.
100257	0.000	.000000	0.00000	0.00E+00	0.021	.073	.190	.390	.652	.853	.959	.993	1.00	1.
102252	0.000	.000000	0.00000	0.00E+00	0.057	.115	.207	.351	.534	.717	.863	.959	.997	1.

`* = used in problem.`

All of the available data are presented in `print table 38`. Data actually used are denoted by an `*`. If any data are overridden by `FMULT` user input, the user data replaces the default data shown in `print table 38`. If the FREYA (METHOD=6) or CGMF (METHOD=7) methods are selected, additional informational messages can be seen in the output file below print table 38.

Example 1:

```
FMULT  98252  SFYIELD=2.34e12  SFNU=0.002 0.028 0.155 0.428 0.732 0.917
              0.983 0.998 1.0  WIDTH=1.207  WATT=1.18 1.03419
```

Example 2:

```
FMULT  94239  WATT=0.885247 3.8026  WIDTH=1.14 SFYIELD=0.0218 SFNU=2.1
```

Example 3:

```
M123         100257   1.0
AWTAB        100257   257.
MX123:N      29252
```

Nuclear cross-section tables for transporting ^{246}Cf, ^{254}Cf, ^{257}Fm, and ^{252}No are not generally available. To model spontaneous fission from these nuclides, it is necessary to do the transport either with a physics model or by substituting cross sections. Physics models are not recommended at low energies. To make a nuclide substitution, the `AWTAB` and `MX` cards must be used. The `AWTAB` card provides the atomic weight ratio for ^{257}Fm, which is not provided in the standard MCNP6 data libraries. The `MX123:N` card in this example substitutes ^{252}Cf, for which there are neutron cross-section data, for the corresponding nuclide (100257) on the `M123` material card.

3.3.3.9 TRANSPORT OPTIONS (TROPT CARD)

Form: `TROPT KEYWORD=value(s) ...`

Table 3-56. Keyword Descriptions for TROPT Card†

Keyword	Value
MCSCAT	**Controls multiple coulomb scattering:** **If MCSCAT=OFF, multiple coulomb scattering is disabled; no angular deflection occurs.** **If MCSCAT=FNAL1. (DEFAULT)** **If MCSCAT=GAUSSIAN.** **If MCSCAT=FNAL2. This option treats ELOSS=STRAG1 as ELOSS=CSDA. (Recommended)**
ELOSS	**Controls slowing down energy losses:** **If ELOSS=OFF, no energy loss occurs during slowing down.** **If ELOSS=STRAG1, CSDA is used with straggling. (DEFAULT)** **If ELOSS=CSDA, Energy loss modeled using only CSDA.**
NREACT	**Controls nuclear reactions:** **If NREACT=OFF, no nuclear reactions occur.** **If NREACT=ON, nuclear reactions allowed (DEFAULT) (DEFAULT)** **If NREACT=ATTEN, attenuation is turned on and absorption weighting occurs at collision.** **If NREACT=REMOVE, the incident particle is killed.**
NESCAT	**Controls nuclear elastic scattering. This keyword has no effect if NREACT=OFF.** **If NESCAT=OFF, acts as a delta-scatter for the elastic process in a transport calculation. For a GENXS calculation, sets the elastic scattring cross section to zero.** **If NESCAT=ON, (DEFAULT)**
GENXS	**Enables the generation of double-differential particle production cross sections and residual nucleus production cross sections from the high-energy nuclear interaction models. (See the section entitled "Application of the GENXS Option," which appears after the table.)** **If the GENXS keyword is absent, standard transport occurs.** **If GENXS is present, but no file name is specified, read the edit input from a file named INXC.** **If GENXS=*filename*, read the edit input from a file named *filename*..**

† The PHYS card parameters for electrons and positrons are not set or modified by the TROPT card entries.

Application of the GENXS *Option*

The GENXS option allows the application of high-energy nuclear interaction models in a cross-section generation mode without particle transport. A source may be specified inside a medium; each history will consist only of the interaction of the source particle at the source energy with the components of the medium. The tallied outcome from the event consists of the energies and direction cosines of the secondary particles and the recoil nuclei. In typical applications, the material composition will be a single isotope; however, averaged results may be obtained for a natural multi-isotopic element or a complex composition. A GENXS calculation is independent of the material density specification.

The `GENXS` option requires two input files: the standard MCNP6 INP file and an accompanying auxiliary INXC file. To invoke the `GENXS` cross-section-generating option, specify “`GENXS`” or “`GENXS` *`filename`*” on the `TROPT` card. The content and format of the edited output are determined by the content of the auxiliary input file associated with the `GENXS` option. If `GENXS` is specified on the `TROPT` card without a user-provided file name, by default the output tally edit information will be read from a file named "INXC." If a file name is provided with the `GENXS` keyword, the output tally edit information will be read from the user-specified *`filename`*. In either case, the absence of the required file will produce a fatal error. A description of the INXC file structure and an example follow this discussion.

To calculate inelastic secondary particle production only, turn off the elastic scattering by setting `NESCAT=OFF` on the `TROPT` card. Isotopic elastic scattering cross sections will be set to zero and the total cross section will equal the nonelastic cross section. All histories will sample the nonelastic interaction model. [Note that this applies only to the `GENXS` option; in a transport calculation, `NESCAT=OFF` implies a delta-scatter for the elastic process.]

To examine only elastic scattering, use `NREACT=ATTEN` on the `TROPT` card. All histories will sample the elastic scattering model and produce results for the scattered projectile and the recoil nucleus.

In the output data for a multi-isotopic composition, quoted cross sections are a weighted average of the isotopic cross sections, weighted by the input atom fractions. Thus, the cross-section output represents average cross sections per atom in the composition. Results will reflect the variance introduced by sampling for the target isotope.

Energy- and angle-integrated results are provided as yield as well as cross section. The term “yield” might be better defined as “multiplicity”. The nonelastic yield for a given particle type is the number of secondary particles of that type produced per nonelastic event. The elastic yield is per elastic event and is always unity. The "*`iyield`*" input option allows single- and double-differential results to be provided as yield rather than cross section, with the above normalization.

<u>INXC File Structure</u>: The INXC input is based on an128-column "card" format and each requested case may require as many as seven cards. With the exception of the formatted title cards, all data provided in the INXC file are entered as list-directed input. Repeat counts are allowed. A forward slash (/) may be used to terminate an input line; unread variables following a slash are assigned the default value(s). A description of the seven input cards follows:

Card 1: 80-character problem title

Card 2: *`ncase kplot l_res`*

ncase Defines the number of desired double-differential cross-section edits. (DEFAULT=0)

kplot If nonzero, write cross-section edits to the MCNP6 MCTAL file. (DEFAULT=0)
Note: Plotting is available only with the MCTAL file.

l_res If *l_res*=0, no residual nuclei are calculated; if *l_res*≠0, perform a residual nuclei edit. (DEFAULT=0)

For each of the *ncase* *cases, repeat the following cards 3 through 7, as required.*

Card 3: 128-character case title

Card 4: *nerg nang ntype fnorm imom iyield*

nerg The number of energy (momentum) bin boundaries. (DEFAULT=0, i.e., produce only energy-integrated values)

nang The absolute value, |*nang*|, provides the number of angle bin boundaries. For *nang*>0, cosine bins are specified; for nang<0, degree bins are specified. (DEFAULT=0, i.e., produce only angle-integrated energy spectra values)

ntype The number of particle types to be tallied, including elastic scattering as a special case. If *ntype*=0, all allowed particle types are included in the tally, including elastic scattering and elastic recoil. (DEFAULT=0)

fnorm A normalization factor for the double-differential cross-section edit. (DEFAULT=1)
Note: Use *fnorm*=1000.0 to convert output to millibarns.

imom If nonzero, treat the input energy bins as momentum bins (MeV/c) rather than energy bins (MeV). The output double-differential cross-section edits will be per unit momentum. (DEFAULT=0)

iyield If nonzero, the output will be differential multiplicities or yields rather than differential cross sections. Multiplicities for nonelastic reactions are defined with respect to the nonelastic cross section; for elastic scattering, the differential multiplicity is with respect to the elastic cross section. (DEFAULT=0)

Card 5: Energy (momentum) bin boundaries (present if *nerg*>0).

Four modes of input are allowed. The values are energy in MeV or, if *imom*≠0, momentum in MeV/c:

1) All bins E_i for i=1,…,*nerg* may be specified in increasing order.

2) If only one energy (momentum) value E_1 is entered, then $E_i = iE_1$ for i=2,…,*nerg*.

3) If N<*nerg* bins E_i for i=1,…,N are entered in increasing order, then $E_i = E_{i-1} + (E_N - E_{N-1})$ for i=N+1,…,*nerg*

4) If only two values, V_1 and V_2, are entered, with $V_1<0$ and $V_2>0$, then $E_{nerg} = V_2$ and $\log_{10}(E_{i-1}/E_i) = V_1$ for i=1,…,*nerg*-1 (equal-lethargy spacing).

Card 6: Angle bin boundaries (present if *nang*≠0).

For nang>0, cosine bins are entered by one of the following options:

1) Cosine bins μ_i for i=1,…,*nang* are entered in increasing order; μ_{nang} is always set to 1.

2) If a null record"/" is present, *nang* equally spaced cosine bins $-1<\mu_i\leq 1$ are defined with $\mu_{nang}=1$.

3) If only one value is entered, then the entered value is μ_1 and $\mu_{nang}=1$; the remaining cosine boundaries are interpolated uniformly.

4) If two (or more) values are entered, then the first entered value is μ_1, the second is μ_{nang-1}, and $\mu_{nang}=1$; the remaining cosine boundaries are interpolated uniformly.

For nang<0, the degree bins are entered by one of the following options:

1) Degree bins ϕ_i for i=1,…,*nang* are entered in decreasing order; ϕ_{nang} is always set to 0.

2) If a null record"/" is present, *nang* equally spaced degree bins $180<\phi_i\leq 0$ are defined with $\phi_{nang}=0$.

3) If only one value is entered, then the entered value is ϕ_1 and $\phi_{nang}=0$; the remaining cosine boundaries are interpolated uniformly.

4) If two (or more) values are entered, then the first entered value is ϕ_1, the second is ϕ_{nang-1}, and $\phi_{nang}=0$; the remaining cosine boundaries are interpolated uniformly.

Card 7: Particle types to be tallied for this case (present if *ntype*>0).

Entries are a set of flags, k_i, for i=1, *ntype*. These flags identify the particle types to be included in a single cross-section edit case. Negative entries ($k_i<0$) indicate tallies related to elastic scattering. Values of $k_i>0$ designate the tallying of production of the indicated particles type by nonelastic processes. *Warning*: These particle-type identifiers are not exactly the same as defined by the general MCNP6 numbering scheme for particle type (with the proviso the K^0 and anti-K^0, as described above). Users therefore should choose values for `ntype` carefully. The allowed k_i flag values are the following:

Table 3-57. Particle Type Designators for the `ntype` k_i flag

Flag k_i	Particle	Flag k_i	Particle	Flag k_i	Particle
1	neutron	9	μ^-	17	K^0
2	photon	10	μ^+	18	anti-K^0
3	electron (e^-)	11	ν_e	19	anti-proton
4	positron (e^+)	12	anti-ν_e	20	anti-neutron
5	proton	13	ν_m	21	deuteron (^2H)
6	π^+	14	anti-ν_m	22	triton (^3H)
7	π^-	15	K^+	23	hellion (^3He)
8	π^0	16	K^-	24	alpha (^4He)
-1	elastic scattered projectile				
-2	elastic recoil nucleus				

In the absence of any nonelastic reaction models, only the elastic cases will produce a meaningful tally.

When the default (`ntype=0`) is taken, all 26 edit types are allowed. Only brief output is produced when no secondaries of a given type occur. The ordering by particle type in the output is the following: proton, neutron, π^+, π^0, π^-, K^+, K^0, anti-K^0, K^-, anti-proton, anti-neutron, deuteron, triton, helion, alpha, photon, electron, positron, μ^-, μ^+, ν_e, anti-ν_e, ν_m, anti-ν_m, elastic scattered projectile, elastic recoil nucleus.

Example 1:

INP: MCNP6 Input File

```
Test problem: RECOIL2
1 1 -16.654 -1 2 -3
2 0         -4 (1:-2:3)
3 0          4

1 cz    4.0
2 pz   -1.0
3 pz    1.0
4 so   50.0
```

```
m1    74180 0.001300  74182 0.263000  74183 0.143000
      74184 0.306700  74186 0.286000
sdef  erg = 23080 par = 5 dir = 1 pos = 0 0 0 vec 0 0 1
imp:h   1 1 0
phys:h  23080
mode    h
print   40 110 95
nps     10000000
prdmp   2j -1
tropt   genxs nreact atten
```

INXC: Associated GENXS Input File

```
Test problem: RECOIL2
5,1,1/
Elastic scattering edit
0,-200,1/
2.0/                         ! 200 bin boundaries, 2 deg to 0 deg
-1/                          ! elastic scattered projectile
Elastic scattering energy edit
125,0,1/
23079,23079.01/              ! 125 10-keV bins above 23.079 GeV
-1/                          ! elastic scattered projectile
Elastic recoil angle edit
0,102,1/
0.0,0.02/                    ! 101 boundaries mu=0 to 0.02&1.0
-2/                          ! elastic recoil nucleus
Elastic recoil energy edit
125,0,1/
0.01/                        ! 125 10-keV bins below 1.25 MeV
-2/                          ! elastic recoil nucleus
Elastic recoil momentum edit
150,0,1,,1/
5/                           ! 150 5-MeV/c bins below 750 MeV/c
-2/                          ! elastic recoil nucleus
```

In this cross-section generation (GENXS) problem, 23.08-GeV protons impinge upon natural tungsten. Note that the `GENXS` keyword of the `TROPT` card of the MCNP6 INP file does not specify a user-supplied file name; therefore, MCNP6 expects an auxiliary input file named INXC to be available. Five cross-section edit cases plus the residual nucleus edit are specified. A MCTAL file is written for plotting. Because only elastic scattering occurs, all the cases are chosen to be single-differential cross sections only (i.e., *nerg*=0 or *nang*=0):

1) $d\sigma/d\Omega$ for the projectile, binned by degrees;
2) $d\sigma/dE$ for the projectile, binned by energy;
3) $d\sigma/d\Omega$ for the recoil nuclei, binned by cosine;

4) dσ/dE for the recoil nuclei, binned by energy; and
5) dσ/dp for the recoil nucleus, binned by momentum.

OUTP: Resultant MCNP6 Output File Excerpt

```
1 Distribution of residual nuclei:

                        Cross Section (b)
     Z = 74  all A     1.11594E+00 0.0000
             A = 180   1.40752E-03 0.0089
             A = 182   2.91615E-01 0.0005
             A = 183   1.59094E-01 0.0008
             A = 184   3.42476E-01 0.0005
             A = 186   3.21350E-01 0.0005

Summary by charge number:

  Z    Cross Section (b)     Mean Recoil (MeV)
 74   1.11594E+00 0.0000    1.30329E-02 0.0008

Summary by mass number:

  A     Cross Section (b)    Mean Recoil (MeV)
180    1.40752E-03 0.0089   1.39919E-02 0.0233
182    2.91615E-01 0.0005   1.31164E-02 0.0016
183    1.59094E-01 0.0008   1.30618E-02 0.0021
184    3.42476E-01 0.0005   1.30351E-02 0.0015
186    3.21350E-01 0.0005   1.29360E-02 0.0015

Mean weight of residual nuclei per event    3.97430E-01 0.0000
Number of residual nuclei outside of table range:      0
```

Because the computation is for only elastic scattering from a composition (natural element), the cross section shown for production of a particular residual nucleus is just $f_i \sigma_i^e$ per atom in the element and the cross section for any residual with charge number Z=74 is

$$\sum_{i=1,\ldots,5} f_i \sigma_i^e \ ,$$

i.e., the average elastic cross section per atom in the composition. Because the attenuation weighting option was used and every event is an elastic event, the quantity "`mean weight of residual nuclei per event`" equals the ratio of the mean elastic cross section to the mean total cross section for the element.

Example 2:

INP01: MCNP6 Input File

```
MCNP6 test: p + U238 by CEM03.03 at 1 GeV, nevtype=66
1 1 1.0   -1  2  -3
2 0       -4  (1:-2:3)
3 0        4

1  cz    4.0
2  pz   -1.0
3  pz    1.0
4  so   50.0

sdef   erg=1000  par=H  dir=1  pos=0 0 0  vec 0 0 1
imp:h   1 1 0
phys:h  1000
mode    h
LCA     8j 1     $ use CEM03.03
tropt   genxs inxc01  nreact on  nescat off
print   40 110 95
nps     1000000
prdmp   2j -1
```

INXC01: Associated GENXS Input File

```
MCNP6 test: p + U238 at 1 GeV for TR applications
1 1 1 /
Cross Section Edit
56 0 9 /
5. 10. 15. 20. 25. 30. 35. 40. 45. 50. 55. 60. 65. 70. 75. 80.
85. 90. 95. 100. 120. /
1 5 6 7 8 21 22 23 24 /
```

In this example, the yields (i.e., production cross sections) of products from a thin ^{238}U target bombarded by 1-GeV protons are calculated. The SDEF card of the INP file defines a 1000-MeV proton beam source pointed in the direction of the z-axis. This beam bombards ^{238}U, which fills a cylinder with a 4-cm radius oriented on the z-axis from z=-1 to z=1 cm. The provided LCA card parameters select the CEM03.03 event generator for this calculation. The card indicates a GENXS problem with an auxiliary input file named INXC01. We will calculate only inelastic secondary particle production (NREACT=ON) and we turn off the elastic scattering (NESCAT=OFF).

The input parameters of the INCX file indicate that one double-differential cross-section edit is requested, the results are to be written to the MCTAL file, and a residual nuclei edit is desired. The fourth card of the input file specifies angle-integrated energy spectra with 56 energy bin boundaries for nine particle types. The 56 energy bin boundaries are defined on the fifth card (on multiple lines) using a combination of user-provided values (the first 21 values) and code-generated values (the final 25 values). The nine particle types to tally are defined on the final card of the INCX input file using flag values to specify neutron, proton, π^+, π^-, π^0, deuteron, triton, ^{3}He, and ^{4}He.

INP01.o: Resultant MCNP6 Output File Excerpt

```
1 Distribution of residual nuclei:

                        Cross Section (b)
     Z =  1  all A     3.72774E+00 0.0010
             A =   2   2.64148E+00 0.0011
             A =   3   1.08626E+00 0.0016
     Z =  2  all A     1.56336E+00 0.0015
             A =   3   2.09100E-01 0.0032
             A =   4   1.34273E+00 0.0016
             A =   6   1.12506E-02 0.0135
             A =   8   2.76052E-04 0.0861
     Z =  3  all A     2.60266E-02 0.0090
             A =   6   8.27338E-03 0.0158
             A =   7   1.33507E-02 0.0125
             A =   8   3.58050E-03 0.0239
             A =   9   8.22021E-04 0.0499
     Z =  4  all A     8.39607E-03 0.0157
             A =   7   9.16083E-04 0.0473
             A =   9   3.31262E-03 0.0249
             A =  10   3.75840E-03 0.0233
             A =  11   3.76249E-04 0.0737
             A =  12   3.27173E-05 0.2500
     Z =  5  all A     3.64593E-03 0.0238
             A =   8   1.02241E-05 0.4472
             A =  10   1.14919E-03 0.0422
             A =  11   1.39253E-03 0.0384
             A =  12   9.44711E-04 0.0465
             A =  13   1.49273E-04 0.1170
     Z =  6  all A     2.80551E-03 0.0270
             A =  10   1.63586E-05 0.3536
             A =  11   1.22690E-04 0.1291
             A =  13   8.40425E-04 0.0493
             A =  14   8.26111E-04 0.0497
             A =  15   2.18797E-04 0.0967
             A =  16   2.86276E-05 0.2673
     Z =  7  all A     1.13897E-03 0.0424
             A =  12   2.04483E-06 1.0000
             A =  13   8.17932E-06 0.5000
             A =  14   2.37200E-04 0.0928
             A =  15   5.25521E-04 0.0624
             A =  16   1.32914E-04 0.1240
             A =  17   2.33110E-04 0.0937
```

```
.
.
.
    Z = 35  all A     7.15465E-02 0.0053
            A =  73   1.43138E-05 0.3780
            A =  74   3.29217E-04 0.0788
            A =  75   1.24530E-03 0.0405
            A =  76   2.92206E-03 0.0264
            A =  77   5.38608E-03 0.0195
            A =  78   6.02611E-03 0.0184
            A =  79   9.08926E-03 0.0150
            A =  80   7.63744E-03 0.0163
            A =  81   8.99316E-03 0.0150
            A =  82   6.54959E-03 0.0176
            A =  83   7.09147E-03 0.0170
            A =  84   4.52930E-03 0.0212
            A =  85   4.75627E-03 0.0207
            A =  86   2.40881E-03 0.0291
            A =  87   2.05096E-03 0.0316
            A =  88   1.10421E-03 0.0430
            A =  89   7.66811E-04 0.0516
            A =  90   3.35352E-04 0.0781
            A =  91   2.04483E-04 0.1000
            A =  92   6.33897E-05 0.1796
            A =  93   2.45379E-05 0.2887
            A =  94   1.63586E-05 0.3536
            A =  95   2.04483E-06 1.0000
    Z = 36  all A     9.17208E-02 0.0046
```

Of particular interest is the production of ^{87}Br and ^{88}Br, primary delayed neutron emitters with relatively long half-lives of 55.60 and 16.29 s, respectively. From this portion of the output, we see that the cross section for the production of ^{87}Br is equal to 2.05096E-03 b (±3.16%) and that of ^{88}Br is 1.10421E-03 b (±4.30%). We also see in the output file four isotopes of lithium, including ^{9}Li, and cross sections for the production of ^{17}N and ^{16}C. These three isotopes are also important delayed neutron emitters, although their half-lives are only 0.178, 4.173, and 0.747 s, respectively.

3.3.3.10 UNCOLLIDED SECONDARIES (UNC CARD)

The historical definition of an un-collided particle in MCNP6 is any particle that has not undergone a collision since its creation, whether as a source particle or as a secondary particle. This definition, in which secondary particles are created as uncollided particles, makes separation of the contribution to a tally from the direct source and contribution from secondary particles difficult. Identification of the un-collided components is particularly useful for users who employ track-length tallies in radiography applications instead of next-event estimators.

The `UNC` (un-collided secondaries) card allows the user to control if secondaries are born as un-collided or collided particles. When created as collided particles, secondaries inherit the number of collisions of their parent particle.

Form 1 (cell card entry): `UNC:<pl>` *j*

Form 2 (data card): `UNC:<pl>` j_1 j_2 ... j_i ... j_N

Table 3-57. Description of Input Parameter for UNC Card

Input Parameter	Description
<pl>	**Particle designator.**
J	**If *j*=0, then secondaries are considered to be collided for the cell.** **If *j*=1, then secondaries are considered un-collided for the cell. (DEFAULT)**
j_i	**If j_i=0, then secondaries are considered to be collided for cell *i*.** **If j_i=1, then secondaries are considered un-collided for cell *i*. (DEFAULT)** **Number of entries equals number of cells in the problem, *N*.**

Default: j_i=1, secondaries are considered un-collided for cell *i*

Use: Optional. Useful for separating the contribution resulting from un-collided source particles from that of secondaries that do not collide after their creation.

Example 1:

```
UNC:P     1  0  0
```

In this example photons are defined to be un-collided if created in cell 1. If photons are created in cells 2 or 3 from secondary processes, these photons inherit the number of collisions of the parent particle. If a photon inherits the number of collisions of the parent, then the number of collisions is always greater than or equal to one.

3.3.3.11 MAGNETIC FIELD TRACKING

MCNP6 provides two methods to simulate magnetic field effects on charged particles [BUL04, BUL11]. The first method utilizes transfer maps produced by the beam dynamics simulation and analysis code COSY INFINITY [BER02]. This method is fast and accurate; however, its use is limited to void cells only (i.e., in as vacuum) and to ensembles of particles with a fairly small energy spread. The second method, particle ray tracing, is based on an algorithm adopted from the MARS [MOK95, MOK00, MOK03] transport code. This method can be applied to both void and material cells and is valid over a very large range of particle energies. In addition, for the ray tracing method, MCNP6 includes an option that simulates third-order aberrations for quadrupole magnets caused by fringe field effects by providing edge kicks for particles entering and exiting the magnet faces. This latter feature is especially important for proper particle transport through proton radiography beam lines and magnetic lenses.

3.3.3.11.1 TRANSFER MAPS (COSYP AND COSY CARDS)

COSY INFINITY is a beam optics code that utilizes numerical integration and differential algebraic techniques to generate transfer maps based on a Taylor series expansion of a particle's canonical variables [FAV99]. These transfer maps represent the functional relation between the phase-space coordinates of a particle that has passed through a region of magnetic field and its phase-space coordinates before entering the field region. In the transfer map approach to particle transport, the actual trajectories that the particles follow through the field region do not appear explicitly; in applying precomputed maps, charged particles are transported from an initial location to a final location in one step by applying the transfer maps to the initial phase space coordinates.

Although the COSY map method provides a fast and accurate method for transporting charged particles in magnetic fields, the transfer map method has several limitations. First, map methods can only be used in void regions. Also, the COSY maps are limited to only one particle type. In addition, the Taylor expansions used in applying the maps have a finite volume of convergence in phase space. The convergence volume has a very complicated shape in five dimensions (*x*, *y*, *dx*, *dy*, *p*), requiring that the shape of the phase-space volume and the order of the Taylor series needed in order to get a given accuracy in final particle position is not easily predicted in practice and can be checked only by particle tracking. For example, a map to fifth order in energy deviation might be applied with good accuracy to particles with energies within 10% of the reference energy, but not to those with 50% deviation. In other words, COSY maps are specific to particle momentum; therefore, a particle with significantly different energy or mass than what was used to create the map will not be transported correctly.

<u>Summary of known limitations of transfer map method:</u>

- COSY maps can only be applied to void cells.
- COSY maps are specific to particle momentum. Therefore, a particle with significantly different energy or mass than what was used to create the map will not be transported correctly.
- No information about the magnetic fields is written to the output file.
- COSY maps are limited to only one particle type

The following `COSYP` card describes the COSY map parameters:

Form: `COSYP` *prefix axsh axsv emap*$_1$ *emap*$_2$ ... *emap*$_N$

Table 3-58. Magnetic Field Parameter Input (COSYP)

Input Parameter	Description
Prefix	**Set *prefix*=*k*, where *k* is the prefix number of the COSY map files. Note: COSY map files must reside in the working directory.**
Axsh	**Horizontal axis orientation** **If *axsh*=1, the *x*-axis is the horizontal axis. (DEFAULT)** **If *axsh*=2, the *y*-axis is the horizontal axis.** **If *axsh*=3, the *z*-axis is the horizontal axis.**
Axsv	**Vertical axis orientation** **If *axsv*=1, the *x*-axis is the vertical axis.** **If *axsv*=2, the *y*-axis is the vertical axis. (DEFAULT)** **If *axsv*=3, the *z*-axis is the vertical axis.**
$emap_i$	**Set $emap_i=e_i$, where e_i is the operating beam energy of the i^{th} map assigned. (DEFAULT is the energy of the i^{th} COSY map.)**

Use: Optional. Use with COSY maps.

The following `COSY` card assigns COSY map numbers to individual cells:

Form 1 (cell card entry): `COSY=`*m*

Form 2 (data card): `COSY` m_1 m_2 ... m_K

where m_i=the COSY map number for cell *i*.

Use: Use with COSY maps.

Default: No map is assigned to the cell.

Example 1:

```
cosyp   57 2 1 23070 11r
cosy    3j 1 j 2 j 3 j 4 10j 5 j 5 j 6 j 6
```

In this example, the COSY map files are prefixed with 57. The horizontal axis is the *y*-axis, and the vertical axis is the *x*-axis. The operating energy for all twelve maps assigned is 23070 MeV. Field maps are assigned to twelve cells. Table 3-60 lists the map assignments.

Table 3-60. COSY Map Assignment for the Example

Map Number	COSY Map File Name	Cell Numbers
1	571*	4
2	572*	6

Map Number	COSY Map File Name	Cell Numbers
3	573*	8
4	574*	10
5	575*	21 and 23
6	576*	25 and 27

* The COSY map files 571, 572, 573, 574, 575, and 576 must be in the working directory.

3.3.3.11.2 Particle Ray Tracing (BFLD and BFLCL Cards)

To overcome the limitations of transfer maps, MCNP6 has implemented direct magnetic field tracking utilizing numerical integration methods. These routines were adopted from the MARS high-energy particle transport code. Tracking in a void and material is performed by a higher-order numerical integration algorithm, with a maximum step size controlled by the user. Within a step, the trajectory is approximated by a segment of the helical trajectory corresponding to a constant field equal to the field at the midpoint of the step, i.e., the field variation within the step is neglected. A solution of a 3D equation of trajectory in such a field provides the new direction cosines and new particle coordinates at the end of the step. With appropriate parameters, this algorithm provides extremely high accuracy of tracking.

For quadrupole fields, MCNP6 includes a model to include the effect of the magnet fringe fields. This can be approximated by applying hard-edge kicks to the particle as it enters and leaves the magnetic field cell. An option for edge kicks has been implemented for the quadrupole magnetic field model. For a particle traveling along the *z*-axis, the following equations describe the position and momentum jumps applied to a particle as it enters the upstream fringe field of a quadrupole [FOR84]:

$$\delta x = \frac{Gp}{q}\left[\frac{x^3}{12} + \frac{xy^2}{4}\right]$$

$$\delta t_x = \frac{Gp}{q}\left[\frac{xy}{2}t_y - \frac{x^2+y^2}{4}t_x\right]$$

$$\delta y = -\frac{Gp}{q}\left[\frac{y^3}{12} + \frac{x^2 y}{4}\right]$$

$$\delta t_y = -\frac{Gp}{q}\left[\frac{xy}{2}t_x - \frac{x^2+y^2}{4}\right]t_y$$

In these equations, t_x and t_y are the direction cosines of the momentum vector. The quantity G is the quadrupole gradient (in *T/m)* and p/q is the particle rigidity (in T-m). In order to conserve energy, t_z is also recalculated using the formula

$$t_z = \sqrt{1 - t_x^2 - t_y^2}$$

For particles passing through the downstream fringe field of a quadrupole, the equations are the same, except that *Gp/q* is replaced everywhere by *–Gp/q*.

Summary of known limitations of particle ray tracing method:

- COSY maps can only be applied to void cells.
- A particle can get lost, especially for complicated geometries and lattice cells.
- In rare cases, MCNP6 could hang in an infinite loop.
- No information about the magnetic fields is written to the output file.

The magnetic field tracking option is accessed by use of the magnetic field definition card, `BFLD`.

Form: `BFLDn type KEYWORD=value(s)`

Table 3-61. Input Description for BFLD Card

Input Parameter	Description
N	**The value *n* represents the magnetic field number.**
Type	**`CONST`, magnetic field is a dipole field. `QUAD`, magnetic field is a quadrupole field. `QUADFF`, magnetic field is a quadrupole field with fringe field edge kicks.**
Keyword	**Value(s)**
`FIELD`	**For `CONST`, `FIELD`= the magnetic field strength (Tesla). For `QUAD` or `QUADFF`, `FIELD`=the magnetic field gradient (Tesla/cm).**
`VEC`	**For `CONST`, `VEC`=the direction of the magnetic field. For `QUAD` or `QUADFF`, `VEC`=the plane that corresponds to the *x*-axis of a focusing quadrupole. (DEFAULT: `VEC=0 0 1`)**
`MXDEFLC`	**Maximum deflection angle per step size (mrad). (DEFAULT: `MXDEFLC=10`)**
`MAXSTEP`	**Maximum step size (cm). (DEFAULT: `MAXSTEP=100`)**
The following keywords only apply to quadrupole fields:	
`AXS`	**The direction cosines of the quadrupole beam axis—do not need to be normalized. (DEFAULT: `AXS=0 0 1`)**
`FFEDGES`	**List of surface numbers to which fringe field edge kicks are to be applied. (Applies to *type*=`QUADFF` only)**
`REFPNT`	**A point anywhere on the quadrupole beam axis. (DEFAULT: `REFPNT=0 0 0`)**

Use: Optional. If the *type* parameter of the `BFLD` card is not provided, a fatal error occurs.

The `BFLCL` card assigns magnetic field to the cells.

Form 1 (cell card entry): `BFLCL` m

Form 2 (data card): `BFLCL` m_1 m_2 ... m_K

where m_i is the magnetic field number for cell i.

Default: m_i=0 (no magnetic field assigned to the cell)

Example 1:

```
bfld1   CONST  FIELD .03  VEC 0 1 0
bflcl   2j  1
```

A constant magnetic field of strength 0.03 Tesla is applied to cell 3. The field is in the positive y direction.

Example 2:

```
bfld2  QUADFF  FIELD 0.195  FFEDGES = 31 2i 34
bflcl  31j 2 0 2
```

A quadruple magnet field of gradient 0.195 T/cm is assigned to cells 32 and 34. Fringe-field edge kicks are applied to surfaces 31, 32, 33, and 34.

Example 3:

```
bfld3   QUAD  FIELD 0.116
        VEC 0.5 0.5 0.707
        AXS 0.85 -0.14 -0.5
        REFPNT 40 30 100
        MXDEFLC 10 MAXSTEP=1
bflcl   101j 3 0 3 7j 3 0 3
```

A quadrupole magnetic field of gradient 0.116 T/cm is assigned to cells 102, 104, 112, and 114. The axis of the quadrupole is along the vector 0.85 -0.14 -0.5, and the *x*-axis (focusing plane) is along the vector 0.5 0.5 0.707. The maximum step size is 1 cm, and the maximum angular deflection is 10 mrads.

3.3.3.12 FIELD GRAVITATIONAL FIELD

The `FIELD` card was historically an undocumented feature in earlier MCNP releases that allowed the user to model planetary gravitational effects on neutrons, which results in their orbiting the planet. This capability is not tested in the current version and may be deprecated if there is no user interest in this capability. People interested in this topic should send an email to mcnp6@lanl.gov.

3.3.4 Data Cards Related to Source Specification

Every MCNP6 problem has one of four sources: general source (SDEF card), surface source (SSR card), criticality source (KCODE card), or user-supplied source. All can use source distribution functions, specified on SI, SP, SB, and DS cards.

INDEX OF SOURCE INPUT INFORMATION		
Mnemonic	**Description**	**Section**
SDEF	General Source Definition	3.3.4.1
SI	Source Information	3.3.4.2
SP	Source Probability	3.3.4.3
SB	Source Bias	3.3.4.4
DS	Dependent Source Distribution	3.3.4.5
SC	Source Comment	3.3.4.6
SSW	Surface Source Write	3.3.4.7
SSR	Surface Source Read	3.3.4.8
KCODE	Criticality Source	3.3.4.9
KSRC	Criticality Source Points	3.3.4.10
KOPTS	Criticality Calculations Options	3.3.4.11
HSRC	Shannon Entropy Source Distribution	3.3.4.12
BURN	Depletion/Burnup	3.3.4.13
SOURCE and SRCDX	Subroutines SOURCE and SRCDX	3.3.4.13

3.3.4.1 SDEF GENERAL SOURCE DEFINITION

Guidance: Volume and Surface Source Descriptions

The specification of a source variable has one of the following three forms:

1. a scalar or vector, in which a single, explicit value is given for the specified variable (e.g., CEL=1 or POS=0 0 6);
2. a distribution number, *n*, prefixed by a D, in which the specified source variable may have multiple values that will be sampled from distribution SI. (For example., CEL=D1 indicates that multiple cell numbers will appear on the SI1 card and will be sampled using probabilities entered on the associated SP1 card.); or
3. the name of another variable prefixed by an F, followed by a distribution number prefixed by a D. (For example., POS=FCEL=D1 indicates that the position specification

will depend on the cell(s) specified on the SI1 card.) Only one level of dependence is allowed. Each distribution may be used for only one source variable. None of the position-related keywords (i.e., CEL, SUR, RAD, AXS, EXT, X, Y, Z, and CCC) can be a dependent distribution of POS.

The above scheme translates into three levels of source description. The first level exists when a source variable has an explicit or default value (for example, a single energy) or a default distribution (for example, an isotropic angular distribution). The second level occurs when a source variable is given by a probability distribution. This level requires the SI and/or SP cards. The third level occurs when a variable depends on another variable. This level requires the DS card.

MCNP6 samples the source variables in an order set up according to the needs of the particular problem. Each dependent variable must be sampled after the variable it depends on has been sampled. If the value of one variable influences the default value of another variable or the way it is sampled, as SUR influences DIR, they may have to be sampled in the right order. The scheme used in MCNP6 to set up the order of sampling is complicated and may not always work. If it fails, a message will be printed. The fix in such instances may be to use explicit values or distributions instead of depending on defaults.

The source variables SUR, VEC, NRM, and DIR are used to determine the initial direction of source-particle flight. The direction of flight is sampled with respect to the reference vector VEC, which can itself be sampled from a distribution. The polar angle is the sampled value of the variable DIR. The azimuthal angle is sampled uniformly in the range from 0° to 360°. If VEC and DIR are not specified for a volume distribution of position (SUR=0), an isotropic distribution of direction is produced by default. If VEC is not specified for a distribution on a surface (SUR=0), the vector normal to the surface, with the sign determined by the sign of NRM, is used by default. If DIR is not specified for a distribution on a surface, the cosine distribution [p(DIR)=2×DIR, 0<DIR<1] is used by default. A biased distribution of DIR can be used to make more source particles start in a direction toward the tallying regions of the geometry. The exponential distribution function (−31, Section 3.3.4.3) is usually most appropriate for this.

The source variables SUR, POS, RAD, EXT, AXS, X, Y, Z, and CCC are used in various combinations to determine the coordinates (x,y,z) of the starting positions of the source particles. With them you can specify three different kinds of volume distributions and three different kinds of distributions on surfaces. Degenerate versions of those distributions provide line and point sources. More elaborate distributions can be approximated by combining several simple distributions, using the S option of the SI and DS cards.

A description of each SDEF keyword appears in Table 3-62. Following the table and its notes are more detailed discussions of volume and surface source specification. Examples of the general source follow discussion if the SI, SP, SB, and DS cards.

Form: `SDEF KEYWORD=value(s) ...`

Table 3-62. General Source Variables (SDEF)

Keyword	Value
CEL	**Cell number.** **[DEFAULT: Determined from the position of the particle, and possibly the direction of the flight of the particle if the position is on a surface of a cell].**
SUR	**Surface number. (See Note 1.)** **[DEFAULT: SUR=0, which indicates a cell (volume) source]** **Always required when source points lie on the boundary (surface) of a cell.**
ERG†	**Kinetic energy (MeV).** **(DEFAULT: ERG=14)**
TME	**Time (shakes). (See Note 2.)** **(DEFAULT: TME=0)**
DIR	**μ, the cosine of the angle between VEC and the particle's direction of flight. (Azimuthal angle is always sampled uniformly in 0° to 360°.) (See Note 3.)** **(DEFAULT for volume source: μ is sampled uniformly in -1 to 1, i.e., the source is isotropic.)** **(DEFAULT for surface source: $p(\mu)=2\mu$ in 0 to 1 , i.e., cosine distribution.)**
VEC	**Reference vector for DIR in vector notation.** **(DEFAULT for volume source: Required unless source is isotropic.)** **(DEFAULT for surface source: Vector normal to the surface with sign determined by NRM.)**
NRM	**Sign of the surface normal.** **(DEFAULT: NRM=+1)**
POS	**Reference point for position sampling in vector notation.** **(DEFAULT: POS=0,0,0)**
RAD	**Radial distance of the position from POS or AXS.** **(DEFAULT: RAD=0)**
EXT	**For a volume source is the distance from POS along AXS.** **For a surface source is the cosine of angle from AXS.** **(DEFAULT: EXT=0)**
AXS	**Reference vector for EXT and RAD in vector notation.** **(DEFAULT: No direction)**
X	**X-coordinate of position.** **(DEFAULT: X=0)**
Y	**Y-coordinate of position.** **(DEFAULT: Y=0)**
Z	**Z-coordinate of position.** **(DEFAULT: Z=0)**

Keyword	Value
CCC	**Cookie-cutter cell number. (See Notes 4 and 5.)** **(DEFAULT: no cookie-cutter cell)**
ARA	**Area of surface. (Required only for direct contributions to point detectors from plane surface source.)** **(DEFAULT: none)**
WGT	**Particle weight (input as explicit value only).** **(DEFAULT: WGT=1)**
TR	**Source particle transformation number (TR=*n*) or distribution of transformations (TR=D*n*). Corresponding TR card(s) is required. (Section 3.3.1.3) (See Notes 6 and 7.)** **(DEFAULT: none)**
EFF	**Rejection efficiency criterion for position sampling (input as explicit value only). (See Note 8.)** **(DEFAULT: EFF=0.01)**
PAR	**Source particle type(s) by symbol or number (e.g., PAR=H or PAR=9).* For a complete list of particle types, see Table 2-2.** **Use a distribution for sampling multiple particle types.** **To specify a particular heavy ion as a source particle, set PAR to ZZZAAA, where ZZZAAA is the isotope identifier of the ion.** **Cosmic Particles:** **If PAR=[-]CR, the source is a combination of all cosmic particles** **If PAR=[-]CH or PAR=C1001, the source contains cosmic protons only** **If PAR=[-]CA or PAR=C2004, the source contains cosmic alphas only** **If PAR=[-]C7014, the source contains cosmic nitrogen only** **If PAR=[-]C14028, the source contains cosmic silicon only** **If PAR=[-]C26056, the source contains cosmic iron only** **When the negative sign is omitted from these options, the SDEF WGT keyword (i.e., source normalization) is set to the integral 2π flux obtained from the Castagnoli and Lal [CAS80] analytic equation (as corrected by Masarik & Reedy, 1996). If the cosmic particle designator is preceded by a negative sign, then the particle weight normalization only considers the SDEF WGT information provided by the user.** **Background Particles (see Note 9):** **If PAR=[-]BG, the background is a combination of all background particles (currently limited to neutrons and gammas)** **If PAR=[-]BN, the background contains neutrons only** **If PAR=[-]BP, the background contains gammas only** **If the negative sign is omitted, the SDEF WGT keyword (i.e., source normalization) is multiplied by values contained in the BACKGROUND.dat file. If the negative sign is included, then the source normalization is taken only from the SDEF WGT keyword.**

Keyword	Value
PAR	**Spontaneous Fission (see section below entitled *Spontaneous Fission Sources—Physics and Tally Normalization*):** **If PAR=SF, normalize summary and tally information by the number of spontaneous-fission neutrons.** **If PAR=-SF, normalize summary and tally information by the number of histories (generally, the number of spontaneous fissions).** **Spontaneous Neutrons:** **If PAR=SN, decay neutrons will be created based on the relative activities of the unstable isotopes in the material(s) located at the source location(s).** **Spontaneous Photons:** **If PAR=SP, decay gammas will be created based on the relative activities of the unstable isotopes in the material(s) located at the source location(s).** **Spontaneous Betas:** **If PAR=SB, decay betas will be created based on the relative activities of the unstable isotopes in the material(s) located at the source location(s).** **Spontaneous Positrons:** **If PAR=ST, decay betas will be created based on the relative activities of the unstable isotopes in the material(s) located at the source location(s).** **Spontaneous Alphas:** **If PAR=SA, decay alphas will be created based on the relative activities of the unstable isotopes in the material(s) located at the source location(s).** **All-particle Spontaneous Decay:** **If PAR=SD, all decay particles (SN,SP,SB,SA,ST) will be created based on the relative activities of the unstable isotopes in the material(s) located at the source location(s). Decay particle types that are missing from the MODE card will be omitted (with a related warning message)** **To specify the decay particles from a particular heavy ion as the source, set PAR to ZZZAAA, where ZZZAAA is the isotope identifier of the ion and set the energy of the ion to zero (ERG=0.0). Requires that heavy ions (#) be specified on the MODE card.** **(DEFAULT: If no MODE card, PAR=N.)** **(DEFAULT: If MODE card in INP file, lowest IPT number or symbol represented on MODE card.)**
DAT *m d y*	**Date to use for cosmic–ray (PAR=CR,CH,CA) and background (PAR=BG,BN,BP) sources (see Note 10):** *m* **An integer value representing the month of the year (1≤*m*≤12)** *d* **An integer value representing the day of the month (1≤*d*≤31)** *y* **A 4-digit integer representing the year**

Keyword	Value
LOC *lat lng alt*	**Location of cosmic particle source (see Note 11):** *lat* latitude ($-90 \le$ *lat* ≤ 90, relative to equator; negative values are south of the equator and positive values are north of the equator) *lng* longitude ($-180 \le$ *lng* ≤ 180, relative to Greenwich, UK; negative values are west longitude and positive values are east longitude) *alt* altitude in km of cosmic particles when PAR=CR,CH,CA (DEFAULT: *alt*=65.0 km), or elevation in km of the background source when PAR=BG,BN,BP (no default).
BEM *exn eyn bml*	**Beam emittance parameters (see Note 12):** *exn* normalized beam emittance parameter, ε_{nx}, for phase-plane coordinates x, x' (π-cm-radians) *eyn* normalized beam emittance parameter, ε_{ny}, for phase-plane coordinates y, y' (π-cm-radians) *bml* distance from the aperture to the spot, L (cm) (DEFAULT: none)
BAP *ba1 ba2 u*	**Beam aperture parameters (see Note 13):** *ba1* beam aperture half-width in the x transverse direction, x_0 (cm) *ba2* beam aperture half-width in the y transverse direction, y_0 (cm) *u* unused, but must be set to an arbitrary value (DEFAULT: none)

† If there is a negative *igm* on the MGOPT card, which indicates a special electron-photon multigroup problem, ERG on the SDEF card is interpreted as an energy group number, an integer.

* In MCNP5, the specification of PAR=4 would result in a positron. However, in MCNP6, PAR=4 indicates a negative muon.

Default: Isotropic point source at position=[0 0 0], time=0, energy=14 MeV, and particle weight=1.

Use: Required for problems using the general source. Optional for problems using the criticality source. Reminder: an equals sign (=) following a keyword is optional.

Note 1: If the source location is on any surface (including "extended" surfaces of macrobodies) used to describe the cell that contains that source, the SUR keyword must be used. A source can lie on an extended surface used to describe any other cell of the problem.

Note 2: Emitted source decay gammas are assumed to arise from instantaneous activity of a large pool of decaying isotopes; time behavior is defined by the TME keyword. If an isotope emits multiple gamma lines, the emissions will not necessarily be correlated. Isotopes with half-lives longer than 1×10^{18} seconds (~3.17×10^{10} years) are treated as stable. When the decay gammas of a heavy ion are specified as the source, Table 110 of the output file will list the sampled heavy-ion isotopes but not the created gamma lines.

Note 3: Discrete values of DIR are allowed. DIR=1 gives a mono-directional source in the direction of VEC. This is sometimes useful as an approximation to an actual source that is at a large distance from the geometry of the problem. In most cases discrete values of DIR will prevent direct contributions to point detectors from being scored. The direct contribution will be scored only if the source is on a plane surface, is sampled uniformly in area within a circle (using RAD sampled from SP −21 1), VEC is perpendicular to the surface (the default), and DIR=1. A cookie-cutter cell is allowed and a value of ARA is necessary. Discrete values of DIR with DXTRAN are generally wrong because $p(\mu)=0.5$ is assumed.

Note 4: Cookie-cutter rejection is available for both cell and surface sources. If CCC is present, the sampled position is accepted if it is within cell CCC and is resampled if it is not. It is recommended that cookie-cutter cells be bounded by surfaces used for no other purpose in the problem and that the cookie-cutter cell cards appear at the end of the list of cell cards. Also, keep the cookie-cutter cell as simple as possible. For example, for a surface source, the intersection of the cookie-cutter cell with the source surface is what matters. For a plane surface source, an infinitely long cell of uniform cross section bounded by planes and cylinders is usually adequate.

Note 5: *Warning!* The combination of either CEL or CCC rejection with biased sampling of the position is nearly always an *unfair game*. If the user employs this combination, he must ensure that the game is fair; MCNP6 cannot detect this error.

Note 6: A general transformation of the generated source may be specified with a single transformation TR=*n* or with a distribution of transformations TR=D*m*. In either case, all SDEF parameters relating to particle position or direction are interpreted as being in an auxiliary coordinate system in which the source specification is simpler. A general transformation is applied to a source particle after its coordinates and direction cosines have been determined in the auxiliary coordinate system. Particle coordinates are modified by both rotation and translation, while direction cosines are modified only by rotation. The source after transformation is treated as a volume source (i.e., surface number not defined); the cell for the source particle is determined after transformation. (SUR and CEL are used only in the initial generation procedure.) To avoid the possibility of lost particles, do not place the transformed source exactly on a surface of the physical geometry. With the form TR=*n*, a transformation card TR*n* must be specified. With the form TR=D*m*, in addition to the TR cards, the user must provide SI*m*, SP*m*, and possibly SB*m* cards. If a distribution of transformations is specified, the *option* parameter on the corresponding SI*m* card must be L. The *option* parameter on the SP*m* and SB*m* cards may be blank, D, or C.

Note 7: Sources may be translated to different locations with the TR option. For example, the source transformation capability allows the user to rotate the direction of an accelerator beam or move the entire beam of particles in space. In addition, this capability is useful for setting up the source as an accelerator beam and then using the translation as a distribution to repeat the accelerator source at different locations and orientations. The TR option can be dependent on other source variables. For example, the particle type can depend on the translated source location:

```
SDEF    CEL=FTR=D3   PAR=FTR=D1   TR=D2    ,
```

or the translated source location can be a dependent distribution function of cell:

```
SDEF    CEL=D2       TR=FCEL=D5
```

Note 8: The efficiency criterion EFF applies to both CCC and CEL rejection. If in any source cell or cookie-cutter cell the acceptance rate is too low (the default value of EFF is 0.01), the problem is terminated for inefficiency. To increase efficiency, the user is encouraged to revise the source description. If a source efficiency lower than 0.01 is unavoidable, specify a lower value for EFF.

Note 9: The BG, BN, and BP options require that the user: (1) properly normalize the source in a spherical volume (WGT = sphere surface area/3.0), cylindrical volume (WGT = cylindrical surface area/3.4), cube volume (WGT = cube surface area/3.7), spherical surface (WGT=πr^2), or some other enclosed surface (WGT set to a central cell tally that has unit flux); (2) use the appropriate SDEF keywords to specify an isotropic uniform spatial distribution within these volumes or a cosine-weighted uniform distribution on any enclosing surface; (3) ensure that the background source volume is large compared to the geometry of interest (i.e., a radius or diameter that is 10 times that of the interior geometry); and (4) ensure that the BACKGROUND.dat file is in the local directory or in the DATAPATH directory. When the "-" sign is omitted from these options, the WGT normalization will be further modified by the neutron and/or gamma flux normalization provided in the BACKGROUND.dat file, as well as being multiplied by the neutron/cosmic-photon elevation scaling factor (see LA-UR-14-21331). The elevation scaling is only performed when the LOC elevation (3rd entry) differs from that of the selected BACKGROUND.dat grid-point elevation. This scaling will be omitted when the LOC elevation is specified as “-1” or when the grid-point location is over seawater. These background source options require use of the LOC keyword and the sampling of this source ignores any specification for the ERG keyword. The LOC keyword identifies the normalization and energy spectrum to be sampled from the BACKGROUND.dat file.

Note 10: The DAT keyword is used with the PAR=BG,BN,BP option to scale the background fluxes from the date specified in the background.dat file to the date specified by the DAT keyword. It can be used with the PAR=BG,BN,BP option when the cosmic source is intended for use within the Earth's atmosphere (in which case solar modulation effects are included). When the keyword DAT specifies a date between 1936 and 2014, linear interpolation of the yearly solar modulation values determines the appropriate modulation. Specified dates prior to 1936 or after 2014 use a sine wave fit to approximate the solar modulation based on the measured data available for 1936-2014.

Note 11: The keyword LOC is used only the PAR=CR, CH, CA, BG, BN, or BP options and should be specified when the cosmic or background source is intended for use within the Earth's atmosphere. Omission of the LOC keyword with the PAR=CR, CH, or CA option provides a cosmic source appropriate for interplanetary analysis. The 47th entry on the DBCN card (see Section 3.3.7.3.2) can be used to switch between the default Clem formulation [CLE04] and the

Lal formation [CAS80]. When the LOC keyword is used, the SKYMAP.dat file must be available in the local directory or in the DATAPATH directory. The skymap data file contains rigidity data on an approximate 5° latitude resolution (non-uniform spacing) and 20° longitude resolution (uniform spacing). Based on the LOC keyword, the algorithm uses a closest-match approach, first finding the closest longitude match followed by the closest latitude match. Fractional values are allowed after the LOC keyword—however, these are converted to the nearest integer degree for comparison to the skymap data. The PAR=CR, CH, CA option will automatically include heavy ions if they are included on the MODE card, unless the Lal source is specified.

Note 12: The PAR=SD, SN, SP, SB, ST, SA, and ZZZAAA (with ERG=0) options require time integration of daughter production at each level within a decay chain. This is facilitated by setting all decay constants to unity and uniformly spacing all time bins within 20 s (or ~20 decay levels), which will include all decay particle production within most decay chains (i.e., an equilibrium production). The user can adjust the integration time, and thus the number of decay levels, by modifying the 55th entry on the DBCN card. For example, setting this to ~1.0 s will result in daughter production and related decay particle production from just the precursor. If long-lived radionuclides are included (HL<1.5768E16 s) the user must increase the 10th entry on the DBCN card to obtain related decay particle production. This will also increase the fidelity of the time integration by increasing the number of time steps from 99 to 234.

Note 13: In a multiple-source-particle problem, the "energy per source particle" given in the summary tables is normalized to the source particle weight for each source particle type. If the particle type is not a source particle (listed on the MODE card, but not on SDEF), then the "energy per source particle" is normalized to the source particle weight of the lowest particle type.

Note 14: To simplify the description of the beam parameters BEM and BAP, the beam is referenced to the *z*-axis and the aperture is described as if it lies in the *x*-*y* plane. Other SDEF keywords, namely POS, AXS, and VEC, are employed to describe the location and orientation of the beam. These three keywords specify the center of the aperture, the beam direction, and the azimuthal orientation of the beam, respectively. The Figure 3-3 caption explains further the keyword relationships.

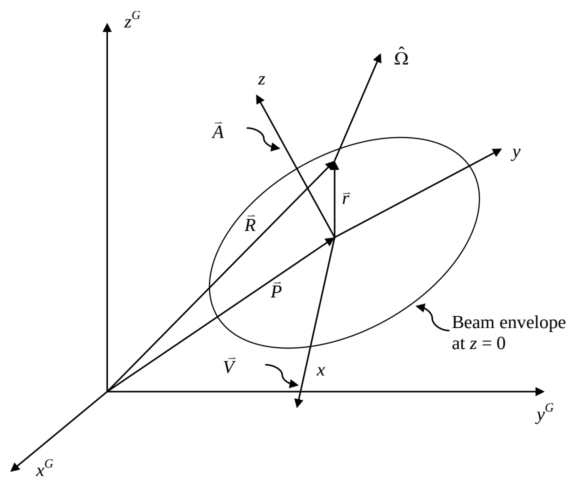


Figure 3-3. Locating and aiming a beam in MCNP6 involves a transformation from local (x,y,z) to global (x^G,y^G,z^G) coordinates. The beam aperture is located in the local-coordinate x-y plane at the entrance to the drift region (z=0) at position $\vec{P}$ ("POS"). The beam envelope is aligned in the direction $\vec{A}$ ("AXS") parallel to the +z local-coordinate direction with the azimuthal orientation given by $\vec{V}$ ("VEC"). Particle emission is in the direction $\hat{\Omega}$ at the local-coordinate position $\vec{r}$ (the global position $\vec{R}$) as determined by beam parameters and Monte Carlo sampling.

Volume Source Specification:

The three volume distributions are Cartesian, spherical, and cylindrical. A volume distribution can be used in combination with the CEL or CCC keywords to sample uniformly throughout the interior of a cell. A Cartesian, spherical, or cylindrical region that completely contains a cell is specified and is sampled uniformly in volume. If the sampled point is found to be inside the cell, it is accepted. Otherwise it is rejected and another point is sampled. If you use this technique, you must make sure that the sampling region really does contain every part of the cell because MCNP6 has no way of checking for this. Cookie-cutter (CCC) rejection can be used instead of or in combination with CEL rejection.

A Cartesian volume distribution is specified with the keywords X, Y, and Z. A degenerate case of the Cartesian distribution, in which the three variables are constants, defines a point source. A single point source can be specified easily by providing values of X, Y, and Z on the SDEF card. If several source points need to be specified, it is usually easier to use a degenerate spherical distribution for each point. Other degenerate cases of the Cartesian distribution are a line source and a rectangular plane source.

A Cartesian distribution is an efficient shape for the CEL rejection technique when the cell is approximately rectangular. It is much better than a cylindrical distribution when the cell is a long thin slab. The Cartesian distribution is limited in that the faces can only be perpendicular to the coordinate axes.

A spherical volume distribution is specified with the keywords POS and RAD. The keywords X, Y, Z, and AXS *must not* be specified or the distribution will be assumed to be Cartesian or cylindrical. The sampled value of the vector POS defines the center of the sphere. The sampled value of RAD defines the distance from the center of the sphere to the position of the particle. The position is then sampled uniformly on the surface of the sphere of radius RAD. Uniform sampling in volume is obtained if the distribution of RAD is a power law with a=2, which is the default case. If RAD is not specified, the default is zero. This is useful because it specifies a point source at the position POS. A distribution for POS, with an L on the SI card, is the easiest way to specify a set of point sources in a problem.

A common use of the spherical volume distribution is to sample uniformly in the volume between two concentric spherical surfaces. The two radii are specified on the SI card for RAD and the effect of an SP*n* -21 2 card is obtained by default.

A cylindrical volume distribution is specified with the keywords POS, AXS, RAD, and EXT. The axis of the cylinder passes through the point POS in the direction AXS. The position of the particles is sampled uniformly on a circle whose radius is the sampled value of RAD, centered on the axis of the cylinder. The circle lies in a plane perpendicular to AXS at a distance from POS which is the sampled value of EXT. A useful degenerate case is EXT=0, which provides a source with circular symmetry on a plane (i.e., a thin disk source).

A common use of the cylindrical distribution is to sample uniformly in volume within a cylindrical shell. The distances of the ends of the cylinder from POS are entered on the SI*n* card for EXT and the inner and outer radii are entered on the SI*n* card for RAD. Uniform sampling between the two values of EXT and power law sampling between the two values of RAD, with a= 1 which gives sampling uniform in volume, are provided by default.

Caution: Never position any kind of degenerate volume distribution so that it lies on a defined surface of the problem geometry. Even a bounding surface that extends into the interior of a cell can cause trouble. If possible, use one of the surface distributions instead. Else, move to a position a small distance from the surface. This positioning will make no detectable difference in the answers, but will prevent particles from getting lost.

Surface Source Specification:

The value of the keyword SUR is non-zero for a distribution on a surface. The shape of the surface can be a spheroid, sphere, cylinder, or plane. (A spheroid is an ellipse revolved around one of its axes.) If X, Y, and Z are specified, their sampled values determine the position. The user must in this case make sure that the point really is on the surface because MCNP6 does not check. If X, Y, and Z are not specified, the position is sampled on the surface SUR. With the exception of a spherical surface, the SUR keyword does not automatically provide source points on the listed surface. The user must still use the X, Y, Z, POS, AXS, RAD, and EXT keywords to ensure the source points actually lay on the prescribed surface. For a surface source, sampling using CEL rejection is not an option; however, cookie-cutter rejection can be used.

If the value of SUR is the name of a spheroidal surface, the position of the particle is sampled uniformly in area on the surface. A spheroid for this purpose must have its axis parallel to one of the coordinate axes. Although there is no provision for easy non-uniform or biased sampling on a spheroidal surface, a distribution of cookie-cutter cells could be used to produce a crude non-uniform distribution of position.

If the value of SUR is the name of a spherical surface, the position of the particle is sampled on that surface. A spherical surface source does not have to be on a cell-bounding problem surface. If the vector AXS is not specified, the position is sampled uniformly in area on the surface. If AXS is specified, the sampled value of EXT is used for the cosine of the angle between the direction AXS and the vector from the center of the sphere to the position point. The azimuthal angle is sampled uniformly in the range from 0° to 360°. A non-uniform distribution of position, in polar angle only, is available through a non-uniform distribution of EXT. A biased distribution of EXT can be used to start more particles from the side of the sphere nearest the tallying regions of the geometry. The exponential distribution function (-31, Section 3.3.4.3) usually is the most appropriate way to specify this behavior. The keyword DIR may be specified without VEC, allowing VEC to default to the outward surface normal.

Cylindrical surface sources must be specified as degenerate volume sources. For a cylindrical surface source, the cylindrical surface can be, but does not have to be, a cell-bounding problem surface specified by the keyword SUR. If the cylindrical surface is a problem surface, then the surface number must be specified on the SDEF card with the SUR keyword. The default of VEC is the surface normal. If both DIR and VEC are specified, then particle directions are relative to VEC rather than to the cylindrical surface normal. DIR may be specified without VEC, causing VEC to default to the outward surface normal.

If the value of SUR is the name of a plane, the position is sampled on that plane. The sampled value of POS must be a point on the plane. The user must make sure that POS really is on the plane because MCNP6 does not check. The sampled position of the particle is at a distance from POS equal to the sampled value of RAD. The position is sampled uniformly on the circle of radius RAD centered on POS. Uniform sampling in area is obtained if the distribution of RAD is a power law with a=1, which is the default in this case.

Guidance: Defining Embedded Source Distribution Information

Source distributions may be embedded within each other to describe accelerator micro-pulses and other phenomena. The format to specify an embedded source is

```
SDEF   TME=( D11 < D12 < D13 )
```

or, for distributions of distributions, the following form may be used:

```
SDEF   TME=D41
SI41   S  51  ( D11 < D12 < D13 ) 52
```

In both cases, distributions 11, 12, 13 are all for the same variable, time. Distribution 11 covers a small time range that is repeated as often as needed to fill exactly the larger time range of distribution 12. Similarly, distribution 12 is repeated as often as needed to fill exactly the even larger time range of distribution 13. (See Example 20.)

Note that the parentheses are optional and that the designator "D" on the SI card with "S" option is also optional. Thus

```
SDEF   TME=( D11 < D12 < D13 )        and
SDEF   TME=  D11 < D12 < D13          are equivalent.
```

Also,

```
SI41   S  51  ( D11 < D12 < D13 ) 52         ,
SI41   S  51    D11 < D12 < D13   52         ,
SI41   S  51  (  11 <  12 <  13 ) 52         , and
SI41   S  51     11 <  12 <  13   52         are all equivalent.
```

The embedded distributions must start at zero or a fatal error message is issued. For (D11<D12<D13) the lowest value on the SI11 and SI12 cards must be zero. The embedding distribution, D13, can have any range.

The embedded distributions should fit within each other (nearly) exactly. If they do not there the fatal error message, "embedded distribution *nn* has improper range" is issued and the distribution will spill into the next bin and have a strange normalization for values in its last bin.

Only continuous source distributions such as ERG, TME, X, Y, Z, DIR, RAD and EXT may use embedded distributions.

Guidance: Defining a Source in a Repeated Structures or Lattice Geometry

Hint: Carefully study print table 110 in the MCNP6 output file to ensure that the proper source path and position are being sampled when repeated structures are used in a source description.

When the source is specified in a repeated structure part of the geometry, the CEL parameter on the SDEF card must have a value that is a path, enclosed in parentheses, from level *n* to level 0 (i.e., the highest level), where *n* is not necessarily the bottom level:

$$\mathrm{CEL}=(c_n<c_{n-1}<...<c_0)$$

In this specification c_i is either zero or a cell in the universe that fills cell c_{i-1}, or is D*m* for a distribution of cells in the repeated structure case. A distribution of cells (i.e., D*m*) is not valid for a lattice; however, a range of lattice elements may be specified. (Cell designator c_i can have a minus sign, but D*m* cannot. This is discussed below.) If c_i=0, the cell at that level is searched for. If c_i is one specific element in a lattice, it is indicated as

```
...<ci[i j k]<...
```

The coordinate system for position and direction sampling (PDS) is the coordinate system of the first negative or zero c_i in the source path starting from the right and proceeding left. Each entry in the source path represents a geometry level, where level zero is the last specified source path entry, level one is the second entry to the left, and so forth. Level zero is above level one and level two is below level one. The PDS level is the level associated with the PDS cell or PDS coordinate system. All levels above the PDS level must be included in the source path. Levels below the PDS level need not be specified, and when given, may include one or more zero entries. When the path has no negative or zero entry, the default PDS level is the first (i.e., lowest) entry in the source path.

Position rejection is done in cells at all levels where $c_i \neq 0$, but if any c_i has a negative universe number on its cell card and is at or above the PDS level, higher level cells are not checked.

The following chart illustrates the concept of the PDS level:

CEL Source Path	**Cell of PDS Level**	**PDS Level**
`(5<6<7<8)`	5	3
`(6<-7<8)`	7	1
`(0<4<0<-6<7<8)`	6	2
`(0<6[0 0 0]<-7[1 0 0]<8)`	7	1
`(0<6[0 0 0]<7[1 0 0]<8)`	Will be determined	3

A range of lattice indices may be specified to produce a uniform sampling among those lattice elements. The ability to sample source points from a range of lattice indices requires the use of a fully specified `FILL` card for the listed lattice cell. The sampling is accomplished using rejection on all possible lattice elements. Note that the `SDEF` keyword `EFF` may need to be decreased to accommodate sampling of a small portion of a large lattice. A lattice cell without indices results in uniform sampling in all elements if a fully specified `FILL` card is provided. Uniform sampling is applied to lattice cell entries in the source path that lack an explicit lattice index *and* that are at or above the PDS level. Lattice cells not defined by the expanded `FILL` card must include an explicit lattice index when at or above the PDS level. Rejection of automatically sampled lattice elements depends on the entry before the lattice cell number in the source path.

Assume the following cell descriptions:

Cell 7 is a 3-element lattice defined using the following data entries:

```
lat=1 u=1 fill=0:2 0:0 0:0  1 2 3
```

Cells 8 and 9 are members of universe 2

Cells 10 and 11 are members of universe 3

Cell 7 is a lattice with three existing elements: `[0 0 0]`, which is filled by itself `[u=1]`; `[1 0 0]`, which is filled by cells 8 and 9 `[u=2]`; and `[2 0 0]`, which is filled by cells 10 and 11 `[u=3]`. The following combinations show which elements are accepted and which are rejected.

CEL Source Path	Accepted	Rejected
`7`	All elements	None
`(0<7)`	All elements	None
`(8<7)`	`[1 0 0]`	`[0 0 0]`, `[2 0 0]`
`(10<7)`	`[2 0 0]`	`[0 0 0]`, `[1 0 0]`

The sampling efficiency for cell 7 in the OUTP file will reflect the element rejections. Lattice cell entries that lack an explicit lattice index *and* are below the PDS level are not sampled. Instead, the appropriate lattice element is determined by the input source position.

Lattice element sampling is independent from position sampling. First a lattice element is chosen, then a position is chosen. If the sampled position is not in the sampled lattice element, the position is resampled until it is in the specified source path and in the lattice element chosen or until an efficiency error occurs. The lattice elements will not be resampled to accommodate the sampled position. Lattice element rejection is done only as described above.

Using the previous description of lattice cell 7, add that cell 6 is filled by cell 7. The source path becomes `(0<7<6)`. Three elements of the lattice exist `[fill=0:2 0:0 0:0]` but element `[0 0 0]` now is cut off by cell 6. Lattice element `[0 0 0]` still will be sampled one-third of the time. The first time element `[0 0 0]` is sampled a fatal error will occur because the sampled position, no matter what it is, will be rejected because element `[0 0 0]` does not exist. *Caution*: Implement automatic lattice sampling carefully and ensure that all of the lattice elements specified on the expanded `FILL` card really do exist.

Note that the format of the `CEL` source path is the same as for tally cards. See Section 3.3.5.1.4 for more information about specifying the path for repeated structures or lattices for tallies.

Shorthand: Specifying Multiple Cell Paths for Repeated Structures or Lattices

The source cell path input format also allows a shorthand notation for one source cell path to represent a number of source paths, similar to the way that one "tally 4" path sequence enclosed in parentheses can represent a number of separate tallies. For example, the input source path (5<7 8 9 10 11<1) is interpreted by MCNP6 as the five paths (5<7<1), (5<8<1), (5<9<1), (5<10<1), and(5<11<1). The sequence order of these paths is determined from left to right in the original input master path. Similarly, single or multiple lattice indexes within the square brackets of path (5<3[...]<2) can have the following four optional input forms for the *ijk* index data for lattice cell element(s) with the FILL array defined on the cell 3 card:

i	Indicates the i^{th} lattice element of cell 3 as defined by the FILL array using only one count index; e.g., *i*=1 is the first element.
i j k	Indicates a lattice element from the FILL array using the three indexes.
$i_1{:}i_2\ j_1{:}j_2\ k_1{:}k_2$	Indicates a range of one or more lattice elements, where the ":" and last entry of any of the three pairs can be omitted if that lattice element does not vary.
U=*m*	Specifies all of the lattice elements that have universe "m".

For the third specification form listed above, MCNP6 will create "*n*" source paths, where

$$n=(i_2-i_1+1)\times(j_2-j_1+1)\times(k_2-k_1+1)$$

with the order of these "*n*" paths being the order of the indexes changing from left to right with the left index varying most rapidly. For the fourth specification, the "*n*" source paths are the number of lattice elements with universe "*m*," where the order of the source paths is the order in the FILL matrix for cell 3. Since the SP card must specify the corresponding probabilities, this sequence order may be important. This sequence of the split paths is shown in the "cell" column of print table 10 of the OUTP file.

When more than one cell (or lattice cell) is specified on more than one level in the source input path, MCNP6 splits into multiple paths with the variation most rapid from the left. However, the first level (level *n*) and the last level (level 0) entered in the source input path can only have one entry. The path in this new format must always be enclosed in parentheses, but there must not be any inner parentheses in the path.

Spontaneous Fission Sources—Physics and Tally Normalization:

Note: Eighteen nuclides are available for a spontaneous fission source (PAR=SF): ^{232}Th, ^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{242}Cm, ^{244}Cm, ^{249}Bk, and ^{252}Cf.

If more than one spontaneous-fission nuclide is present in a source cell, the fissioning nuclide will be chosen proportionately to the product of its atom fraction and the spontaneous-fission yield for each nuclide. If no spontaneous-fission nuclide is found in a specified source cell, the code exits with a BAD TROUBLE error, "spontaneous fission impossible."

The number of spontaneous-fission neutrons then is sampled. The spontaneous-fission multiplicity data of Santi [SAN04] and references cited by him are used by default. Alternatively, the LLNL FREYA or CGMF fission model can be used (see the `FMULT` card for more details). The energies are sampled from a Watt spectrum with appropriate spontaneous-fission parameters for the selected nuclide. Only the first spontaneous-fission neutron from each history is printed. If the spontaneous fission samples a multiplicity of zero—that is, no neutrons for a given spontaneous fission—then the history is omitted from the first 50 history lists of `print table 110`. The number of source particles is the number of spontaneous-fission neutrons, which will be $\bar{\nu}$ times the requested number of source histories on the `NPS` card.

The spontaneous fission source is different from most other `SDEF` fixed sources. Let

N = the number of source-particle histories run in the problem,
W = the average source particle weight, and
$\bar{\nu}$ = the average number of spontaneous fission neutrons per fission.

For most other fixed-source (`SDEF`) problems,

summary table source tracks = N,
summary table source weight = W, and
summary tables and tallies are normalized by N.

For the spontaneous fission source, `SDEF PAR=SF`,

summary table source tracks = $\bar{\nu} \cdot \mathrm{N}$,
summary table source weight = W, and
summary tables and tallies are normalized by $\bar{\nu} \cdot \mathrm{N}$, the number of spontaneous fission neutrons.

For the spontaneous fission source, `SDEF PAR=-SF`,

summary table source tracks = $\bar{\nu} \cdot \mathrm{N}$
summary table source weight = $\bar{\nu} \cdot \mathrm{W}$, and
summary tables and tallies are normalized by N, the number of spontaneous fissions.

3.3.4.2 SI SOURCE INFORMATION

Form: `SIn option i1 ... ik`

Table 3-59. Source Information Card (SI)

Input Parameter	Description
n	**Distribution number from corresponding distribution number on SDEF card.** **Restriction: 1≤*n*≤999**
option	**Determines how the *i* values are interpreted.** **If *option* is absent or *option*=H, *i* values are monotonically increasing histogram bin upper boundaries (scalar only). (See Note 1.) (DEFAULT)** **If *option*=L, *i* values are discrete source variable values (e.g., cell numbers or energies of photon spectrum lines).** **If *option*=A, *i* values are points where a probability density is defined. Entries must be monotonically increasing, with the lowest and highest values defining the range of the variable. (See Note 2.)** **If *option*=S, *i* values are distribution numbers. (See Note 3.)**
i_1 ... i_k	**Source variables or distribution numbers**

Default: SI*n* H i_i ... i_k

Note 1: The H option is an integral, bin-wise method for describing a source distribution. It is integral in the sense that the fundamental differential distribution (e.g., particles/MeV for energy) must be integrated over an interval and its integration value placed on the SP card, corresponding to the upper bin value listed on the SI card. For example, if an energy differential distribution is integrated from E1 to E2 [and these are the first two entries (i_1 and i_2) on the SI card], then the integration value over this interval is listed as the 2nd entry (p_2) on the corresponding SP card.

Note 2: When the A option is used, the entries on the SI card are values of the source variable at which the probability density is defined. The A option is a differential, point-wise method for describing a source distribution. The fundamental differential distribution is placed directly on the SP card, in a point-wise fashion. For each point listed on the SI card, the corresponding value of the differential distribution is listed on the SP card. For example, if an energy differential distribution has a value of V1 at E1 and V2 at E2, then the SI entries i_1 and i_2 become E1, E2 and the SP entries p_1 and p_2 become V1, V2. Typically, the first entry on the SP card would not be zero (although it can be). To sample this description of a source variable, the code must integrate the point-wise distribution and formulate an integral, bin-wise cumulative distribution for sampling (i.e., basically do what the user had to do when using the H option). To accomplish this, the code uses a corrected trapezoidal (i.e., linear) integration scheme, along with linear interpolation for intra-bin sampling. While this integration scheme is fairly accurate, users are encouraged to increase the number of points on their SI/SP cards and note effects to tallies to ensure this linear integration scheme is adequate for their specified differential distribution. Included in `print table 10` are the integral, bin-wise cumulative distribution that will be used when sampling the associated source variable and the renormalized input differential distribution.

Note 3: The S option on the SI card allows sampling among distributions, one of which is chosen for further sampling. This feature makes it unnecessary to fold distributions together and is essential if some of the distributions are discrete and others are linearly interpolated. The distributions listed on an SI card with the S option can themselves have the S option. MCNP6 can handle this structure to a depth of about 20. Each distribution number on the SI card can be prefixed with a D, or the D can be omitted. If a distribution number is zero, the default value for the variable is used. A distribution can appear in more than one place with an S option, but a distribution cannot be used for more than one source variable.

3.3.4.3 SP SOURCE PROBABILITY

Form 1: SP*n* *option* p_1 ... p_k

Form 2: SP*n* *-f a b*

The first form of the SP card, where the first entry is positive or non-numeric, indicates that it and its SI card define a probability distribution function. The entries on the SI card are either values of the source variable or, when the S option is used, distribution numbers. The entries on the SP card are probabilities that correspond to the entries on the SI card.

The second form of the SP card, where the first entry is negative, indicates that a built-in analytic function is to be used to generate a continuous probability density function for the source variable. Built-in functions can be used only for scalar variables.

Table 3-60. Source Probability Card (SP)

Input Parameter	Description
n	Distribution number from corresponding distribution number on SDEF and SI cards. Restriction: $1 \le n \le 999$
option	Determines how the *p* values are interpreted. (See Note 1.) If *option* is absent, it is the same as D for an H or L distribution on the SI card or probability density for an A distribution on the SI card. (See Note 2.) If *option*=D, *p* values are bin probabilities for an H or L distribution on the SI card. (See Notes 3 and 4.) (DEFAULT) If *option*=C, *p* values are cumulative bin probabilities for an H or L distribution on the SI card. (See Notes 5 and 6.) If *option*=V, *p* values are for cell distributions; probability is proportional to cell volume (× p_i if p_i are present). (See Note 5.) If *option*=W, *p* values are intensities for a mix of particle sources. Negative *p* values corresponding to SF or SP sources indicate cell numbers, the volumes of which will be used for the computation of the intensity. (See Note 6.)

Input Parameter	Description
p_1 ... p_k	**Source variable probabilities.** **Restriction: Must be zero for 1st histogram bin**
-*f*	**Designator (negative number) for a built-in function.**
a *b*	**Parameters for the built-in function. (Refer to Table 3-65 and Appendix D.)**

Default: SP*n* D p_1 ... p_k

Note 1: Probabilities on the SP card need not be normalized.

Note 2: When the A option is used on the SI card, the numerical entries on the associated SP card are values of the probability density corresponding to the values of the variable on the SI card. This set of SI and SP values creates a curve from which intermediate values are linearly interpolated. The first and last entries on the SP card will typically be zero, but non-zero values are allowed.

Note 3: When the H option is used on the SI card, the first numerical entry on the corresponding SP card must be zero and the following entries are bin probabilities or cumulative bin probabilities, depending on whether the D or C option on the SP card is selected. The variable is sampled by first sampling a bin according to the bin probabilities and then sampling uniformly within the chosen bin.

Note 4: When the L option is used on the SI card, the entries on the associated SP card are either probabilities of those discrete values or cumulative probabilities, depending on whether the D or C option is selected.

Note 5: The V option on the SP card is a special case used only when the source variable is CEL. This option is useful when the cell volume is a factor in the probability of particle emission. If MCNP6 cannot calculate the volume of such a cell and the volume is not provided on a VOL card, a fatal error results.

Note 6: The W option of the SP card allows the user to specify intensities for a mix of particle sources. The intensities will be normalized, as is done for all MCNP6 source distributions; however the factor used to renormalize the intensities will be applied to the source weight to give the tallies the correct magnitude. The SP*n* W distribution specification can only be applied to particle distributions.

Description of Built-In Probability Density and Bias Functions

Table 3-61. Special Source Probability Functions

Keyword	Function No. and Input Parameters	Description
ERG	**-2** a	**Maxwell fission spectrum**
ERG	**-3** a b	**Watt fission spectrum**
ERG	**-4** a b	**Gaussian fusion spectrum**
ERG	**-5** a	**Evaporation spectrum**
ERG	**-6** a b	**Muir velocity Gaussian fusion spectrum**
ERG	**-7** a	**Exponential decay**
DIR, RAD, or EXT	**-21** a	**Power law:** $p(x) = c\lvert x\rvert^{a}$
DIR or EXT	**-31** a	**Exponential:** $p(\mu) = ce^{\lvert a\rvert\mu}$
TME or X,Y,Z	**-41** a b	**Gaussian distribution of time, *t*, or of position coordinates *x*, *y*, *z* (for beam sources)**

<u>*f* = `-2`</u> Maxwell fission energy spectrum: $p(E) = CE^{1/2}\exp(-E/a)$, where a is temperature in MeV. (See Appendix D.)

Default: a =1.2895 MeV

<u>*f* = `-3`</u> Watt fission energy spectrum: $p(E) = C\exp(-E/a)\sinh(bE)^{1/2}$.

Default: a =0.965 MeV, b =2.29 MeV^{-1}. See Appendix D for additional parameters appropriate to neutron-induced fission in various materials and for spontaneous fission.

<u>*f* = `-4`</u> Gaussian fusion energy spectrum: $p(E) = C\exp\left[-\left((E-b)/a\right)^{2}\right]$, where a is the width in MeV and b is the average energy in MeV. Width here is defined as the ΔE above b where the value of the exponential is equal to e^{-1}. If a<`0`, it is interpreted as a temperature in MeV and b must also be negative. If b=`-1`, the D-T fusion energy is calculated and used for b. If b=`-2`, the D-D fusion energy is calculated and used for b. Note that a is not the full-width-at-half-maximum (FWHM) but is related to it by $FWHM = 2a(\ln 2)^{1/2}$.

Default: a =-0.01 MeV, b =-1 (DT fusion at 10 keV).

f = -5 Evaporation energy spectrum: $p(E) = CE\exp(-E/a)$.

Default: a =1.2895 MeV.

f = -6 Muir velocity Gaussian fusion energy spectrum: $p(E) = C\exp-\left[\left(E^{1/2} - b^{1/2}\right)/a\right]^2$, where a is the width in MeV$^{1/2}$, and b is the energy in MeV corresponding to the average speed. Width here is defined as the change in velocity above the average velocity $b^{1/2}$, where the value of the exponential is equal to e^{-1}. To get a spectrum somewhat comparable to f=-4, the width can be determined by $a = (b + a_4)^{1/2} - b^{1/2}$, where a_4 is the width used with the Gaussian fusion energy spectrum. If a <0, it is interpreted as a temperature in MeV. If b =-1, the D-T fusion energy is calculated and used for b. If b =-2, the D-D fusion energy is calculated and used for b.

Default: a =-0.01 MeV, b =-1 (D-T fusion at 10 keV).

f = -7 Exponential decay: $\alpha(t) = \alpha_0 (1/2)^{t/a}$. Allows the creation of a source with an exponential decay shape. The activity at TME=0 is given by α_0. The parameter a is the half-life in shakes.

Default: a =1.

f = -21 Power law: $p(x) = c|x|^a$.

The default depends on the variable. For DIR, a =1. For RAD, a =2, unless AXS is defined or SUR≠0, in which case a =1. For EXT, a =0.

f = -31 Exponential: $p(\mu) = ce^{a|\mu|}$.

Default: a =0.

f = -41 Gaussian distribution of time t or position coordinates x,y,z: $p(t) = c\exp\left[-\left(1.6651092\,(t-b)/a\right)^2\right]$, where a is the width at half maximum and b is the mean. For time, a and b are in shakes, while for position variables, the units are centimeters. Note: This distribution may be written in normal form as $p(t) = c\exp\left[-(t-b)^2 / 2\sigma^2\right]$. The FWHM is thus $a = (8\ln 2)^{1/2}\sigma$.

Default: a =no default, b =0.

The built-in functions can be used only for the variables shown in Table 3-65. Any of the built-in functions can be used on SP cards, but only -21 and -31 can be used on SB cards. If a function is used on an SB card, only that same function can be used on the corresponding SP card. The combination of a regular table on the SI and SP cards with a function on the SB card is not allowed.

A built-in function on an SP card can be biased or truncated or both by a table on SI and SB cards. The biasing affects only the probabilities of the bins, not the shape of the function within each bin. If it is biased, the function is approximated within each bin by *n* equally probable groups such that the product of *n* and the number of bins is as large as possible but not over 300. Unless the function is -21 or -31, the weight of the source particle is adjusted to compensate for truncation of the function by the entries on the SI card.

Special defaults are available for distributions that use built-in functions:

1. If SB *f* is present and SP *f* is not, an SP *f* with default input parameters is, in effect, provided by MCNP6.
2. If only an SI card is present for RAD or EXT, an SP -21 with default input parameters is, in effect, provided.
3. If only SP -21 or SP -31 is present for DIR or EXT, an SI 0 1 for -21, or SI -1 1 for -31, is, in effect, provided.
4. If SI *x* and SP -21 are present for RAD, the SI is treated as if it were SI 0 *x*.
5. If SI *x* and SP -21 or SP -31 are present for EXT, the SI is treated as if it were SI -*x* *x*.

3.3.4.4 SB SOURCE BIAS

The SB card is used to provide a probability distribution for sampling that is different from the true probability distribution on the SP card. Its purpose is to bias the sampling of its source variable to improve the convergence rate of the problem. The weight of each source particle is adjusted to compensate for the bias. All rules that apply to the first form of the SP card apply to the SB card.

Form 1: SB*n* *option* b_1 ... b_k

Form 2: SB*n* -*f* *a* *b*

where *n*, *option*, *f*, *a*, and *b* are the same as for the SP card, except that the only values allowed for -*f* are -21 and -31, and the b_1 ... b_k are source-variable-biased probabilities.

Default: SB*n* D b_1 ... b_k

3.3.4.5 DS DEPENDENT SOURCE DISTRIBUTION

The DS card is used instead of the SI card for a variable that depends on another source variable, as indicated on the SDEF card. No SP or SB card is used. MCNP6 first determines the value of the independent variable as usual by sampling the probability function of the independent variable. Then the value of the dependent variable is determined according to the form of the DS card.

Form 1: `DSn` *option* j_1 ... j_k

Form 2: `DSn` `T` i_1 j_1 ... i_k j_k

Form 3: `DSn` `Q` v_1 s_1 ... v_k s_k

The first form of the `DS` card has several possibilities. If the `SI` card of the independent variable has a histogram distribution of *m* bins (*m*+1 entries) and the `DS` card has the blank or `H` option, the `DS` card must have *m*+1 entries to specify *m* bins. The first entry need not be zero. If the sampled value of the independent variable is $i_i+[f(i_{i+1}-i_i)]$, then the value of the dependent variable is $j_i+[f(j_{i+1}-j_i)]$, where the terms in *f* are used only for continuous distributions. The interpolation factor *f* always exists whether or not it is needed for the independent distribution.

The second form of the `DS` card specifies the `T` option. When the `T` option is selected, the sampled value of the independent variable is sought among the i_i, and if a match is found, the independent variable gets the value j_i. If no match is found, the dependent variable gets its default value. The purpose of the `T` option is to shorten the input when a dependent variable should usually get the default value.

When the `Q` option is used on a `DS` card, as it is in the third form, the v_i define a set of bins for the independent variable. The sampled value of the independent variable is compared with the v_i, starting with v_1, and if the sampled value is less than or equal to v_i, the distribution s_i is sampled for the value of the dependent variable. The value of v_i must be greater than or equal to any possible value of the independent variable. If a distribution number s_i is zero, the default value for the variable is used. The `Q` option is the only form of the `DS` card that can be used when the distribution of the independent variable is a built-in function.

Table 3-62. Dependent Source Distribution Card (DS)

Input Parameter	Description
N	**Distribution number.** **Restriction: $1 \le n \le 999$**
Option	**Determines how the *j* values are interpreted.** **If *option* is absent or *option*=H, source variable values in continuous distribution, for scalar variables only. (DEFAULT)** **If *option*=L, discrete source variable values follow. (See Note 1.)** **If *option*=S, distribution numbers follow. (See Notes 1 and 2.)**
T	**Values of the dependent variable (j_i) follow values of the independent variable (i_i), which must be a discrete scalar variable.**
i_i	**Values of the independent variable.**
j_i	**Values of the dependent variable.**
Q	**Distribution numbers (s_i) follow values of the independent variable (v_i), which must be a scalar variable.**

Input Parameter	Description
v_i	**Monotonically increasing set of values of the independent variable.**
s_i	**Distribution numbers for the dependent variable.**

Default: DS*n* H j_1 ... j_k

Note 1: If the L or S option is used on the DS card, *m* entries are required to specify *m* discrete values (for all options on the independent variable except H). (See the note that follows for a histogrammed independent variable.) It is not necessary for the distributions of the independent and dependent variables to be both discrete or both continuous. All combinations work correctly.

Note 2: If the S option is used on the DS card and the independent variable has a histogram defined by *m*+1 SI entries, then *m* numbers must appear on the DS card. Recall that the first bin of a histogram distribution must have an SP value of 0.0. The code will assume that the first independent histogram bin is ignored. A fatal error will result if a dependent source value is assigned to the first histogram bin.

Examples of the General Source (SDEF) with SI, SP, and SB

Example 1:

```
SDEF
```

This card specifies a 14-MeV isotropic point source at position 0,0,0 at time 0 with weight 1 (all defaults).

Example 2:

```
SDEF   ERG=D1  POS=x y z  WGT=w
SI1    H   e1  e2 ... ek
SP1    D    0  p2 ... pk
SB1    D    0  b2 ... bk
```

This is a point isotropic source at *x*,*y*,*z* with a biased histogram energy distribution and average source particle weight *w*. The starting cell is not specified. MCNP6 will determine it from the value of *x*, *y*, and *z*.

Example 3:

```
SDEF   SUR=m  AXS=i j k  EXT=D6
SB6    −31   1.5
```

This is a source on surface *m*. The presence of AXS and EXT implies that surface *m* is a sphere because AXS and EXT are not otherwise used together for sources on a surface. By default, the particles are emitted in a cosine distribution. They are emitted outward if the positive normal to the sphere is outward, which it is for all the spherical surface types but might not be if the sphere is specified as type SQ. The position on the surface is biased toward the direction *i*,*j*,*k* by an exponential bias (specified by -31). Table 2.8 of the MCNP5 Theory Manual[X-503a] shows the effect of the biasing parameter on the maximum and minimum source particle weights and the cumulative probability distribution. By default, MCNP6 provides the effect of two cards: SI6 −1 1 and SP6 -31 0.

Example 4:

```
SDEF   SUR=999   NRM=−1   DIR=D1   WGT=1.13097e6
SB1    −21 2
void
f4:n   1 2 3 4
vol    1 5r
imp:n  1.0 4r  0.0
```

These data cards illustrate how an inward-directed (NRM=-1), biased cosine source on a spherical surface can be used to stochastically calculate the volume of MCNP6 cells. All materials are voided in the problem (VOID card) and all non-zero importance are set to 1 (IMP:N card). In this example, the surface source is placed on the surface of a 600-cm-radius sphere (SUR=999) that surrounds the cells of interest and the source weight (WGT) is set to 1.13097e6 cm^2 (πr^2). All volumes are forced to unity (VOL card). Type 2 and type 4 flux tallies will provide estimates of the areas and volumes of the cells, respectively. By default, MCNP6 provides the effect of two cards: SI1 0 1 and SP1 −21 1. The directional bias by the SB1 card causes higher track density toward the center of the sphere, where presumably the cells of greatest interest lie, than it would be if the unbiased cosine distribution were used. This bias, incidentally, provides a zero-variance estimate of the (known) volume of the sphere 999..

Example 5:

```
SDEF   CEL=D3  POS=0 6 0  EXT=D1  RAD=D2  AXS= 0 1 0
SI3    L (1<10[0 0 0]<11) (1<10[1 0 0]<11) (1<10[2 0 0]<11)
         (1<10[0 1 0]<11) (1<10[1 1 0]<11) (1<10[2 1 0]<11)
```

The SDEF card creates a cylindrical volume source oriented along the *y*-axis with radius specified by the SI2 source information and SP2 source probability cards and extent given by SI1 and SP1. This CEL source specification for repeated-structures geometries is consistent with the repeated-structures tally format. The old-style format (listing cells in the opposite order separated by ":") is no longer recognized and will produce a fatal error.

Example 6:

```
SDEF  POS=0 0 0  RAD=1  EXT=D1  AXS=1 0 0  SUR=5
SDEF  POS=0 0 0  RAD=1  EXT=D1  AXS=1 0 0  SUR=5  DIR=D2
SDEF  POS=0 0 0  RAD=1  EXT=D1  AXS=1 0 0  DIR=D2
```

The first `SDEF` card specifies a cylindrical source on surface `5` with default cosine distribution relative to the surface normal. The second `SDEF` card specifies a cylindrical source on surface `5` with a specified angular distribution that is relative to the cylindrical surface normal. The third `SDEF` source specification is similar except that a degenerate volume source is used to specify the cylindrical surface source (i.e., omitting the `SUR` keyword) with a specified angular distribution relative to the surface normal.

Example 7:

```
SDEF   DIR=1  VEC=0 0 1  X=D1  Y=D2  Z=0  CCC=99  TR=1
SP1    -41  fx  0
SP2    -41  fy  0
TR1    x0 y0 z0   cosθ -sinθ 0   sinθ cosθ 0   0 0 1
```

The `SDEF` card sets up an initial beam of particles traveling along the *z*-axis (`DIR=1`, `VEC=0 0 1`). Information on the *x*- and *y*-coordinates of particle position is detailed in the two `SP` cards. The *z*-coordinate is left unchanged. The first entry on the `SP` cards is `-41`, indicating sampling from a built-in Gaussian distribution. The second `SP` card entry is the full width half maximum (FWHM) of the Gaussian in either the *x*or *y* direction. This value must be computed for the *x*- and *y*-axes by the user as follows: $f_x = (8\ln 2)^{1/2} a = 2.35482a$ and $f_y = (8\ln 2)^{1/2} b = 2.35482b$, where *a* and *b* are the standard deviations of the Gaussian in the *x* and *y* directions, respectively. (More details are provided in Section 4.3.2.) The third entry represents the centroid of the Gaussian in either the *x* or *y* direction. It is recommended the user input zero for this third entry and handle any transformations of the source with a `TR` card. The specification of the cookie-cutter cell `99` for source rejection prevents the beam Gaussian from extending infinitely. The `TR` card performs a rotation of the major axis of the source distribution. Other beam examples appear in Section 4.3.2.

Example 8:

```
SDEF    ERG=D1  POS=x y z  CEL=m  RAD=D2
        EXT=D3  AXS=i j k
SP1    −3
SI2    r1  r2
SI3    l
```

This source is distributed uniformly in volume throughout cell *m*, which presumably approximates a cylinder. The cell is enclosed by a sampling volume centered at *x*,*y*,*z*. The axis of the sampling volume is the line through *x*,*y*,*z* in the direction *i*,*j*,*k*. The inner and outer radii of the sampling volume are r_1 and r_2, and it extends along *i*,*j*,*k* for a distance from *x*,*y*,*z*. The user has to make sure that the sampling volume totally encloses cell *m*. The energies of the source particles are sampled from the Watt fission spectrum using the default values of the two parameters, making it a Cranberg spectrum. By default, MCNP6 interprets `SI3 l` as if it was actually `SI3 −l +l` and provides the effect of two cards: `SP2 −21 1` and `SP3 −21 0`.

Example 9:

```
SDEF    SUR=m  POS=x y z  RAD=D1  DIR=1  CCC=n
SI1     r
```

This is a mono-directional source emitted from surface *m* in the direction of the positive normal to the surface. The presence of POS and RAD implies that surface *m* is a plane because POS and RAD are not otherwise used together for sources on a surface. The position is sampled uniformly in area on the surface within radius *r* of point *x*,*y*,*z*. The user must make sure that point *x*,*y*,*z* actually lies on surface *m*.. The sampled position is rejected and resampled if it is not within cookie-cutter cell *n*. The starting cell is found from the position and the direction of the particle. By default, MCNP6 interprets `SI1 r` as if it were actually `SI1 0 r` and provides the effect of card `SP1 −21 1`.

Example 10:

```
SDEF   PAR=SF  CEL=D1  POS=D2  RAD=FPOS=D3
```

Spontaneous-fission source in which source points will be started from within defined spheres (POS, RAD) and limited to fission cells by CEL. Each sampled source point will be a spontaneous-fission site (PAR=SF) producing the appropriate number of spontaneous-fission neutrons per fission at the appropriate energy with isotropic direction.

Example 11:

```
SDEF    PAR=D1
SI1 L   1  9  3006  26056  92238
SP1     1  1   0.1    0.3    0.5
```

Five different source particles are sampled in this example: neutrons; protons; and the three heavy ions—^{6}Li, ^{56}Fe, and ^{238}U. The relative sampling frequency is given by the probability parameters on the SP1 card.

****

ASIDE:* PAR=D*n

Note the following when using a distribution specification for the PAR keyword:

1. The characters L, A, H, S, Q, and T are reserved as SI and DS card options. L=discrete source variables, S=distribution numbers, etc. If the first entry on the SI or DS card is L, A, H, S, Q, or T, it will be interpreted as a distribution option. To list source particles types L, A, H, S, Q, or T, either the corresponding particle numbers (10,34,9,33,5,32) must be used or L, A, H, S, Q, or T must appear as the second or later particle type. Generally, it is best to specify the discrete source variable option; therefore, L will be the first entry, followed by the particle types. A second L will be interpreted correctly as particle type L. For example,

   ```
   SI99  L  -H  N  L  Q  F  T  S
   ```

2. Antiparticles may be designated, as usual, with negative entries:

   ```
   SI77  L  -E  N  -H
   ```

3. Either characters (N, P, E, H, D, T,S, A, etc.) or numbers (1, 2, 3, 9, 31, 32, 33, 34, etc.) may be used. For example,

   ```
   SI98  L  -H  3  -32  N
   ```

4. Spontaneous fission may be used as a particle type. For example,

   ```
   SI87  L  SF  N
   ```

5. Particle types may be listed multiple times to give them different energy distributions, angular distributions, etc., in different parts of the problem. For example:

   ```
   SI23  L  N  n  1  n  N
   ```

6. Heavy ions may be specified using the appropriate ZZZAAA identifier for individual ions. Multiple heavy ions may be specified for the source using a distribution. Dependent distributions can be used to specify different energies for different heavy ions. Heavy ion particle energy should be input as total energy, **not** energy/nucleon.

7. Tallies are normalized by dividing the total source weight by the number of source histories. Note that weight (WGT on the SDEF card) cannot be a source distribution (either independent or dependent). The weight of particles in the summary tables is controlled by the SI, SP, SB, and DS cards for the particle distribution. This normalization procedure is described in Example 12 below:

****

Example 12:

```
SDEF   PAR=D1  POS FPAR D2  ERG FPAR D3
SI1   L  H N
SP1      2 1
SB1      1 2
DS2   L  0 0 0  15 0 0
DS3   L  2 3

SDEF   PAR=FPOS D2  POS=D1  ERG FPOS D3
SI1   L  0 0 0  15 0 0
SP1      2 1
SB1      1 2
DS2   L  h n
DS3   L  2 3
```

The first source definition above defines the source particle type, PAR, as the independent variable; while in the second source definition, the source particles specified by PAR depend on the source positions (POS). Both approaches result in the same source distributions.

The total source weight is WGT=1.0 by default. From the SP1 card, the weight of the neutrons that are produced is 0.3333 and the weight of protons that are produced is 0.6667. From the SB1 card, the total number of neutron tracks is $0.6667 \times$ N for neutrons and $0.333 \times$ N for protons (where N is the number of source histories actually run). The energy per source particle is normalized to the source particle weight for each source particle type. If the particle type is not a source particle (e.g., photons in the above problem), then the energy per source particle is normalized to the source particle weight of the lowest particle type. In this example, photon source energy would be normalized in the photon creation-and-loss table by 0.3333, which is the weight of the source neutrons produced.

Example 13:

```
SDEF    POS D1  ERG FPOS D2
SI1     L  5 3.3 6   75 3.3 6
SP1     0.3  0.7
DS2     S  3  4
SI3     H  2 10 14
SP3     D  0  1  2
SI4     −3 a b
```

This is a point isotropic source in two locations, shown by two *x*,*y*,*z*’s on the SI1 card. The code will determine the starting cell. With probability 0.3 the first location will be picked, and with probability 0.7 the second location will be chosen. Each location has a different energy spectrum pointed to by the DS2 card. All other needed source variables will use their default values.

Example 14:

```
SDEF   DIR=1  VEC=0 0 1  X=D1  Y=0  Z=−2 TR=1
SI1    0.0  0.5
SP1    0.0  1.0
TR1    0.5 0.5 0.0   0.4 0.3 0.0   −0.3 0.4 0.0
```

This example generates a source uniform on a straight line from (*x*,*y*,*z*)=(`0.5`,`0.5`,`-2.0`) to (*x*,*y*,*z*)=(`0.9`,`0.8`,`-2.0`) in the +*z* direction. In the auxiliary coordinate system, the source is easily created as uniform from (`0.0`,`0.0`,`−2.0`) to (`0.5`,`0.0`,`-2.0`) and then transformed.

Example 15:

```
SDEF       TR=D1
SI1  L     1    3    5
SP1  D     1.0  1.0  1.0
SB1  C     0.2  0.5  1.0
```

In this example, a distribution of transformations is specified using `TR=D1` on the `SDEF` card. Three transformations are assigned: `TR1`, `TR3`, and `TR5`. The `L` option on the `SI` card is required so that MCNP6 interprets the values as discrete transformation numbers. The *`option`* on the `SP` and `SB` cards may be blank, `D`, or `C`. For this problem, the transformations are equally probable, but are biased to sample `TR1` 20% of the time, `TR3` 30% of the time, and `TR5` 50% of the time.

Example 16:

```
SDEF   TME=D1
SP1    -7   2e8          $ 2e8 shakes=2 seconds
```

The source shape will be represented by exponential decay with a half-life of 2 s.

Example 17:

```
999  0      -999                     $ cookie cutter cell CCC
...
999  SQ     25 100 0 0 0 0 -4 0 0 0  $ surface for cell CCC
...
SDEF   DIR=1  VEC=0 0 1  X=D1  Y=D2  Z=0  CCC=999  TR=D3
SP1    −41  0.470964  0
SP2    −41  0.235482  0
SI3    L  11 22 33
SP3       1  2  3
SB3       1  1  1
TR11     0 0 −2   1 0 0   0 1 0   0 0 1
TR22   −2 0  0   0 1 0   0 0 1   1 0 0
TR33     0 -2 0  0.707107 0 0.707107  0.707107 0 −0.707107  0 1 0
```

In this example, the source particle coordinates are generated in an auxiliary coordinate system in the $(x',y',0)$ plane around the origin with a Gaussian profile (FWHM=`0.470964`) in the x'-coordinate and a Gaussian profile (FWHM=`0.235482`) in the y'-coordinate. The beam is truncated by "cookie cutter cell" `CCC`, which restricts the source to an ellipse corresponding to two standard deviations of the Gaussian distributions in the x'- and y'-coordinates. The subsequent application of the transformation `TR=D3` results in three intersecting beams with the following characteristics:

- Beam 1 is centered at (`0`,`0`,`-2`) with the major axis of the beam distribution along the *x*-axis, emitted in the +*z* direction, with relative intensity 1;
- Beam 2 is centered at (`-2`,`0`,`0`) with the major axis of the beam distribution along the *y*-axis, emitted in the +*x* direction, with relative intensity 2; and
- Beam 3 is centered at (`0`,`-2`,`0`) with the major axis of the beam distribution along the line *x*=*z*, emitted in the +*y* direction, with relative intensity 3.

Example 18:

```
m1  1001   1
    8016   1
    7016   1e-4          $ Unstable isotope N-16
    25054  1e-2          $ Unstable isotope Mn-54
c
sdef par=sp pos= 0 0 0   $ Location of material 1
ACT   DG=LINES
```

The source is defined as decay gammas from the unstable isotopes ^{16}N and ^{54}Mn in material `1`, which is the material located at the user-provided source position coordinates (`0`,`0`,`0`). The two unstable isotopes will be sampled based on their relative activities within material `1`. The default time (`TME=0`) is assumed.

Example 19:

```
mode   p #
sdef   par=7016  erg=0  pos= 0 0 0
ACT    DG=LINES
```

Setting the source particle to the heavy ion ^{16}N (`PAR=7016`) and specifying the energy of the ion as zero (`ERG=0`) defines the source as the decay gammas of ^{16}N. The heavy ions will not be transported. Notice that the heavy-ion symbol, #, appears on the `MODE` card.

Example 20:

```
sdef   erg d21 cel=d11 tme=d41
si41   S  52<51 (D31<32<d33) 61
sp41     .1 .8 .1
si51   A -26 -16
```

```
sp51       0   1
si52   H   0 1 2
sp52       0 1 0
si61   A  32  40
sp61       1   0
si31       0 1 2
sp31       0 1 0
si32       0  16
sp32     -41 8 8
si33     -16  32
sp33       0   1
```

This example illustrates how embedded distributions can reside within distributions of distributions (D41), and can use built-in functions (D32 uses a Gaussian centered at *t*=8 with FWHM=8) and interpolated distributions (D51 and D61 use the SI A option). Distribution D52 is embedded in distribution D51; distribution D31 is embedded in distribution D32, which is embedded in distribution D33. A tally plot of this embedded distribution appears in Figure 3-4.

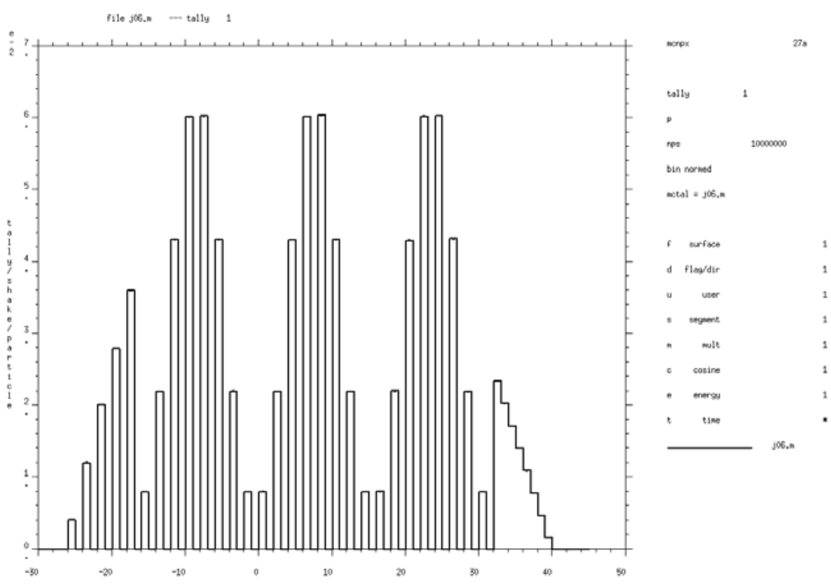


Figure 3-4. MCPLOT plot of tally from -30 to 50 shakes.

Example 21:

```
sdef     cel=d1
si1  L  (4<2[-1:1 -2:2 -3:3]<1)
sp1      1  104r
```

This source definition creates source particles in a subset of a lattice using ranges specified for the lattice elements. The lattice must have been defined using a fully specified `FILL` card.

Example 22:

```
si1  L    n     p     h
sp1  W   3e9   5e9   2e9
```

The source shown here mixes contributions from three source particles and samples them according to their relative magnitudes (neutrons 30%, photons 50%, and protons 20%). The weight assigned to each particle will be the sum of the non-normalized values, 3E9+5E9+2E9=1E10.

Example 23:

```
si1  L   sp    sf      n
sp1  W  -10   -15      3e9
```

The spontaneous photon source will look to cell 10 and use the material and volume to calculate the overall activity that will be substituted into the `SP1` distribution. Correspondingly, the `SF` source will look to the material and volume in cell 15 for the intensity of the spontaneous fission source. (Note that a `+SF` normalizes per spontaneous fission neutron, a `-SF` normalizes per spontaneous fission.) The neutron source is unchanged. After the overall activity is computed, the source distribution normalization will be done as described above and the weight adjustment value passed into the weight parameter.

Example 24:

```
sdef  par=d1 wgt=264
si1   L   sf
sp1   w  -35
```

If the cell specified in the `SP`*`n`* `W` option is a lattice cell, then the code may not know the correct volume for this cell. If the user does not wish to correct the volume using the `VOL` card or cell keyword, a `WGT` keyword can be used with the source as a multiplicative factor. In this example, the spontaneous fission source is weighted by the activity from cell 35, which has been duplicated 264 times in the geometry. The final source weight will be the activity from cell 35×264.

3.3.4.6 SC SOURCE COMMENT

Form: `SC`*`n`* *`comment`* (See Note.)

where *`n`* is a distribution number such that $1 \le n \le 999$, and *`comment`* is user-supplied text describing the source.

Default: No comment.

Note: The `comment` is printed as part of the header of distribution *n* in the source distribution table and in the source distribution frequency table. The & continuation symbol is considered to be part of the comment, not a continuation command.

3.3.4.7 SSW SURFACE SOURCE WRITE

This card is used to write a surface source file or KCODE fission volume source file for use in a subsequent MCNP6 calculation. Include enough geometry beyond the specified surfaces to account for albedo effects.

During execution, surface source information is written to the scratch file WXXA. Upon normal completion, WXXA becomes WSSA. If the run terminates abnormally, the WXXA file will appear instead of WSSA and must be saved along with the RUNTPE file. The job must be continued for at least one more history. At the subsequent normal termination, WXXA disappears and the correct surface source file WSSA is properly written.

Form: SSW s_1 s_2 (c_1 ... c_k) s_3 ... s_k KEYWORD=*value*(*s*) ...

Table 3-63. Surface Source Write Card

Input Parameter	Description
s_i	Problem surface number, with the appropriate sign to indicate sense of inward or outward particle direction, for which particle-crossing information is to be written to the surface source file WSSA. Macrobody facets are allowed.
c_j	Problem cell number. A positive entry denotes a cell the particle is entering. A negative entry specifies a cell that particle is leaving. This option provides a means to include only a portion of tracks crossing a certain surface. (See Notes 1 and 2.)
Keyword	**Values**
SYM	Symmetry option flag. If SYM=0, no symmetry assumed. (DEFAULT) If SYM=1, spherical symmetry assumed. The list of problem surface numbers must contain only one surface and it must be a sphere. (See Note 3.) If SYM=2, write particles to a surface bidirectionally. Otherwise, only particles going out of a positive surface and into a negative surface are recorded.
PTY=<*pl*>$_1$ <*pl*>$_2$ ...	Controls tracks to record. If PTY is absent, record all tracks for all particle types. (DEFAULT) Each <*pl*>$_i$ entry is a particle type selected from those listed in Table 2-2.
CEL=cf_1 cf_2 ...	List of names of all the cells from which KCODE fission source neutrons are to be written, active cycles only. (See Notes 4 and 5.)

Default: SYM=0; no PTY keyword (record tracks for all particle types)

Use: Optional.

Note 1: The SSW card allows a list of one or more cell names, positive or negative, after any of the surface names. The list of cell names must be enclosed in parentheses. If the list of cells is absent, any track that crosses the surface in the "correct direction" (as specified by the positive or negative sign on the surface number) will be recorded. If the list of cells is present, a track will be recorded if it crosses the surface in the correct direction and is either entering a cell in the list whose entry is positive or leaving a cell in the list whose entry is negative.

Note 2: Problem cell numbers, c_i, cannot include chain information; i.e., all cells listed must be at the lowest level. Lattice cells should not be listed because in most cases other cells are filled into a lattice cell. In the rare case that a lattice cell is filled with itself, simply list the lattice cell without any reference to a specific element.

Note 3: If the SYM=1 option is used, the geometry inside the surface must be spherically symmetric and the materials must be symmetric. This symmetric situation only occurs rarely and it is the responsibility of the user to determine whether SYM=1 is appropriate for the problem. If the SYM=1 option is invoked, fewer words per particle need to be written to the surface source file and certain biasing options become available when reading the surface source file. The SYM=1 option cannot be used if CEL is specified.

Note 4: Fission volume sources from a KCODE calculation can be written from active cycles only. The fission neutrons and prompt photons can then be transported in a subsequent calculation using the SSR surface source read fixed-source capability. In a KCODE criticality calculation the fission neutron sources and prompt photons produced from fission during each cycle are written to the WSSA surface source file if the SSW card has the CEL keyword followed by the names of all the cells from which fission source neutrons are to be written. Particles crossing specified surfaces can also be written by specifying s_i.

Note 5: Fission neutrons and photons written to the surface source file in a KCODE calculation can be used as a volume-distributed source in a subsequent calculation. A NONU card should be used so that fission neutrons and photons are not counted twice. Generally a TOTNU card is not required. Total $\bar{\nu}$ is the default for both KCODE and non-KCODE sources. Prompt $\bar{\nu}$ may be invoked by specifying TOTNU NO.

Example 1:

```
SSW    4  -7  19 (45  -46)  16  -83 (49)
```

A track that crosses surface 19 in the correct direction will be recorded only if it is either entering cell 45 or leaving cell 46. A track that crosses surface 83 in the correct direction will be recorded only if it is entering cell 49. A track that crosses surface 4, 7, or 16 in the correct direction will be recorded regardless of what cells it happens to be leaving or entering.

Example 2:

```
SSW    1   2 (3  4)   CEL 8 9
```

A track that crosses surface 2 in the correct direction will be recorded only if it enters cell 3 or 4. A track crossing surface 1 in the correct direction always will be recorded. Particles created from fission events in cells 8 and 9 will be recorded.

3.3.4.8 SSR SURFACE SOURCE READ

This card is used to read a surface source file or KCODE fission volume source file that was created in a previous MCNP6 calculation. The file WSSA must have previously been created using the SSW card; the file must be renamed to RSSA before it can be read by the SSR feature.

The number of particle histories reported in the output file for an SSR calculation is related to the number written to the WSSA file during the SSW procedure, so that proper normalization is preserved. However, a user may specify a different value on the NPS card in the SSR input file than that used in the initial SSW calculation. If the value of the *npp* parameter of the NPS card is smaller than that used in the initial calculation, an appropriate ratio of tracks will be rejected. If the *npp* value is larger than that of the initial calculation, an appropriate duplication of tracks will be sampled. For example, if the SSW calculation used an *npp* value of 100 and the SSR calculation uses an *npp* of 200, then every track is duplicated, each with a different random number seed and each with half the original weight. Note that a larger value of *npp* on the SSR calculation will indeed lower the tally errors until the weight variance contained on the RSSA file dominates. (Therefore, a user should maximize the number of tracks on the RSSA file.) Because the *npp* value can readjust particle weights as described above, some variance reduction parameters (e.g., weight-window bounds) may need to be renormalized for SSR applications.

The problem summary tables for a surface source problem represent the weights of the particles read from the RSSA file, not the weights in the original problem that wrote the surface source. To understand the resultant Problem Summary Tables for an SSR problem, consider the following example:

Run 1:

```
MODE N E
SSW         $ neutrons and electrons written to WSSA file
```

Run 2:

```
MODE N P E
SSR         $ no photons available on RSSA to read
```

The weight creation and loss columns for all particles are normalized by the number of histories run in the problem. For this example, the neutron and electron average energies are determined by normalizing by the respective starting source weights from the RSSA file. Because no photons were available to be read, the photon summary table average energies will be normalized by the first particle source weight from RSSA in the problem, where neutrons have first priority (as in this example), then photons, then electrons, etc.

For the general SSR problem, one or more particle types will have source weights. The average energies in a particle Problem Summary Table are obtained in the following order: 1) if source particles are read from the RSSA file, then the average energies are determined by normalizing by the starting source weight; else 2) the first particle type with source weight will be used for obtaining average summary table energies.

Any variance-reduction technique that requires the input of normalized weight parameters (e.g., weight-window bounds, negative entries on the DD card, etc.) may need to be renormalized for SSW/SSR applications. Consider the following observations and comments:

1) In general, weight-window bounds generated in a SSW calculation are not useful in the SSR calculation, unless the tally identified on the WWG card of the SSW calculation is the same as that desired for the SSR calculation *and* plenty of tracks contributed to that tally during the SSW calculation.
2) A window generated in an SSR calculation will likely have to be renormalized in subsequent runs that use those windows, unless the value on the NPS card remains unchanged. If the value on the NPS card is changed, the WGT keyword on the SSR card can be used to renormalize the source weights to ensure weights are within the window in the source region. Whenever the WGT keyword is used in this fashion, tallies must be properly normalized by using this value on the SD card or the inverse of this value as a multiplier on the FM card.

Form: SSR KEYWORD=*value*(*s*) ...

Table 3-64. Surface Source Read Card

Keyword	Value
OLD= s_1 s_2 ... s_k	**List of *k* problem surface numbers that are a subset of the surfaces on the SSW card that created the file WSSA, now called RSSA. Negative entries are not allowed as filtering is not available based on crossing direction. A positive value (as on the SSW card) simply means to accept all tracks that have crossed that surface regardless of direction. (DEFAULT: All surfaces in original run.)** **Restriction: Macrobody surfaces are allowed.**
CEL= c_1 c_2 ... c_k	**List of *k* cells numbers that represent a subset of the cells on the SSW card that created the file WSSA, now called RSSA. This subset specifies which fission cells to accept of those from the KCODE calculation that wrote the RSSA file. (See Note 1.) (DEFAULT: All cells in original run.)**
NEW= s_{a1} s_{a2} ... s_{ak} s_{b1} s_{b2} ... s_{bk} ... s_{m1} s_{m2} ... s_{mk}	**Problem surface numbers on which the surface source is to start particles in this run. The *k* entries may be repeated to start the surface source in multiple (*m*) transformed locations. In other words, for *m*=1, each particle written from surface s_i in the OLD list will start on surface s_{1i}. For *m*=2, each particle written on surface s_i in the OLD list will start on surface s_{2i}, etc. (See the TR keyword below.) (DEFAULT: Surfaces in the OLD list.)**

Keyword	Value
PTY=<*pl*>$_1$ <*pl*>$_2$ ...	**A blank-delimited list of particle types for which the tracks are to be read. If the PTY keyword is absent, read all tracks for all particle types in the problem. (DEFAULT: PTY absent.) (See Notes 2 and 3.)**
COL	**Collision option flag. If COL=-1, start from the surface source file only those particles that came directly from the source without a collision. If COL=1, start from the surface source file only those particles that had collisions before crossing the recording surface. If COL=0, start particles without regard to collisions. (DEFAULT)**
WGT	**Each particle weight is multiplied by the constant WGT as it is accepted for transport. (DEFAULT: WGT=1)**
TR=*n* or TR=D*n*	**Transformation number, *n*. Track positions and velocities are transformed from the auxiliary coordinate system (the coordinate system of the problem that wrote the surface source file) into the coordinate system of the current problem, using the transformation on the TR card, which must be present in the INP file of the current problem. (See Note 4.) Distribution number, D*n*, where 1≤*n*≤999. Distribution number for a set of SI, SP, and SB cards. If the surface source is transformed into several locations, the SI card lists the transformation numbers and the SP and SB cards give the probabilities and bias of each transformation, respectively. (See Note 5.) (DEFAULT: no transformation)**
PSC=*c*	**A non-negative constant that is used in an approximation to the PSC evaluation for the probability of the surface source emitting a particle into a specified angle relative to the surface normal. (See Note 6 with its associated caution.)**
The following four KEYWORDS are used only with spherically symmetric surface sources, that is, sources generates with SYM=1 on the SSW card.	
AXS=*u v w*	**Direction cosines that define an axis through the center of the surface sphere in the auxiliary (original) coordinate system. This is the reference vector for EXT. (DEFAULT: No axis)**
EXT=D*n*	**Distribution number (1≤*n*≤999) (SI, SP, and SB cards) that will bias the sampling of the cosine of the angle between the direction AXS and the vector from the center of the sphere to the starting point on the sphere surface. (DEFAULT: No position bias)**

Keyword	Value
POA=*c*	**Particles with a polar angle cosine relative to the source surface normal that falls between 1 and *c* will be accepted for transport. All others are disregarded and no weight adjustment is made. (DEFAULT: POA=0)**
BCW=*r zb ze*	**Restriction: 0<*zb*<*ze*** **All particles with acceptable polar angles relative to the surface normal are started so that they will pass through a cylindrical window of radius *r*, starting at *zb* from the center of the source sphere and ending at *ze* from the center. The axis of the cylinder is parallel to the *z*-axis of the auxiliary (original) coordinate system and contains the center of the source sphere. The weight of each source particle is adjusted to compensate for this biasing of position and direction. (DEFAULT: No cylindrical window)**

Use: Required for surface source problems.

Note 1: Problem cell numbers, c_i, cannot include chain information; i.e., all cells listed must be at the lowest level. When a source point is kept for transport, the code determines the cell(s) for all higher levels in the geometry, based on its absolute location (i.e., *x*,*y*,*z* position).

Note 2: By default, all particle types defined with the MODE card are read from the RSSA file if available. Particle types not defined with the MODE card are rejected without weight adjustment. Particle types can be selected from the RSSA file using the PTY keyword.

Note 3: When heavy ions are specified in the problem, the charge and mass for each heavy ion are stored in the surface source file, WSSA, and will be read back to reconstruct the proper source distribution.

Note 4: For each surface s_i in the OLD list, a corresponding surface s_{1i} must appear in the NEW list such that TR*n* transforms the coordinates of a particle written from s_i to be on surface s_{1i} in the current problem. However, if the surfaces s_{1i} are "dummy" surfaces not used in constructing the real geometry, then the transformed source will effectively be treated as a volume source not specifically defined to be on any surface.

Note 5: If NEW is present with multiple (m>1) transformed locations, then the distribution must specify exactly *m* transformations that properly represent the relationship of the $m \times k$ surfaces on the NEW list to the *k* surfaces on the OLD list. Otherwise, the NEW specification is ignored (if present) and the application of TR=D*n* is analogous to its use on the SDEF card. The source after transformation is treated as a volume source (surface number not defined); the cell for the source particle is determined after transformation. It may be wise not to place the transformed source exactly on a surface of the physical geometry (to avoid lost particles in some cases).

Note 6: An exact treatment of point detectors or DXTRAN spheres with a surface source is not possible because the $p(\cos\theta)$ values required for the source contribution are not readily available. To use detectors or DXTRAN with a surface source, an approximate $p(\cos\theta)$ must be specified on the `SSR` card. The most common azimuthally symmetric approximation for an angular emission probability density function is given by

$$p(\cos\theta) = C_c (\cos\theta)^c \qquad c \geq 0$$

The `PSC` value entered is c, the power to which $p(\cos\theta)$ is raised. C_c is a normalization constant calculated in MCNP6 and θ is the angle between the direction vector to the point detector and the surface normal at the point where the particle is to be started. Because surface crossings are recorded in only one direction specified on the `SSW` card, the limits on μ are always between `1` and `0`. A `PSC` entry of zero specifies an isotropic angular distribution on the surface. An entry of `1` specifies a cosine angular distribution that produces an isotropic angular flux on the surface. In the case of a 1D spherical surface source of radius R, a cosine distribution is adequate if the point detector or DXTRAN sphere is more than 4R away from the source. *Caution*: Remember that the value entered for `PSC` is only an approximation. If the point detector or DXTRAN sphere is close to the source sphere and the approximation is poor, the answers will be *wrong*.

Example 1:

Original run:
```
SSW   1   2   3
```

Current run:
```
SSR   OLD  3  2   NEW  6  7  12  13   TR D5   COL 1
SI5  L   4     5
SP5    0.4   0.6
SB5    0.3   0.7
```

Particles starting on surface `1` in the original run will not be started in the current run because surface `1` is absent from the list of `OLD` surface numbers. Particles recorded on surface `2` in the original run will be started on surfaces `7` and `13`, and particles recorded on surface `3` in the original run will be started on surfaces `6` and `12`, as prescribed by the mapping from the `OLD` to the `NEW` surface numbers. The `COL` keyword causes only particles that crossed surfaces `2` and `3` in the original problem after having undergone collisions to be started in the current problem. The `TR` entry indicates that distribution function `5` describes the required surface transformations. According to the `SI5` card, surfaces `6` and `7` are related to surfaces `3` and `2`, respectively, by transformation `TR4`; surfaces `12` and `13` are related to `3` and `2` by `TR5`. The physical probability of starting on surfaces `6` and `7` is 40% according to the `SP5` card, and the physical probability of starting on surfaces `12` and `13` is 60%. The `SB5` card causes the particles from surfaces `3` and `2` to be started on surfaces `6` and `7` 30% of the time with weight multiplier 4/3 and to be started on surfaces `12` and `13` 70% of the time with weight multiplier 6/7.

Example 2:

Original run:
```
SSW     3   SYM 1
```

Current run:
```
SSR     AXS  0 0 1   EXT D99
SI99     -1    0.5    1
SP99    0.75     1
SB99    0.5    0.5
```

All particles written to surface 3 in the original problem will be started on surface 3 in the new problem, which must be exactly the same because no OLD, NEW, COL, or TR keywords are present. Because this is a spherically symmetric problem, indicated by the SYM 1 flag in the original run, the position on the sphere can be biased. It is biased in the *z* direction with a cone bias described by distribution 99.

Example 3:

Original run:
```
SSW     2  4  6
```

Current run:
```
SSR     OLD 2  TR=D1  WGT 6.0
SI1  L  11 22 33
SP1      1  2  3
SB1      1  1  1
TR11     0  0 −3  1 0 0  0 1 0  0 0 1
TR22    −3  0  0  0 1 0  0 0 1  1 0 0
TR33     0 −3  0  0.707 0 0.707  0.707 0 −0.707  0 1 0
```

All particles written from surface 2 in the original problem will be accepted; those written from surfaces 4 and 6 will be rejected. The distribution D1 will be sampled for each accepted particle and one of the transformations TR11, TR22, or TR33 will be applied. In this case, the particle current across surface 2 in the original problem will be applied as three intersecting beams in the *x*, *y*, and *z* directions. The relative intensities are 2:3:1 respectively, but the sampling rate is the same in all three directions through use of the SB card.

3.3.4.9 KCODE CRITICALITY SOURCE

The KCODE card specifies the MCNP6 criticality source that is used for determining k_{eff}. The criticality source uses total fission $\bar{\nu}$ values unless overridden by a TOTNU NO card and applies only to neutron problems. In a MODE N,P problem, secondary photon production from neutrons is turned off during inactive cycles. SSW particles are not written during inactive cycles.

Fission sites for each cycle are those points generated by the previous cycle. For the initial cycle, fission sites can come from an SRCTP file from a similar geometry, from a KSRC card, or from a volume distribution specified by an SDEF card.

Since the mid-2000s, there have been many detailed studies on the theory and practice of performing Monte Carlo criticality calculations. These studies have resulted in a set of “best practices” for performing KCODE calculations with MCNP, and are fully described in a section of the MCNP Reference Collection on the MCNP website, “Best Practices - Convergence, Bias, Statistics.” To summarize:

Convergence of the fission source shape should be assessed with plots of the Shannon entropy vs. cycle. To avoid bias from the renormalization of the fission source each cycle, it is very strongly recommended that at least 10,000 neutrons/cycle should be specified on the KCODE card, with even larger numbers for large reactor problems. The initial guess for the source distribution (via KSRC, srctp, or SDEF) should be a reasonable representation covering the fissionable regions of a problem.

Form: `KCODE` *nsrck rkk ikz kct msrk knrm mrkp kc8*

Table 3-69 Criticality Source Card (KCODE)

Input Parameter	Description
nsrck	**Number of source histories per cycle. (DEFAULT: *nsrck*=1000)**
rkk	**Initial guess for k_{eff}. (See Note 1.) (DEFAULT: *rkk*=1.0)**
ikz	**Number of cycles to be skipped before beginning tally accumulation. (DEFAULT: *ikz*=30)**
kct	**Total number of cycles to be done. If *kct*=0, never terminate on the number of cycles, but terminate on time. (DEFAULT: *kct*=*ikz*+100)**
msrk	**Number of source points for which to allocate storage. (See Note 2.) (DEFAULT: *msrk*=maximum of 4500 or 2 × *nsrck*)**
knrm	**Controls normalization of tallies. If *knrm*=0, normalize tallies by weight. (DEFAULT) If *knrm*=1, normalize tallies by number of histories.**
mrkp	**Maximum number of cycle values on MCTAL or RUNTPE files. (DEFAULT: *mrkp*=6500)**
kc8	**Controls the number of cycles over which summary and tally information are averaged. If *kc8*=0, average over all cycles. (See Note 3.) If *kc8*=1, average over active cycles only. (DEFAULT)**

Defaults: See Table 3-69.

Use: Required for criticality calculations.

Note 1: If in the first cycle the source being generated overruns the current source, the initial guess (*rkk*) is probably too low. The code then proceeds to print a comment, continues without writing a new source, calculates k'_{eff}, reads the initial source back in, and begins the problem using k'_{eff} instead of *rkk*. If the generated source again overruns the current source after the first cycle, the job terminates and either a better initial guess (*rkk*) or more source space (*msrk*) should be specified on the next try.

Note 2: If an SRCTP file with a larger value of *msrk* is read for the initial source, the larger value is used.

Note 3: Setting the parameter *kc8* to zero causes tallies and summary table information to be for both active and inactive cycles and should not be used. Setting *kc8*=0 also results in strange MCTAL file normalization.

3.3.4.10 KSRC CRITICALITY SOURCE POINTS

This card contains up to *nsrck* (*x*,*y*,*z*) triplets that are locations of initial source points for a KCODE calculation. At least one point must be in a cell containing fissile material and points must be away from cell boundaries. It is not necessary to input all *nsrck* coordinate points. MCNP6 will start approximately (*nsrck*/number of points) particles at each point. Usually one point in each fissile region is adequate, because MCNP6 will quickly calculate and use the new fission source distribution. The energy of each particle in the initial source is sampled from a Watt fission spectrum hardwired into MCNP6, with a =0.965 MeV, b =2.29 MeV^{-1}.

An SRCTP file from a previous criticality calculation can be used instead of a KSRC card. If the current problem has a lot in common with the previous problem, using the SRCTP file may save some computer time. Even if the problems are quite different, the SRCTP file may still be usable if some of the points in the SRCTP file are in cells containing fissile material in the current problem. Points in void or zero importance cells will be deleted. The number of particles actually started at each point will be such as to produce approximately *nsrck* initial source particles.

An SDEF card also can be used to sample initial source points in fissile material regions. The SDEF card parameters applicable to volume sampling can be used: CEL, POS, RAD, EXT, AXS, X, Y, Z; and CCC, ERG, and EFF. If a uniform volume distribution is chosen, the early values of k_{eff} will likely be low because too many particles are put near where they can escape, just the opposite of the usual situation with the KSRC card. Do not change the default value of WGT for a KCODE calculation.

Form: KSRC x_1 y_1 z_1 x_2 y_2 z_2 ...

where x_i, y_i, and z_i are the locations of the initial source points.

Default: None. If this card is absent, an SRCTP source file or SDEF card must be supplied to provide initial source points for a criticality calculation.

Use: Optional card for use with criticality calculations.

3.3.4.11 KOPTS CRITICALITY CALCULATIONS OPTIONS

By invoking options on the KOPTS card, the user can request that MCNP6 produce the point-kinetics parameters for criticality: the neutron generation time (Λ), the effective delayed neutron fraction (β_{eff}), and Rossi-α.

MCNP6 computes the point-kinetics parameters in a forward calculation with only the existing random walks by breaking the active cycles of a KCODE calculation into sequential blocks of fission generations. For best results of the KOPTS card, the system should be as near critical (k_{eff}=1) as possible.

Form: KOPTS KEYWORD=*value(s)* ...

Table 3-70. Criticality Options Card

Keyword	Value
BLOCKSIZE=*ncy*	Controls the number of cycles in every outer iteration. Number of cycles, *ncy*, in blocks for adjoint weighting. (DEFAULT: *ncy*=10) Restriction: *n*≥2 (See Notes 1, 2, and 3.)
KINETICS=[YES/NO]	If KINETICS=YES, calculate point-kinetics parameters. If KINETICS=NO, do not calculate point-kinetics parameters. (DEFAULT)
PRECURSOR=[YES/NO]	If PRECURSOR=YES, calculate detailed precursor information. If PRECURSOR=NO, do not calculate detailed precursor information. (DEFAULT) (See Note 4.)
KSENTAL=*fileopt*	Select format of sensitivity profiles output file, KSENTAL. (See Note 5.) If *fileopt*=MCTAL, write the sensitivity profiles in a MCTAL-like file, from which the profiles may be plotted using MCPLOT. (See Note 6.) If no format is specified, print no file. (DEFAULT) (No other options are available at this time.)
FMAT=[YES/NO]	Turns on FMAT Yes/No (DEFAULT=NO)
FMATSKIP=*fmat_skip*	(DEFAULT=4 OR 5)
FMATNCYC=*fmat_ncyc*	(DEFAULT=0 OR 10)
FMATSPACE=fmat_space	(DEFAULT=0 OR 3)
FMATACCEL=[YES/NO]	(DEFAULT=NO)
FMATREDUCE=[YES/NO]*	(DEFAULT=NO) (Unused)

Keyword	Value
FMATNX=*fmat_nx*	**(DEFAULT=0)**
FMATNY=*fmat_ny*	**(DEFAULT=0)**
FMATNZ=*fmat_nz*	**(DEFAULT=0)**

Note 1: Specification of BLOCKSIZE without setting KINETICS=YES is allowed, but MCNP6 will try to do adjoint weighting without tallying anything.

Note 2: The default block size of 10 cycles produces results with sufficient accuracy for most problems of interest. Using fewer cycles per block introduces greater bias from truncation, but provides a more statistically efficient calculation. Larger blocks are more accurate, but the accuracy gained for larger block sizes is often small relative to the increased computer time required to preserve the statistical precision. Users are encouraged to check whether the selected block size is sufficient for their application by running a larger block size and comparing the results. For small, leakage-dominated systems, the block size can often be reduced to 5.

Note 3: Because sensitivity coefficients (see the KSEN card, Section 3.3.5.23) are adjoint weighted, they theoretically require infinitely many cycles before a tally may be performed. In practice, the default BLOCKSIZE value of 10 generations is usually more than sufficient to get accurate results.

Note 4: If PRECURSOR=YES, then KINETICS must be set to YES.

Note 5: The KSENTAL keyword requires there be at least one KSEN card (see Section 3.3.5.23) specified in the MCNP6 input file.

Note 6: The MCTAL format of the sensitivity profiles is much like the standard MCTAL file except that the symbols for bins have different meanings: F=cells (with 0 denoting all cells); D=unused; U=unused; S=isotopes; M=reaction numbers; C=cosine bins; E=energy bins; and T=incident energy bins (for fission chi or scattering laws). The tally plotter, MCPLOT, may be loaded to plot these results. The results should be normalized to be per unit lethargy with the "LETHARGY" option and plotted on a semi log-x scale for visually accurate area plots.

Example 1:

```
KOPTS   BLOCKSIZE=15  KINETICS=YES  PRECURSOR=YES
```

Both standard kinetics parameters and detailed precursor information are requested. Because the `BLOCKSIZE` value is not the default, we assume the user determined from empirical studies that 15 generations per block are needed for the application.

3.3.4.12 HSRC MESH FOR SHANNON ENTROPY OF FISSION SOURCE DISTRIBUTION

To assist users in assessing the convergence of the fission source distribution, MCNP6 computes a quantity called the Shannon entropy of the fission source distribution, H_{src}. To compute H_{src}, it is necessary to superimpose a 3D grid on a problem encompassing all of the fissionable regions, and then to tally the number of fission sites in a cycle that fall into each of the grid boxes. The user may specify a particular grid to use in determining H_{src} by means of the `HSRC` input card. If the `HSRC` card is provided, users should use a small number of grid boxes (e.g., 5–10 in each of the *x*, *y*, and *z* directions), chosen according to the symmetry of the problem and layout of the fuel regions. If the `HSRC` card is not provided, MCNP6 will automatically determine a grid that encloses all of the fission sites for the cycle. The number of grid boxes will be determined by dividing the number of histories per cycle by 20 and then finding the nearest integer for each direction that will produce this number of equal-sized grid boxes, although not fewer than 4×4×4 will be used. If the grid is automatically determined by MCNP6, it will be expanded as necessary if fission source sites for a cycle fall outside of the grid. (The grid size will not be reduced.) If the grid is provided by the user using the `HSRC` card, then MCNP6 will issue warning messages either if 90% of the grid-boxes have zero scores for a cycle or if 25% of the fission source is located outside of the grid. Either of these messages is an indication that the user-supplied grid was poorly chosen for computing H_{src}. While H_{src} may not be computed reliably, there is no effect on k_{eff} or other tallies.

Form: `HSRC` n_x x_{min} x_{max} n_y y_{min} y_{max} n_z z_{min} z_{max}

Table 3-71. Shannon Entropy Card (HSRC)

Input Parameter	Description
n_x	**Number of mesh intervals in *x* direction, n_x>0.**
x_{min}	**Minimum *x*-value for mesh.**
x_{max}	**Maximum *x*-value for mesh.**
n_y	**Number of mesh intervals in *y* direction, n_y>0.**
y_{min}	**Minimum *y*-value for mesh.**
y_{max}	**Maximum *y*-value for mesh.**
n_z	**Number of mesh intervals in *z* direction, n_z>0.**
z_{min}	**Minimum *z*-value for mesh.**
z_{max}	**Maximum *z*-value for mesh.**

Default: None. If this card is absent, if fewer than nine entries are supplied, or if $n_x \times n_y \times n_z \leq 0$, MCNP6 will automatically create a mesh that encloses all of the fission source sites in a cycle. This automatic mesh will be expanded if necessary on later cycles. The minimum number of mesh cells for the automatic mesh is 4×4×4. If the `HSRC` card is supplied, one or more intervals may be specified for each of the *x*, *y*, and *z* directions.

Use: Optional card to specify the mesh for computing Shannon entropy of the fission source distribution in criticality calculations.

3.3.4.13 BURN DEPLETION/BURNUP (KCODE PROBLEMS ONLY)

Requirement: The CINDER.dat library file contains decay, fission yield, and 63-group cross-section data not calculated by MCNP6. This library file must be present and accessible by MCNP6 for the burnup capability to work properly. To be accessible, the CINDER.dat file must reside in either the working directory or the DATAPATH.

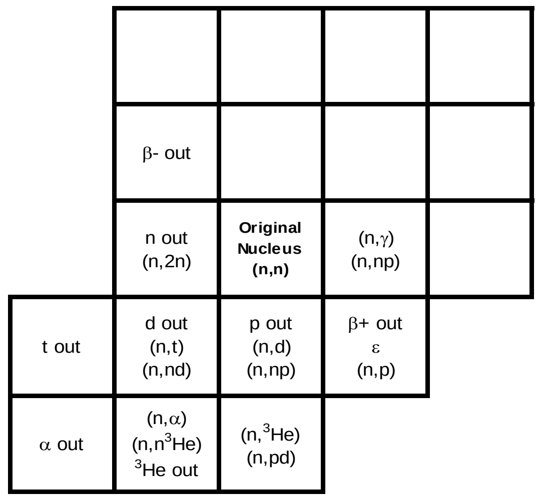
MCNP6 depletion is a linked process involving steady-state flux calculations in MCNP6 and nuclide depletion calculations in CINDER90. MCNP6 runs a steady-state calculation to determine the system eigenvalue, 63-group fluxes, energy-integrated reaction rates, fission multiplicity (ν), and recoverable energy per fission (Q values). CINDER90 then takes those MCNP6-generated values and performs the depletion calculation to generate new atom densities for the next time step. MCNP6 takes these new atom densities and generates another set of fluxes and reaction rates. The process repeats itself until after the final time step specified by the user.

Steady-state particle transport in MCNP6 includes only those isotopes listed on the material cards, selected from a fission product tier (presented in Table 3-72), or produced by the isotope generator algorithm. This algorithm captures only the daughter reactions and a few other residual reactions of the isotopes specified on the materials card; not the entire isotope decay chain. These daughter products are depicted in Figure 3-5, which provides the relative locations of the products of various nuclear processes on the Chart of the Nuclides. To track the buildup of additional decay-chain isotopes in the transport calculation, the isotopes must be listed on the material (`M`) card. If decay-chain isotopes of interest are not initially present, the user must add these isotopes to the material card (`M`) by providing appropriate isotope identifiers (`zaid`$_i$) with low atomic/weight fraction values (`fraction`$_i$) (e.g., 1E-36).

Table 3-72. Fission Product Content Within Each Burnup Tier

Tier1	Tier 2	Tier 3
		^{69}Ga ^{71}Ga
		^{70}Ge ^{72}Ge ^{73}Ge ^{74}Ge ^{76}Ge
	^{74}As ^{75}As	^{74}As ^{75}As
		^{74}Se ^{76}Se ^{77}Se ^{78}Se ^{79}Se ^{80}Se ^{82}Se
	^{79}Br ^{81}Br	^{79}Br ^{81}Br
	^{78}Kr ^{80}Kr ^{82}Kr ^{83}Kr ^{84}Kr ^{86}Kr	^{78}Kr ^{80}Kr ^{82}Kr ^{83}Kr ^{84}Kr ^{85}Kr ^{86}Kr

Tier1	Tier 2	Tier 3
	^{85}Rb ^{87}Rb	^{85}Rb ^{86}Rb ^{87}Rb
		^{84}Sr ^{86}Sr ^{87}Sr ^{88}Sr ^{89}Sr ^{90}Sr
	^{89}Y	^{89}Y ^{90}Y ^{91}Y
^{93}Zr	^{90}Zr ^{91}Zr ^{92}Zr ^{93}Zr ^{94}Zr ^{96}Zr	^{90}Zr ^{91}Zr ^{92}Zr ^{93}Zr ^{94}Zr ^{95}Zr ^{96}Zr
	^{93}Nb	^{93}Nb ^{94}Nb ^{95}Nb
^{95}Mo	^{95}Mo	^{92}Mo ^{94}Mo ^{95}Mo ^{96}Mo ^{97}Mo ^{98}Mo ^{99}Mo ^{100}Mo
^{99}Tc	^{99}Tc	^{99}Tc
^{101}Ru	^{101}Ru ^{103}Ru	^{96}Ru ^{98}Ru ^{99}Ru ^{100}Ru ^{101}Ru ^{102}Ru ^{103}Ru ^{104}Ru ^{105}Ru ^{106}Ru
	^{103}Rh	^{103}Rh ^{105}Rh
	^{102}Pd ^{104}Pd ^{105}Pd ^{106}Pd ^{108}Pd ^{110}Pd	^{102}Pd ^{104}Pd ^{105}Pd ^{106}Pd ^{107}Pd ^{108}Pd ^{110}Pd
	^{107}Ag ^{109}Ag	^{107}Ag ^{109}Ag ^{111}Ag
	^{106}Cd ^{108}Cd ^{110}Cd ^{111}Cd ^{112}Cd ^{113}Cd	^{106}Cd ^{108}Cd ^{110}Cd ^{111}Cd ^{112}Cd ^{113}Cd ^{114}Cd ^{116}Cd
		^{113}In ^{115}In
	^{120}Sn	^{112}Sn ^{113}Sn ^{114}Sn ^{115}Sn ^{116}Sn ^{117}Sn ^{118}Sn ^{119}Sn ^{120}Sn ^{122}Sn ^{123}Sn ^{124}Sn ^{125}Sn ^{126}Sn
		^{121}Sb ^{123}Sb ^{124}Sb ^{125}Sb ^{126}Sb
		^{120}Te ^{122}Te ^{123}Te ^{124}Te ^{125}Te ^{126}Te ^{128}Te ^{130}Te ^{132}Te
	^{127}I ^{129}I ^{135}I	^{127}I ^{129}I ^{130}I ^{131}I ^{135}I
^{131}Xe ^{134}Xe	^{124}Xe ^{126}Xe ^{128}Xe ^{129}Xe ^{130}Xe ^{131}Xe ^{132}Xe ^{134}Xe ^{135}Xe ^{136}Xe	^{123}Xe ^{124}Xe ^{126}Xe ^{129}Xe ^{130}Xe ^{131}Xe ^{132}Xe ^{133}Xe ^{134}Xe ^{135}Xe ^{136}Xe
^{133}Cs ^{137}Cs	^{133}Cs ^{134}Cs ^{135}Cs ^{136}Cs ^{137}Cs	^{133}Cs ^{134}Cs ^{135}Cs ^{136}Cs ^{137}Cs
^{138}Ba	^{138}Ba	^{130}Ba ^{132}Ba ^{133}Ba ^{134}Ba ^{135}Ba ^{136}Ba ^{137}Ba ^{138}Ba ^{140}Ba
		^{138}La ^{139}La ^{140}La
		^{136}Ce ^{138}Ce ^{139}Ce ^{140}Ce ^{141}Ce ^{142}Ce ^{143}Ce ^{144}Ce
^{141}Pr	^{141}Pr	^{141}Pr ^{142}Pr ^{143}Pr
^{143}Nd ^{145}Nd	^{143}Nd ^{145}Nd ^{147}Nd ^{148}Nd	^{142}Nd ^{143}Nd ^{144}Nd ^{145}Nd ^{146}Nd ^{147}Nd ^{148}Nd ^{150}Nd
	^{147}Pm ^{148}Pm ^{149}Pm	^{147}Pm ^{148}Pm ^{149}Pm ^{151}Pm
	^{147}Sm ^{149}Sm ^{150}Sm ^{151}Sm ^{152}Sm	^{144}Sm ^{147}Sm ^{148}Sm ^{149}Sm ^{150}Sm ^{151}Sm ^{152}Sm ^{153}Sm ^{154}Sm
	^{151}Eu	^{151}Eu ^{152}Eu ^{153}Eu ^{154}Eu ^{155}Eu ^{156}Eu ^{157}Eu
	^{152}Gd ^{154}Gd ^{155}Gd ^{156}Gd ^{157}Gd ^{158}Gd ^{160}Gd	^{152}Gd ^{153}Gd ^{154}Gd ^{155}Gd ^{156}Gd ^{157}Gd ^{158}Gd ^{160}Gd
		^{159}Tb ^{160}Tb
		^{156}Dy ^{158}Dy ^{160}Dy ^{161}Dy ^{162}Dy ^{163}Dy ^{164}Dy
	^{165}Ho	^{165}Ho
		^{162}Er ^{164}Er ^{166}Er ^{167}Er ^{168}Er ^{170}Er



n	=	neutron	α	=	alpha particle
p	=	proton	β^-	=	electron
d	=	deuteron	β^+	=	positron
t	=	triton	ε	=	electron capture
γ	=	gamma			

Figure 3-5. Nuclides selected for inclusion by the Isotope Generator Algorithm.

When the information is not specified by MCNP6, CINDER90 uses inherent intrinsic cross-section and decay data to track the time-dependent reactions of 3400 nuclides. MCNP6 can only track energy-integrated reaction-rate information for isotopes containing transport cross sections. For isotopes not containing transport cross-section information, MCNP6 calculates a 63-group flux that is sent to CINDER90. This flux data then is matched with a 63-group cross-section set inherent within CINDER90 to generate 63-group reaction rates. These resultant reaction rates are then energy integrated to determine the total reactions occurring.

Burnup is given in units of gigawatt days (GWD) per metric tones of uranium (MTU), where MTU is the sum of masses of isotopes containing ≥90 protons.

Form: `BURN KEYWORD=`*`value(s)`* `...`

Table 3-73. Depletion/Burnup (BURN)

Keyword	Value
`TIME=`t_1 t_2`...`	Incremental time duration t_i for each successive burn step. Time unit is days. (See Note 1.) (DEFAULT: one time step lasting one day)

Keyword	Value
PFRAC=f_1 f_2 ...	Fraction f_i of total system power (pwr) applied to burn step t_i. *Caution*: If only a single PFRAC value (f_1) is provided, but multiple time steps (t_i) are specified, the first time step (t_1) will be assigned a power fraction of f_1; subsequent time steps will have a power fraction of 0. A PFRAC entry of 0 will result in a decay step only without calculation of reaction rates (DEFAULT: f_i=1.0 for all t_i.)
POWER=pwr	Total recoverable fission system power (MW). (DEFAULT: POWER=1.0)
MAT=m_1 m_2 ...	Material number m_i of material to be burned. Corresponds identically to material number specified on a material specification card Mm. (DEFAULT: burn all materials) If m<0, then recoverable energy per fission and neutrons per fission are computed and contribute to the power normalization, but the material is not burned. (See Note 2.)
OMIT= m_1 n_1 j_{11} j_{12} ... j_{1n_1} m_2 n_2 j_{21} j_{22} ... j_{2n_2} . . .	For each specified material number, m_i, omit the following n_i isotopes from the transport calculation: j_{i1} j_{i2} … j_{in_i}. Each j_{in_k} must be provided in the form ZZZAAA, where ZZZ is the isotope's atomic number and AAA is its atomic mass number. If m_1=-1, then the omitted nuclide list is applied to all materials and m_2, m_3, etc., are not allowed.
AFMIN= af_1 af_2	af_1=Atom fraction below which an isotope will no longer be tracked in the transport calculation. If the atom fraction of an isotope falls below this limit, the atom fraction is set to 0. (DEFAULT: af_1=1.0E-10) af_2=Transmutation chain convergence criteria used in CINDER90. (DEFAULT: af_2=1.0E-10)

Keyword	Value
BOPT=b_1 b_2 b_3	b_1=Q value multiplier. (DEFAULT: b_1=1.0) The parameter b_2 is used to control the ordering and content of the output and is the additive result of two integer values: b_2=I1+I2. The first value, I1, selects among three tiers (see Table 3-72) of fission product content: If I1=0, include only Tier 1 fission products. (DEFAULT) If I1=10, include Tier 2 fission products, a more comprehensive set of fission products yet still a subset of Tier 3. If I1=20, include Tier 3 fission products, which comprise fission products in ENDF/B-VII.0 that have CINDER90 yield information. The second value, I2, selects among four ordering options: If I2=1, order output inventory high to low based on mass. (DEFAULT) If I2=2, order output inventory high to low based on total activity. If I2=3, order output inventory high to low based on specific activity. If I2=4, order output inventory based on increasing ZZZAAA. If b_2>0, output will be printed at end of job only. (DEFAULT) If b_2<0 output will be printed at end of each burn step. The parameter b_3 allows the user to disallow the use of high-energy physics models. If b_3=-1, a fatal error will occur if tabular data are unavailable for any isotope. (DEFAULT) If b_3=0, the atom fraction of any data using a model is set to 0. If b_3=1, use cross-section models for nuclides not containing tabular data and then allow CINDER90 to calculate the 1-group cross section for these nuclides by importing a 63-group flux and matching to a 63-group cross-section set..
MATVOL=v_1 v_2 ... v_n	Used to provide the volume of all cells containing a burn material in a repeated structure or lattice geometry. Each v_i entry is the volume of all cells containing burn material m_i. If MATVOL is used, then each m_i entry on the MAT keyword must have a corresponding v_i entry on MATVOL. (See Note 3.)

Table 3-73. Additional Depletion/Burnup (BURN) (continued)

Keyword

MATMOD=	nt	ts_1	nm_1	$mn_{1,1}$	$k_{1,1}$	$z^1_{1,1}$	$c^1_{1,1}$	$z^2_{1,1}$	$c^2_{1,1}$	...	$z^{k_{1,1}}_{1,1}$	$c^{k_{1,1}}_{1,1}$
				$mn_{1,2}$	$k_{1,2}$	$z^1_{1,2}$	$c^1_{1,2}$	$z^2_{1,2}$	$c^2_{1,2}$	...	$z^{k_{1,2}}_{1,2}$	$c^{k_{1,2}}_{1,2}$
				.	.						.	
				.	.						.	
				.	.						.	
				mn_{1,nm_1}	k_{1,nm_1}	z^1_{1,nm_1}	c^1_{1,nm_1}	z^2_{1,nm_1}	c^2_{1,nm_1}	...	$z^{k_{1,nm_1}}_{1,nm_1}$	$c^{k_{1,nm_1}}_{1,nm_1}$
		ts_2	nm_2	$mn_{2,1}$	$k_{2,1}$	$z^1_{2,1}$	$c^1_{2,1}$	$z^2_{2,1}$	$c^2_{2,1}$	...	$z^{k_{2,1}}_{2,1}$	$c^{k_{2,1}}_{2,1}$
		.		$mn_{2,2}$	$k_{2,2}$	$z^1_{2,2}$	$c^1_{2,2}$	$z^2_{2,2}$	$c^2_{2,2}$	...	$z^{k_{2,2}}_{2,2}$	$c^{k_{2,2}}_{2,2}$
		.		.	.						.	
		.		.	.						.	
		.		.	.						.	
		.		mn_{2,nm_2}	k_{2,nm_2}	z^1_{2,nm_2}	c^1_{2,nm_2}	z^2_{2,nm_2}	c^2_{2,nm_2}	...	$z^{k_{2,nm_2}}_{2,nm_2}$	$c^{k_{2,nm_2}}_{2,nm_2}$
		.										
		.										
		ts_{nt}	nm_{nt}	$mn_{nt,1}$	$k_{nt,1}$	$z^1_{nt,1}$	$c^1_{nt,1}$	$z^2_{nt,1}$	$c^2_{nt,1}$	...	$z^{k_{nt,1}}_{nt,1}$	$c^{k_{nt,1}}_{nt,1}$
				$mn_{nt,2}$	$k_{nt,2}$	$z^1_{nt,2}$	$c^1_{nt,2}$	$z^2_{nt,2}$	$c^2_{nt,2}$	...	$z^{k_{nt,2}}_{nt,2}$	$c^{k_{nt,2}}_{nt,2}$
				.	.						.	
				.	.						.	
				.	.						.	
				$mn_{nt,nm_{nt}}$	$k_{nt,nm_{nt}}$	$z^1_{nt,nm_{nt}}$	$c^1_{nt,nm_{nt}}$	$z^2_{nt,nm_{nt}}$	$c^2_{nt,nm_{nt}}$	...	$z^{k_{nt,nm_{nt}}}_{nt,nm_{nt}}$	$c^{k_{nt,nm_{nt}}}_{nt,nm_{nt}}$

Values

Keyword Input Parameter	Description
Nt	Total number of time steps for which concentration changes are specified.

ts_i	Integer identifying the ordinal position of the time step from the TIME keyword (1 for 1st, 2 for 2nd, etc.) at which to change nuclide concentrations of material(s) mn_{i,j_i}, where j_i=1,2,...,nm_i. If ts_i is entered as a positive value, new concentration values will be applied discretely at t_i and $t_{i+1/2}$. If ts_i is entered as a negative value, new concentration values will be applied at t_i and t_{i+1} and linearly interpolated to provide a concentration value at $t_{i+1/2}$. (If ts_i is negative at t_i and the concentrations of any of the altered isotopes at t_{i+1} is equal to the concentration set at t_i, then the concentrations of the altered isotopes will be set to the value at t_i for t_i, $t_{i+1/2}$, and t_{i+1}. At $t_{i+3/2}$, the isotopes will undergo a normal depletion and the concentrations will not be set to the value at t_{i+1}.) (See Notes 4 and 5.)
nm_i	Total number of materials at time step ts_i that incur nuclide concentration changes. For each time step identifier ts_i (i=1,2,...,nt) there must be a corresponding nm_i value.
mn_{i,j_i}	Sequential material number for which to change nuclides at time step ts_i for material j_i, where j_i=1,2,...,nm_i. If mn_{i,j_i} is a positive value, concentration must be given as an atom or weight fraction. If mn_{i,j_i} is a negative value, concentration must be given as atom or gram density.
k_{i,j_i}	Number of nuclides of the material mn_{i,j_i} for which concentration values follow. For each material mn_{i,j_i} (j=1,2,...,nm_i) there must be a corresponding k_{i,j_i} value.
$z_{i,j_i}^{k_{i,j_i}}$	Nuclide (in ZZZAAA format) of material mn_{i,j_i} for which a new concentration value immediately follows. There must be k_{i,j_i} pairs of associated nuclide and concentration values.
$c_{i,j_i}^{k_{i,j_i}}$	Concentration value for the nuclide $z_{i,j_i}^{k_{i,j_i}}$ of material mn_{i,j_i}. If $c_{i,j_i}^{k_{i,j_i}}$ is positive, values are interpreted as atom fractions or atom densities. If $c_{i,j_i}^{k_{i,j_i}}$ is negative, values are interpreted as weight fractions or gram densities.

Keyword

SWAPB=	nt	ts_1	nu_1	u_1	$n_{1,i_1j_1k_1}$	$n_{1,i_2j_1k_1}$	...	$n_{1,ijk}$	...	$n_{1,i_2j_2k_2}$
				u_2	$n_{2,i_1j_1k_1}$	$n_{2,i_2j_1k_1}$	...	$n_{2,ijk}$	...	$n_{2,i_2j_2k_2}$
				.	.					.
				.	.					.
				.	.					.
				u_{nu_1}	$n_{nu_1,i_1j_1k_1}$	$n_{nu_1,i_2j_1k_1}$	...	$n_{nu_1,ijk}$	...	$n_{nu_1,i_2j_2k_2K}$
		ts_2	nu_2	u_1	$n_{1,i_1j_1k_1}$	$n_{1,i_2j_1k_1}$	...	$n_{1,ijk}$	...	$n_{1,i_2j_2k_2}$
		.		u_2	$n_{2,i_1j_1k_1}$	$n_{2,i_2j_1k_1}$	...	$n_{2,ijk}$	...	$n_{2,i_2j_2k_2}$
		.		.	.					.
		.		.	.					.
		.		.	.					.
		.		u_{nu_2}	$n_{nu_2,i_1j_1k_1}$	$n_{nu_2,i_2j_1k_1}$	...	$n_{nu_2,ijk}$	...	$n_{nu_2,i_2j_2k_2}$
		.								
		.								
		ts_{nt}	nu_{nt}	u_1	$n_{1,i_1j_1k_1}$	$n_{1,i_2j_1k_1}$	...	$n_{1,ijk}$	...	$n_{1,i_2j_2k_2}$
				u_2	$n_{2,i_1j_1k_1}$	$n_{2,i_2j_1k_1}$	...	$n_{2,ijk}$	...	$n_{2,i_2j_2k_2}$
				.	.					.
				.	.					.
				.	.					.
				$u_{nu_{nt}}$	$n_{nu_{nt},i_1j_1k_1}$	$n_{nu_{nt},i_2j_1k_1}$	...	$n_{nu_{nt},ijk}$	...	$n_{nu_{nt},i_2j_2k_2}$

Values

Keyword Input Parameter	Description
Nt	Number of time steps for which to change the definition of the filling universe(s).
ts_i	Integer identifying the ordinal position of the time step [from the TIME keyword (1 for 1st, 2 for 2nd, etc.)] at which to change the specification of the filling universe(s). (Change can be made only after a corrector step.)
nu_i	Total number of FILL specifications to be changed at time step ts_i.
u_j	Filling universe number for which the specification is to be changed. (Only a finite universe can be used to fill a cell and it must be a lattice.)
$n_{j,ijk}$	Revised fully specified FILL, listing the universe numbers for each cell of the finite lattice, but omitting the range specification (i.e., i_1:i_2 j_1:j_2 k_1:k_2.). (See the FILL card, Section 3.3.1.5.3.) (See Note 6.)

Use: The depletion/burnup capability is limited to criticality (KCODE) problems.

Note 1: Burning with large time steps that encounter large flux-shape changes during the time step will lead to inaccurate calculations. Use time steps small enough to capture the flux-shape change accurately over time.

Note 2: For negative material numbers, m_i, specified on the `MAT` keyword, the recoverable energy per fission and neutrons per fission are computed for use in the power normalization procedure and the calculation of fission power fractions. A fatal error results if every material number is negative.

Note 3: To compute correctly isotopic masses and fluxes for burn materials, the volume of these materials must be either calculated by MCNP6 or provided by the user (on the `VOL` or `MATVOL` cards). For lattices or repeated structures, MCNP6 calculates the volume of each cell, but does not account for multiple occurrences of cell volumes. Therefore, if cells containing a burn material are repeated, then the volume calculated by MCNP6 will not represent the total volume of burn material and the user must provide the correct information on the `MATVOL` card.

Note 4: When using the `MATMOD` keyword, if ts_i is negative at t_i and the concentrations of any of the altered isotopes at t_{i+1} is equal to the concentration set at t_i, then the concentrations of the altered isotopes will be set to the value at t_i for t_i, $t_{i+1/2}$, and t_{i+1}. At $t_{i+3/2}$, the isotopes will undergo a normal depletion and the concentrations will not be set to the value at t_{i+1}.

Note 5: When using the `MATMOD` keyword of the `BURN` card, if a burn material is set to have a concentration change at t_1, then the atom density of that isotope at $t_{1/2}$ is set to the initial value specified at t_0. This is only set for the initial midpoint time step; the rest of the calculation will follow the procedure described for the ts_i parameter.

Note 6: The ability to "swap" or redefine universes is limited to universes of the same level. The universe need not be actively in the geometry (i.e. the universe may be truncated out of view by the bounding surfaces and still be able to be swapped). Also, you cannot swap a universe that does not pre-exist in the geometry.

Example 1:

```
BURN    TIME = 100 70  MAT = 1 3 4  POWER=1.0  PFRAC = 1.0 1.0
        BOPT= 1.0 -12 1
M1      8016.60c   4.5854e-2
        92235.60c  1.4456e-4
        92238.60c  1.9939e-2
        94238.60c  1.1467e-4
        94239.60c  1.0285e-3
        94240.60c  7.9657e-4
        94241.60c  3.3997e-4
        94242.60c  5.6388e-4
M2      2004       -1.0
M3      40000.60c  -1.0
```

```
M4      1001.60c   4.7716e-2
        8016.60c   2.3858e-2
        5010.60c   3.6346e-6
        5011.60c   1.6226e-5
MT4     lwtr.01t
```

In this example, materials M1, M3, and M4 are burned at 1 MW for 100 days and then 70 more days. Only material M1 contains fissionable actinides; therefore M3 and M4 incur transmutation only. The 2nd entry on the BOPT card sets the ordering of the output and selection of the fission product tier. Because the 1st digit of the 2nd entry is "1", the 2nd fission product tier will be used. Because the 2nd digit of the 2nd entry is "2", the order of the output isotope inventory will be based on high to low total activity. Because the 2nd BOPT entry is negative, output will be given at the end of each burn step. Isotope inventories will be given for each individual burn material as well as the sum over all burn materials.

Example 2:

```
BURN    TIME = 15.0 30.0 30.0  MAT = 3 4  POWER = 2.0
        OMIT = 3 3 8017 92234 92239 4 1 92234  BOPT =1.0 -11
        AFMIN= 1e-20 1e-12 MATMOD =1 2 1 4 1 5010 0.1
```

Materials M3 and M4 are burned for 15, 30, and 30 days at a power level of 2 MW. Excluded from the burn of M3 are three isotopes ^{17}O, ^{234}U, and ^{239}U; excluded from M4 is ^{234}U. Output is produced at the end of each burn step and ordered by decreasing mass, using Tier-2 fission products. Isotopes with an atom fraction above 1e-20 will be kept for transport. The decay chain convergence criteria is set to a tighter tolerance (1e-12), leading to a possibly improved prediction of the transmutation at the cost of a longer CINDER calculation. A material modification will be incurred for one time step, time step 2, for one material, M4, and one nuclide within that material, ^{10}B. At time step 2, the ^{10}B atom fraction in M4 will be manually set to 10%.

Example 3:

```
BURN  TIME = 25 17  MAT = 2 3 POWER = 5.1
      BOPT =1.0 24 MATVOL=4 2
        SWAPB 2 1 1 900 4 4 4
                        4 5 5
                2 1 900 4 5 4
                        5 4 4
```

Example three assumes a geometry where M2 is contained within a cell that is within universe 4 and M3 is contained within a cell that is within universe 5. Both universe 4 and 5 are assumed to be at the same level. Also assumed is that the volume of M2 within a cell within universe 4, and the volume of M3 within a cell within universe 5, are both 1 cm^3. Both universe 4 and 5 are assumed filled into universe 900. Both M2 and M3 are burned for 15, and 17 days at a power level of 5.1 MW. Burnup output is produced only at the end of the entire calculation and ordered by increased ZZZAAA, using Tier-3 fission products. Because M2 and M3 are within repeated structures, the MATVOL keyword sets the total volume of M2 to 4 cm^3 and M3 to 2 cm^3; otherwise CINDER90 would burn the material assuming the cell specified volume of 1 cm^3. Universe 900 is then modified by a swap at both time steps, where universe 4 and 5 locations are altered. Because a MATVOL keyword is used, and only a single universe is incurring a swap, the user must not add extra universe 5's or subtract universe 4's from the swapped universe.

3.3.4.14 SUBROUTINES SOURCE AND SRCDX

Users may write their own source subroutines to bypass the standard source capabilities. If no SDEF, SSR, or KCODE card is provided in the MCNP6 input file, then MCNP6 will look for a subroutine called SOURCE. This subroutine must be supplied by the user. In addition, if there are detectors or DXTRAN, MCNP6 also will require a SRCDX routine. (Section 4.3.4 contains an example of a SOURCE subroutine and Section 4.3.5 discusses the SRCDX subroutine.) The parameters that must be specified within the SOURCE subroutine are listed and defined in Table 3-74. Prior to calling subroutine SOURCE, isotropic direction cosines *u,v,w* (pbl%r%u, pbl%r%v and pbl%r%w) are calculated and need not be specified if you want an isotropic distribution.

Table 3-74. Source Variables Required for each Source Particle*

Code Source Variable	Variable Description
pbl%r%erg	the energy of the particle (MeV)**
pbl%r%tme	the time when the particle started (shakes)
pbl%r%x, pbl%r%y and pbl%r%z	the position of the particle
pbl%r%u, pbl%r%v and pbl%r%w	the direction of the flight of the particle
pbl%i%ipt	the type of particle
pbl%r%wgt	the statistical weight of the particle
pbl%i%icl	the cell where the particle started
pbl%i%jsu	the surface where the particle started, or zero if the starting point is not on any surface

* Additional variables may have to be defined if there are point detectors or DXTRAN spheres in the problem.

** pbl%r%erg has a different meaning in a special case. If there is a negative *igm* on the MGOPT card, which indicates a special electron-photon multigroup problem, ERG on the SDEF card is interpreted as an energy group number, an integer.

The SI, SP, and SB cards also can be used with the SOURCE subroutine, although modifications to other parts of MCNP6 may be required for proper initialization and to set up storage. A random number generator RANG( ) is available for use by SOURCE for generating random numbers between 0 and 1. Up to 200 numerical entries can be entered on each of the IDUM and RDUM cards for use by SOURCE. The IDUM entries must be integers and the RDUM entries floating point numbers.

If you are using a detector or DXTRAN and your source has an anisotropic angular distribution, you will need to supply an SRCDX subroutine to specify PSCs (i.e., probability of the surface source emitting a particle into a specified angle relative to the surface normal) for each detector or DXTRAN sphere.

There are unused variables stored in the particle bank that are reserved for the user. These are called SPARE(M), M=1, MSPARE, where MSPARE=7. Depending on the application, you may need to reset them to 0 in SOURCE for each history; MCNP6 does not reset them.

Example 1:

```
subroutine source
  ! dummy subroutine.  Aborts job if source subroutine is
  ! missing. If nsr==USER_DEFINED_SOURCE, a subroutine
  ! source must be furnished by the user.

  ! At entrance, a random set of direction cosines, pbl%r%u,
  ! pbl%r%v, pbl%r%w has been define

  ! .. Use Statements ..
  use mcnp_interfaces_mod, only : expirx
  use mcnp_debug
  use pblcom

  implicit none

  pbl%i%ipt = 1
  pbl%i%jsu = 0
  pbl%i%icl = 1
  pbl%r%x = 2
  pbl%r%y = 3
  pbl%r%z = 4
  pbl%r%u = 1
  pbl%r%v = 0
  pbl%r%w = 0
  pbl%r%erg = 8
  pbl%r%tme = 0
  pbl%r%wgt = 1

  ! call expirx(0,'source','you need a source subroutine.')
  return
end subroutine source
```

The above source.F90 subroutine is used to represent a the SDEF card, `SDEF par=n erg=8 vec=1 0 0 dir 1 wgt=1 tme=0 pos 2 3 4`. It is assumed that the source is in cell 6, which is the 1st cell number listed in the input. The expirx call must be commented out; otherwise the compiled source will still result in:

```
bad trouble in subroutine source of mcrun

 you need a source subroutine.
```

3.3.5 Data Cards Related to Tally Specification

Tally cards are used to specify what type of information the user wants to gain from the Monte Carlo calculation. Options include such tallies as current across a surface, flux at a point, heating in a region, etc. This information is requested by the user by using a combination of cards described in this section. To obtain tally results, only the F card is required; the other tally cards provide various optional features.

The *n* associated with the tally-type specification is a user-chosen tally number ≤99999999; choices of *n* are discussed in the following section. When a choice of *n* is made for a particular tally type, any other input card used to refine that tally description (such as E*n* for energy bins) is given the same value of *n* by the user.

Much of the information on these cards is used to describe tally "bins," or subdivisions, of the tally space into discrete and contiguous increments such as cosine, energy, or time. Usually when the user subdivides a tally into bins, MCNP6 also can provide the total tally summed over appropriate bins (such as over all energy bins). Absence of any bin specification card results in one unbounded bin rather than one bin with a default bound. No information is printed about the limits on the unbounded bin.

If there are reflecting surfaces or periodic boundaries in the problem, the user may have to normalize the tallies in some special way. (This can be done by setting the weight of the source particles or by using the FM or SD cards.)

Printed with each tally bin is the relative error of the tally corresponding to one standard deviation. These errors *cannot* be believed reliable (hence neither can the tally itself) unless the error is fairly low. Results with errors greater than 50% are useless, those with errors between 20% and 50% can be believed to within a factor of a few, those with errors between 10% and 20% are questionable, and results with errors less than 10% are generally (but not always) reliable, except for detectors. Detector results are generally reliable if their associated relative errors are below 5%. The tally fluctuation charts at the end of the output file base their results on the information from one specified bin of every tally. (See the TF card.) This bin also is used for the weight-window generator and is subject to ten statistical checks for tally convergence, including calculation of the variance of the variance (VOV). The VOV can be printed for all bins in a tally by using the DBCN card. A tally is considered to be converged with high confidence only when it passes all ten statistical checks.

INDEX OF TALLY INPUT INFORMATION		
Mnemonic	**Description**	**Section**
F	Standard Tallies	3.3.5.1
FIP/FIR/FIC	Array of Point Detector Tallies	3.3.5.1.2
FC	Tally Comment	3.3.5.2
E	Tally Energy	3.3.5.3
T	Tally Time	3.3.5.4
C	Tally Cosine	3.3.5.5
FQ	Print Hierarchy	3.3.5.6
FM	Tally Multiplier	3.3.5.7
DE/DF	Dose Energy/Dose Function	3.3.5.8
EM	Energy Multiplier	3.3.5.9
TM	Time Multiplier	3.3.5.10
CM	Cosine Multiplier	3.3.5.11
CF	Cell Flagging	3.3.5.12
SF	Surface Flagging	3.3.5.13
FS	Tally Segment	3.3.5.14
SD	Segment Divisor	3.3.5.15
FU	Special Tally or TALLYX Input	3.3.5.16
TALLYX	User-Supplied TALLYX Subroutine	3.3.5.17
FT	Special Treatments for Tallies	3.3.5.18
TF	Tally Fluctuation	3.3.5.19
NOTRN	Direct-Only Contributions	3.3.5.20
PERT	Tally Perturbation—Differential Operator	3.3.5.21
KPERT	Reactivity Perturbations—Adjoint Weighting	3.3.5.22
KSEN	k_{eff} Sensitivity Coefficients—Adjoint	3.3.5.23
TMESH	Superimposed Mesh Tally A	3.3.5.24
FMESH	Superimposed Mesh Tally B	3.3.5.25
SPDTL	Lattice Speed Tally Enhancement	3.3.5.26

3.3.5.1 F STANDARD TALLIES

MCNP6 offers an array of standard tallies to the user. These include particle current, particle flux (across a surface, in a cell, at a detector point), energy deposition, collision heating, fission energy deposition, pulse height, and charge deposition. All tallies are normalized to be per source particle unless a different normalization has been specified with the WGT keyword on the SDEF card, changed by the user with a TALLYX subroutine, or normalized by weight in a criticality (KCODE) calculation.

Table 3-75: Tally designators

Mnemonic	Tally Description	F*n* units	*F*n* units
F1:<*pl*>	**Current integrated over a surface**	**particles**	**MeV**
F2:<*pl*>	**Flux averaged over a surface**	**particles/cm^2**	**MeV/cm^2**
F4:<*pl*>	**Flux averaged over a cell**	**particles/cm^2**	**MeV/cm^2**
F5*a*: <*pl*>	**Flux at a point or ring detector**	**particles/cm^2**	**MeV/cm^2**
FIP5: <*pl*>	**Array of point detectors for pinhole flux image**	**particles/cm^2**	**MeV/cm^2**
FIR5: <*pl*>	**Array of point detectors for planar radiograph flux image**	**particles/cm^2**	**MeV/cm^2**
FIC5: <*pl*>	**Array of point detectors for cylindrical radiograph flux image**	**particles/cm^2**	**MeV/cm^2**
F6:<*pl*>	**Energy deposition averaged over a cell**	**MeV/g**	**jerks/g**
+F6	**Collision heating**	**MeV/g**	**N/A**
F7: <*pl*>	**Fission energy deposition averaged over a cell**	**MeV/g**	**jerks/g**
F8:<*pl*>	**Energy distribution of pulses created in a detector by radiation**	**pulses**	**MeV**
+F8:<*pl*>	**Charge deposition**	**charge**	**N/A**

The tallies are identified by tally type and particle type as follows. Tallies are given the numbers 1, 2, 4, 5, 6, 7, 8, or increments of 10 thereof, and are given a particle designator :<*pl*>, where <*pl*> is chosen from Table 2-2. Thus you may have as many of any basic tally as you need, each with different energy bins, or flagging bins, or anything else. The designations F4:N, F14:N, F104:N, and F234:N are all legitimate neutron cell flux tallies; they could all be for the same cell(s) but with different energy or multiplier bins, for example. Similarly F5:P, F15:P, and *F305:P are all photon point detector tallies. Having both an F1:N card and an F1:P card in the same INP file is not allowed. The tally number may not exceed 99,999,999.

Several tally types allow multiple particles. For example, an energy deposition tally for both neutrons and gammas, F6:N,P, may be specified. In the case of collision heating, +F6 always applies to all particles in a problem; therefore this tally has no particle designator. For pulse-height tallies photons/electrons are a special case: F8:P,E is the same as F8:P and F8:E. Also, F8 tallies may have particle combinations such as F8:N,H.

Tally types 1, 2, 4, and 5 are normally weight tallies; however, if the F card is flagged with an asterisk (for example, *F1:N), energy times weight will be tallied. The asterisk flagging also can be used on tally types 6 and 7 to change the units from MeV/g to jerks/g. No asterisk can be used in combination with the + on the +F6 or +F8 tallies. The asterisk on a tally type 8 converts from a pulse-height tally to an energy deposition tally. All of the units are shown in the Table 3-75.

Tally type 8 has many options. The standard F8 tally is a pulse-height tally and the energy bins are no longer the energies of scoring events, but rather the energy balance of all events in a history. In conjunction with the FT8 card (Section 3.3.5.18), the F8 tally can be an anticoincidence pulse-height tally, a neutron coincidence capture tally, or a residual nuclei production tally. When flagged with an asterisk, *F8 becomes an energy deposition tally. In addition, F8 can be flagged with a plus (+) to convert it from an energy deposition tally (flagged with an asterisk) to a charge deposition tally. The +F8 tally is the negative particle weight for electrons and the positive weight for positrons. The +F8:E tally can be checked against an F1:E type surface tally with the FT1:E ELC option to tally charge.

Only the F2 surface flux tally requires the surface area. The area calculated is the total area of the surface that may bound several cells, not a portion of the surface that bounds only a particular cell. An exception to this statement occurs if one uses a repeated structures format to describe the tally bin(see Section 3.3.5.1.4). If you need only the segment of a surface, you might segment the full surface with the FS card (see Section 3.3.5.14) and use the SD card (see Section 3.3.5.15) to enter the appropriate values. You can also redefine the geometry as another solution to the problem. Similarly, tally types 4, 6, and 7 require the cell volume, which can be automatically calculated or supplied by the user via the VOL (Section 3.3.1.1) or SD (Section 3.3.5.15) cards. The total number of detectors is restricted to 100. The total number of different tallies is limited to 9999. Note that a single type 5 tally may create more than one detector.

For any tally, if the tally label of the surface or cells in a given bin exceeds eleven characters, including spaces, an alphabetical or numerical designator is defined for printing convenience. The MCNP6-supplied designator [e.g., G is (1 2 3 4 5 6)], will be printed with the tally output. This labeling scheme is usually required for tallies over the union of a long list of surfaces or cells or with repeated structure tallies.

3.3.5.1.1 Surface and Cell Tallies (Tally Types 1, 2, 4, 6, and 7)

Simple Form: F*n*:<*pl*> s_1 ... s_k

General Form: F*n*:<*pl*> s_1 (s_2 ... s_3) (s_4 ... s_5) s_6 s_7 ... [T]

Table 3-76. Surface and Cell Tally Cards (F1:*n*, F2:*n*, F4:*n*, F6:*n*, F7:*n*)

Input Parameter	Description
N	**Tally number.** **Restriction:** *n*≤99999999
<*pl*>	**Particle designator. (See Note 1.)**
s_i	**Problem number of surface or cell for tallying. (See Note 2.)**
T	**Total over specified surfaces or cells for F1 tallies; average over specified surfaces or cells for F2, F4, F6, and F7 tallies. (Optional) (See Note 3.)**

Use: In the simple form above, MCNP6 creates *k* surface or cell bins for the requested tally, listing the results separately for each surface or cell. In the more general form, a bin is created for each surface or cell listed separately and for each collection of surfaces or cells enclosed within a set of parentheses. Entries within parentheses also can appear separately or in other combinations. Parentheses indicate that the tally is for the union of the items within the parentheses. For unnormalized tallies (tally type `1`), the union of tallies is a sum, but for normalized tallies (types `2`, `4`, `6`, and `7`), the union results in an average. See Section 3.3.5.1.4 for an explanation of the repeated structure and lattice tally format.

Note 1: Tally type `7` allows `N` only.

Note 2: Only surfaces that define cell boundaries and that are listed in a cell card description can be used on `F1` and `F2` tallies.

Note 3: The symbol `T` entered on surface or cell `F` cards is shorthand for a region that is the union of all of the other entries on the card. A tally is made for the individual entries on the `F` card plus the union of all the entries. The entry is optional.

Note 4: Surface flux tallies require an approximation when counting grazing contributions, that is, for contributions where the dot product of the particle direction and the surface normal are between -0.001 and 0.001 (the current default, new in MCNP6.2). The grazing angle cutoff can be reset using the 24th entry on the DBCN card; i.e., "DBCN 23j 0.1" changes the grazing angle cutoff from the MCNP6.2 value of ±0.001 to the historic MCNP value of ±0.1.

Aside: Surface Flux Tally (F2)

For particles grazing the surface, $1/|\mu|$ (where μ is the cosine of the angle that the particle track makes with the surface normal) is very large and MCNP approximates the surface flux estimator in order to satisfy the requirement of one central limit theorem. An unmodified surface flux estimator has an infinite variance, and thus confidence intervals could not be formed via the central limit theorem, because the central limit theorem requires a finite variance. For this reason, MCNP sets $|\mu| = 0.0005$ when $|\mu| < 0.001$; because of this approximation, the F2 tally is not an exact estimate of the surface flux. . (The grazing angle cutoff cosine can be changed using the 24th entry on the DBCN card.)

While the numeric values may vary, this is the standard approximation used in Monte Carlo codes. This approximation is accurate when the angular flux is isotropic or linearly anisotropic with respect to μ on the surface and the limits of the flux integral with respect to μ are symmetric. However, these assumptions may become invalid on external surfaces or in other cases of one-way surface crossings; when exactly tangent crossing is not possible because of the geometry of the problem; or when cosine bins are used. Users should be especially careful in these cases. More details may be found in FAV11a and FAV11b.

***Aside: Energy Deposition Tally* (`F6`)**

In the energy range where nuclear data tables are available, the neutron, photon, and proton energy deposition is determined using the heating numbers from the nuclear data tables. These heating numbers are estimates of the energy deposited per unit track length. In addition, the de/dx ionization contribution for electrons and/or protons is added in for `MODE E` or `MODE H`.

Above that tabular energy limit, or when no tabular data is available, energy deposition is determined by summing several factors. For charged particles, ionization (de/dx) energy is deposited uniformly along the track length (which is important to keep in mind when doing a mesh tally). All other energy deposition is calculated at the time of a nuclear interaction. The energies of secondary particles, if they are not to be tracked (i.e., not included on the `MODE` card) will be deposited at the point of the interaction. Nuclear recoil energy will be deposited at the point of interaction unless heavy ion transport is specified (i.e., `MODE #`).[1]

To obtain the most accurate energy deposition tallies possible, the user must include all potential secondary particles on the `MODE` card. (Users may wish to omit electrons, provided they fully understands how energy deposition for photons is done.) The energy deposition for non-tracked secondary particles generally assumes all energy is deposited locally at the collision site. The exception is for neutral particles (photons, neutrinos, etc.), which generally travel far from the collision site. Heating is included for these secondary particles only if they are listed on the `MODE` card and `F6` card. The assumption of local energy deposition for non-tracked secondary particles is poor, especially when the energies of the secondaries are high, or when the user is simulating thin volumes. When secondary particles are indicated on the `MODE` card, MCNP6 will subtract their energies from the heating values, and energy deposition will be handled in the regular process of tracking those particles.[2]

When there are no library heating data available, de/dx, nuclear recoil, and the energies of some non-tracked secondary particles are added to the `F6` collision estimator. A secondary particle can be produced either by collision or by particle decay.[3] In MCNP6, the energies of neutral particles will never be added to the collision estimator (this includes neutrons, photons, neutrinos, π^0, and neutral kaons). Therefore, it is especially important for the user to

---

[1] Tracking of residual nuclei is important in small volumes where the recoil nucleus might leave the cell. This is especially important in light ion recoils (such as a scattered hydrogen nucleus). Light ion recoil from elastic collisions is an option on the `PHYS:N` and `PHYS:H` cards.

[2] Energies of particles that fall below minimum energy cutoffs will also be deposited locally. The user must be certain that the value of these cutoff energies will not cause the results of the `F6` tally to be in error.

[3] Note that the π^0, if included on the `MODE` card, will be transported before it decays, even though its lifetime is 8.4×10^{-17} seconds. This allows the user to use MCNP6 tallies for that particle.

include all possible secondary particles on the MODE card (especially photons and neutrinos), in order to get the most accurate energy deposition tally.

MCNP6 has the track-length heating (F6:<*pl*>) tally, where <*pl*> can be any particle or combination of particles. In addition, MCNP6 also has a collision heating (+F6) tally, which contains energy deposition from all particles in the problem. Note that the PEDEP keyword in a Type 1 mesh tally is analogous to the F6:<*pl*> tally, and the Type 3 mesh tally is analogous to the +F6 tally, although the normalizations will be different. Since the mesh tallies score energy deposition within a mesh cell, which may contain more than one material, normalization is per unit volume. The units of this tally are MeV/source-particle. In the F6 and +F6 tallies, material density is available for the chosen cells, and normalization is MeV/gm/source-particle.

Example 1:

```
F2:N    1  3  6  T
```

This card specifies four neutron flux tallies, one across each of the surfaces 1, 3, and 6 and one which is the average of the flux across all three of the surfaces.

Example 2:

```
F1:P  (1  2) (3  4  5) 6
```

This card provides three photon current tallies, one for the sum over surfaces 1 and 2; one for the sum over surfaces 3, 4, and 5; and one for surface 6 alone.

Example 3:

```
F371:N    (1  2  3) (1  4) T
```

This card provides three neutron current tallies, one for the sum over surfaces 1, 2, and 3; one for the sum over surfaces 1 and 4; and one for the sum over surfaces 1, 2, 3, and 4. The point of this example is that the T bin is not confused by the repetition of surface 1.

Example 4:

```
+F6    2
```

This card produces energy deposition (MeV/g) from all particles averaged over cell 2. This will include heating values and/or de/dx energy from particles undergoing library interactions (e.g., neutrons, photons, electrons, protons) and de/dx, recoil, and non-tracked secondary particle energy from all model interactions.

3.3.5.1.2 DETECTOR TALLIES (TALLY TYPE 5)

Point detectors, ring detectors, and radiography tallies use an assumption of isotropic scatter for contributions from collisions within the model regime (i.e., generally E>150 MeV). These estimators require the angular distribution data for particles produced in an interaction to predict the "next event." Information on these distributions is available in tabular form in the libraries; however, this information is not available in the required form from physics models used to produce secondary particles above the tabular region. MCNP6 allows up to 100 detectors to be specified.

The user is encouraged to read about detectors before implementing them because they are very susceptible to unreliable results if used improperly. Here are a few hints:

1. Remember that contributions to a detector are not made through a region of zero importance.
2. Ring (rather than point) detectors should be used in all problems with axial symmetry.
3. Flux image detectors should be located in a void because the constant flux neighborhood `ro` is not used. (Such a neighborhood would have to enclose the entire image grid.)
4. A detector located right on a surface probably will cause trouble.
5. Detectors and DXTRAN can be used in problems with the S(α,β) thermal treatment, but the S(α,β) contributions are approximate.
6. Detectors used with reflecting, white, or periodic surfaces give wrong answers.
7. Consider using the `PDn` and `DDn` cards.

Point Detectors:

Form for point detectors: `Fn:<pl>  x1 y1 z1 ±ro1 ... xn yn zn ±ron  [ND]`
(See Note 1.)

Table 3-77. Point Detector Card (F5:*n*)

Input Parameter	Description
N	**User-supplied tally number ending in the numeral 5.** **Restriction: *n*≤99999999**
<pl>	**Particle designator:** **Restriction: N for neutrons or P for photons only.**
x_i y_i z_i	**Coordinates of the i^{th} detector point. (See Note 2.)**
$\pm ro_i$	**Radius of the sphere of exclusion for the i^{th} detector: a positive entry is interpreted as centimeters; a negative entry is interpreted as mean free paths. (Note that a negative entry is illegal in a void.) (See Note 3.)**
ND	**Optional keyword to inhibit the separate printing of the direct contribution for that detector tally. (See Note 4.)**

Ring Detectors:

Form for ring detectors: `Fna:<pl>  ao1 r1 ±ro1 ... aon rn ±ron  [ND]`
(See Note 1.)

Table 3-78. Ring Detector Card (F5*a*:*n*)

Input Parameter	Description
N	**User-supplied tally number ending in the numeral 5.** **Restriction:** $n \leq 99999999$
A	**The letter X, Y, or Z.**
<pl>	**Particle designator:** **Restriction: N for neutrons or P for photons only.**
ao_i	**Distance along axis "*a*" where the ring plane of the i^{th} detector intersects the axis. (See Note 2.)**
r_i	**Radius of the ring of the i^{th} detector in centimeters.**
$\pm ro_i$	**Same meaning as for point detectors, but describes a sphere about the point selected on the i^{th} ring detector. (See Note 3.)**
ND	**Optional keyword to inhibit the separate printing of the direct contribution for that detector tally. (See Note 4.)**

Default: None.

Note 1: For more than one detector with the same *n* or *na* designation, sets of the input parameters (quadruplets for F*n* or triplets for F*na*) are simply continued on the same F*n* or F*na* card.

Note 2: If more than one detector of the same type (an F5:N and an F15:N, for example) are at the same location, the time-consuming contribution calculation upon collision is made only once and not independently for each detector. Thus it is inexpensive to add more than one detector (each with a different response function, for example) at the same location.

Note 3: The radius of the sphere of exclusion, $\pm ro_i$, should be about 1/8 to 1/2 mean free path for particles of average energy at the sphere and zero in a void. Supplying *ro* in terms of mean free path will increase the variance and is not recommended unless you have no idea how to specify it in centimeters. *Caution*: The exclusion sphere must not encompass more than one material. MCNP6 cannot verify this and the consequences may be wrong answers.

Note 4: The printout for detectors is normally in two parts: 1) the total of all contributions to the detector (as a function of any defined bins such as energy) and (2) the direct (or un-collided) contribution to the detector from the source. The direct contribution is always included in the total of all contributions. Adding the symbol ND at the end of a type 5 detector tally card inhibits the separate printing of the direct contribution for that tally. In coupled neutron/photon problems, the direct contribution in photon tallies is from photons created at neutron collisions.

THE RADIOGRAPHY TALLY

MCNP6 can generate simulated radiography images as one would expect to see from an x-ray or pinhole projection of an object containing the particle source. This allows the recording of both the direct (source) image as well as that due to background (scatter). This tool is an invaluable aid to the problem of image enhancement, or extracting the source image from a background of clutter. MCNP6 includes two types of image capability; the pinhole image projection and the transmitted image projection.

The radiography capability is based on point detector techniques, and is extensively described in SNO96 and SNO98. In essence, the radiography focal plane grid is an array of point detectors.

FIP *Pinhole Image Projection*[1]

FIP establishes a flux image through a pinhole to a planar grid. In the pinhole image projection case, a point is defined in space that acts much like the hole in a pinhole camera and is used to focus an image onto a grid which acts much like the photographic film. The pinhole is actually a point detector and is used to define the direction cosines of the contribution that is to be made to the grid. The pinhole position relative to the grid is also used to define the element of the grid into which this contribution is scored. Once the direction is established, a ray-trace contribution is made to the grid bin with attenuation being determined for the material regions along that path. The source need not be within the object being imaged, nor does it need to produce the same type of particles that the detector grid has been programmed to score. The grid and pinhole will image either source or scattered events produced within the object (see `NOTRN` card in Section 3.3.5.20) for either photons or neutrons. These event-type contributions can be binned within the grid tallies by binning as source only, total, or by using special binning relative to the number of collisions contributing cells, etc. Steps to define the image grid for a pinhole image are provided later in this section.

Form: `FIPn:<pl>` x_1 y_1 z_1 *ro* x_2 y_2 z_2 f_1 f_2 f_3 (See Note 1.)

Table 3-79. Pinhole Radiography Card (FIP)

Input Parameter	Description
N	**Tally number, tally type 5.** **Restriction:** ***n*≤99999999**
<*pl*>	**Particle designator.** **Restriction: `N` for neutrons or `P` for photons only.**
x_1, y_1, z_1	**The coordinates of the pinhole center.**

[1] The `PI` card formerly used by MCNPX for pinhole image projection is replaced by the `FIP` card. For convenience to the MCNPX user, the nomenclature is still permitted in this version of the code, but may not be supported in future versions. Users are encouraged to begin using the `FIP` card name instead of `PI`.

Ro	**Always `0` (zero) for this application. Note: Neither the pinhole nor the grid should be located within a highly scattering media.**
x_2, y_2, z_2	**The reference coordinates (center of object) that establish the reference direction cosines for the normal to the detector grid. This direction is defined as being from x_2, y_2, z_2 to the pinhole at x_1, y_1, z_1.**
f_1	**If f_1>0, this value is the radius of a cylindrical collimator, centered on and parallel to the reference direction, which establishes a radial field of view through the object and surrounding materials and onto the image grid. If f_1=0, the value of the radius is "large." (DEFAULT)**
f_2	**The radius of the pinhole perpendicular to the reference direction. If f_2=0, this represents a perfect pinhole. If f_2>0, the point within the pinhole through which the particle flux contribution will pass is picked randomly (i.e., uniformly in area) for each source and scatter event. This simulates a less-than-perfect pinhole.**
f_3	**The distance from the pinhole at x_1, y_1, z_1 to the center of the detector grid along the direction established from x_2, y_2, z_2 to x_1, y_1, z_1. The image grid is perpendicular to this reference vector.**

Note 1: Only one pinhole image tally per `FIP` card is allowed. The point detector Russian roulette game is not used with the `FIP` tally. Consider use of the `NOTRN` card for only direct contributions and the `TALNP` card to reduce the size of the OUTP file for large-image grids. The image grid *should not* be in a scattering material because the point detector average flux neighborhood is not used for flux image tallies.

FIR *and* FIC *Transmitted Image Projection*[1]

`FIR` establishes a flux image on a rectangular radiograph planar grid, and `FIC` establishes a flux image on a cylindrical radiograph grid.

In the transmitted image projection case, the grid acts like a film pack in an x-ray type image, or transmitted image projection. In both cases, for every source or scatter event a ray-trace contribution is made to every bin in the detector grid. This eliminates statistical fluctuations across the grid that would occur if the grid location of the contribution from each event were to be picked randomly, as would be the case if one used a DXTRAN sphere and a segmented surface tally. For each event, source or scatter, the direction to each of the grid points is determined, and an attenuated ray-trace contribution is made. As in pinhole image projection, there are no restrictions as to location or type of source used. These tallies automatically bin

[1] The `TIR` and `TIC` cards formerly used by MCNPX for pinhole image projection is replaced by the `FIR` and `FIC` cards. For convenience to the MCNPX user, the nomenclature is still permitted in this version of the code, but may not be supported in future versions. Users are encouraged to begin using the `FIR` and `FIC` cards name instead of `TIR` and `TIC`.

in a source-only and a total contribution. Steps to define the image grid for transmitted images are provided later in this section.

When this type of detector is being used in a problem, if a contribution is required from a source or scatter event, an attenuated contribution is made to each and every detector grid bin. Because for some types of source distributions very few histories are required to image the direct or source contributions, an additional entry has been added to the NPS card to eliminate unwanted duplication of information from the source. (See Section 3.3.7.1.)

Rectangular grid:

Form: FIR*n*:<*pl*> x_1 y_1 z_1 *ro* x_2 y_2 z_2 f_1 f_2 f_3 (See Note 1.)

Cylindrical grid:

Form: FIC*n*:<*pl*> x_1 y_1 z_1 *ro* x_2 y_2 z_2 f_1 f_2 f_3 (See Note 1.)

Table 3-80. Transmitted Image Projection Cards (FIR and FIC)

Input Parameter	Description
N	**Tally number, tally type 5. Restriction: *n*≤99999999**
<*pl*>	**Particle designator. Restriction: N for neutrons or P for photons only.**
x_1, y_1, z_1	**The coordinates of the center of the detector flux image grid, the extent and spacing of which are defined by the entries on the tally segment (FS) and cosine (C) cards. In the planar rectangular grid case, this point defines the center of the grid. In the cylindrical grid case, this point defines the center of the cylinder on which the grid is established.**
Ro	**Always 0 (zero) in this application. Note: Do not locate the image grid in a scattering material.**
x_2, y_2, z_2	**The reference coordinates (center of object) that establish the reference direction cosines for the outward normal to the detector grid plane, as from x_2, y_2, z_2 to x_1, y_1, z_1. This direction is used as the outward normal to the detector grid plane for the FIR case, and as the centerline of the cylinder for the FIC case.**
f_1	**If f_1=0, both the direct (source) and scattered contributions will be scored at the detector grid. If f_1=-1, only the scattered contributions will be scored. (See Note 2.)**

Input Parameter	Description
f_2	**Radial field of view.** **Planar grid case: Radial restriction relative to the center of the grid to define a radial field of view on the grid for contributions to be made. If f_2=0, no radial restriction exists.. (DEFAULT)** **Cylindrical grid case: Radius of the cylindrical surface of the image grid. If f_2=0, it is a fatal error.**
f_3	**If f_3=0, all flux contributions are directed to the center of each grid bin. If f_3=-1, contributions are made with a random offset from the center of the image grid bin. This offset remains fixed and is used as the offset for contributions to all of the grid bins for this event.**

Note 1: Only one flux image detector is allowed on each FIC or FIR card. The point detector Russian roulette game is not used with FIC or FIR tallies. Consider use of the NOTRN card for only direct contributions, the second entry on the NPS card for limiting the direct FIR contributions, and the TALNP card to reduce size of the OUTP file for large-image grids.

Note 2: The scattered contributions can often be made on a much coarser image grid because there is much less structure to the scattered image. Use f_1=-1 in this case. The NOTRN card can be used to obtain only the direct image with f_1=0.

Defining an FIP, FIR*, or* FIC *Image Grid Using* FS*n and* C*n Cards*

The grid plane is in the two-dimensional *s*-*t* coordinate system where the *s*- and *t*-axes are orthogonal to the reference direction. The *s*- and *t*-dimensions are established from entries on tally segment (FS*n*) and cosine (C*n*) cards, where the tally number *n* matches the flux image tally number.

In the case of FIP and FIR, the image-plane rectangular grid dimensions are defined by setting the first entry on the FS*n* and C*n* cards to the lower limit (in cm) of the first image bin for the s-axis and t-axis, respectively. The other entries on the FS*n* and C*n* cards set the upper limit of each of the bins. These limits are set relative to the intersection of the reference direction and the grid plane.

In the cylindrical (FIC) grid case, the entries on the FS*n* card are the distances along the symmetry axis of the cylinder from x_1,y_1,z_1, and the entries on the C*n* card are the angles in degrees as measured counterclockwise from the positive *t*-axis.

The relationship of the *s*-axis, *t*-axis, and reference direction for the planar image grid is calculated by MCNP6 and follows the right-hand rule. Since the orientation of the *s*-axis and the *t*-axis is dependent on the reference direction in the geometry coordinate system, the MCNP6 tally output should be examined to see the direction cosines of these two planar image grid axes. These limits should be defined taking into account any image size change at the grid caused by magnification. The image grid *should not* be in a scattering material because the point detector average flux neighborhood is not used for flux image tallies.

There is no limit to the number of image grid bins that can be defined by `FS`*n* and `C`*n*. However, it is easy to define a tally with a huge number of point detectors. For example, a 1000 by 1000 grid is the equivalent of 1 million point detectors, which could take a long time to run. Fatal errors will result if the `FS`*n* and `C`*n* card bin specifications are not each monotonically increasing. The default tally fluctuation chart bin is the last `FS`*n* and `C`*n* bin in the total (direct plus scattered) detector tally. `FS0` and `C0` cards for these image tallies are not allowed. The `T` (total) and `C` (cumulative) options for the `FS`*n* and `C`*n* cards are not available for flux image tallies.

The directions of the *t*-axis and *s*-axis of the grid are set up such that if the reference direction (the outward normal to the grid plane) is not parallel to the *z*-axis of the geometry, the *t*-axis of the grid is defined by the intersection of the grid plane and plane formed by the *z*-axis and the point where the reference direction would intersect the grid plane. If the reference direction is parallel to the *z*-axis of the geometry, then the *t*-axis of the grid is defined to be parallel to the *y*-axis of the geometry. The *s*-axis of the grid is defined as the cross product of a unit vector in the "*t*" direction and a unit vector in the reference direction. If the reference direction is not parallel to the *z*-axis, MCNP6 calculates the orthogonal axes. The *s* and *t* image axes direction cosines are printed in the OUTP file.

Example 1:

```
FSn   -20.   99i   15.
Cn    -25.   99i   10.
```

These two cards set up a 100×100 grid that extends from -20 cm to 15 cm along the *s*-axis, from -25 cm to 10 cm along the *t*-axis, and has 10,000 equal sized bins. These bins need not be equal in size nor do they need to be symmetric about the reference direction.

Reading or Plotting the Radiography Tally Output

The output of the two radiography tally options is contained in the MCTAL file. It can be formatted for use with external graphics programs with the GRIDCONV[1] routine. The user is referred to Section 3.3.5.24.6 for information on how to use GRIDCONV. Pinhole and radiography tallies can also be plotted directly in the MCNP6 tally plotter from RUNTPE or MCTAL files using the "`FREE SC`" command to give a 2D contour plot of the *s*- and *t*-axes. They can also be plotted during the course of a calculation by incorporating an `MPLOT` card into the input file or by using the TTY interrupt capability to invoke MCPLOT.

[1] GRIDCONV is not packaged with MCNP6. However, the MCNPX version should be able to read and process most of the output files from MCNP6.

3.3.5.1.3 PULSE-HEIGHT TALLY (TALLY TYPE 8)

The pulse-height tally is a radical departure from other MCNP6 tallies. All other tallies are estimates of macroscopic variables, such as flux, whose values are determined by very large numbers of microscopic events. The pulse-height tally records the energy or charge deposited in a cell by each source particle and its secondary particles. For other tallies it is not necessary to model microscopic events realistically as long as the expectation values of macroscopic variables are correct. For the pulse-height tally, microscopic events must be modeled much more realistically.

The departures from microscopic realism in MCNP6 are everywhere. The number, energies, and directions of the secondary neutrons and photons from a neutron collision are sampled without any correlation between the particles and with no regard for the conservation of energy. The fluctuations in the energy loss rate of an electron are not correlated with the production of knock-on electrons and x-rays. The variance reduction schemes in MCNP6 distort the natural random walk process in various ways; nevertheless, they give correct results for macroscopic tallies when appropriate weighting factors are used.

Problems that give correct pulse height tallies are severely limited. For example, the pulse-height tally does not work well with neutrons because of the non-analog nature of neutron transport that departs from microscopic realism at every turn. One can have a neutron source in a `MODE N P` or `N P E` problem, but only the photons and electrons can be tallied on the `F8` card. The `F8` tally can be used effectively in photon problems. Electron problems may give correct results as long as the tally cells are thick enough for the errors in the energy loss rate to average out. Combining `F8` tallies with a photonuclear bias is a fatal error. MCNP6 tries to detect conditions in a problem that would invalidate pulse height tallies, but it is not able to catch all of them. The user must ascertain that his problem does not violate the necessary conditions for obtaining correct answers.

Scoring the pulse-height tally is done at the end of each history. In the absence of variance reduction, the scoring is reasonably easy to describe. For example, consider a unit weight source and an `F8` tally in cell 7. Suppose that on a given particle history that there are K entries into cell 7 and L departures from cell 7. The tally energy associated with an `F8` tally is the kinetic energy of the particle plus 1.022016 MeV if it is a positron. Particles can enter cell 7 either by crossing a boundary into cell 7 or entering cell 7 as a source event. Particles depart cell 7 either by capture in cell 7 or by crossing a boundary out of cell 7. Let E_i be the i^{th} tally energy of a particle entering cell 7 and let D_j be the j^{th} tally energy of a particle departing cell 7. The total energy deposited in cell 7 is

$$T = \sum_{i=1}^{K} E_i - \sum_{j=1}^{L} D_j \quad .$$

Suppose the pulse height bins are specified on the `E8` card as:

```
E8   T1 T2 T3 T4 T5
```

If $T_{m-1}<T<T_m$, then MCNP6 will post a unit tally in the m^{th} bin. If the problem is analog but the source weight is w_s, then w_s would be posted in the m^{th} bin. If there is an asterisk on the F8 card, then MCNP6 tallies w_s*T in the m^{th} bin. If there is a plus on the F8 card, then MCNP6 posts the net charge change times the w_s into the m^{th} bin. That is, an entering electron or a departing positron constitutes a charge change of -1, whereas a departing electron or an entering positron constitutes a charge change of +1.

The scoring details are more complex with pulse-height tally variance reduction. (BOO02)

One common application of the F8 tally is simulation of the energy distribution of pulses created in a detector by radiation. The union of tallies produces a tally sum, not an average. Cell, user, and energy bin cards are allowed. Flagging and multiplier bins are *not* allowed. Segment, time, and cosine bins are permitted with certain FT options (see Section 3.3.5.18). Use of the dose energy (DE) and dose function (DF) cards is also disallowed with the F8 tally.

The energy bins in the F8 pulse-height tally are different from those of all other tallies. Rather than tally the particle energy at the time of scoring, the number of pulses depositing energy within the bins are tallied. That is, the meaning of the energy bins of a pulse-height tally is the energy deposited in a cell bin by all the physically associated tracks of a history. Care must be taken when selecting energy bins for a pulse-height tally. It is recommended that a zero bin and an epsilon bin be included such as

```
E8    0   1E-5   1E-3   1E-1   ...
```

The zero bin will catch non-analog knock-on electron negative scores. The epsilon (1E-5) bin will catch scores from particles that travel through the cell without depositing energy.

With the FT8 special tally treatments card (Section 3.3.5.18) the F8 tally can become an anticoincidence pulse-height tally (FT8 PHL) or a different kind of tally altogether. For example, FT8 CAP is a neutron coincidence capture tally, and FT8 RES tallies the residual nuclides from physics-model evaporation and fission models. These variations have special rules regarding possible variance reduction, time bins, and other issues.

Pulse-Height Tally Variance Reduction

Variance reduction for F8 tallies is implemented for electrons and photons; however, not a lot of experience exists to guide the user. Experience suggests that weight windows be used instead of geometry splitting for F8 tallies. Many of the variance-reduction techniques that were designed for lowering the variance on other tally types may be used with the F8 tally. Allowed variance reduction techniques include

- Splitting/roulette (IMP card)
- Implicit capture and weight cutoff (CUT card)
- Weight window (WWN card)
- Forced collisions (FCL card)

- Exponential transform (EXT card)
- DXTRAN (DXT card)
- Weight roulette on DXTRAN particle (DD card)
- DXTRAN cell probabilities (DXC card)
- Source biasing (SB card)
- Energy splitting (ESPLT card)
- Time splitting (TSPLT card)

The roulette associated with splitting/roulette (IMP card) and weight windows (WWN card) may be less useful than it is for non-F8 tallies; roulette may be turned off by setting the keyword RR=OFF on the VAR card. Although implicit capture and weight cutoff have been implemented, in most cases these games are turned off by default if an F8 tally is in the problem. An exception occurs if forced collisions also are used in the problem.

Note that the weight-window generator was designed for non-F8 tallies; the generator should not be used for F8 tallies. The generator estimates the importance of a single particle at a phase-space point *P*. The generator cannot estimate the importance of a collection of *K* particles at phase-space points P_1, P_2, ..., P_k. (To see what is involved with making a generator work with F8, see BOO94.) Instead, a useful window often can be generated using a tally such as an F4 tally in the same cell as the F8 tally.

Pulse-Height Tally Variance Reduction: Discussion Using Examples

The MCNP6 pulse height variance-reduction theory is described in detail in BOO92 and BOO02. Two simple examples are given in this manual to give the reader an idea of how MCNP6 does variance reduction with pulse height tallies. The essential idea is that MCNP6's deconvolution method reconstructs physically possible random walks and assigns an appropriate tally weight based on how much the variance reduction has distorted the frequency of obtaining the walks. For example, if a random walk has been made twice as likely to occur in the simulation as it would naturally, then this random walk will be assigned at weight of 1/2 so that the expected tallies are preserved.

Let’s suppose, as depicted in Figure 3-6, that there is a pair annihilation event and an exponential transform is applied to both 0.511-MeV branches. (Assume this is the only variance reduction used.) Because the exponential transform samples a non-analog density, there will be a weight multiplication to account for this. The left branch has a track weight of 1/5 indicating that the left branch's random walk was made 5 times more likely to occur as it would have without applying the exponential transform. Similarly, the right branch has a track weight of 1/3 indicating that the right branch's random walk was made 3 times more likely to occur as it would have without applying the exponential transform. Assuming that none of the E*i* is in the same bin, the tally for the total current into the cell is tallied as

1/5 in the energy bin around E5
1/5 in the energy bin around E7

1/3 in the energy bin around E1
1/3 in the energy bin around E3

and the total current leaving the cell is tallied as

1/5 in the energy bin around E6
1/5 in the energy bin around E7
1/3 in the energy bin around E2
1/3 in the energy bin around E4

By contrast, as explained below, the F8 tally for this history is

(1/5)(1/3) in the energy bin around E5 - E6 + E7 - E7 + E1 - E2 + E3 - E4

Note that the F8 tally depends on the energy deposited collectively by both branches of the pair annihilation event. If the history above had been sampled without the exponential transforms, then the F8 tally would have been

1 in the energy bin around E5 - E6 + E7 - E7 + E1 - E2 + E3 - E4.

Note that the physical walk contributes E5 - E6 + E7 - E7 + E1 - E2 + E3 - E4 regardless of how often the walk is sampled. With the variance reduction applied here, the particular walk sampled occurred 5*3=15 times as often as it would in an analog calculation. Thus, the F8 tally credits the physical energy bin with a weight factor of 1/15, correcting for the fact that the annihilation pair has been made 15 times as likely to execute the walk that contributes E5 - E6 + E7 - E7 + E1 - E2 + E3 - E4 as it should have. Note that it is a physical collection of particles that now carries the tally modification weight because it is the physical collection that tallies to the F8 tally rather than just the individual tracks as with other tallies in MCNP6.

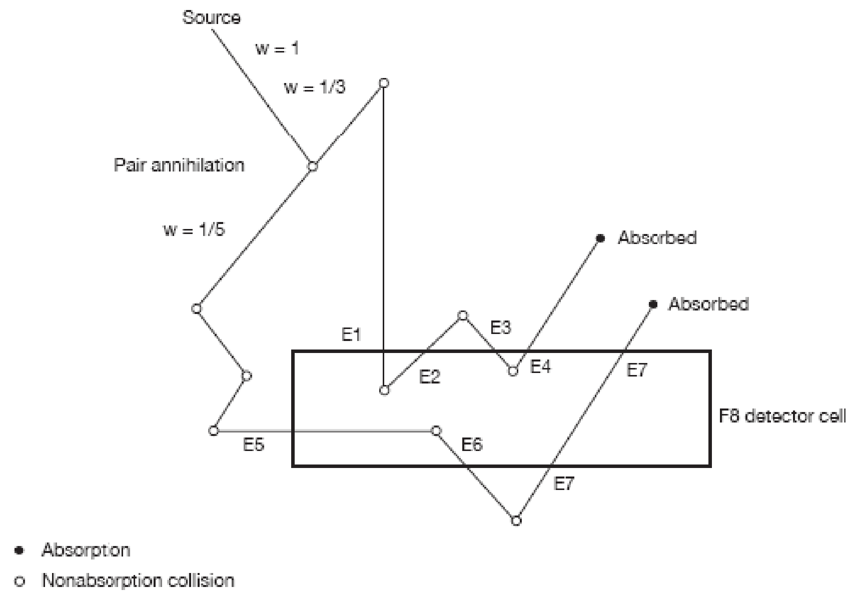


Figure 3-6. Example of exponential transform applied to both branches of a pair annihilation event.

The second example, illustrated by Figure 3-7, considers a 2:1 splitting event and no other variance reduction methods. Note that splitting is a mathematical artifice; only one physical particle exists after crossing the splitting surface. What the splitting does is give two (usually) different samples of the random walk after crossing the splitting surface. Both of these random walks do not physically occur at the same time. If the left split branch occurs then the right split branch does not and vice versa. Because the splitting represents a doubling of the sampling frequency for either branch, the branches are each assigned a weight of 1/2. The energy bins associated with taking the left split branch or the right split branch are, respectively, E5 - E6 + E7 - E7 + E1 - E8 or E5 - E6 + E7 - E7 + E1 - E2 + E3 - E4. The pulse-height tally is thus

1/2 in the energy bin around E5 - E6 + E7 - E7 + E1 - E8

1/2 in the energy bin around E5 - E6 + E7 - E7 + E1 - E2 + E3 - E4.

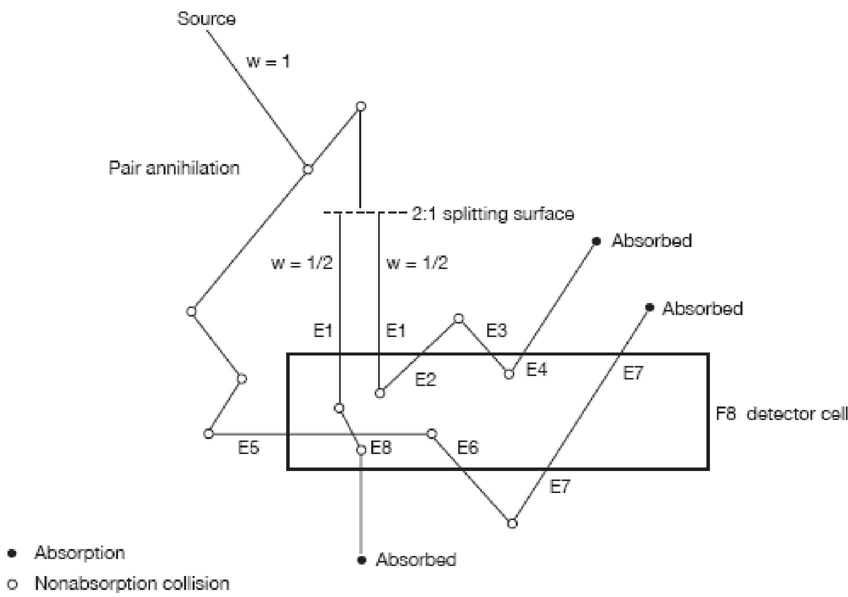


Figure 3-7. Splitting example.

Simple Form: F*n*:<*pl*> s_1 ... s_k ... T (See Note 1.)

General Form: F*n*:<*pl*> s_1 (s_2 ... s_3) (s_4 ... s_5) s_6 s_7 ... T (See Note 1.)

Table 3-81. Pulse-Height Tally Card (F8)

Input Parameter	Description
N	User-supplied tally number, ending in the numeral 8. Restriction: *n*≤99999999
<*pl*>	Particle designator. Standard F8 tallies support only "P,E" (if only one of these is specified, it is expanded to include both). Other particle types should only be specified with the FT PHL or CAP options. (See Note 2.)
s_j	Problem number of cell for tallying, or T for the total across all listed cells..
T	Provide average of tally over specified cells.

Note 1: An asterisk on the F8 card converts the tally from a pulse-height tally to an energy deposition tally. A plus on the F8 card converts the tally from a pulse-height tally to a charge deposition tally in units of charge. Energy binning is not recommended with the +F8 tally.

Note 2: Both photons and electrons will be tallied if present, even if only E or only P is on the F8 card. In other words, F8:P, F8:E, and F8:P,E are all equivalent tallies.

Example 1:

```
+F8:E     1
```

or

```
F1:E      2
FT1 ELC   1
C1       0 1
```

The +F8 charge deposition tally can be checked against an electron F1:E surface tally with the FT ELC option if the volume of the +F8 is exactly enclosed by the surfaces on the F1:E card. For example, if cell 1 is enclosed by spherical surface 2, then the above tallies give the same result provided the two F1 current tally bins (in minus out) are properly subtracted.

3.3.5.1.4 REPEATED STRUCTURES TALLIES (TALLY TYPES 1, 2, 4, 6, 7, AND 8)

Simple Form: F*n*:<*pl*> s_1 ... s_k

General Form: F*n*:<*pl*> s_1 (s_2...s_3) ((s_4 s_5)<(c_1 c_2[i_1...i_2])<U=#<(c_3 c_4 c_5))...[T]

Table 3-82. Repeated Structure Tally Cards

Input Parameter	Description
N	**Tally number.** **Restriction:** $n \leq 99999999$
<*pl*>	**Particle designator.**
s_i	**Problem number of a surface or cell for tallying or U=#.**
c_j	**Problem number of a cell filled with a universe or U=#..**
T	**Average or total over specified surfaces or cells, depending on type of tally. (Optional)**
U=#	**Problem number of a universe used on a FILL card.**
i_i	**Index data for a lattice cell element, with three possible formats (always in brackets):** **If i_i=i_1, then i_i indicates the 1st lattice element of cell c_2, as defined by the FILL array.** **If i_i=i_1:i_2 i_3:i_4 i_5:i_6, then i_i indicates a range of one or more lattice elements. Use the same format as on the FILL card.** **If i_i=i_1 i_2 i_3, i_4 i_5 i_6 , then i_i indicates individual lattice elements (i_1, i_2, i_3), (i_4, i_5, i_6), etc.** **See LAT (Section 3.3.1.5.2) and FILL (Section 3.3.1.5.3) cards for indices explanation.**

Use: Consider using the SPDTL card. (See Section 3.3.5.26)

In the simple repeated-structure tally form, MCNP6 creates k surface or cell bins for the requested tally, listing the results separately for each surface or cell. In the more general form, a bin is created for each surface or cell listed separately and for each collection of surfaces or cells enclosed within a set of parentheses. A tally bin can involve a single tally level or multiple tally levels. Tallies involving repeated structure and lattice geometries can use either form.

Some operators and nomenclature need to be introduced before the explanation of repeated structures and lattice tallies. The left arrow or less than symbol < is used to identify surfaces or cells within levels of repeated structures. See Section 3.3.1.5.1 for an explanation of geometry levels. A tally bin that includes one or more left arrows implies multiple levels, called a chain. Multiple entries enclosed by parentheses at any level of a tally chain indicate the union of the items. Brackets `[ ]` immediately following a filled lattice cell identify one or more elements of that lattice.

Multiple Bin Format

In addition to multiple levels, multiple entries can be used in each level of the tally chain resulting in multiple output bins. Within the parentheses required around the tally bin chain, other sets of parentheses can be used to indicate the union of cells as in a simple tally description, resulting in fewer output tally bins. For example,

$((s_4\ s_5)<(c_1\ c_2\ [i_1\ ...\ i_2])<(c_3\ c_4\ c_5))$

results in one output tally bin and will be the union of the tally in s_4 plus s_5 that fill c_1 or c_2 [elements $i_1\ ...\ i_2$] *and* when c_1 or c_2 fills cells c_3, c_4, or c_5. Removing the first and third inner parentheses, i.e.,

$(s_4\ s_5 < (c_1\ c_2\ [i_1\ ...\ i_2]) < c_3\ c_4\ c_5)$

results in the creation of 2*1*3=6 bins as follows:

$(s_4<(c_1\ c_2\ [i_1\ ...\ i_2])<c_3)$, $(s_5<(c_1\ c_2\ [i_1\ ...\ i_2])<c_3)$,
$(s_4<(c_1\ c_2\ [i_1\ ...\ i_2])<c_4)$, $(s_5<(c_1\ c_2\ [i_1\ ...\ i_2])<c_4)$, and
$(s_4<(c_1\ c_2\ [i_1\ ...\ i_2])<c_5)$, $(s_5<(c_1\ c_2\ [i_1\ ...\ i_2])<c_5)$.

The repeated structure/lattice input tally bin format with levels that have multiple entries automatically creates multiple output tally bins. The total number of bins generated is the product of the number of entries at each level. If parentheses enclose all entries at a level, the number of entries at that level is one and results in the union of all those entries. For unnormalized tallies (type 1, 8), the union is a sum. For normalized tallies (type 2, 4, 6, 7), the union is an average. A symbol T on the tally line creates an additional tally bin that is the union or total of all the other tally bins.

Brackets

Brackets `[ ]` enclose index data for lattice cell elements. Brackets make it possible to tally on a cell or surface only when it is within the specified lattice elements. The brackets must immediately follow a filled lattice cell. Listing a lattice cell without brackets will produce a tally when the tally cell or surface is in *any* element of the lattice, provided the tally cell or surface fills an entry at all other levels in the chain. The use of brackets is limited to levels after the first "<" symbol in the tally specification.

To tally within lattice elements of a real world (level zero) lattice cell, use the special syntax that follows. Cell 3 contains material 1 and is bounded by four surfaces. The F4 card specifies a tally only in lattice element (0,0,0). This syntax is required because brackets can only follow a < symbol:

```
3     1   -1.0   -1234   lat=1
.
.
.
F4:N      (3 < 3 [0 0 0])
```

Universe Format

The universe format, U=#, is a shorthand method of including all cells and lattice elements *filled* by universe #. This format can be used in any level of the tally chain. The following example illustrates valid shorthand U=# descriptions in the left column. The right column shows the tally after the shorthand has been expanded. Cells 4 and 5 are filled with universe 1.

	shorthand	expanded
F4:N	u = 1	4 5
	(u = 1)	(4 5)
	(u = 1 < 2 < 3)	(4 5 < 2 < 3)
	((u = 1) < 2 < 3)	((4 5) < 2 < 3)
	(1 < u = 1 < 2 < 3)	(1 < 4 5 < 2 < 3)
	(1 < (u = 1) < 2 < 3)	(1 < (4 5) < 2 < 3)

In complex geometries, the U=# format should be used sparingly, especially with the multiple bin format. If 100 cells are filled by universe 1 and 10 cells are filled by universe 2, then the tally

`F4:N     (u = 1 < u = 2)` will create 1000 output tally bins.

However,

`F4:N     ((u = 1) < (u = 2))` will create only one output tally bin.

Example 1:

```
F4:N   (5 < 4 < 2 [1 0 0])
```

This example could specify an F4 tally in cell 5 when it is in cell 4, when cell 4 is in cell 2, which is a lattice, and only in lattice element [1,0,0]. While any cell (lattice, filled, or simple) can be entered as a tally cell (e.g., s_1 through s_5), only cells filled with a universe can be used in higher levels (e.g., c_1 through c_5).

The arrows separate different universe levels. Cell `5` in `U=2` is inside cell `4` in `U=1`. For $c_1 < c_2$, c_1 must *not* be in the same universe as c_2. The input tally bin chain involving multiple levels *must* be enclosed by an outer set of parentheses.

Note: Input files with large lattice tallies may run significantly faster if the following conditions apply:

- The lattice is specified fully on the cell fill card, e.g.,
  `FILL -50:50 -50:50 -50:50`.
- The tally chain refers to no more than one cell at each level, except for the lattice cell, which must include the entire range of all indices specified on the corresponding `FILL` card: `F4:P (1 < 2 < 3[-50:50 -50:50 -50:50] < 4)`.

Example 2:

```
21x21x21 void lattice of balls
11 0 -31 u=1 imp:p=1
12 0  31 u=1 imp:p=1
16 0 -32 u=2 imp:p=1
     lat=1 fill= -10:10 -10:10 -10:10 1 9260R
17 0 -33 fill=2 imp:p=1
18 0  33        imp:p=0

31 sph 0 0 0 .5
32 rpp -1 1 -1 1 -1 1
33 rpp -21 21   -21 21   -21 21

mode    p
print
prdmp 2j -3
sdef
nps    10000
f4:p (11<16[-10:10 -10:10 -10:10]<17)
```

This example runs significantly faster with MCNP6 than with MCNP4C. Larger lattices and nested lattices offer even more dramatic speedups.

Use of SD Card for Repeated Structures Tallies

MCNP6 may be unable to calculate required volumes or areas for tallies involving repeated-structure and lattice geometries. For example, a universe can be repeated a different number of times in different cells and the code has no way to determine this. There are two distinct options for entries on the `SD` card relating to repeated structures and they cannot be mixed within a single tally.

The first option is to enter a value for each *first level* entry on the related `F` card. If the entry on the `F` card is the union of cells, the `SD` card value will be the volume of the union of the cells. The following examples illustrate `F` card tally descriptions in the left column. The right column shows the `SD` card entries.

`F4:N`	`(1 < 4 5 6 < 7 8)`	`SD4`	v_1
	`(1 2 3 < 4 5 6 < 7 8)`		$v_1\ v_2\ v_3$
	`(1 2 3 < (4 5 6) < (7 8))`		$v_1\ v_2\ v_3$
	`((1 2 3) < 4 5 6 < 7 8)`		v_{123}

In this example, v_i is the volume of cell i and v_{123} is the volume of the union of cells `1`, `2`, and `3`. Even though the first line creates six tally bins, only one `SD` value is entered. This divisor is applied to all bins generated by the input tally bin. You do not need to know the number of bins generated by each input tally bin in order to use the `SD` card. The last line is the union of cells `1`, `2`, and `3` and only one divisor is entered on the `SD` card.

The second option is to enter a value for each bin generated by the `F` card.

`F4:N`	`(1 < 4 5 6 < 7 8)`	`SD4`	$v_1^1\ \ v_1^2\ \ v_1^3\ \ v_1^4\ \ v_1^5\ \ v_1^6$
	`(1 2 3 < 4 5 6 < 7 8)`		$v_1^1\ \ v_2^2\ \ v_3^3\ \ v_1^4\ \ v_2^5\ \ v_3^6\ \ v_1^7 \ldots v_1^{16}\ \ v_2^{17}\ \ v_3^{18}$
	`(1 2 3 < (4 5 6) < (7 8))`		$v_1\ \ v_2\ \ v_3$
	`((1 2 3) < 4 5 6 < 7 8)`		$v_{123}^1\ \ v_{123}^2\ \ v_{123}^3\ \ v_{123}^4\ \ v_{123}^5\ \ v_{123}^6$

In this example, v_i^j is the volume of cell i for bin j and v_{123}^j is the volume of the union of cells `1`, `2`, and `3` for bin j. If cell i is repeated the same number of times in all six bins generated by the first line above, then all six `SD` values for this input bin will be the same ($v_1^1 = v_1^2 = v_1^3 \ldots$). However, if cell `1` is repeated a different number of times in each bin, then different `SD` values should be entered. The volume is multiplied by the number of times it is repeated. In these cases, the total cell `1` volume for each generated bin will not be calculated. The bin generation order is explained previously in the `F` card section. For the first line above, the bin order is (1<4<7), (1<5<7), (1<6<7), (1<4<8), (1<5<8), and (1<6<8). The second line listed in the above sample generated 18 tally bins, and 18 `SD` values are required in the proper sequence. This option requires the knowledge of both the number and sequence of bins generated by each input tally bin.

3.3.5.2 FC TALLY COMMENT

Form: `FC`*`n`* *`info`*

Table 3-83. Tally Comment Card (FC)

Input Parameter	Description
N	**Tally number.** **Restriction:** $n \leq 99999999$
Info	**Provides title for tally in output and MCTAL file. (See Note 1.)**

Default: No comment.

Use: Encouraged, especially when using a modified or non-standard tally.

Note 1: The FC card can be continued only by blanks in columns 1–5 on succeeding lines. The & continuation symbol is considered part of the comment and not recognized as a continuation command.

3.3.5.3 E TALLY ENERGY

Form: E*n* e_1 ... e_k [NT] [C] (See Note 1.)

Table 3-84. Tally Energy Card (E)

Input Parameter	Description
n	**Tally number. Restriction:** $n \leq 99999999$
e_i	**Upper bound (in MeV) of the** i^{th} **energy bin for tally** *n*. **(See Note 2.)**
NT	**Optional notation at the end of the input line to inhibit the automatic total over all specified energy bins.**
C	**Optional notation at the end of the input line to cause the bin values to be cumulative and the last energy bin to be the total over all energy bins.**

Default: If the E card is absent, there will be one bin over all energies unless this default has been changed by an E0 card.

Use: Required if EM card is used (See Section 3.3.5.9)

Note 1: An E0 card can be used to set up a default energy-bin structure for all tallies. A specific E*n* card will override the default structure for tally *n*.

Note 2: The energies on the E card must be entered in the order of increasing magnitude. If a particle has energy greater than the last entry, it is not tallied and a warning is issued. A comment is printed if the last energy bin is greater than the upper limit specified on the PHYS card.

Example 1:

```
E11    0.1  1  20
```

This card will separate an F11 current tally into four energy bins: (1) from the lower energy cutoff to 0.1 MeV, (2) from 0.1 to 1.0 MeV, (3) from 1.0 to 20.0 MeV, and (4) a total over all energy.

3.3.5.4 T TALLY TIME

Form 1: T*n* t_1 ... t_k [NT] [C] (See Note 1.)

Form 2: T*n* KEYWORD=*value*(*s*) ... (See Note 3.)

Table 3-85. Tally Time Card (T)

Input Parameter	Description
n	**Tally number. Restriction: *n*≤99999999**
t_1 ... t_k	**Upper bound (in shakes) of the *i*th time bin for tally *n*. (See Note 2.)**
NT	**Optional notation at the end of the input line to inhibit the automatic total over all specified time bins.**
C	**Optional notation at the end of the input line to cause the bin values to be cumulative and the last time bin to be the total over all time.**
Keyword	**Values**
CBEG	**Reference starting time in shakes (sh) (DEFAULT: CBEG=0)**
CFRQ	**Frequency of cycling in 1/sh or 1/time width**
COFI	**Dead time interval in shakes**
CONI	**Alive time interval in shakes**
CSUB	**Number of subdivisions to use within alive time (DEFAULT: CSUB=1)**
CEND	**Reference ending time in shakes (optional)**

Default: If the T card is absent, there will be one bin over all times unless this default has been changed by a T0 card; CBEG=0; CSUB=1.

Use: Required if TM card is used (See Section 3.3.5.10). Consider FQ card.

Reminder: 1 shake = 1E-8 seconds

Note 1: A T0 card can be used to set up a default time-bin structure for all tallies. A specific T*n* card will override the default structure for tally *n*.

Note 2: For Form 1 of the tally times card, the times on the T card must be entered in the order of increasing magnitude. If a particle has a time greater than the last entry, it is not be tallied and a warning is issued. A comment is printed if the last time bin is greater than the time cutoff specified on the CUT card. For point detector tallies, time bins can exceed the time cutoff so that particles will score at detectors remote from the main body of the system. Setting the time cutoff lower than the last time bin will inhibit unproductive transport of slow neutrons in the system and will increase the efficiency of the problem.

Note 3: The Form 2 keyword entries allow for automatic creation of cyclic time bins. The standard time entries and keyword entries are mutually exclusive within a given `T` card. If `CEND` is specified, all cyclic time bins are generated for the first cycle and these are repeated out to the `CEND` time. Keyword entries can be in any order.

Example 1:

```
T2      -1   1   1.0+37   NT
```

This will separate an `F2` flux surface tally into three time bins: (1) from -∞ to -1.0 shake, (2) from -1.0 shake to 1.0 shake, and (3) from 1.0 shake to 1.0e37 shakes, effectively infinity. No total bin will be printed in this example.

Example 2:

```
T1   CBEG=0.0  CFRQ=1000e-8  COFI=0.000005e8  CONI=0.0005e8  CSUB=5
```

This example specifies a reference starting time of 0 sh with a frequency of 1000 Hz (1E-5 sh^{-1}). The dead time of 5 μs (`COFI`) results in a time bin from 0–500 sh that includes missed tally scores during the dead time. The alive-time of 0.5 ms (`CONI`), with the specified five subdivisions (`CSUB`), results in five time bins equally spaced from 500–50500 sh. A final time bin from 50500–100000 sh will be provided for tally scores made after the alive time. Note that using the "e8" and "e-8" form shown here makes it easy to couch the entries in seconds and hertz rather than using the native unit of shakes.

3.3.5.5 C TALLY COSINE (TALLY TYPE 1 AND 2)

Form 1: C*n* c_1 ... c_k [T] [C] (See Note 1.)

Form 2: *C*n* ϕ_1 ... ϕ_k [T] [C] (See Notes 1 and 2.)

Table 3-86. Cosine Card (C)

Input Parameter	Description
n	**Tally number.** **Restriction:** $n \leq 99999999$
c_i	**Upper cosine limit of the i^{th} angular bin for surface current or flux tally n. (See Notes 3 and 4.)** **Restrictions:** $c_1 > -1$ **and** $c_k = 1$**, where** c_k **is the entry for the last bin**

ϕ_i	**Upper angular limit of the *i*th angular bin for surface current or flux tally *n*. expressed in degrees. (See Notes 3 and 4.)** **Restrictions: ϕ_1<180 and ϕ_k=0, where ϕ_k is the entry for the last bin**
T	**Optional notation at the end of the input line to provide the total over all specified angular bins.**
C	**Optional notation at the end of the input line to cause the bin values to be cumulative and the last angular bin to be the total over all angles.**

Default: If the C card is absent, there will be one bin over all angles unless this default has been changed by a C0 card.

Use: For use with tally types 1 and 2 only. Required if CM card is used. Consider FQ card.

Note 1: A C0 card can be used to set up a default angular bin structure for all tallies. A specific C*n* card will override the default structure for tally *n*. The selection of a single cosine bin for an F1 tally gives the total and not the net current crossing a surface.

Note 2: The asterisk (*) on the Cn card causes the entries to be interpreted as degrees.

Note 3: Whether entered as degrees or cosines, the entries on the C card must be such that the cosine is monotonically increasing, beginning with the cosine of the largest angle less than 180° to the normal and ending with the normal (i.e., cos=1). A lower cosine bound of -1 is set in the code and should not be entered on the card.

Note 4: The angular limits described by the C card are defined with respect to the positive normal to the surface at the particle point of entry. An FT card with an FRV v_1 v_2 v_3 option can be used to make the cosine bins relative to the vector *u*,*v*,*w*. The positive normal to the surface is always in the direction of a cell that has positive sense with respect to that surface.

Example 1:

```
C1     -0.866  -0.5   0   0.5  0.866  1
*C1       150   120  90    60     30  0
```

Either card will tally currents within the following angular limits (1) 180° to 150°, (2) 150° to 120°, (3) 120° to 90°, (4) 90° to 60°, (5) 60° to 30°, and (6) 30° to 0° with respect to the positive normal. No total will be provided.

Example 2:

As an example of the relationship between a surface normal and sense for the C1 card, consider a source at the origin of a coordinate system and a plane (PY) intersecting the +*y* axis. An entry of 0 and 1 on the C1 card will tally all source particles transmitted through the plane in the 0 to 1 cosine bin (0° to 90°) and all particles scattered back across the plane in the `-1` to `0` cosine bin (90° to 180°). A plane (`PY`) intersecting the -*y* axis will result in a tally of all source particles transmitted through the second plane in the `-1` to `0` bin (90° to 180°) and all particles scattered back across the plane in the `0` to `1` bin (0° to 90°). Note that the positive normal direction for both planes is the same, the +*y* axis.

3.3.5.6 FQ PRINT HIERARCHY

This card can be used to change the order in which the output is printed for the tallies. For a given tally, the default order is changed by entering a different ordering of the letters, space delimited.

Form: FQ*n* a_1 a_2 ... a_8 (See Note 1.)

Table 3-87 Print Hierarchy Card (FQ)

Input Parameter	Description
n	**Tally number.** **Restriction: *n*≤99999999**
a_i	**Letters representing all eight possible types of tally bins: 1≤*i*≤8. (See Note 2.)** **F—cell, surface, or detector bins** **D—direct or flagged bins** **U—user bins** **S—segment bins** **M—multiplier bins** **C—cosine bins** **E—energy bins** **T—time bins**

Default: Order as given above. The tally will be printed in the output file in blocks of time (rows) and energy (columns). Any other bins in a tally will be listed vertically down the output page.

Use: Highly recommended. Prints tallies in more easily readable blocks in the output file without affecting answers.

Note 1: An `FQ0` card can be used to change the default order for all tallies. A specific `FQ` card will then override that order for tally *n*.

Note 2: A subset of the letters can be used, in which case MCNP6 places them at the end of the `FQ` card and precedes them with the unspecified letters in the default order. The first letter is for the outermost loop of the nest in the tally printout coding. The last two sets of bins make a table—the next to last set goes vertically, and the last set of bins goes horizontally in the table. (Default order is a table in `E` and `T`; any other bins in a tally will be listed vertically down the output page.)

Example 1:

```
FQ4    E   S   M
```

The output file printout will be tables with multiplier bins across the top, segments listed vertically, and these segment-multiplier blocks printed for each energy.

3.3.5.7 FM TALLY MULTIPLIER

The `FM` card basically multiplies any tallied quantity (flux, current) by any cross section to give nearly all reaction rates plus heating, criticality, etc. That is, the `FM` card is used to calculation any quantity of the form

$$C\int \varphi(E)R_m(E)dE \ ,$$

where $\varphi(E)$ is the energy-dependent fluence (particles/cm^2) and $R_m(E)$ is an operator of additive and/or multiplicative response functions from the MCNP6 cross-section libraries or specially designated quantities. Note that some MCNP6 cross-section-library reaction numbers (*R*) are different from ENDF/B (MT) reaction numbers. The constant *C* is any arbitrary scalar quantity that can be used for normalization. The material number *m* must appear on an `M`*m* card, but need not be used in a geometrical cell of the problem.

Form: `FM`*n* (*bin set 1*) (*bin set 2*) ... `[T]` `[C]`

Table 3-88. Tally Multiplier Card (FM)

Input Parameter	Description
n	**Tally number.** **Restriction:** *n*≤99999999
(*bin set i*)	**Represents** ((*multiplier set 1*) (*multiplier set 2*) ... (*attenuator set*)) , **where** *attenuator set*=*c* -1 m_1 px_1 m_2 px_2 ... **(See Note 1.)** **and** *multiplier set i*=*c* *m* (*reaction list 1*) (*reaction list 2*) ... **and** *special multiplier set i*=*c* *k*.
c	**Multiplicative constant. (See Note 2.)**
-1	**Flag indicating attenuator rather than multiplier set.**
m	**Material number identified on an** `M`*m* **card.**
px	**Density times thickness of attenuating material; interpreted as atom density if positive, and mass density if negative.**

Input Parameter	Description
k	**Special multiplier option.** **If *k*=-1, the tally is multiplied by 1/weight and the tally is the number of tracks (or collisions for the F5 tally).** **If *k*=-2, the tally is multiplied by 1/velocity and the tally is the neutron population integrated over time, or the prompt removal lifetime.** **If k=-3, the tally will be multiplied by the microscopic cross section of the first interaction. This option can be used with the LCA NOACT=-2 option to convert multiplicities into secondary production cross sections with units of barns. (See Note 3.)**
(*reaction list i*)	**Sums and products of ENDF or special reaction numbers. (See Note 4.)**
T	**Optional notation at the end of the input line to provide the total over all specified bins. (If absent, a total over all bins is not provided.)**
C	**Optional notation at the end of the input line to cause the bin values to be cumulative and the last bin to be the total over all bins.**

Use: Optional. Use the attenuators only when they are thin. When used with tally types 6 and 7, only the multiplicative constant can be specified. Disallowed for tally type 8.When used with mesh tallies, only one multiplier set and reaction list per mesh tally is permitted. If *m*=0 for a multiplier set, the reaction cross sections for the material in which the particle is traveling are used.

Note 1: An attenuator set of the form *c* −1 *m px* includes one layer and allows the tally to be modified by the factor $e^{-\sigma_{tot} px}$ representing an exponential line-of-sight attenuator. This capability makes it possible to have attenuators without actually modeling them in the problem geometry. *Caution*: The assumption is made that the attenuator is thin, so that simple exponential attenuation without buildup from scattering is valid.

The attenuator set can include more than one layer, in which case the factor is $e^{-\sigma_1 px_1 - \sigma_2 px_2}$. The attenuator set can also be part of a bin set, for example,

((c_1 m_1 R_1) (c_2 m_2 R_2) (c_3 −1 m_3 px_3))

in which case the attenuation factor is applied to every bin created by the multiplier sets. Note that both the inner and the outer parentheses are required for this application.

Note 2: If the *c* entry is negative (for type 4 tally only), *c* is replaced by |*c*| times the atom density of the cell where the tally is made.

Note 3: The special multiplier option with *k*=-3 works for all incident particle types except electrons; however, for charged particles, caution should be exercised because for some charged particles maximum cross sections are used instead of actual cross sections.

Note 4: A reaction list consists of one or more reaction numbers delimited by spaces and/or colons. A space between reaction numbers means multiply the reactions. A colon means add the reactions. The hierarchy of operation is multiply first and then add. One bin is created for each reaction list. No parentheses are allowed within the reaction list.

The reaction cross sections are microscopic (with units of barns) and not macroscopic. Therefore, if the constant c is the atomic density (in atoms/barn-cm), the results will include the normalization "per cm^3."

Any number of ENDF/B (MT) or special (*R*) reactions can be used in a multiplier set as long as they are present in the MCNP6 cross-section libraries, or in special libraries of dosimetry data. If neither a material number nor any reactions are given, the tally simply is multiplied by the constant c.

Use of Parentheses:

1. If a given multiplier set contains only one reaction list, the parentheses surrounding the reaction list can be omitted. Parentheses within a reaction list are forbidden.
2. If a given bin set consists of more than a single multiplier or attenuator set, each multiplier or attenuator set must be surrounded by parentheses, and the combination must also be surrounded by parentheses.
3. If the `FM` card consists only of a single bin set, and that bin set consists only of a single multiplier or attenuator bin, surrounding parentheses can be omitted.

Special Reaction Numbers:

In addition to the standard ENDF reaction numbers (e.g., MT=1, 2, and 16, representing σ_{tot}, σ_{el}, and $\sigma_{n,2n}$, respectively), Table 3-89 lists the non-standard special *R* numbers that may be used.

Table 3-89. ENDF/B Special Reaction Numbers

Reaction Type	Special Reaction Number (*R*)	Microscopic Cross-Section Description
Neutron	-1	Total cross section without thermal
	-2	Absorption cross section
	-3	Elastic cross section without thermal
	-4	Average neutron heating number (MeV/collision)
	-5	Gamma-ray production cross section , barns
	-6	Total fission cross section
	-7	Fission $\bar{\nu}$, prompt or total
	-8	Fission Q (MeV/fission)
Many Nuclides	-4	Average heating numbers (MeV/collision)
	-5	Gamma-ray production cross section, barns

Reaction Type	**Special Reaction Number (*R*)**	**Microscopic Cross-Section Description**
	-7	Fission $\bar{\nu}$ (prompt or total)
	-8	Fission Q (MeV/fission)
Photoatomic	-1	Incoherent scattering cross section
	-2	Coherent scattering cross section
	-3	Photoelectric cross section, with fluorescence
	-4	Pair production cross section
	-5	Total cross section
	-6	Average photon heating number
Proton†	±1	Total cross section
	±2	Non-elastic cross section
	±3	Elastic cross section
	±4	Average proton heating number
Photonuclear‡	1	Total cross section
	2	Non-elastic cross section
	3	Elastic cross section
	4	Average photonuclear heating number
Neutron and Photon Multigroup	-1	Total cross section
	-2	Fission cross section
	-3	Nubar data
	-4	Fission chi data
	-5	Absorption cross section
	-6	Stopping powers
	-7	Momentum transfers
Electrons	1	de/dx electron collision stopping power
	2	de/dx electron radiative stopping power
	3	de/dx total electron stopping power
	4	Electron range
	5	Electron radiation yield
	6	Relativistic β^2
	7	Stopping power density correction
	8	Ratio of rad/col stopping powers
	9	Drange

Reaction Type	Special Reaction Number (*R*)	Microscopic Cross-Section Description
	10	dyield
	11	MG array values
	12	QAV array values
	13	EAR array values

† On the LA150H proton library, the only available reaction (beyond ±1,2,3,4) is MT=5 and its multiplicities, 1005, 9005, 31005, etc. The multiplicity reaction numbers are specified by adding 1000 times the secondary particle number to the reaction number. For interaction reaction MT=5, the multiplicities are 1005 for neutrons, 9005 for protons, 31005 for deuterons, etc. The proton multiplicity, MT=9001, 9004, 9005, etc., is generally available, along with the total cross section and heating number, MT=1, MT=4.

‡ The principal photonuclear cross sections are the following: 1=total, 2=non-elastic, 3=elastic, 4=heating, and >4=various reactions such as 18=(γ,*f*). The photonuclear yields (multiplicities) for various secondary particles are specified by adding 1000 times the secondary particle number to the reaction number. For example, 31001 is the total yield of deuterons (particle type `D`=31), 34001 is the total yield of alphas (particle type `a`=34), and 1018 is the total number of neutrons (particle type `n`=1) from fission.

The total and elastic cross sections, MT=1 and MT=2, are adjusted for temperature dependence. All other reactions are interpolated directly from the library data tables. Note that for tritium production, the *R* number differs from one nuclide to another. Note also that tally types 6 and 7 already include reactions, so the `FM`*n* card makes little sense for *n*=`6` or `7`. Generally only the constant-multiplier feature should be used for these tally types. Photon production reactions can be specified according to the MTRP prescription in Appendix F of the MCNP5 Vol. III Developer's Guide.

Photonuclear and proton cross sections may be used in tally multipliers on the `FM` card, however the applicability of the tally is limited to the upper energy included in the related cross-section library.

In perturbed problems, the `PERT` card (Section 3.3.5.21) keyword `RXN` can affect the cross sections used with the `FM` card tally multipliers. If a tally in a cell is dependent on a cross section that is perturbed, then $R_{ij'} \neq 0$ and a correction is made to the $R_{1j'}=0$ case. For this required $R_{1j'}$ correction to be made, the user must ensure that the *R* reactions on the `FM` card are the same as the `RXN` reactions on the `PERT` card *and* that the `FM` card multiplicative constant *c* is negative, indicating multiplication by the atom density to get macroscopic cross sections. For example, if *R*=`−6` for fission on the `FM` card, you should not use `RXN=18` for fission on the `PERT` card. If *c*`>0`, the cross sections are not macroscopic; it is assumed that there is no tally dependence on a perturbed cross section, $R_{1j'}=0$, and no correction is made. The same correction is automatically made for the `F6` tally and the KCODE k_{eff} calculation, and for an `F7` tally if the perturbation reaction is fission because these three tallies all have implicit associated `FM` cards.

It is always wise to plot the desired cross sections first to see if they are available with the expected reaction numbers in the data library. The tally multipliers treat the data the same as the data are treated in transport: the cross section at the lowest energy is extended down to E=0 for protons with reaction identifier MT<0; the cross section at the highest energy of the table is extended to E=∞ for proton interaction cross sections with MT<0; and for photonuclear interaction cross sections, MT<1000. These extrapolations can be seen in the cross-section plots. Examples below include total energy deposition (Example 3), track length criticality estimate (Example 4), total energy deposited for materials not present in geometry (Example 5), and lifetime calculation/reaction rates (Example 6).

Example 1:

Case 1: `FM`*n* *c* *m* r_1 r_2 : r_3

Case 2: `FM`*n* c *m* r_1 r_2 : r_1 r_3

Case3: `FM`*n* *c* *m* r_1 (r_2 : r_3)

These cases reiterate that parentheses cannot be used for algebraic hierarchy within a reaction list. The first case represents one reaction list (i.e., one bin) calling for reaction r_3 to be added to the product of reactions r_1 and r_2. The second case produces a single bin with the product of reaction r_1 with the sum of reactions r_2 and r_3. The third case creates two bins, the first of which is reaction r_1 alone; the second is the sum of r_2 and r_3, without reference to r_1.

Example 2:

Case 1:
```
F2:N     1  2  3  4
FM2     (c1) (c2) (c3) (c4)  T
```

Case 2:
```
F12:N    1  2  3  4
FM12     c1
```

Case 3:
```
F22:N   (1 2 3)  4  T
FM22    (c1) (c2) (c3) (c4)
```

These three cases illustrate the syntax when only the constant-multiplier feature is used. All parentheses are required in these examples. Tally `F2` creates 20 bins: the flux across each of surfaces `1`, `2`, `3`, and `4` with each multiplied by each constant c_1, c_2, c_3, c_4, and the sum of the four constants. Tally `F12` creates 4 bins: the flux across each of surfaces `1`, `2`, `3`, and `4` with each multiplied by the constant c_1. Tally `F22` creates 12 bins: the flux across surface `1` plus surface `2` plus surface `3`, the flux across surface `4`, and the flux across all four surfaces with each multiplied by each constant c_1, c_2, c_3, and c_4. An `FQ` card with an entry of `F M` or `M F` would print these bins of the tallies in an easy-to-read table rather than strung out vertically down the output page.

Example 3 (Total Energy Deposition):

```
F4:P      1
FM4      -1 2 -5 -6
SD4       1
F6:P      1
SD6       1
```

Multiplying the photon flux by volume (`SD4 1`) times the atom density (`-1`) for material `2` times the photon total cross section (`-5`) times the photon heating number (`-6`) is the same as the `F6:P` photon heating tally multiplied by mass (`SD6 1`), namely the total energy deposition in cell `1`. Note that positive photon reaction numbers are photonuclear reactions. Note also that the `SD` card replaces the normal divisor (volume for `F4` and mass for `F6`) with new values (both `1` in this example). By overriding the MCNP6-computed cell volume and mass with values of `1`, you effectively multiply the unmodified `F4` and `F6` tallies by the volume and mass, respectively, yielding the score for the entire cell.

Example 4 (Track Length Criticality Estimate):

```
F4:n    1
FM4    -1 3 -6 -7
SD4     1
```

Multiplying the neutron flux by volume (`SD4 1`) times the atom density (`-1`) for material `3` times the fission multiplicity, $\bar{\nu}$ (`-7`), times the fission cross section (`-6`) gives the track-length estimate of criticality for cell `1`.

Example 5 (Total Energy Deposited for Materials Not Present in Geometry):

Using MCNP6 tallies, there are two ways to obtain the energy deposited in a material in terms of rads (1 rad=100 ergs/g). When the actual material of interest is present in the MCNP6 model, the simplest way is to use the heating tally with units MeV/g in conjunction with *c*`=1.602E-08` on the companion `FM` card, where *c*=(1.602E-06 ergs/MeV)/(100 ergs/g). When the material is not present in the model, rads can be obtained from type 1, 2, 4, and 5 tallies by using an `FM` card where *c* is equal to the factor above times $N_o \eta \times 10^{-24}/A$, where N_o is Avogadro's number and η and *A* are the number of atoms/molecule and the atomic weight, respectively, of the material of interest. This value of *c* equals ρ_a/ρ_g as discussed in Section 5.3.4 of the MCNP5 Theory Manual[X-503a]. The implicit assumption when the material is not present is that it does not affect the radiation transport significantly. In the reaction list on the `FM` card, you must enter `-4 1` for neutron heating and `-5 -6` for photon heating. For both `F4` and `F6`, if a heating number from the data library is negative, it is set to zero by the code.

Example 6 (Lifetime Calculation/Reaction Rates):

```
F4:N   1
SD4    1
FM4    (-1 1 16:17) $ bin 1 = (n,xn) reaction rate
       (-1 1 -2)    $ bin 2 = capture (n,0n) reaction rate
       (-1 1 -6)    $ bin 3 = fission reaction rate
       (1 -2)       $ bin 4 = prompt removal lifetime=flux/velocity
M1     92235  –94.73   92238  –5.27
```

This `F4` neutron flux tally from a Godiva criticality problem is multiplied by four `FM` bins and will generate four separate tally quantities. The user can divide bin 4 by bins 1, 2, and 3 to obtain the (*n*,*xn*) lifetime, the (*n*,0*n*) lifetime, and the (*n*,*f*) lifetime, respectively. The `FM4` card entries are:

c	= −1	multiply by atomic density of material 1
m	= 1	material number on material card
r_1	= 16:17	reaction number for (*n*,2*n*) cross section *plus* reaction number for (*n*,3*n*) cross section
r_2	= −2	reaction number for capture cross section
r_3	= −6	reaction number for total fission cross section
r_4	= 1 -2	prompt removal lifetime = flux/velocity = time integral of population

3.3.5.8 DE AND DF DOSE ENERGY AND DOSE FUNCTION

This feature allows you to enter a point wise response function (such as flux-to-dose conversion factors) as a function of energy to modify a regular tally, or apply a built-in conversion/response function.

Form: DE*n* *a* e_1 ... e_k (See Note 1.)

and DF*n* *b* f_1 ... f_k (See Note 1.)

or DF*n* IU=*j* FAC=*f* *int* IC=*i* (See Note 2.)

Table 3-90. User-Specified Dose Energy (DE) & Dose Function (DF) Cards

Input Parameter	Description
N	**Tally number. (See Note 3.)** **Restriction: $n \leq 99999999$**
e_i	**The i^{th} energy value (in MeV).**
f_i	**The value of the dose function corresponding to e_i.**

A	**Interpolation method for energy table. (See Notes 4 and 5.)** **If *a*=LOG, logarithmic interpolation. (DEFAULT)** **If *a*=LIN, linear interpolation.**
B	**Interpolation method for dose function table. (See Note 5.)** **If *b*=LOG, logarithmic interpolation. (DEFAULT)** **If *b*=LIN, linear interpolation.**
Keyword	**Value**
IU	**Controls units.** **If IU=1, US units (rem/h/source_particle[1]). Required for IC=99.** **If IU=2, international units (sieverts/h/source_particle) (DEFAULT)**
FAC	**Normalization factor for dose.** **If FAC=-1, then use ICRP60 (1990) normalization (i.e., normalize results to Q=20)** **If FAC=-2, then use LANSCE albatross response function.** **If FAC=-3, then use quality factors based on stopping powers (see IC=99 in Table 3-91).** **If FAC>0, then is user-supplied normalization factor. (DEFAULT: FAC=1.0)**
IC	**IC is standard dose function as given in Table 3-91. Or a standard response function as given in Table 3-101. (DEFAULT: IC=10)**
Int	**Energy interpolation. (Note: Dose interpolation always linear.)** **If *int*=LOG, then LOGLIN interpolation.† (DEFAULT)** **If *int*=LIN, then LINLIN interpolation.†**

† Note that the interpolation parameter, *int*, may be set either to LOG or LIN and placed anywhere among the keyword specifications.

Default: If *a* or *b* is missing, LOG interpolation is used.

Default: IC=10; for IC=10 and 40, *int*=LOG; for IC=20 and 31–39, recommended analytic parameterization.

Use: Optional. Tally comment card recommended.

Note 1: When both the DE and DF cards are present to provide a user-specified dose table, they must have the same number of numerical entries and they must be monotonically increasing in energy. Particle energies outside the energy range defined on these cards use either the highest or the lowest value.

Note 2: In addition to allowing user-supplied dose functions, the dose conversion capability provides several standard default dose functions. These are invoked by omitting the DE card and using keywords on the DF card.

[1] Conversion factor is based on units: (rem/hr)/(dose_tally_particle/cm^2-s)

Note 3: If *n* is zero on the DE and DF cards, the function will be applied to all tallies that do not have DE and DF cards specifically associated with them.

Note 4: By default MCNP6 uses log-log interpolation between the points rather than a histogram function as is done for the EM card. The energy points specified on the DE card do not have to equal the tally energy bins specified with the E card for the F tally. Unlike EM card use, there can be many points on the DE and DF cards, but the response can be tallied in only a few energy bins such as one unbounded energy bin.

Note 5: LIN or LOG can be chosen independently for either table. Thus any combination of interpolation (log-log, linear-linear, linear-log, or log-linear) is possible. The default log-log interpolation is appropriate for the ANSI/ANS flux-to-dose rate conversion factors; kermas for air, water, and tissue; and energy absorption coefficients.

Table 3-91. Standard Dose Functions

Value of IC	Description
Neutron Dose Function	
10	ICRP-21 1971
20	NCRP-38 1971, ANSI/ANS-6.1.1-1977
31	ANSI/ANS-6.1.1-1991 (AP anterior-posterior)
32	ANSI/ANS-6.1.1-1991 (PA posterior-anterior)
33	ANSI/ANS-6.1.1-1991 (LAT side exposure)
34	ANSI/ANS-6.1.1-1991(ROT normal to length & rotationally symmetric)
40	ICRP-74 1996 ambient dose equivalent
Photon Dose Function	
10	ICRP-21 1971
20	Claiborne & Trubey, ANSI/ANS 6.1.1-1977
31	ANSI/ANS-6.1.1-1991 (AP anterior-posterior)
32	ANSI/ANS-6.1.1-1991 (PA posterior-anterior)
33	ANSI/ANS-6.1.1-1991 (LAT side exposure)
34	ANSI/ANS-6.1.1-1991 (ROT normal to length & rotationally symmetric)
35	ANSI/ANS-6.1.1-1991 (ISO isotropic)

Value of IC	Description
Special Dose Functions	
99	**ICRP-60 effective-dose conversion function for energy deposition tallies. This function uses a lookup of the stopping power, *S*(*E*,*p*) to create a multiplier of the absorbed dose. A table of quality factors, *Q*, is provided for neutrons; other neutral particles must have energy deposition modeled through charged particles for accurate effective dose tallies. The stopping power lookup is performed using the appropriate charged particle stopping power:** $$Q_{ICRP-60}(S(E,p)) = \left\{ \begin{array}{ll} 0 < S(E,p) \le 10 & Q_{ICRP-60} = 1 \\ 10 < S(E,p) \le 100 & Q_{ICRP-60} = 0.32 \times S(E,p) - 2.2 \\ 100 > S(E,p) & Q_{ICRP-60} = \frac{300}{\sqrt{S(E,p)}} \end{array} \right\}$$ **where the stopping power is in keV/μm.**

Example 1:

```
DE5         e1  e2  e3  e4 ... ek
DF5    LIN  f1  f2  f3  f4 ... fk
```

This example will cause a point detector tally to be modified according to the dose function *f*(E) using logarithmic interpolation on the energy table and linear interpolation on the dose function table.

Example 2:

```
DF0    IC 40  IU 1  LIN  FAC 123.4
```

This example will cause all tallies to use standard dose function `40` (neutron ambient dose equivalent ICRP-74 1996) with US units (rem/h/source_particle), linear interpolation, and a normalization of `123.4`.

Example 3:

```
FC6    Helium-4 (alpha) dose equivalent (Sv)
F6:A   77
DF6    IC=99  IU=2  FAC=-3
```

This example causes the ICRP-60 dose function to produce a tally that gives results in Sv/h for alpha particles in cell 77. Note that the source strength must be weighted by source particles/sec.

3.3.5.9 EM ENERGY MULTIPLIER

The EM*n* card can be used with any tally (specified by *n*) to scale the usual current, flux, etc. by a response function. There should be one entry for each energy entry on the corresponding E*n* card.

When a tally is being recorded within a certain energy bin, the regular contribution is multiplied by the entry on the EM*n* card corresponding to that bin. For example, a dose rate can be tallied with the appropriate response function entries. Tallies can also be changed to be per unit energy if the entries are $1/\Delta E$ for each bin, where ΔE is the width of the corresponding energy bin. Note that this card modifies the tally by an energy-dependent function that has the form of a histogram and not a continuous function. It also requires the tally to have as many energy bins as there are histograms on the EM*n* card. If neither of these two effects is desired, see the DE and DF cards.

Form: EM*n* m_1 ... m_k (See Note 1.)

Table 3-92. Energy Multiplier Card (EM)

Input Parameter	Description
n	**Tally number.** **Restriction:** $n \le 99999999$
m_i	**Multiplier to be applied to the i^{th} energy bin.**

Default: None.

Use: Requires E card (See Section 3.3.5.3). Tally comment recommended.

Note 1: A set of energy multipliers can be specified on an EM0 card that will be used for all tallies for which there is not a specific EM card.

3.3.5.10 TM TIME MULTIPLIER

The TM card can be used with any tally to scale the usual current, flux, etc. by a response function. There should be one entry for each time entry on the corresponding T card. Note that this card modifies the tally by a time-dependent function that has the form of a histogram and not a continuous function. For example, tallies can be changed to be per unit time if the entries are $1/\Delta T$ for each bin, where ΔT is the width or the corresponding time bin.

Form: TM*n* m_1 ... m_k (See Note 1.)

Table 3-93. Time Multiplier Card (TM)

Input Parameter	Description
N	**Tally number.** **Restriction:** $n \le 99999999$
m_i	**Multiplier to be applied to the i^{th} time bin.**

Default: None.

Use: Requires `T` card (See Section 3.3.5.4). Tally comment recommended.

Note 1: A set of time multipliers can be specified on a `TM0` card that will be used for all tallies for which there is not a specific `TM` card.

3.3.5.11 CM COSINE MULTIPLIER (TALLY TYPES 1 AND 2 ONLY)

The `CM` card can be used with an `F1` or `F2` tally to scale the usual current by a response function. There should be one entry for each cosine entry on the corresponding `C` card. Note that this card modifies the tally by an angular-dependent function that has the form of a histogram and not a continuous function. For example, To get the directionally dependent `F1` tally results to be per steradian, the i^{th} entry on the `CM1` card is $1/\left[2\pi\left(\cos\theta_i - \cos\theta_{i-1}\right)\right]$ where θ_0 is 180°.

Form: `CM`*n* m_1 ... m_k (See Note 1.)

Table 3-94. Cosine Multiplier Card (CM)

Input Parameter	Description
n	**Tally number.** **Restriction:** $n \leq 99999999$
m_i	**Multiplier to be applied to the i^{th} cosine bin.**

Default: None.

Use: Tally types 1 and 2. Requires `C`*n* card (See Section 3.3.5.5). Tally comment recommended.

Note 1: A set of cosine multipliers can be specified on a `CM0` card that will be used for all `F1` or `F2` tallies for which there is not a specific `CM` card.

3.3.5.12 CF CELL FLAGGING (TALLY TYPES 1, 2, 4, 6, 7)

Particle tracks can be "flagged" when they leave designated cells and the contributions of these flagged tracks to a tally are listed separately in addition to the normal total tally. This method can determine the tally contribution from tracks that have passed through an area of interest.

The cell flag is turned on only upon leaving a cell. A source particle born in a flagged cell does not turn the flag on until it leaves the cell.

The flagged tallies are the contribution to the tally made by a particle or it’s progeny that ever had it’s cell flag set by leaving the flagged cell or cells designated on the CF card. For example, a flagged photon tally can be scored in by either a photon leaving the flagged cell or a neutron leaving a flagged cell, which leads to a photon that is tallied. Caution, a particle that is killed on a surface will have it’s surface flag set but not have it’s cell flag.

Both a CF and an SF card can be used for the same tally. The tally is flagged if the track leaves one or more of the specified cells or crosses one or more of the surfaces. Only one flagged output for a tally is produced from the combined CF and SF card use.

Form: CF*n* c_1 ... c_k

Table 3-95. Cell-Flagging Card (CF)

Input Parameter	Description
n	**Tally number.** **Restriction:** $n \le 99999999$
c_j	**Problem cell numbers whose tally contributions are to be flagged. A negative cell number requires that a collision occurs in that cell in order for the flag to be set upon exit from the cell.**

Default: None.

Use: Not with detectors or pulse-height tallies; instead consider the FT card with the ICD keyword. Consider FQ card.

Example 1:

```
F4:N    6   10   13
CF4     3   4
```

In this example the flag is turned on when a neutron leaves cell 3 or 4. The print of Tally 4 is doubled. The first print is the total track length flux tally in cells 6, 10, and 13. The second print is the tally in these cells for only those neutrons that have left cell 3 or 4 at some time before making their contribution to the cell 6, 10, or 13 tally.

3.3.5.13 SF SURFACE FLAGGING (TALLY TYPES 1, 2, 4, 6, 7)

Particle tracks can be "flagged" when they cross designated surfaces and the contributions of these flagged tracks to a tally are listed separately in addition to the normal total tally. This method can determine the tally contribution from tracks that have crossed a surface of interest.

The flagged tallies are the contribution to the tally made by a particle or it's progeny that ever had it's surface flag set by crossing the flagged surface or surfaces designated on the SF card. For example, a flagged photon tally can be scored in by either a photon crossing the flagged surface or a neutron crossing the flagged surface, which leads to a photon that is tallied.

Both a CF and an SF card can be used for the same tally. The tally is flagged if the track leaves one or more of the specified cells or crosses one or more of the surfaces. Only one flagged output for a tally is produced from the combined CF and SF card use.

Form: SFn s_1 ... s_k

Table 3-96. Surface-Flagging Card (SF)

Input Parameter	Description
N	**Tally number** **Restriction:** $n \le$ 99999999.
s_i	**Problem surface numbers whose tally contributions are to be flagged.**

Default: None.

Use: Not with detectors; instead consider the FT card with the ICD keyword. Not with pulse-height tallies (F8).Consider FQ card.

Example 1:

```
F4:N    6   10
SF4     30
```

In this example, the flag is turned on when a neutron leaves surface 30. The print of Tally 4 is doubled. The first print is the total track length flux tally in cells 6 and 10. The second print is the tally in these cells for only those neutrons that have crossed surface 30 at some time before making their contribution to cells 6 or 10.

3.3.5.14 FS TALLY SEGMENT (TALLY TYPES 1, 2, 4, 6, 7)

This card allows you to subdivide a cell or a surface of the problem geometry into segments for tallying purposes without having to specify extra cells just for tallying. The segmenting surfaces specified on the FS card are listed with the regular problem surfaces, but they need not be part of the actual geometry and hence do not complicate the cell/surface relationships. The cell or surface to be segmented, however, must be part of the problem geometry.

Form: FS*n* s_1 ... s_k [T] [C]

Table 3-97. Tally Segment Card (FS)

Input Parameter	Description
n	**Tally number.** **Restriction:** $n \le$ 99999999
s_i	**Signed problem number of a segmenting surface. (See Note 1.)**
T	**Optional notation at the end of the input line to require the automatic total over all bins. (If absent, a total over all bins is not provided.)**
C	**Optional notation at the end of the input line to cause the bin values to be cumulative and the last time bin to be the total over all bins.**

Default: No segmenting.

Use: Not with detectors. Not with `F8` pulse-height tallies. May require `SD` card. Consider `FQ` card.

Note 1: If *k* surfaces are entered on the `FS`*n* card, *k* +1 surface or volume segments (and tally bins) are created. If the symbol `T` is on the `FS`*n* card, there will be an additional total bin. Tally *n* is subdivided into *k*+1 segment bins according to the order and sense of the segmenting surfaces listed on the `FS`*n* card as follows:

Bin #1	The portion of tally *n* with the same sense with respect to surface s_1 as the sign given to s_1;
Bin #2	The portion of tally *n* with the same sense with respect to surface s_2 as the sign given to s_2, but excluding that already scored in a previously listed segment.
Bin #*k*	The portion of tally *n* with the same sense with respect to surface s_k as the sign given to s_k, but excluding that already scored in a previously listed segment.
Bin #*k* +1	The remaining portion of tally *n* not yet tallied, i.e., everything else.
Bin #*k* +2	The total tally for the entire surface or cell if `T` is present on the `FS`*n* card.

If the symbol *T* is absent from the `FS`*n* card, MCNP6 calculates the tally only for each segment (including the *k*+1 "everything else" segment). If multiple entries are on the `F`*n* card, each cell or surface in the tally is segmented according to the above rules. For tally types 1 or 2, the segmenting surfaces divide a problem surface into segments for the current or flux tallies. For tally types 4, 6, or 7, the segmenting surfaces divide a problem cell into segments. For normalized tallies, the segment areas (for type 2), volumes (for type 4), or masses (for types 6 and 7) may have to be provided. See the discussion under the `SD`*n* card (Section 3.3.5.15).

Example 1:

```
F2:N   1
FS2   -3  -4
```

This example subdivides surface `1` into three sections and calculates the neutron flux across each of them. There are three prints for the `F2` tally: 1) the flux across that part of surface `1` that has negative sense with respect to surface `3`; 2) the flux across that part of surface `1` that has negative sense with respect to surface `4,` but that has not already been scored (and so must have positive sense with respect to surface `3`); and 3) everything else (that is, the flux across surface `1` with positive sense with respect to both surfaces `3` and `4`).

It is possible to get a zero score in some tally segments if the segmenting surfaces and their senses are not properly specified. In Example 1 above, if all tallies that are positive with respect to surface 3 are also all positive with respect to surface 4, the third segment bin will have no scores.

Example 2:

```
F2:N     1
FS2     -3    4
```

The order and sense of the surfaces on the FS2 card are important. This example produces the same numbers as does Example 1 but changes the order of the printed flux. Bins two and three are interchanged.

Example 3:

```
F1:N     1  2  T
FS1     -3     T
```

This example produces three current tallies: 1) across surface 1, 2) across surface 2, and 3) the sum across surfaces 1 and 2. Each tally will be subdivided into three parts: 1) that with a negative sense with respect to surface 3, 2) that with a positive sense with respect to surface 3, and 3) a total independent of surface 3.

3.3.5.15 SD SEGMENT DIVISOR (TALLY TYPES 1, 2, 4, 6, 7)

For segmented cell volumes or surface areas defined by the FS card that are not automatically calculated by MCNP6, the user can provide volumes (tally type 4), areas (tally type 2), or masses (tally types 6 and 7) on this segment divisor card to be used by tally *n*. Tally type 1 (the current tally) is not normally divided by anything, but with the SD1 card the user can introduce any desired divisor, for example, area to tally surface current density. This card is similar to the VOL and AREA cards but is used for specific tallies, whereas VOL and AREA used for the entire problem geometry.

Form: SD*n* $(d_{11}\ d_{12}\ ...\ d_{1m})\ (d_{21}\ d_{22}\ ...\ d_{2m})\ ...\ (d_{k1}\ d_{k2}\ ...\ d_{km})$

Table 3-98. Segment Divisor Card (SD)

Input Parameter	Description
n	**Tally number** **Restriction:** *n* **cannot be zero;** *n*≤99999999
k	**Number of cells or surfaces on F card, including T if present.**
m	**Number of segmenting bins on the FS card, including the remainder segment, and the total segment if FS has a T.**
d_{ij}	**Area, volume, or mass of** j^{th} **segment of the** i^{th} **surface or cell bin for tally** *n*.

Use: Not with detectors. The parentheses [( )] are optional. May be required with FS card. Can be used without FS card.

MCNP6 uses the following hierarchy for determining the volume, area, or mass:

For cell or surface without segmenting (tally types 2, 4, 6, and 7):

a) non-zero entry on SD card
b) non-zero entry on VOL or AREA card
c) volume, area, or mass calculated by MCNP6
d) fatal error

For cell or surface with segmenting (tally types 2, 4, 6, and 7):

a) non-zero entry on SD card
b) volume, area, or mass calculated by MCNP6
c) fatal error

For surface in a type 1 tally:

a) non-zero entry on SD card
b) no divisor

Example:

```
F4:N    1  2  3  T
SD4     1  1  1  1
```

Note that the SD card can be used to define tally divisors even if the tally is not segmented. In this example the tally calculates the flux in the three cells plus the union of the three cells. The VOL card can be used to set the volume divisor of the three cells (to unity, for example), but it cannot do anything about the divisor for the union. Its divisor is the sum of the volumes (whether MCNP6-calculated or user-entered) of the three cells. However, the divisors for all four of the cell bins can be set to unity by means of the SD card. These entries override entries on the VOL and AREA cards. See Section 3.3.5.1.4 for use with repeated structure tallies.

3.3.5.16 FU SPECIAL TALLY OR TALLYX INPUT

This card is used with a user-supplied tally modification subroutine TALLYX and some cases of the FT card. If the FU card has no input parameters, TALLYX will be called but no user bins will be created. The *k* entries on the FU card serve three purposes: 1) each entry establishes a separate user tally bin for tally *n*, 2) each entry can be used as an input parameter for TALLYX to define the user bin it establishes, and 3) the entries appear in the output as labels for the user bins.

Form: FU*n* [x_1 x_2 ... x_k] [NT] [C]

Table 3-99. TALLYX Input Card (FU)

Input Parameter	Description
N	**Tally number.** **Restriction:** $n \le 99999999$
x_i	**Input parameter establishing user bin** i**.**
NT	**Optional entry to inhibit MCNP6 from automatically providing the total over all specified bins.**
C	**Optional entry that causes the bin values to be cumulative.**

Default: If the FU card is absent, subroutine TALLYX is not called.

Use: Used with a user-supplied TALLYX subroutine or FT card.

Programming Hint:

IPTAL(3,1,ITAL) is the pointer to the location in the TDS array of the word preceding the location of the data entries from the FU card. Thus if the FU card has the form shown above,

TDS(L+1) = x_1
TDS(L+2) = x_2
.
.
.
TDS(L+k) = x_k

where L = IPTAL(3,1,ITAL)
k = IPTAL(3,4,ITAL)−1
= IPTAL(3,3,ITAL)−1
n = JPTAL(1,ITAL)
ITAL = program number of the tally

MCNP6 automatically provides the total over all specified user bins. The total can be inhibited for a tally by putting the symbol NT at the end of the FU card, which changes the variables such that:

k = IPTAL(3,4,ITAL)−1
= IPTAL(3,3,ITAL)

The symbol C at the end of the FU card causes the bin values to be cumulative, in which case

```
IPTAL(3,3,ITAL) = IPTAL(3,4,ITAL)
IPTAL(3,6,ITAL) = 1.
```

The discussion of the IPTAL and JPTAL arrays in the MCNP6 Developer's Guide and the following description of TALLYX may be useful.

3.3.5.17 TALLYX USER-SUPPLIED SUBROUTINE

TALLYX is called whenever a tally with an associated FU card but no FT card is scored.

Use: Called for tally *n* only if an `FU` card is in the INP file.

Programming Hint:

The locations of the calls to TALLYX are such that TALLYX is the very last thing to modify a score before it is posted in the tally. TALLYX calls can be initiated by more than one `FU`*n* card for different values of *n*; a branch must be constructed inside the subroutine based on which tally `F`*n* is calling TALLYX, where *n*=`JPTAL(1,ITAL)`. TALLYX has the following form:

```
subroutine tallyx(t,ib)
   ! t is the input and output tally score value.
   ! ib controls scoring. see the user's manual.
   use mcnp_params
   use mcnp_global
   use mcnp_debug
   implicit none

   ! .. Scalar Arguments ..
   real(dknd), intent(inout) :: t
   integer,    intent(inout) :: ib

   ! Add User-Supplied FORTRAN Statements here
   return
end subroutine tallyx
```

The quantity *t* (first argument of TALLYX) that is scored in a standard tally can be multiplied or replaced by anything. The modified score *t* is then put into one of the *k* user bins established by the `FU` card. In TALLYX(*t*,*ib*) the second argument *ib* is defined to allow for more than one pass through TALLYX per tally score. By default, *ib*=`0`, which means make one pass through the MCNP6 coding where user bin tally scores are posted. If the user sets *ib* <`0` in TALLYX, no score will be made. If the user sets *ib*>`0`, passes through the user bin loop including TALLYX will be made until *ib* is reset to zero. This scheme allows for tally modification and posting in more than one user bin. The variable *ibu* is the variable designating the particular user bin established by the `FU` card. Its value is `1` before the first pass through the user bin loop. The indices of the current user, segment, cosine, energy, and time bins (*ibu*, *ibs*, *ibc*, *ibe*, and *ibt*, respectively) and the flag *jbd* that indicates flagged- or direct-versus-not are in the module TSKCOM for optional modification by TALLYX. Note that the index of the multiplier bin is not available and cannot be modified. The variable *ntx* is from the module TSKCOM. It is set equal to *nx* just before the `CALL TALLYX` in TALLYD, TALLY, and TALPH. The variable *nx* is set to unity just before the start of the user bins loop and is incremented after the `CALL TALLYX`, so *ntx* contains the number of the TALLYX call. An example of using *ntx* to tally in every user bin before leaving the user bin loop follows:

```
subroutine tallyx(t,ib)
   use mcnp_params
```

```
      use mcnp_global
      use mcnp_debug
      use tskcom, only: ibu

      implicit none

      ! .. Scalar Arguments ..
      real(dknd), intent(inout) :: t
      integer,    intent(inout) :: ib

      t = whatever_you_want

      ibu = ntx
      ib = 1
      if (ntx > iptal(3,4,ital)-1) ib=0

      return
   end subroutine tallyx
```

If *ibu* is out of range, no score is made and a count of out-of-range scores is incremented. If excessive loops through TALLYX are made, MCNP6 assumes *ib* has been incorrectly set and terminates the job with a BAD TROUBLE error (excessive means greater than the product of the numbers of bins of all kinds in the tally). Several examples of the FU card and TALLYX appear in Section 4.2.8 The procedure for implementing a TALLYX subroutine is the same as for the user-provided SOURCE subroutine.

3.3.5.18 FT SPECIAL TREATMENTS FOR TALLIES

Form: FT*n* id_1 $p_{1,1}$ $p_{1,2}$ $p_{1,3}$ ... id_i $p_{i,j}$ $p_{i,k}$ $p_{i,l}$..

Table 3-100. Special Treatment for Tallies Card (FT)

Input Parameter	Description
n	**Tally number.** **Restriction:** $n \le 99999999$
id_i	**The alphabetic keyword identifier for a special treatment. (See list below.)**
$p_{i,j}$	**Input parameters for the special treatment specified by id_i: either a number, a parenthesis, or a colon. (See Note 1.)**
Keyword	**Description**
FRV	**Fixed arbitrary reference direction for tally 1 or 2 cosine binning.**
GEB	**Gaussian energy broadening.**
TMC	**Time convolution.**
INC	**Identify the number of collisions.†**

ICD	**Identify the cell from which each detector score is made.†**
SCX	**Identify the sampled index of a specified source distribution.**
SCD	**Identify which of the specified source distributions was used.†**
ELC	**Electron current tally.**
PTT	**Put different multigroup particle types in different user bins.†**
PHL	**Pulse-height light tally with anticoincidence.†**
CAP	**Coincidence capture.**
RES	**Heavy-ion and residual isotopes.†**
TAG	**Tally tagging.†**
LET	**Linear energy transfer. Energies as stopping powers.**
ROC	**Receiver Operator Characteristic (ROC) curve generation.**
PDS	**Point detector sampling.**
FFT	**First fission tally.†**
COM	**Compton image tally.**

† Requires an FU card; treatments that require or allow an FU card are not compatible with each other.

Default: If the FT card is absent, there is no special treatment for tally *n*.

Use: Optional; as needed.

Note 1: The syntax and meaning of the $p_{i,j}$ is different for each id_i. A special treatment may cause a set of user bins or possibly a set of some other kind of bins to be created. The information in the $p_{i,j}$ allows the number and kind of those bins to be inferred easily. More than one special treatment can be specified by a given tally except for combinations of INC, ICD, SCD, PTT, PHL, RES, TAG, and FFT. Only one of these special treatments can be used by a tally at one time because all require user bins making them mutually exclusive.

Descriptions of the eighteen available special treatments follow with an explanation of the allowed parameters for each:

1. FRV v_1 v_2 v_3

The v_i are the xyz components of vector **V**, not necessarily normalized. If the FRV special treatment is in effect for a type 1 or 2 tally, the direction **V** is used in place of the vector normal to the surface as the reference direction for getting the cosine for binning.

2. GEB *a* *b* *c*

The parameters specify the full width at half maximum (FWHM) of the observed energy broadening in a physical radiation detector: $FWHM = a + b\sqrt{E + cE^2}$, where E is the energy of the particle. The units of *a*, *b*, and *c* are MeV, $MeV^{1/2}$, and 1/MeV, respectively. The energy actually scored is sampled from a Gaussian with that FWHM.

3. TMC *a* *b*

All particles should be started at time zero. The tally scores are made as if the source was actually a square pulse starting at time *a* and ending at time *b*.

4. INC

No parameters follow the INC keyword but an FU card is required (see Section 3.3.5.16). Its bin boundaries are the number of collisions that have occurred in the track. The user can control if secondary particles are considered un-collided (default) or collided at their creation with use of the UNC card (see Section 3.3.3.10). If the INC special treatment is in effect, the call to TALLYX that the presence of the FU card would normally trigger does not occur. Instead *ibu* is set by calling JBIN with the number of collisions as the argument. To capture all particles, the last FU bin value should be a very large number.

5. ICD

No parameters follow the keyword ICD but an FU card is required (see Section 3.3.5.16). Its bins are the names of some or all of the cells in the problem. If the cell from which a detector score is about to be made is not in the list on the FU card, the score is not made. The result is that the detector tally is subdivided into bins according to which cell had the source or collision resulting in the detector score. TALLYX is not called. The selection of the user bin is done in TALLYD.

6. SCX *k*

The parameter *k* is the name of one of the source distributions and is the *k* that appears on the SI*k* card. One user bin is created for each bin of source distribution *k* plus a total bin. The scores for tally *n* are then binned according to which bin of source distribution *k* the source particle came from. The score of the total bin is the score you would see for tally *n* without the special treatment, if source distribution *k* is not a dependent distribution.

Caution: For a dependent distribution, the score in the total bin is the subtotal portion of the score from dependent distribution *k*.

7. SCD

No parameters follow the keyword SCD but an FU card is required (see Section 3.3.5.16). Its bins are a list of source distribution numbers from SI*k* cards. The scores for tally *n* are then binned according to which distribution listed on the FU card was sampled. This feature might be used to identify which of several source nuclides emitted the source particle. In this case, the source distributions listed on the FU card would presumably be energy distributions. Each energy distribution is the correct energy distribution for some nuclide known to the user and the probability of that distribution being sampled from is proportional to the activity of that nuclide in the source. The user might want to include an FC card that tells to what nuclide each energy distribution number corresponds.

Caution: If more than one of the source distributions listed on the FU card is used for a given history, only the first one used will score.

8. ELC *c*

The single parameter *c* of ELC specifies how the charge of a particle is to affect the scoring of an F1 tally. Normally, an F1 tally gives particle current without regard for the charge of the particles. Additionally, this treatment can create separate bins for particles and antiparticles. There are three possible values for *c*:

- specify *c*=1 to cause negatively charged particles to make negative scores,
- specify *c*=2 to put charged particles and antiparticles into separate user bins, and
- specify *c*=3 for the effect of both *c*=1 and *c*=2.

If *c*= 2 or 3, three user bins (e.g., positrons, electrons, and total) are created.

9. PTT

No parameters follow the keyword PTT but an FU card is required (see Section 3.3.5.16). Its bins are a list of atomic weights in units of MeV of particles masquerading as neutrons in a multigroup data library. The scores for tally *n* are then binned according to the particle type as differentiated from the masses in the multigroup data library. For example, 0.511 0 would be for electrons and photons masquerading as neutrons.

10. PHL [n t_{a1} b_{a1} t_{a2} b_{a2} ... t_{an} b_{an}] [det_1]
[m t_{b1} b_{b1} t_{b2} b_{b2} ... t_{bm} b_{bm}] [det_2]
[j t_{c1} b_{c1} t_{c2} b_{c2} ... t_{cj} b_{cj}] [det_3]
[k t_{d1} b_{d1} t_{d2} b_{d2} ... t_{dk} b_{dk}] [det_4] [0] [TDEP *tg tt*]

The PHL option models a pulse-height tally with anticoincidence. This option allows the F8 tally to be based on energy/light deposition in up to four regions as specified via F6 tallies. Requires an FU card (see Section 3.3.5.16).

The parameters for keyword PHL are the following:

n	is the number of F6 tallies for the first detector region,
t_{ai} b_{ai}	are the pairings of tally number and F-bin number (see Table 3-102) for the n F6 tallies of the first detector region,
det_1	is an optional detector descriptor chosen from Table 3-101 for the first detector region,

m	is the number of F6 tallies for the second detector region,
t_{bi} b_{bi}	are the pairings of tally number and F-bin number for the *m* F6 tallies of the second detector region,
det_2	is an optional detector descriptor chosen from Table 3-101 for the second detector region,
j	is the number of F6 tallies for the third detector region,
t_{ci} b_{ci}	are the pairings of tally number and F-bin number for the *j* F6 tallies of the third detector region,
det_3	is an optional detector descriptor chosen from Table 3-101 for the third detector region,
k	is the number of F6 tallies for the fourth detector region,
t_{di} b_{di}	are the pairings of tally number and F-bin number for the *k* F6 tallies of the fourth detector region,
det_4	is an optional detector descriptor chosen from Table 3-101 for the fourth detector region,
0	a zero entry terminates input for PHL detectors entries and allows for other FT options to follow,
TDEP *tg tt*	is a keyword option that specifies a tally that will be used as a trigger for the related T8 card. The first optional TDEP entry (*tg*) specifies the trigger tally number and the second optional TDEP entry (*tt*) specifies an energy threshold (MeV).

The F-bin descriptor specified after each tally, b_{ai} or b_{bi}, may be “0”, indicating that the referenced tally includes a lattice description of multiple lattice elements. When this option is specified, all tallies within that PHL region must also include the “0” descriptor for b_{ai} or b_{bi} and all tallies must be over the same lattice cell and elements. When this option is used in both PHL regions, the related F8 F-bins are modified, with an appropriate warning message, to include J x K bins, where J is the number of lattice elements included in PHL Region 1 and K is the number of lattice elements included in PHL Region 2. The output of Tally 8 will include coincidence results for all J x K bins, along with appropriate cell labels (e.g., 1[0 1 1]+2[0 0 0], which is the combination of lattice cell 1, element [0 1 1], with lattice cell 2, element [0 0 0]). This special F-bin descriptor is typically used with the FT COM option to create a Compton image of a radiation source.

Table 3-101. Detector Descriptors for the FT PHL Option

Detector Type	Detector Name	Primary Particle Type(s)	Response Parameter	Default Value	Notes
^{3}He	HE3-1	Proton, Triton, Helion	M	100	42.3 eV/ion pair
BF_3	BF3-1	Alpha, Lithium	M	100	36.0 eV/ion pair
Li Glass	LIG-1	Triton, Alpha	QF	5.0e-4 cm/MeV	Generic value
LiI	LII-1	Triton, Alpha	QF	5.0e-4 cm/MeV	Generic value
ZnS+LiF	ZNS-1	Triton, Alpha	QF	5.0e-4 cm/MeV	Generic value
NaI	NAI-1	Electron	QF	3.4e-4 cm/MeV	Astro. Phys., 33, p. 40
BGO	BGO-1	Electron	QF	6.5e-4 cm/MeV	NIM A, 484, p. 251
CsI	CSI-1	Electron	QF	1.5e-4 cm/MeV	NIM A, 484, p. 251
BC-400	BC4-1	Electron	QF	4.6e-3 cm/MeV	NIM A, 438, p. 322
HPGe	HPG-1	Electron	G	1.0	3.0 eV/ion pair
M=multiplication, QF=quenching factor, G=gain					

When a detector descriptor is specified, built-in particle-dependent response functions are automatically applied to all listed tallies (e.g., t_{a1}, t_{a2}, ... for det_1). For photon detectors, these include material-dependent electron response functions (e.g., light output, current, etc.). For neutron detectors, these include material-dependent electron or light-ion response functions. Additional details on references regarding these parameters can be found in the source code (Source/src/fluence_to_dose.F90).

The gas detectors are treated by multiplying the charged-particle energy deposition by the inverse of the gas Work Function (see Notes in Table 3-100) and the detector E-field multiplication (Response Parameter). The units for this response function are pico-Coulombs (pC) per source particle, thus this detector response is further multiplied by the electron charge per ion pair (1.6e-7 pC). The user can override the default multiplication by appending an underscore and a multiplication value to the Detector Name (e.g., HE3-1_25.0).

The scintillation detectors are treated by Birks' Law [BIR64], which is generally in good agreement with measured data for Z<6 and particle energies less than ~50 MeV/amu. The stopping powers used in Birks' Law are the total stopping powers calculated by MCNP for each particle type. The units for this response function are 1-MeVee photons per source particle (MeVee=MeV electron-equivalent). For absolute visible light photons per source particle, one must multiply this response by the number of visible light photons produced by a 1-MeV electron (which is typically given by the detector manufacturer or can be found in the literature). The default Birks' quenching factors (QF) are given in Table 3-101, however the user may override these values by appending an underscore and a QF value to the detector name (e.g., LIG-1_2.5e-3).

The semi-conductor detector is treated similarly to a gas detector, except the Work Function is typically much lower (~3 eV/ion pair) and the multiplication is replaced by the gain. The units for this response are also pC per source particle. The user can override the default gain by appending an underscore and new gain value to the detector name (e.g., HPG-1_2.5).

When *m* is non-zero, indicating the use of two or more detector regions, an FU card is required for the F8 tally. The entries on the FU card are presented in units of MeV (unless modified by DE/DF cards associated with the specified F6 tallies) and must increase monotonically. Similarly, if *j* or *k* is non-zero, the energy bins must be specified with C (tally cosine) and FS (tally segment) cards, respectively. The particle type indicated on the F8 tally does not matter because this tally allows a combination of light output from various particle types. If b_{an} is zero, then the number of cell bins on the F8 card must match that on the corresponding t_{an} tally card, which is useful for a lattice pulse-height PHL tally.

The TDEP keyword allows the T8 values to be relative to the first contribution to any FT8 PHL tally. Invoking TDEP allows pulse distributions from different histories to be relative to the same start time rather than distributed in absolute time with significant variation based on when a particle reaches the detector. TDEP can also be followed by one or two entries, where the first entry (*tg*) is a tally number and the second (*tt*) is an energy threshold. If an energy threshold value is provided, the reference time on the T8 card is whenever the specified tally has a value greater than the specified threshold. The specified tally can be the same number as the F8 tally, in which case TDEP depends on the sum of the PHL F6 tallies, or it can be a single F6 tally that is specified in any region of the FT PHL option. If the tally number has a format of 8.3, for example, then the trigger tally is the sum of all F6 tallies that are specified for region 3 of the FT PHL option. The default TDEP tally number is the corresponding F8 tally number and the default energy threshold is 0 MeV.

Time-Dependent* F8 *Tallies Using the Pulse Height Light* (PHL) *Option.

The T (time bin) card is allowed with pulse-height tallies (F8), but only when used in conjunction with the FT PHL option. In this case, the time-dependent energy deposition is taken from the associated F6 tally(s). If the time entries on the F8 card do not match those provided for the various F6 tallies, a fatal error is issued. If the associated F6 tallies do not have T cards, then one matching the F8 tally will be created automatically.

Example 1:

Case 1

```
F8:N       5
FT8   PHL  1  6  1  0
      GEB  a  b  c
E8         1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0
F6:E       5
DE6   LIN  1.0  1.5   2.0   2.5   3.0   3.5  10.0
DF6   LIN  1.0  0.99  0.98  0.97  0.96  0.95  0.92
```

Case 2

```
F8:N 5
FT8   PHL  1  6  1  1  16  1 0
      GEB  a  b  c
E8         1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0
FU8        1.5  2.5  3.5  4.5  5.5  6.5  7.5  8.5
F6:E       5
DE6   LIN  1.0  1.5   2.0   2.5   3.0   3.5  10.0
DF6   LIN  1.0  0.99  0.98  0.97  0.96  0.95  0.92
F16:E      6
DE16  LIN  1.0  1.5   2.0   2.5   3.0   3.5  10.0
DF16  LIN  1.0  0.99  0.98  0.97  0.96  0.95  0.92
```

In both cases, the F6 tallies convert energy deposition to equivalent light (units of MeV, photons, or MeVee, depending on the units of the associated DF card). SD cards are not required with the F6 tallies because these divisors renormalize only the printed output for the F6 tallies and not the values stored in the tally arrays (thus, the F8 tally will result in the same value, regardless of whether the F6 tally has an SD card). The DE/DF conversion is based on the incident particle energy, and the values on the DF card should be the dL/dE for that incident particle energy. Thus, the F6 tally will multiply the dL/dE values by the energy deposition to give the light output (ΔL) summed over each track. Also, no energy bins exist for the F6 tallies. The F8 tally uses the total light output. Energy bins (E6 card) can be added, but the F8 tally will use the value from the total bin. Similarly, for other bins associated with the F6 tally, in each case, the TFC bin is used to extract the value for the F8 tally (see the TF card to alter this). The FT GEB cards are used to perform Gaussian broadening on these tally values; however, this is done only at the end of the particle history to determine the light output value used in the pulse-height tally.

In Case 1, the electron light output from only one region (cell 5) is used to subdivide the pulse-height tally. In this case, a pulse of 1 (input source weight) is put into the first E8 bin when the light output in cell 5 is <1 MeV. It is placed in the second E8 bin when the light output is between 1 and 2 MeV, etc. A zero F6 tally will result in no F8 tally.

In Case 2, the light output from two regions (cells 5 and 6) is used to subdivide the pulse-height tally. This case is useful for coincidence/anticoincidence applications. A pulse of 1 (input source weight) is put into the second E8 bin and into the second FU8 bin when the light output in cell 5 is 0<L<1.0 MeV *and* the light output in cell 6 is 0<L<1.5 MeV. This pulse is put into the second E8 bin and into the third FU8 bin when the light output in cell 5 is 0<L<1.0 MeV *and* the light output in cell 6 is between 1.5 and 2.5 MeV. A zero light output in both cells will result in no F8 tally. A zero light output in cell 5 (tally 6) with a non-zero light output in cell 6 (tally 16) will result in a pulse in the first E8 bin and the corresponding FU8 bin. Similarly, for a zero light output in cell 6 and a non-zero light output in cell 5, a pulse will be put into the first FU8 bin and the corresponding E8 bin. Note that the E8 and FU8 bins do not have to be the same and typically would not be unless the detector regions were of similar material and size. Separate F6 tallies (as in Case 2, F6 and F16) are needed only when the two regions have different light conversion functions. If the two regions are of the same material, then a single F6 tally can be used as follows:

Example 2:

```
F8:N 5
FT8   PHL  2  6  1  6  2  0
E8         1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0
FU8        1.5  2.5  3.5  4.5  5.5  6.5  7.5  8.5
F6:E       5  6
DE6   LIN  1.0  1.5  2.0  2.5  3.0  3.5  10.0
DF6   LIN  1.0  1.1  1.2  1.3  1.4  1.5  1.6
```

In this example, the light output from the two regions (cells 5 and 6), which are included on the same F6 tally, is used to subdivide the pulse-height tally.

Currently, it is not important what cell is listed on the F8 card because this tally is made only at the end of a particle history and depends only on the tally results of the listed F6 tallies. Having multiple cells listed on the F8 card is meaningful only when the F-bin parameter (i.e., b_{an} or b_{bn}) of the FT PHL option is zero, indicating a lattice grid of detector regions. Otherwise, each additional F8 cell bin simply will be a duplicate of the first cell bin.

Example 3:

```
F6:H     1
F16:T    1
F8:h,t   1
FT8      PHL  2 6 1 16 1  0
T8       10 20 30 40 50 60 70 80 90 100 1e37
```

In this example, the proton (F6) and triton (F16) energy depositions in cell 1 are combined into a pulse-height tally (F8) using the FT PHL option. The time-dependent behavior of these pulses is segregated into 11 time bins: 0--10 shakes, 10--20 shakes, etc. To obtain the time-dependent pulse shape, time-dependent energy depositions are obtained from the tallies identified by the PHL option. To accomplish this, the 11 specified T8 bins are applied to the associated F6 and F16 tallies with the automatic creation of matching T6 and T16 cards. (A warning message is generated when these cards are created.)

11. CAP [-m_c] [-m_o] i_1 i_2 [GATE *td tw*] [EDEP *tg tt*]

The FT8 capture tally scores the number of captures in specified combinations of nuclides at the end of each history. Time gating with predelay and gate width is optional [SWI04]. It is particularly useful for neutron coincidence detectors. In addition, captures may be written to an auxiliary output file, PTRAC. Section 3.3.7.2.4 describes the PTRAC capture file.

The FT8 CAP option converts the pulse-height tally to a neutron capture tally. Variance reduction is no longer allowed, time bins are allowed (unlike other F8 tallies), cosine bins are used to store capture frequencies and moments, and print table 118 is created in the output file.

The parameters for keyword CAP are described as follows:

- m_c is the optional maximum number of captures (Default=21),
- m_o is the optional maximum number of moments (Default=12), and
- i_n are the capture nuclides such as 3006 or 5010 for ^{6}Li or ^{10}B, respectively.

In addition, the time gate keyword GATE may appear with its parameters, *td* and *tw*, where

- *td* is the predelay time and
- *tw* is the gate width;

and the energy deposition keyword EDEP may appear with its parameters, *tg* and *tt*, where

- *tg* is the trigger tally number and
- *tt* is the trigger tally threshold (MeV) (Default=0.0).

The EDEP keyword specifies to record a capture whenever tally *tg* produces an energy deposition greater than *tt*. Tally *tg* can be any F6 or F8 tally, but is usually the related F8 tally of the FT CAP option (which is the default).

Example 1:

```
F8:N        2  (5  6)  7  T
FT8   CAP  3006   5010
T8          1   7LOG   1E8
```

In this example, captures and moments are tallied in cells 2, 7, in the combination of 5 and 6 and in the total over cells 2, 5, 6, 7. The captures by either ^{6}Li or ^{10}B are tallied.

Results are tabulated in time bins at 1, 10, 100, 1000, 1e4, 1e5, 1e6, 1e7, and 1e8 shakes—that is, in the range of 10 nanoseconds to 1 second.

Example 2:

```
F8:N         4
FT8 CAP    2003   GATE  0.5  0.4
```

In this example, ^{3}He captures and moments are tallied in cell `4`. There is a time gate with a predelay of `0.5` shakes (5e-9 seconds) and a width of `0.4` shakes (4e-9 seconds).

Example 3:

```
*F8:H,T   999
F18:N      999
FT18       CAP  EDEP  8  0.001
```

In this example, a capture is scored in Tally 18 whenever there is an `F8` tally that exceeds 0.001 MeV.

The addition of the predelay and time gate width changes the capture tally scoring. When a neutron is captured at time t0 in the specified cell by the specified nuclide, the gate is "turned on." If the predelay is t1 and the gate width is t2, then all captures between t0 + t1 and t0 + t1 + t2 are counted. For a history with no captures, no events are scored. With one capture, 0 events are scored. With two captures, the first turns on the time gate at time t0 and scores 0; the second will score one event if it is captured between t0 + t1 and t0 + t1 + t2, or score another 0 if outside the gate.

Caution: Coincidence counting of capture multiplicities and moments requires analog capture: `CUT:N 2J 0 0`. Calculations must be totally analog with no variance reduction. Fission multiplicity also is required: `PHYS:N J 100 3J -1`. An `FT8 CAP` tally in an input file will automatically set analog capture, fission multiplicity, and exit with error messages if variance reduction is used.

The capture tallies may be written to a PTRAC file for further analysis by auxiliary codes. See Section 3.3.7.2.4 on the `PTRAC` card extensions.

12. `RES [`z_1 z_2`]` or `RES [`za_1 za_2 `...]`

The interaction of high-energy particles with target nuclei causes the production of many residual nuclei. The generated residual nuclei can be recorded to an `F8` tally if used with an `FT8 RES` special treatment option. The residuals are recorded at each physics model interaction as well as each neutron library interaction.. The residual data can be accumulated for the entire geometry (when no cells are listed) or for specific cells listed on the `F8:#` card. A specific list of ZAIDs may also be requested on the `FT RES` card. Requires an FU card (see Section 3.3.5.16).

The `FT8 RES` capability can also be used with type 1, 2, 4, and 6 heavy-ion tallies (`F`*n*`:#`) to segregate the score into bins according to the heavy ion that produced the score.

By default, the `FT RES` card with no entries causes the corresponding tally to create a user bin for each of the 2200+ possible residual nucleus ion types. A range of bins may be selected by specifying lower and upper proton numbers, z_1 and z_2, which correspond to a range of possible z values. If z_1 and z_2 are specified and a residual is generated with a higher or lower z, the residual will not be scored in the tally. To specify an explicit list of heavy ions to be tallied, provide ZZZAAA identifiers (za_i) after the `RES` keyword. Specifying the elemental ZAID option, such as 26000 for iron, will include all isotopes of that element into a single bin.

When used with the `F8:#` tally, the `FT RES` card yields a list of residual nuclides produced by all neutron-induced reactions and model reactions of all incident particle types (photon and proton library reactions do not yet produce residuals). The residual tallies can be obtained either with or without the emission of delayed neutrons and/or delayed gammas. Residual tallies can be obtained for analog or non-analog (implicit capture) neutron transport. The residuals are just the residuals of the nuclear reactions and not their decay products.

For models that include light-ion recoil and the neutron capture ion algorithm (NCIA) (activated using the 7th entry on the `PHYS:N` card, see Section 3.3.3.2.1), reaction residuals are included in the `FT8 RES` tally. In most instances, reaction residuals are determined using the ENDF reaction specifications for simple-multi-particle reactions. In rare instances, e.g., neutron bombardment of ^{6}Li(n,t)α, the ENDF reaction specifications can result in only light-ion production. In such cases, the heaviest light-ion residual is selected.

Example 1:

```
F4:#    6
FT4 RES  8016  20040  26000  92238
```

This combination of tally cards creates a track length tally in cell 6 and then creates four user bins for the isotopes 8016, 20040, 26000, and 92238. All iron isotopes (26000) are placed into a single bin.

Example 2:

```
F8:#   1  100  T
FT8    RES  25  27
```

The entries on the `F8` tally card are cell numbers for which residuals are to be tallied. In this example, residual tallies are requested for cell 1, cell 100, and for cells 1 and 100 combined. The entries on the `FT8 RES` card specify the range of possible Z-values for which to tally the residuals. Here, residuals with atomic numbers between (and including) Z=25 and Z=27 will be scored.

Example 3:

```
F8:#   1  100  T
FT8    RES  25054 25055 25056  26055 26056 26057  27056 27057 27058
```

The entries on the `F8` tally card are cell numbers for which residuals are to be tallied. In this example, residual tallies are requested for cell 1, cell 100, and for cells 1 and 100 combined. The entries on the `FT8 RES` card specify a list of isotopes for scoring residuals. Production for specific isotopes of Mn, Fe, and Co will be included for this `F8` tally.

The `FT8 RES` capability is particularly useful with the eighth LCA card entry, *`noact`*. When `noact=–2` on the `LCA` card, the source particle immediately collides in the source material. All subsequent daughter particles then are transported without further collision, as if in a vacuum. The `F8` tally with an `FT8 RES` special tally treatment is then simply the distribution of nuclides resulting from a single collision.

For additional information involving fission multiplicity see the discussion presented in Section 3.3.3.8. More capture tally information and examples appear in Section 4.2.5, Examples 5 and 6. To inspect a residual nuclei tally example, go to Section 4.2.5, Example 7.

13. `TAG` *`a`*

Tally tagging allows the user to separate a tally into components based on how and where the scoring particle was produced. This feature is available for both standard (`F1`, `F2`, `F4`, `F6`, `F7`) and detector (`F5`) tallies. Requires an FU card (see Section 3.3.5.16).

The single required parameter *`a`* of the keyword `TAG` specifies how scatter is to be treated (i.e., whether the creation tag on a particle should be retained or a separate scatter tag be invoked). More specifically,

if *a*=1 particles undergoing elastic scattering will lose their tag and bremsstrahlung and annihilation photons will be included in the “scatter” bin (i.e., FU “0” bin);

if *a*=2 particles undergoing elastic scattering will lose their tag, but bremsstrahlung and annihilation photons will be segregated (see appropriate FU bins below);

if *a*=3 particles undergoing elastic scattering will retain their production tag. If a particle has multiple production events, the tag will be for the last production event. For example, a neutron undergoing fission followed by (*n*,2*n*) would have the (*n*,2*n*) tag. If a particle undergoes an elastic scatter, its previous tag is retained (i.e., no need for FU “0” bin);

if *a*=4 same conditions as *a*=3 except Compton photoatomic interactions retain their tag. Neutron interactions behave identically as *a*=3.

Binning specifications for the tagged tally must be provided on the `FU` special tally card. Each *bin*$_i$ entry on the card requests three distinct pieces of tagging information:

1) a cell of interest where particles are produced;
2) a target nuclide from which the particle is emitted; and
3) a reaction MT identifier, or, in the case of spallation, a residual nuclide of interest, or a special designator (see below).

The format on the `FU` card when used in association with the tagging treatment is

`FU`*n*   *bin*$_1$ *bin*$_2$ ... *bin*$_N$ `[NT]`

where each tagging *bin*$_i$ has the form CCCCCZZAAA.RRRRR and

CCCCC	represents a user cell number (Note: Leading zeros are not required.)
ZZAAA	represents a 5-digit isotope identifier for a target nuclide where ZZ is the atomic number and AAA is the atomic mass number (Note: ZZ is limited to two characters, therefore nuclides with Z>99 cannot be tagged.)
RRRRR	specifies a reaction identifier for library interactions or a residual nuclide ZZAAA identifier for high-energy model interactions or a special designator.

By default, a total over all specified bins is provided for the `FU` special tally; add the `NT` parameter after the last specified bin to suppress this total. A list of special cases for the CCCCCZZAAA.RRRRR `FU` card entries appears later in this section.

If cell tagging is not desired, the CCCCC portion of the tag should be omitted or, alternatively, set to "`00000`". In either case, tally contributions will be accumulated for all cells for that `FU` bin, provided the ZZAAA.RRRRR portion of the tag is satisfied. In the case of particle production from electrons, which are material based (not nuclide specific), the CCCCC input should be used to identify the cell and the ZZAAA input should be set to "`00000`". The suffix RRRRR refers to a standard ENDF reaction number for library interactions [e.g., "`00102`" stipulates (n,γ)] or, in the case of high-energy model interactions, RRRRR refers to a residual nuclide ZZAAA identifier (e.g., "`06012`" for ^{12}C).

In general, a zero input for any portion of the tag results in the sum of all contributions related to the entry. For example, the tag "`0000092000.00000`" will collect all tally contributions for which any isotope of uranium (z=92) produced the particle making the tally. However, the tag "`0000000000.00000`" is reserved for elastic-scattered particles. Note that each tally contribution is made only to the first `FU` bin that satisfies the tag description (i.e., those that have not already been tallied). If no appropriate `FU` bin is found, the tally contribution is not made; however a special "everything else" *bin*$_i$ (i.e., "`1e10`") can be specified to collect any portion of the tally that falls into no other bin. When the "everything else" bin is used, then the user is assured that the "user-bin total" bin will reproduce the original tally as if the `FT`*n* `TAG` option had not been used.

Special designations for CCCCCZZAAA:

`-0000000001`	or	`-1`	source particle tag for all cells
`-CCCCC00001`			source (i.e., un-collided) particle tag for cell CCCCC
`0000000000`	or	`0`	elastic-scattered particle tag
`10000000000`	or	`1e10`	everything else tag

Photon tally special designations for ZZAAA.RRRRR:

`00000.00001`	bremsstrahlung from electrons
`ZZ000.00003`	fluorescence from nuclide ZZ
`00000.00003`	K x-rays from electrons
`00000.00004`	annihilation photons from e-
`ZZ000.00005`	Compton photons from nuclide ZZ
`ZZAAA.00006`	muonic x-rays from nuclide ZZAAA
`00000.00007`	Cerenkov photons

Electron tally special designations for ZZAAA.RRRRR:

`ZZ000.00001`	photoelectric from nuclide ZZ
`ZZ000.00003`	Compton recoil from nuclide ZZ
`ZZ000.00004`	pair production from nuclide ZZ
`ZZ000.00005`	Auger electron from nuclide ZZ
`00000.00005`	Auger electron from electrons
`00000.00006`	knock-on electrons

Neutron and photon tally special designations for ZZAAA.RRRRR:

`ZZAAA.99999`	delayed particles from fission of ZZAAA

The RRRRR reaction tag also includes all the MT reactions listed for neutrons, but selecting RRRRR is complicated by the inconsistencies of ENDF and other table data evaluations. For fission, RRRRR=18 will not always catch all fission reactions. For example, in ^{239}Pu RRRRR=18, but in ^{240}Pu RRRRR=19, 20, 21 and all three must be listed to catch ^{240}Pu fission. Likewise, RRRRR=16 only tags (*n*,2*n*) reactions; RRRRR=17 must be used to get (*n*,3*n*) reactions. And then there are the exceptions. For example, photons from fission in ^{235}U have the tag RRRRR=3, which is inelastic, and is also the tag of photons created by (*n*,*xn*).

Example 1:

```
F1:N   10
FT1    TAG  1
FU1    0000092235.00016  0000092235.00000  1e10
```

If an (*n*,2*n*) neutron that is produced from an interaction with ^{235}U contributes to the `F1` tally, then its contribution will be included only in the first `FU` bin even though its tag also will satisfy the criteria for the 2nd `FU` bin. Thus, the order of the `FU` bin tags is important for segregating the tally. Note that neutrons produced by some other reaction with ^{235}U will be placed in the 2nd `FU` bin and neutrons produced by reactions with other target nuclides will be placed in the last ("everything else") bin. The sum of these three bins should preserve the value of the original `F1:N` tally.

Example 2:

```
F1:P  1
FT1   TAG  1
FU1   0.0  01001.00102  01001.00000
           26056.00102  26056.00051  26056.00052
           26056.24052  26056.26053  26056.26054  26056.26055
           26056.00000
```

All elastic-scattered photons (i.e., coherent) will be put into the `FU` "`0.0`" bin. All capture gammas from ^{1}H will be put into the `01001.00102` bin; all remaining gammas from ^{1}H interactions will be put into the `01001.00000` bin. All capture gammas from ^{56}Fe will go into the `26056.00102` bin; all (*n*,*n*') 1st level gammas will go into the `26056.00051` bin; all (*n*,*n*') 2nd level gammas will go into the `26056.00052` bin; all de-excitation gammas from the spallation of ^{56}Fe into ^{52}Cr will go into the `26056.24052` bin; etc. All remaining gammas produced from ^{56}Fe interactions will go into the `26056.00000` bin.

Example 3:

```
F5:P  0 0 0 1
FT5   TAG  3
FU5   -1.0  0000106012.00005  0000106012.00000
            0000026056.00102  0000026056.00000
            0000000000.00051
           10000000000.00000
```

In this case, all collided photons will retain their original creation tag. All source photons will go into the `-1.0` bin. All Compton photons from ^{12}C in cell `1` will be put into the 2nd bin; all remaining photons produced from interactions with ^{12}C in cell `1` will go into the 3rd bin. All capture gammas from ^{56}Fe will go into the 4th bin; all remaining photons/gammas produced from interactions with ^{56}Fe will go into the 5th bin. All (*n*,*n*') 1st level gammas will be put into the 6th bin, and all remaining photons/gammas that were not included in any of the previous bins will be placed in the last bin.

14. `LET`

The linear energy transfer (`LET`) special tally option allows track length tallies to record flux as a function of stopping power instead of energy. When the `FTn LET` option is specified, the values provided in the energy bins are interpreted as stopping power values with units of MeV/cm. This option can only be applied to charged particle tallies.

Example 1:

```
fc4     Proton flux LET
f4:h    77
e4      1e-2  99ilog  6e4
ft4     LET
```

This example is a tally that records the proton flux in cell 77 for a `LET` tally. The tally results are recorded in 100 bins of stopping power from 0.01 to 60000 MeV/cm.

15. `ROC` *`nhb`* `[`*`m`*`]`

The `ROC` special tally option separates tallies into two components, signal and noise. During a calculation, the signal and noise tally values are saved for each specified batch of histories. These distributions of tally values are formed into signal and noise probability distribution functions (PDFs). Integration of the signal PDF (labeled as the Probability of Detection, PD) is plotted as a function of the integral of the noise PDF (labeled as the Probability of False Alarm, PFA), resulting in the printed Receiver-Operator Characteristic (ROC) curve. A table of the PDF values is provided in Table 163 of the OUTP file.

To specify the “signal” portion of a tally, use entries 1–8 on an associated `TF` card; to specify the "noise" portion, use `TF` entries 9–16. The `ROC` keyword parameter *nhb* sets the number of histories per batch. This parameter sets the 5th entry (the TFC frequency) on the `PRDMP` card. The *nhb* value should represent the total number of source particles emitted over the time interval of interest. The *npp* value on the `NPS` card should be set to a multiple of *nhb*; the *npp* value will then be used to determine the number of sampled batches. We recommend that *npp* should be 50–100 times the value of *nhb*. The optional parameter *m* specifies the maximum number of batches that will be kept and analyzed. The default value is 100. We recommend *m* be greater than 50 and perhaps two times the number of batches planned, even considering possible continue-runs. (This value cannot be increased in a continue-run file.) If there are multiple tallies with `ROC` entries, the maximum *m* value is used. The `WGT` keyword on the `SDEF` card should be set to the default value of unity.

Example 1:

```
f1:n   1
t1     1e8  1e37
tf1    j j j j j j j 2  j j j j j j j 1
ft1    ROC  1000
```

In this example, tally `F1` scores the current of neutrons crossing surface `1`. This tally is divided into two time bins, neutrons arriving before 1 second (i.e., 1×10^8 shakes) and those arriving after 1 second (i.e., `1e37` shakes). The `TF` card associates the second time bin as the “signal” and the first as the “noise.” The signal and noise currents are accumulated for each batch of 1000 particle histories. The resulting tally values are formed into signal and noise PDFs that are integrated and plotted in Table 163 as a ROC curve for this tally.

Another ROC curve example is provided in Section 4.2.5 Example 42.

16. `PDS` *`c`*

This pre-collision estimator augments the post-collision next-event estimator that has historically been used for point flux estimation in MCNP6. The pre-collision next-event estimator includes the contribution of all possible reactions before the collision isotope and resulting reaction are sampled. This procedure has the advantage of providing an improved expected estimate per collision, but with a significant increase in computational costs per collision. This improved sampling technique removes the requirement to suppress coherent scattering for photon transport problems that include photon next-event estimators. The sampling of all possible scattering reactions generally provides an increase in the Figure of Merit (FOM) for most photon problems. This increase in the FOM can be significant when the contribution to a photon next-event estimator is primarily from forward scattering. For most neutron problems there is not typically a large increase in the FOM. However, for both photons and neutrons the pre-collision next-event estimator increases the convergence rate as measured by the time to pass MCNP6's ten statistical checks.

The single parameter, c, specifies how the sampling of the collision is performed for the next-event estimator:

- if *`c`*`=-1` Next-event estimator sampling is performed post-collision; only a single reaction and isotope is sampled (historic MCNP4 and MCNP5 behavior)
- if *`c`*`=0` Same as *`c`*`=-1` (DEFAULT)
- if *`c`*`=1` Next-event estimator sampling is performed using post-collision sampling of the collision isotope and pre-collision sampling of all reaction channels. (Recommended for photons.)
- if *`c`*`=2` Next-event estimator sampling is performed using pre-collision sampling of all collision isotopes and pre-collision sampling of all reaction channels.

Recommendation: Using either `PDS 1` or `PDS 2` allows the user to perform next-event estimator tallies with photon coherent scattering enabled.

For neutron next-event estimator tallies the user should perform scoping calculations with `PDS=-1`, `1`, and `2`. The user should check the 10 statistical tests of the three runs to assess which parameter provides the best compromise between convergence and FOM. Using a pre-collision estimator for neutrons will typically reduce the computational time needed to pass the 10 statistical checks but result in a lower FOM.

Example 1:

```
f5p   100.0 50.0 25.0 0.0  $ post-collision next-event estimator
ft5   pds -1               $ F5 tally is post-collision
c
```

```
f15p  100.0 50.0 25.0 0.0  $ pre-collision next-event estimator
ft15  pds 1                $ F15 tally is pre-collision
```

In this example the pre-collision next-event estimator and the post-collision next-event estimator are compared for a photon tally located at x=100 cm, y=50 cm, and z=25 cm.

17. `FFT [LKJI]`

A single parameter may follow the `FFT` keyword and an `FU` card is required (see Section 3.3.5.16).. The optional LKJI parameter toggles on/off the first-fission treatment for the various physics packages, as explained below. The related `FU` card segregates the tally into contributions according to which fission occurred first. `FU` entries should be ZZZAAAs of fissionable nuclides. Additionally, an `FU` entry of "`0`" should be included to score all contributions that are not associated with any other `FU` bin, an `FU` entry of "`16`" will score (*n*,*xn*) reactions instead of fission if they occur before any fission, and an entry of "`18`" will score first fissions from any nuclide that is not listed on the `FU` card. The bins may be entered in any order. The LKJI parameter combines four binary toggles that specify which physics packages should be included with the FFT treatment, such that:

I = 0/1 Omit/include neutron-induced fissions treated by library physics (E<~20 MeV)
J = 0/1 Omit/include photon-induced fissions treated by library physics
K = 0/1 Omit/include neutron spontaneous fissions (PAR=SF source particles)
L = 0/1 Omit/include neutron and photon-induced fissions treated by model physics

The default value for LKJI=0001, which is equivalent to LKJI=1 and is the default action if LKJI is omitted. To turn on the full FFT treatment, one would specify LKJI=1111.

Cell flagging (`CF` card, Section 3.3.5.12) and surface tally segmenting (`FS` card, Section 3.3.5.14) have somewhat different meanings when the `FFT` special tally treatment is used. Unlike the standard tally segmenting, in which the segment identifies where the score is made, `FFT` tally segmenting identifies where the first fission occurs. Unlike the standard tally flagging, which flags cells through which the track has passed before scoring, `FFT` cell flagging flags cells in which the first fission occurred. Cell flagging and surface segmenting work for cells and surfaces at the lowest level so when `FFT` is specified, these lowest-level cells/surfaces will be the location of the first fission. If a CF card is used with the FFT option on any tally, then the use of a CF card without the FFT option is prohibited on any other tally, and the related CF card is ignored and a warning is issued.

Example 1:

```
FT1   FFT
FU1   92238  0  16  18  94241  92235  94239
```

If an (*n*,*xn*) reaction occurs before a fission, then the 16 bin records a score. If the particle has its first fission in a listed nuclide (92235, 92238, 94239, 94241), then that nuclide bin records a score provided 16 has no score. If the first fission is not a listed nuclide, the 18 bin records a score provided 16 has no score. The 0 bin records a score if no other bin has a score.

18. `COM t a`

The FT8 COM tally option produces a Compton image stored in an associated FIR radiography tally `t` using algorithm `a` (optional, currently there is one algorithm so a=1). The Compton image is formed from a FT8 PHL specification of dual-region coincidences of planar lattice tallies. At the end of each particle history, Compton/photoelectric energy deposition in the front/back of these dual-panel detectors is used to create a circular "image" of the incident photon on a specified image plane. The FT8 PHL enhancement is used to obtain coincidences of front-panel energy deposition with back-panel energy deposition, on a voxel-by-voxel (or element-by-element) basis. For example, if the front-panel detector consists of a 5x5 lattice and the back-panel detector consists of a 10x10 lattice, then the FT8 PHL option produces coincident pulses for 25x100=2500 voxel combinations. The Compton electron energy deposition scored in a front-panel voxel (E_f) is correlated to the photoelectric energy deposition in a back-panel voxel (E_b), via the Compton Equation, to produce the Compton angle of scatter and thus determine a conical angle of incidence. Here is the form of the Compton Equation that is used to obtain the conical angle of incidence:

$\cos(\theta) = 1 - m_e\,[1/E_b - 1/(E_f+E_b)]$, where m_e is taken as 0.511 MeV.

Restrictions on E_f and E_b include: (1) $E_f < E_b$, and (2) $E_f > E_{ft}$ and $E_b < E_{bt}$, where E_{ft} and E_{bt} are threshold energies set by the user on the corresponding E8 and FU8 cards. The first of these is required to formulate a backward conical image (and helps ensure a Compton/photoelectric reaction occurred), while the latter is needed to reduce image clutter from voxel leakage (electron escape, Brems., etc.). The FT8 COM processing algorithm is currently quite simple in that it takes the center-point of the front-panel voxel and that of the back-panel voxel to form a line which is then intersected with the image plane (at point P). Using the equation above, a radial distance from point P is determined and scores are made to various grid elements intersected by the circle about P (see Fig. 3-8). A simple algorithm is used, based on the size of the grid elements, to determine the number of sample points to score around the circle. A pulse of the source weight is scored in each image-plane grid element that overlaps a circular sample point.

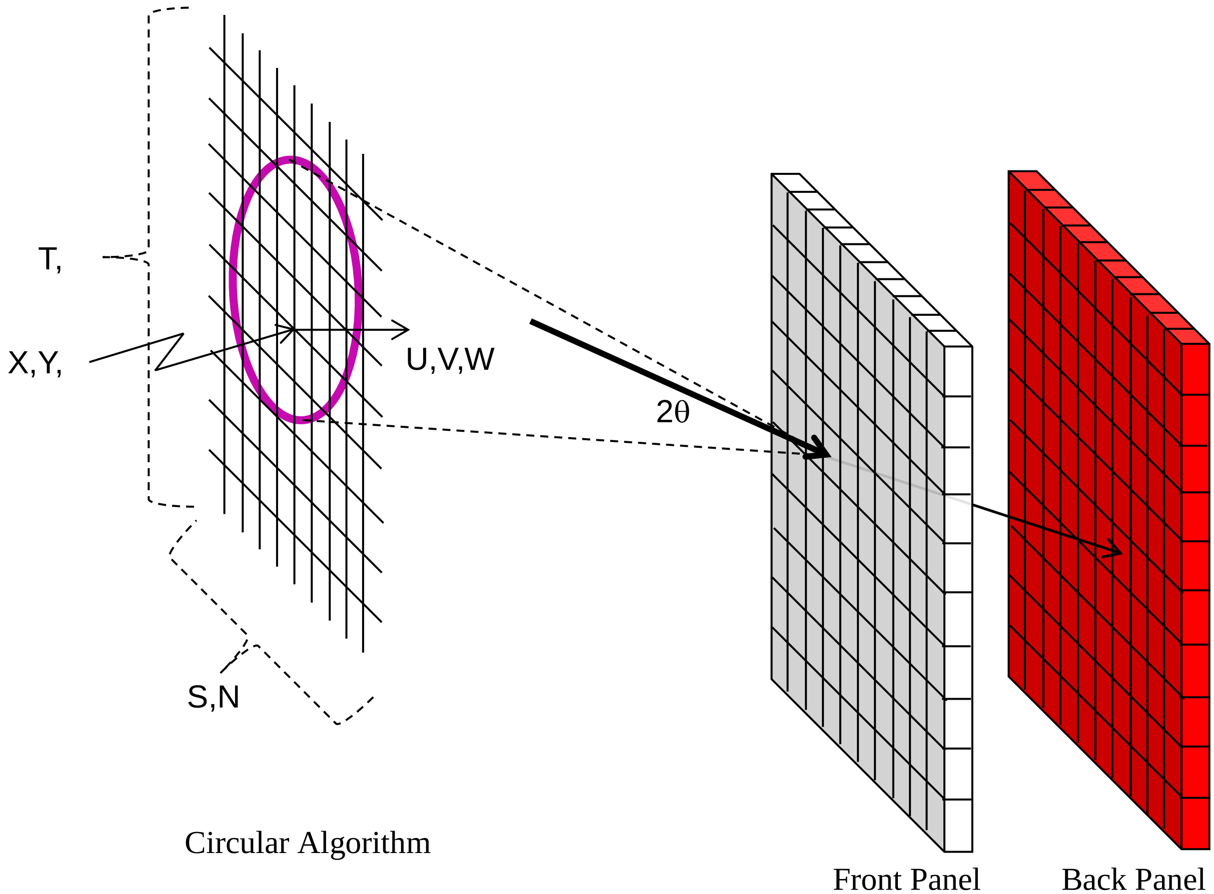


Figure 3-8. Diagram of a Compton imaging detector, along with a circular sample on the image plane.

An associated FIR radiography tally will be used to set up the image grid, with corresponding tally segment (FS card) and cosine (C card) bins. The FIR tally format is listed in Table 3-80

The COM option is allowed only on F8 tallies and must be used with a corresponding dual-region PHL option. The tallies specified with the PHL option must involve multi-element lattices and use the special F-bin descriptor of “0”. While the lattices in the two regions can differ in size and number of elements, tallies specified within a region must tally over the same lattice cell and elements (but can include contributions from different particle types). This feature fully supports repeated-structures geometries.

Example 1:

```
2-MeV photons into Si grid
1 1 -2.3 -1 lat=1 u=1       imp:p=1
           fill=0:0 -2:2 -2:2 1 24r
2 1 -2.3 -2 lat=1 u=2       imp:p=1
```

```
           fill=0:0 -2:2 -2:2 2 24r
3 0      -3   fill=1        imp:p=1
4 0      -4   fill=2        imp:p=1
5 0      -5 4 3             imp:p=1
6 0       5                 imp:p=0

1 rpp  -1 1  -1 1  -1 1
2 rpp   4 6  -1 1  -1 1
3 rpp  -1 1  -5 5  -5 5
4 rpp   4 6  -5 5  -5 5
5 sph  0 0 0  100

m1  14028 1
mode p e
cut:p,e 2j 0 0 $ Analog capture
sdef par=p pos=-5 3 3 erg=2
fir5 -5 0 0  0  0 0 0  1 1 1
FS5 -10 9i 10
C5  -10 9i 10
f16:e (1<1[0:0 -2:2 -2:2]<3)
f26:e (2<2[0:0 -2:2 -2:2]<4)
f8:e  1
ft8   PHL 1 16 0    $ Region 1
          1 26 0    $ Region 2
          0
      COM 5 1
e8   0.2 100 NT
fu8  0.2 100 NT
tf8  j j 2 j j j 2 j
```

This example involves a 2-MeV isotropic photon source located off-center (-5,3,3) at ~4 cm from two 1x5x5 Si panels, with the back panel 3 cm behind the front (front panel is centered at -1,0,0) . The Si voxels are 2x2x2 cm, making the panels 2x10x10 cm overall in size. The image plane is coincident with the source location, so it too is ~4 cm from the front panel detector. The size of the image plane is 20 cm in each direction, with 10 grid elements along these “S” and “T” axes. The energy thresholds are set to 0.2 MeV on the E8 and FU8 cards. The TF8 card uses the 2nd user and energy bins for the TFC and it is the values in these bins that are used in solving the Compton image equation given above.

3.3.5.19 TF TALLY FLUCTUATION

This card specifies the bin for which the tally fluctuation chart statistical information is calculated and the weight-window generator results are optimized. In addition, two separate tally bins can be specified to distinguish the "signal" vs. "noise" portions of a tally for ROC curve generation. (See special tally treatment FT ROC in Section 3.3.5.18.)

The `TF` card allows you to change the default bin for a given tally and specify for which tally bin the chart and all the statistical analysis output will be printed. The set of eight entries on a `TF` card correspond (in order) to the list of bin indices for the eight dimensions of the tally bins array. The order is fixed and not affected by an `FQ` card.

Form 1: TF*n* i_f i_d i_u i_s i_m i_c i_e i_t

Form 2: TF*n* i_{f1} i_{d1} i_{u1} i_{s1} i_{m1} i_{c1} i_{e1} i_{t1} i_{f2} i_{d2} i_{u2} i_{s2} i_{m2} i_{c2} i_{e2} i_{t2}
(See Note 1.)

Table 3-102. Tally Fluctuation Card (TF)

Input Parameter	Description
N	**Non-zero tally number.** **Restriction:** $n \le 99999999$
i_f	**The bin number of the cell, surface, or detector bin (F-bin) on F card. (DEFAULT: i_f=1, first bin)**
i_d	**The bin number of the total, flagged, or un-collided flux (D-bin). (DEFAULT: i_d=1, total flux)**
i_u	**The bin number of the user bin (U-bin). (DEFAULT: i_u=last bin) (See Note 2.)**
i_s	**The bin number of the segment bin (S-bin). (DEFAULT: i_s=last bin)**
i_m	**The bin number of the multiplier bin on FM card (M-bin). DEFAULT: i_m=1, first bin)**
i_c	**The bin number of the cosine bin (C-bin). (DEFAULT: i_c=last bin)**
i_e	**The bin number of the energy bin (E-bin). (DEFAULT: i_e=last bin)**
i_t	**The bin number of the time bin (T-bin). (DEFAULT: i_t=last bin)**

Use: Whenever a particular tally bin is more important than the default bin. Particularly useful in conjunction with the weight-window generator. Also used to specify signal vs noise components of a ROC curve.

Note 1: The second input format is used only with the `FT`*n* `ROC` tally option. In this case, the first 8 entries represent bins associated with the signal component while the second 8 entries identify the noise component. (See Section 3.3.5.18.) To support `ROC` curve generation, the entry format allows multiple bins to be specified for each entry: a single bin (e.g., 10), a range of bins (e.g., 10-12), a list of bins (e.g., 10,11,12), or a combination of these formats (e.g., 10-12,13,14). However, only the first bin listed in each entry is used for generating the TFC output, weight-window generation, and statistical analysis.

Note 2: You may find the J feature useful to jump over last entries. Remember that totals are calculated for energy, time, and user bins (unless inhibited by using NT), so that last for eight energy bins is 9. If one segmenting surface divides a cell or surface into two segments, last in that case is 2, unless T is used on the FS card, in which case last is 3. If there are no user bins or cosine bins, for example, last is 1 for each; last is never less than 1.

The Tally Fluctuation Chart:

At the end of the output, one chart for each tally is printed to give an indication of tally fluctuations; that is, how well the tally has converged. The tally mean, relative error, variance of the variance, Pareto slope (see Section 6.9.7 of the MCNP5 Theory Manual[X-503a]), and figure of merit (FOM=1/(σ2*t*), where σ is the relative error printed with the tally and *t* is computer time in minutes) are printed as functions of the number of histories run. The FOM should be roughly constant. The `TF`*n* card determines for which bin in tally *n* the fluctuations are printed. It also determines which tally bin is optimized by the weight-window generator (`WWE` or `WWT` and `WWG` or `WWGT` cards).

The mean printed in a chart will correspond to some number in the regular tally print. If you have more than one surface listed on an `F2` card, for example, the default chart will be for the first surface only; charts can be obtained for all surfaces by having a separate tally for each surface.

Example 1:

Suppose an `F2` tally has four surface entries, is segmented into two segments (the segment plus everything else) by one segmenting surface, and has eight energy bins. By default one chart will be produced for the first surface listed, for the part outside the segment, and totaled over energy. If we wish a chart for the fifth energy bin of the third surface in the first segment, we would use

```
TF2   3  2J  1  2J  5
```

Example 1:

```
TF2   3  2J  1  2J  5  J
```

In this example, statistics will be calculated based on the 3rd surface, 1st segment, and 5th energy bin provided in Tally 2. Without this card, statistics will be performed on the 1st surface, 1st segment, and the total of all energy bins.

Example 2:

```
TF1    2 j 10-12,13,88 1-2 j 7,8,9 1-99 2   j 1 j j 2 j j j
```

Note that spaces are not allowed within a comma-delimited list of bins and/or bin ranges. Spaces continue to be used to delimit the eight bin-type entries. The first eight entries specify the bins that constitute the signal component of the tally, while the second eight entries specify the bins that constitute the noise component of the tally.

3.3.5.20 NOTRN DIRECT-ONLY NEUTRAL-PARTICLE POINT DETECTOR CONTRIBUTIONS

Form: `NOTRN`

Default: None.

Use: This option works with point-detector tallies as well as pinhole or transmitted image tallies. If the `NOTRN` card appears in the INP file, no transport of the neutral particle source particles takes place, and only the direct neutral particle source contributions are made to the detectors and the detector grid. This is especially useful for checking the problem setup or doing a fast calculation to generate the direct source image. (A `NOTRN` card is not allowed in a continue run.)

TALLY PERTURBATIONS AND REACTIVITY SENSITIVITIES

MCNP6 offers two flavors of perturbation theory, one based on the differential operator (`PERT` card) and two others based on adjoint weighting (`KPERT` and `KSEN` cards). Both methods offer advantages and disadvantages. The differential operator technique is based on a Taylor series expansion and works very well for generalized responses in fixed-source problems. In eigenvalue problems, however, the differential operator methodology may produce inaccurate results because the MCNP6 implementation does not account for the perturbation of the fission source distribution. The adjoint-based methodology implicitly captures the perturbation in the fission source; however, it is only capable of finding the change in reactivity resulting from perturbations in cross sections and not other responses.

Should a user desire estimates of changes in reactivity for reactor physics applications or sensitivity coefficients to the k-eigenvalue, then the adjoint-based methodology is appropriate. An important limitation of the adjoint-based methods as implemented in MCNP6 is that they do not consider perturbations that may arise from scattering laws or from fission emission spectra; this limitation has been shown to lead to spurious results. For perturbations where the dominant effects are from absorption or the scattering is mostly isotopic, the results tend to agree well with those from direct cross-section substitutions and from the adjoint-methodology code TSUNAMI-3D [REA09], which employs multigroup cross-section data rather than continuous-energy data.

3.3.5.21 PERT TALLY PERTURBATIONS—DIFFERENTIAL OPERATOR

This card allows perturbations in cell material density, composition, or reaction cross-section data. The perturbation analysis uses the first and second order differential operator technique. Perturbation estimates are made without actually changing the input material specifications. Multiple perturbations can be applied in the same run, each specified by a separate `PERT` card.

There is no limit to the number of perturbations because dynamic memory is used for perturbation storage. The entire tally output is repeated for each perturbation, giving the estimated differential change in the tally, or this change can be added to the unperturbed tally (see the METHOD keyword). For this reason, the number of tallies and perturbations should be kept to a minimum. However, an entire parameter study can be done with just two PERT cards [FAV16]. A track length estimate of perturbations to k_{eff} is automatically estimated and printed for KCODE problems.

Form: PERT*n*:<*pl*> KEYWORD=*value*(*s*) ...

Table 3-103. Perturbation Card (PERT)

Input Parameter	Description
n	Unique, user-selected, arbitrary perturbation number. Restriction: 0<*n*≤99,999,999
<*pl*>	Particle designator. Only three options allowed: neutron (N); photon (P); or combined neutron-photon (N,P). Not available for other particles.
Basic Keywords	**Description**
CELL=c_1 c_2 ...c_k	Comma or space delimited list of cells, c_1 ... c_K, to which to apply the perturbation. Required.
MAT=*m*	Single material number, *m* (corresponding to an M*m* card), with which to fill all cells listed in CELL keyword.† Must have a corresponding M card. (See Note 1.)
RHO=*r*	Single value of perturbed density of cells listed after the CELL keyword. (See Note 2.) If RHO>0, the perturbed density is given in units of atoms/b-cm. If RHO<0, the perturbed density is given in units of g/cm^3.
Advanced Keywords	**Description**
METHOD=*j*	Controls tally printing and specifies the number of terms to include in the perturbation estimate. (See Note 3.) If METHOD=+1, perform 1st and 2nd order perturbation calculation and print the differential change in the unperturbed tally. (DEFAULT) If METHOD=-1, perform 1st and 2nd order perturbation calculation and print the perturbed tally. If METHOD=+2, perform 1st order perturbation calculation only and print the differential change in the unperturbed tally. If METHOD=-2, perform 1st order perturbation calculation only and print the perturbed tally. If METHOD=+3, perform 2nd order perturbation calculation only and print the differential change in the unperturbed tally. If METHOD=-3, perform 2nd order perturbation calculation only and print the perturbed tally.
ERG=e_{LB} e_{UB}	Two entries, e_{LB} and e_{UB}, that provide the lower and upper bounds of the energy range to which the perturbations are to be applied. (DEFAULT: all energies) (See Note 4.)

RXN=r_1 r_2 ...	**ENDF/B reaction number(s) that identify one or more specific reaction cross sections to perturb. (See Note 5.) (DEFAULT: RXN=1 for neutrons and multigroup, RXN=-5 for photons.)** **Restriction: RXN reaction numbers must be identical to FM card reaction numbers.**

† Use MAT only if the perturbation changes the material from one cell material to another. Use with caution especially if more than one nuclide in the material is changed. New nuclides cannot be added in the new material card.

Default: METHOD=+1; ERG=all energies; RXN=1 for neutrons and multigroup, RXN=-5 for photons.

Use: Optional. The CELL keyword, which identifies one or more perturbed problem cells, is required. Additionally, either the MAT or RHO keyword must be specified.

Note 1: Composition changes can only be made through the use of the MAT keyword. If the RHO keyword is omitted, the MAT keyword is required. Certain composition changes (discussed in "Limitations/Cautions" below) are prohibited.

Note 2: If the MAT keyword is absent, the RHO keyword is required.

Note 3: The ability to produce first- and second-order Taylor series expansion terms separately enables the user to determine the significance of including the second-order estimator for subsequent runs. If the second-order results are a significant fraction (20%–30%) of the total, then higher order (or other) terms are necessary to predict accurately the change in the unperturbed tally. In such cases, the magnitude of the perturbation should be reduced to satisfy this condition. Typically, this technique is accurate to within a few percent for up to 30% changes in the unperturbed tally. It is *strongly* recommended that the magnitude of the second order term be determined before the user continues with this capability. Classical first-order sensitivity analysis requires only the first-order term, METHOD=2; in this case, the relative magnitude of the second-order term is irrelevant.

Note 4: The ERG keyword is usually used with the RXN keyword to perturb a specific cross section over a particular energy range.

Note 5: The RXN keyword allows the user to perturb a single reaction cross section of a single nuclide in a material, all reaction types of a single nuclide, a single reaction for all nuclides in a material, and a set of cross sections for all nuclides in a material. Relevant non-standard special *R* numbers, listed in Table 3-89, can be used. Those that are irrelevant and therefore cannot be used are −4, −5, −7, and −8 for neutrons; −6 for photons; and −3, −4, −6, and −7 for multigroup problems. If these irrelevant *R* numbers are used, the following fatal error will be printed: "fatal error. reaction # illegal in perturbation #."

`RXN` reaction numbers must be consistent with `FM` card reaction numbers (see Section 3.3.5.7) if the perturbation affects the tally cross section. The specification `RXN=-6` is most efficient for fission, although MT=18, MT=19, or MT=-2 (multigroup) also work for k_{eff} and `F7` tallies.

PERT Card Limitations/Cautions:

1. The perturbation method is limited to the 1st and 2nd order terms of a Taylor series expansion. Examine the 1st and 2nd order terms separately for large (>30%) perturbations to determine the significance of the 2nd order terms. If 2nd order terms are a significant fraction (20%–30%) of the total perturbation, inaccurate tallies can result. (Warning message is generated.) See Note 3 above.
2. Nuclide fraction changes (`MAT` keyword) are assumed to be independent and, consequently, differential cross terms are ignored. Stated another way, when multiple isotopes are perturbed at once, the perturbation estimate is the sum of the independent nuclide perturbations and does not include the 2nd-order differential term. Therefore, it is very important to change only one isotope density in each PERT card, or to change all isotope densities the same relative amount [FAV16].
3. `FM` tallies in perturbed cells can be wrong. Surface tallies and tallies in perturbed cells are safe. (Warning message is generated.)
4. Detector (`F5`) and pulse-height tallies (`F8`) are not compatible with the `PERT` card. (i.e., give zero perturbation).
5. DXTRAN is not compatible with the `PERT` card. (Fatal error message is generated.)
6. You cannot un-void a region. That is, if you take a region originally specified as void and put in a material in that region with the perturbation technique, a fatal error message is generated. However, you can specify a region as containing a material and use the `PERT` card to make it void by setting `RHO=0`.
7. You cannot introduce a new nuclide into a material composition. (A fatal error message is generated.) However, you can set up the problem with a mixture of all nuclides of interest and use `PERT` cards to remove one or more nuclides.
8. Although there is no limit to the number of perturbations, each perturbation increases running time by 10%–20%.
9. Some perturbations (those with small changes) converge slowly.
10. The track length estimate of k_{eff} in criticality calculations assumes the fundamental eigenvector (fission distribution) is unchanged in the perturbed configuration. This approximation can lead to serious errors [FAV02]. For the effect of a perturbation on k_{eff}, use the KPERT card (Sec. 3.3.5.22)
11. Use caution when selecting the multiplicative constant and reaction number on `FM` cards used with `F4` tallies in perturbation problems. The track length correction term $R_{1j'}$ is made only if the multiplicative constant on the `FM` card is negative (indicating macroscopic cross sections with multiplication by the atom density of the cell). If the multiplicative constant on the `FM`

card is positive, it is assumed that any FM card cross sections are independent of the perturbed cross sections. If there is a reaction (RXN) specified on the PERT card, the track length correction term R_{1j} is set only if the exact same reaction is specified on the FM card. For example, an entry of RXN=2 (elastic cross section) on the PERT card is not equivalent to the special elastic reaction -3 on the FM card (the user should either enter 2 as the reaction of the FM card and RXN=2 on the PERT card or -3 on FM and -3 on PERT.)

12. Limited to N and/or P problems.

Example 1:

```
PERT1:N,P    CELL=1   RHO=0.03
```

This perturbation specifies a density change to 0.03 atoms/b-cm in cell 1. This change is applied to both neutron and photon interactions.

Example 2:

```
PERT3:N,P   CELL=1 10i 12   RHO=0   METHOD=-1
```

This perturbation makes cells 1 through 12 void for both neutrons and photons. The estimated changes will be added to the unperturbed tallies.

Example 3:

```
60  13  -2.34   105 -106  -74   73  $ mat 13 at 2.34 g/cm3
  .
  .
  .
M13    1001 -0.2  8016 -0.2  13027 -0.2  26000 -0.2  29000 -0.2
M15    1001 -0.2  8016 -0.2  13027 -0.2  26000 -0.2  29000 -0.4
PERT1:P   CELL=60  MAT=15  RHO=-2.808  RXN=51 9i 61,91  ERG=1,20
        METHOD=2
PERT2:P   CELL=60          RHO=-4.68   RXN=2   METHOD=2
```

This example illustrates first-order sensitivity analysis. The first PERT card generates the first-order Taylor series terms Δc_1 for changes in tallies caused by a p = 100% increase in the Cu cross section (ENDF/B reaction types 51–61 and 91) above 1 MeV. To effect a p% change for a specific isotope, set up a perturbed material mimicking the original material, except multiply the composition fraction of the perturbed isotope by $1 + p$ (−0.2 to −0.4). The density of the perturbed material is the density of the original material (2.34 g/cm^3) multiplied by the ratio of the sum of the weight fractions of the perturbed material (1.2) to the sum of the weight fractions of the unperturbed material (1.0), or RHO = (–2.34 g/cm^3 × 1.2/1.0) = –2.808 g/cm^3. This change must be made to RHO to maintain the other nuclides in their original amounts. Otherwise, after MCNP normalizes the M15 card and multiplies the constituent weight fractions by the unperturbed material density, the density of all of the constituents would be perturbed, which is not the intent. When MCNP normalizes the M15 card and multiplies the constituent weight fractions by the correctly modified material density, the density of the unperturbed isotopes will be unchanged, but the density of the perturbed isotope will be changed by a factor 1 + *p*, as intended.

The first-order sensitivity of response *c* is calculated in post processing using $S = \Delta c_1/(c_0\, p)$, and *p* is arbitrary [FAV16].

The second PERT card (PERT2:p) gives the first-order Taylor series terms Δc_1 for changes in tallies caused by a 100% increase in the elastic (RXN=2) cross section of material 13. RHO=−2.34 g/cm^3 × 2 = −4.68 g/cm^3.

Example 4:

```
M4        6000.60C  0.5   6000.50C  0.5
M6        6000.60C  1
M8                        6000.50C  1
PERT1:N   CELL=3   MAT=6   METHOD=-1
PERT2:N   CELL=3   MAT=8   METHOD=-1
```

The perturbation capability can be used to determine the difference between one cross-section evaluation and another. The difference between these perturbation tallies will give an estimate of the effect of using different cross-section evaluations.

Example 5:

```
1  1  0.05   -1  2  -3    $ mat 1 at 0.05 x 10^24 atoms/cm^3
  .
  .
  .
M1       1001  0.1   8016  0.2    92235  0.7
M9       1001  0.1   8016  0.22   92235  0.7
F14:N    1
FM14    -1  1  -6  -7                  $ keff estimator for cell 1
PERT1:N   CELL=1   MAT=9   RHO=0.051   METHOD=1
PERT2:N   CELL=1   MAT=9   RHO=0.051   METHOD=-1
```

These perturbations involve a 10% increase in the oxygen atom fraction of material `1` (`RHO`=0.05×[1.02/1.0]=0.051). The effect of this perturbation on tally `14`, which is a track length estimate of k_{eff}, will be provided as a differential change (`PERT1`) as well as with this change added to the unperturbed estimate of k_{eff} (`PERT2`). Note: If the `RHO` keyword is omitted from the `PERT` cards, the ^{235}U composition will be perturbed, which can produce invalid results. (See Limitation/Caution #10.)

Example 6:

The MCNP6 perturbation capability assumes that changes in the relative concentrations or densities of the nuclides in a material are independent and neglects the cross-differential terms in the second-order perturbation term when changing two or more cross sections at once. In the case illustrated below there will be a large FALSE second-order perturbation term.

```
M1        6000.50c  0.5   6012.50c  0.5
M2        6000.50c  0.9   6012.50c  0.1
PERT1:N   CELL 1   MAT 2
```

The perturbation should be zero because `6000.50c` is exactly the same as `6012.50c`, making materials `M1` and `M2` identical. In fact, the first-order term will be zero (`METHOD 2`, correct) but the second-order term will be wrong because of the differential cross term.

Example 7:

There is no problem if all the nuclides have the same density change (`RHO` option but no `MAT` option). There is also no cross term problem if only one nuclide has a density change, for example:

```
cell 1 material 1 density rho=3.0
  .
  .
  .
M1       1001  2   8016  1
M2       1001  2   8016  2
PERT1:N  CELL 1  MAT 2  RHO=4.0
```

The cell density times the normalized atom fraction of `1001` is unchanged (3×2/3=4×2/4) and only the density of `8016` is changed (from 3×1/3 to 4×2/4). However, there will be a second-order cross-differential term that is neglected when the cell density times nuclide fraction changes for more than one nuclide in a perturbed material. Therefore, if the `MAT` keyword is used for a perturbation, the first- and second-order terms should be examined. If the second-order perturbation term is small relative to the first-order term (`METHOD 3` and `METHOD 2`), then generally the differential cross term is small and the perturbed tally can be accepted with confidence.

3.3.5.22 KPERT REACTIVITY PERTURBATIONS—ADJOINT WEIGHTING

The adjoint-weighted perturbation methodology invoked by the `KPERT` card was designed to investigate changes in k_{eff} as a result of material substitution. While this method, in theory, allows for more general perturbations, it introduces an approximation in the handling of scattering laws that can lead to large and unacceptable deviations in scattering sensitivities. Additionally, the user interface was designed with material substitution with mind; using it for sensitivity coefficient calculations may be cumbersome for some users. For sensitivity coefficient calculations, see the `KSEN` card (Section 3.3.5.23). Multiple `KPERT` cards are permitted in a single input file.

Form: `KPERT`*n* `KEYWORD=`*value(s)* ...

Table 3-104. Reactivity Perturbation (KPERT)

Input Parameter	Description
n	**Unique, user-selected, arbitrary perturbation number.** **Restriction: `0<n≤10,000`**
Keyword	**Description**
CELL= c_1 c_2 ... c_k	**Comma or space delimited list of cells, c_1 ... c_K, to which to apply the perturbation. Required.**
MAT= m_1 m_2 ... m_k	**List of materials that are to be substituted in each of the perturbed cells listed in the CELL keyword. Each cell must be associated with exactly one material number and each unique material identifier number must have an associated M card. (See Note 1.)**
RHO= r_1 r_2 ... r_k	**List of densities corresponding to each of the perturbed cells listed in the CELL keyword. Each cell specified on the CELL keyword must be associated with exactly one density value specified on the RHO keyword. (See Note 2.)** **If r_i>0, the perturbed density is given in units of atoms/b-cm^2.** **If r_i<0, the perturbed density is given in units of g/cm^3.**
ISO= z_1 z_2 ... z_n	**List of ZAIDs that the perturbation impacts. The list applies to all cells in the CELL list. (See Note 3.) (DEFAULT: all isotopes assumed affected)**
RXN= rx_1 rx_2 ... rx_m	**List of MT or special reaction numbers that the perturbation impacts. The list applies to all cells in the CELL list. (See Note 4.) Table 3-106 provides a list of acceptable entries. (DEFAULT: all reactions assumed affected)**
ERG= e_1 e_2 ... e_j	**List of energies (MeV), in ascending order, over which to apply the perturbation. (See Note 6.) (DEFAULT: all energies)**
LINEAR=[YES/NO]	**Provides the ability to force an unperturbed fission source, yielding a linear equation to estimate the change in reactivity that arises from a change in cross sections.†** **If LINEAR=YES, do not use the perturbed fission source in the denominator.** **If LINEAR=NO, use the perturbed fission source in the denominator. (DEFAULT)**

† Many applications, such as the calculation of sensitivity coefficients demand the use of linear-perturbation theory in which the denominator is unperturbed.

Default: ISO=all isotopes; RXN=all reactions; ERG=all energies; LINEAR=NO

Use: Optional. The CELL keyword, which identifies one or more perturbed problem cells, is required. Additionally, either the MAT or RHO keyword must be specified.

Note 1: If the RHO keyword is absent, the MAT keyword is required. Use the MAT keyword, for example, to test the effect of changing the enrichment of a particular set of cells.

Note 2: If the MAT keyword is absent, the RHO keyword is required. This keyword allows the user to perform density perturbations. RHO may be used in addition to the MAT keyword to perturb both the material and the density of the cells specified in the CELL keyword list.

Note 3: The ISO keyword is useful for testing the effect of individual nuclides.

Note 4: The RXN keyword is useful for testing the effect of individual reactions.

Note 5: The ERG keyword is similar to energy binning with tallies, except that there is no implied lower bound of 0 MeV.

Example 1:

```
KPERT5    CELL=1 4  MAT=2 2  RHO=-19.1 -19.1
```

This perturbation takes whatever materials are in cells 1 and 4 and makes them both material 2 with a mass density of 19.1 g/cm^3.

Example 2:

```
KPERT98    CELL=10  RHO=-18.6  RXN=18
```

This perturbation looks at the effect on the fission reaction (MT=18) when the mass density of the material in cell 10 is changed to 18.6 g/cm^3.

Example 3:

```
KPERT1    CELL=22 26  MAT=92 92  ISO=92238.70c RXN=51 39i 91
          ERG=0 2 5 20  LINEAR=YES
```

This perturbation judges the impact of ^{238}U inelastic scattering in cells 22 and 26 by a change to material 92. The perturbation is further broken down by energy, with regions of less than 2 MeV, between 2 and 5 MeV, and between 5 and 20 MeV. The perturbation is also linear.

3.3.5.23 KSEN K_{EFF} SENSITIVITY COEFFICIENTS—ADJOINT WEIGHTING

The KSEN card [KIE12, KIE13] provides the ability to compute sensitivity coefficients of the effective multiplication *k* (i.e., k_{eff}) for nuclear data. These types of calculations are useful for code validation and the development of benchmark suites applicable to specific sets of applications, for the design of critical (integral) experiments, and for uncertainty quantification. This computation is done in a KCODE calculation using the KSEN card; fixed-source problems are not appropriate for KSEN. Multiple KSEN cards are permitted in a single input file.

The methods employed are based upon linear-perturbation theory using adjoint weighting, the same as those used by TSUNAMI-3D for this purpose. The adjoint weighting is performed in a single forward calculation using the Iterated Fission Probability method. The capability is specifically designed for use in continuous-energy calculations, and while it is possible to use this option in multigroup calculations, MCNP6 does not compute the effect of the cross-section self-shielding on the sensitivity coefficients.

Form: `KSENn sen KEYWORD=value(s) ...`

Table 3-105. k_{eff} Sensitivity Coefficients (KSEN)

Input Parameter	Description
N	Unique, user-selected, arbitrary perturbation number. Restriction: $0<n\le999$
Sen	Type of sensitivity. If *sen*=XS, a cross-section or nuclear data sensitivity is specified. (Thkind of sensitivity supported at this time.)
Keyword	**Description**
ISO=z_1 z_2 ...z_n	List of ZAIDs for which sensitivities are desired. (DEFAULT: all data tables in the problem)
RXN=rx_1 rx_2 ...rx_m or, equivalently. MT=rx_1 rx_2 ...rx_m	List of reaction MT numbers or special reaction numbers. Table 3-106 provides a list of acceptable entries. [DEFAULT: total cross section without $S(\alpha,\beta)$])
ERG=e_1 e_2 ...e_j	List of energy bin boundaries, in ascending order, over which to provide the sensitivities. For cross sections and fission ν, the energies are taken to be those entering the collision (incident energy). For secondary distributions of fission chi and scattering laws, the energies are taken to be energies exiting the collision. If used, a minimum of two entries are required to establish at least one lower and upper boundary. (See Note 1.) (DEFAULT: all energies)
EIN=e_1 e_2 ...e_k	Specifies a range of incident energy bins. (See Note 1.) Only used for fission-chi (-1018) or scattering law (-1002 or -1004) sensitivities. (DEFAULT: all energies)
LEGENDRE	The LEGENDRE keyword is followed by a single integer (> 0) stating the order of Legendre moments to calculate sensitivities for (e.g., “LEGENDRE = 3” would give the keff sensitivity to the P1, P2, and P3 Legendre scattering moments) any scattering law sensitivity. If present calculates the scattering law sensitivity to Legendre moments instead of as a function of cosine binning. Note that to do this, MCNP needs a background cosine grid that may be provided by the user with the COS keyword. If this is not provided, a default cosine grid of 200 equally spaced cosine bins from -1 to 1 is used.
COS=c_1 c_2 ...c_n	Specifies a range of direction-change cosines for the scattering events. Only used for scattering law (-1002 or -1004) sensitivities. (DEFAULT: all angles)
CONSTRAIN=[YES/NO]	Only used for fission-chi (-1018) or scattering law (-1002 or -1004) sensitivities. If CONSTRAIN=NO, do not renormalize the energy (or cosine) sensitivity distribution. If CONSTRAIN=YES, renormalize the energy (or cosine) sensitivity distribution. (See Note 2.) (DEFAULT)

Default: `ISO`=all isotopes in the problem; `RXN=`total cross section without $S(\alpha,\beta)$; `ERG`=all energies; `EIN=`all energies, `COS`=all angles; `CONSTRAIN=YES`

Use: Optional. If the `KSEN` card is used, the `KOPTS` card is recommended (see Section 3.3.4.11) .

Note 1: Unlike tallies, there is no implied zero lower-energy-bin boundary.

Note 2: Increasing a distribution in one region of energy (or cosine) space needs to be offset by decreases elsewhere to preserve the condition that the distribution be normalized to a constant value, typically one. For most applications, users should use the default, i.e., renormalize the sensitivities. Full normat\lization [FAV17] is applied.

Note 3: For cross sections and fission nu, the energies listed on ERG are taken to be those entering the collision, whereas for secondary distributions of fission chi and scattering laws they are taken to be energies exiting the collision.

MCNP6 has the ability to subdivide sensitivities by spatial zone. These can be done either as a collection of cells or materials. The keywords on the KSEN card to do this are:

CELL = C1 (C2 C3) …

MAT = M1 (M2 M3) …

Each entry defines a spatial zone, and like with tally specifications, cells or materials may be grouped by parentheses. Duplicate cells or materials are allowed. A KSEN card may not have both the CELL and the MAT; doing this both ways requires multiple instances of KSEN. To summarize:

CELL List of cell numbers of the problem for spatial zoning. Each entry defines a spatial zone and multiple cells may be grouped into a single spatial zone with parentheses. Duplicate cells are allowed.

MAT Like the CELL keyword except material numbers are used as opposed to cell numbers. Zones are defined to encompass all cells containing that material.

Table 3-106. Allowed Reaction Numbers for KSEN with Continuous-Energy Physics

Nuclear Data	MT Number	Special Reaction Number
Total	**1**	**--**
Total+$S(\alpha,\beta)$	**--**	**-1**
Capture	**--**	**-2**

Elastic	**2**	**--**
Total Inelastic	**4**	**--**
Elastic+$S(\alpha,\beta)$	**--**	**-3**
Total Fission	**18**	**-6**
First-Chance Fission	**19**	**--**
Second-Chance Fission	**20**	**--**
Third-Chance Fission	**21**	**--**
Fourth-Chance Fission	**38**	**--**
Total Fission ν	**452**	**-7**
Prompt Fission ν	**456**	**--**
Delayed Fission ν	**455**	**--**
(n,2nd)	**11**	**--**
(n,2n)	**16**	
(n,3n)	**17**	**--**
(n, $n\alpha$)	**22**	**--**
(n, $n3\alpha$)	**23**	**--**
(n, $2n\alpha$)	**24**	**--**
(n, np)	**28**	**--**
(n, $n2\alpha$)	**29**	**--**
(n, $2n2\alpha$)	**30**	**--**
(n,nd)	**32**	**--**
(n,nt)	**33**	**--**
(n, n^3He)	**34**	**--**
(n,$nd2\alpha$)	**35**	**--**
(n,$nt2\alpha$)	**36**	**--**
(n,4n)	**37**	**--**
(n, $2n$p)	**41**	**--**
(n, $3n$p)	**42**	**--**
(n, $n2$p)	**44**	**--**
(n, npα)	**45**	**--**
(n,γ)	**102**	**--**
(n,p)	**103**	**--**
(n,d)	**104**	**--**
(n,t)	**105**	**--**
(n,^{3}He)	**106**	**--**
(n,α)	**107**	**--**
Inelastic Levels (1–40)	**51, 52, ..., 90**	**--**

Inelastic Continuum	**91**	**--**
Total Fission Chi	**--**	**-1018**
Prompt Fission Chi	**--**	**-1456**
Delayed Fission Chi	**--**	**-1455**
Total Scatter Law	**--**	**-1001**
Elastic Scatter Law	**--**	**-1002**
Inelastic Scatter Law	**--**	**-1004**

Example 1:

```
KSEN3  XS
```

Default behavior. Gives the total cross-section sensitivities (integrated over all energies) to all isotopes and $S(\alpha,\beta)$ laws in the problem.

Example 2:

```
KSEN14  XS  ISO=92235.70c 92238.70c  MT=-1 2 4 -6
```

Gives total, elastic, inelastic, and fission cross-section sensitivities for ^{235}U and ^{238}U.

Example 3:

```
KSEN8  XS  ISO=1001.70c lwtr.10t  MT=2 4  ERG=0.0 0.625e-6 0.1 20
```

Gives ^{1}H elastic scattering and the light-water $S(\alpha,\beta)$ inelastic scattering kernel sensitivities as a function of energy with bins between 0 and 0.625 eV, 0.625 eV to 100 keV, and 100 keV to 20 MeV.

Example 4:

```
KSEN99  XS   ISO=94239.70c  MT=-1018  ERG=0 0.1 1.0 2.0 5.0 10.0 20.0
             EIN=0 2.5 8.0 20.0  CONSTRAIN=NO
```

Gives ^{239}Pu fission-chi sensitivities as a function of outgoing and incident energy. The incident energy bins are 0 to 2.5 MeV, 2.5 to 8 MeV, and 8 to 20 MeV. For each of these, a fission-chi sensitivity is given for the six energy bins specified by the `ERG` keyword. The sensitivity is also not renormalized, which is normally discouraged.

Example 5:

```
KSEN8016  XS  ISO=8016.70c  MT=-1002  ERG=0 19i 20  COS=-1 0 1
```

Gives ^{16}O elastic scattering law sensitivities for 1-MeV (outgoing) energy bins from 0 to 20 MeV. Each outgoing energy bin is subdivided into two cosine bins for forward and back scattering. The sensitivity includes neutrons scattering at all possible incident energies.

Example 6:

```
KSEN101  XS  CELL=10 20 (10 20)  ERG=SCALE-238
```

Gives total cross section sensitivities for all isotopes in the problem with an energy binning defined by SCALE's 238-group library. Three energy-resolved sensitivity profiles are given: one for cell 10, another for cell 20, and a third for both (the sum of the sensitivities for cells 10 and 20).

Example 7:

```
KSEN101  XS  RXN=-1002 -1004  LEGENDRE=5  ISO=26056.70c  MAT=20
```

Gives the sensitivities for the first five Legendre moments of elastic and inelastic scattering of ^{56}Fe, but only for cells with material 20. The default cosine grid of 200 equally spaced intervals from -1 to 1 is used for computing the Legendre moment sensitivities because the COS keyword is not specified.

Other options may be controlled by use of the KOPTS card, which contains various options for KCODE calculations. The two options are BLOCKSIZE, which controls the number of cycles in every outer iteration, and KSENTAL, which controls output printing of a results file for sensitivity profiles. The format for these is as follows:

KOPTS   BLOCKSIZE = *NCY*   KSENTAL = *FILEOPT*

The NCY argument denotes the number of cycles. A greater number leads to better accuracy of the answer, but the results will be less statistically resolved. The default is 10 cycles, which has been shown to be conservative for almost all cases and still preserves a reasonable about of statistical precision. For small, leakage dominated systems, this can often be reduced to 5.

The FILEOPT argument gives a file format for printing the sensitivity profiles. The default is to print no file. In MCNP6, two file formats are available: MCTAL and TSUNAMI-B. The MCTAL format has MCNP print the sensitivity profiles in a special file called ksental which is similar to an mctal file for tallies, and can be plotted by MCPLOT. The TSUNAMI-B format is defined in the SCALE6 Manual. The concepts used by MCNP and SCALE are not necessarily compatible depending on the sensitivity profile options in either code, so the TSUNAMI-B format may not be able to capture everything that MCNP can compute. A description of the formats are given below.

An example illustrating these concepts:

```
KOPTS   BLOCKSIZE = 5   KSENTAL = TSUNAMI-B
```

By default MCNP prints the sensitivity profiles to the output file. These are located below "the box" with the *k* results with the heading "nuclear data sensitivity profiles". The ordering of results changes depending upon the requested information. Regardless, the sensitivities are presented as the sensitivity result (integrated over an energy bin) and its associated relative uncertainty. Note that because sensitivities may either be positive or negative, those near zero may have a very large (greater than one) relative uncertainty, but the absolute uncertainty may be quite small.

If no energy bins are requested, then the sensitivities will be presented as:

```
ZAID        REACTION        SENS        REL UNC
```

If energy bins are requested, then the sensitivities will be presented as a function of energy for each isotope and reaction:

```
ELOW        EHIGH           SENS        REL UNC
```

Here ELOW and EHIGH denote the energy bin boundaries. These energy-resolved results may be plotted for visualization in various plotting programs (GNUPLOT, MS Excel, etc.). When doing so, it is usually recommended to plot the profiles per unit lethargy (divide each sensitivity by the logarithm of the ratio of EHIGH to ELOW) on a semi log-x scale. Doing so makes it visually accurate in that areas under curves are visually representative of magnitudes of sensitivity coefficients integrated over energy ranges.

If incident energy grids for secondary distributions are requested, then an energy-resolved profile in the above format is given for each incident energy bin. For cosine bins, if an ERG card is specified, then additional grids in the above format is given for each cosine bin. If no ERG card is specified, but COS bins are, then the following results are given for all outgoing energies:

```
CLOW        CHIGH           SENS        REL UNC
```

Here CLOW and CHIGH are the lower and upper cosine bounds.

It is also possible to have the results printed to a special MCTAL-formatted file called “ksental”. This is done with the KOPTS keyword and a discussion of its use may be found in Section III.

The MCTAL file format is very much like the standard MCTAL file except that the symbols for bins have different meanings. These are:

F = spatial zones as cells or materials (0 denoting all cells)
D = unused
U = unused
S = isotopes
M = reaction MTs
C = cosine bins
E = energy bins
T = incident energy bins (for fission chi or scattering laws)

The MCNP tally plotter, MCPLOT may be loaded to plot these results. Again, the results should be normalized to be per unit lethargy with the "lethargy" option and plotted on a semi log-x scale for visually accurate area plots.

The TSUNAMI-B format is given in the SCALE6 Manual (See Table M18.A.2 in the SCALE6.1 Manual for a full description). Since the SCALE and MCNP6 sensitivity capabilities are different, not all concepts in each code perfectly translate. In writing the TSUNAMI-B file format, MCNP will do the following:

- Multiple energy grids, which is possible in MCNP by multiple uses of the KSEN card, are not supported by TSUNAMI-B. To handle this, each instance of the KSEN card is listed in the file one after the other. For use in SCALE plotting tools, these will need to be split into multiple files.
- Unlike MCNP, energy units in SCALE are in eV, not MeV. The TSUNAMI-B format gives the energies in eV.
- The concept of a unit is not defined in MCNP, and the portion of the header that reports a unit number will give a 0 if no spatial zoning is involved, 1 if the zoning is by cell, and 2 if it is by material. The entry that follows (normally the region within the unit) is an enumeration of each spatial zone (the first zone has a "1", the second a "2", and so on).
- MCNP may not be able to compute the volume of a region. In this case, MCNP prints zero to the TSUNAMI-B file.
- In the place where TSUNAMI-B reports the number of uses of the region, MCNP reports the number of spatial zones on this instance of KSEN.
- For fission chi sensitivities, the ones reported are automatically summed over all incident energy grids as the TSUNAMI-B format does not support this.
- The TSUNAMI-B format does not support scattering laws, so these are omitted.

SUPERIMPOSED MESH TALLIES: TWO VERSIONS

MCNP6 offers two different mesh tallies to the user. The `TMESH` tally (Section 3.3.5.24) was developed for the MCNPX code, while the `FMESH` tally (Section 3.3.5.25) was developed for MCNP5. Although similar, each method is characterized by its own syntax, card format, and output files. The user is encouraged to read about both methods and choose the one that is most appropriate for his or her problem.

3.3.5.24 TMESH SUPERIMPOSED MESH TALLY A

Form: (See Section 3.3.5.24.1)

The TMESH tally is a method of graphically displaying particle flux, dose, or other quantities on a rectangular, cylindrical, or spherical grid overlaid on top of the standard problem geometry. Particles are tracked through the independent mesh as part of the regular transport problem. The contents of each mesh cell are written to the RUNTPE file and can be plotted with the MCNP6 geometry plotter superimposed over a plot of the problem geometry. The TMESH tally data are also written to the MCTAL file and can be plotted with the MCNP6 tally plotter, MCPLOT.

Further, the TMESH tally data are written to the MDATA file at the end of each initial-run or continue-run. The MDATA file can be converted into a number of standard formats suitable for reading by various graphical analysis packages. Although the conversion program, GRIDCONV (Section 3.3.5.24.6), is not supplied as part of the overall MCNP6 package, the MCNPX version should be able to read and process most of the output files from MCNP6. Analysis of this data is limited only by the capabilities of the graphical program being used.

Four different mesh-tally types are provided by TMESH:, depending on the information the user wishes to view.

Type 1: Track-Averaged Mesh Tally (Section 3.3.5.24.2)
Type 2: Source Mesh Tally (Section 3.3.5.24.3)
Type 3 Energy Deposition Mesh Tally (Section 3.3.5.24.4)
Type 4: DXTRAN Mesh Tally (Section 3.3.5.24.5)

Each of the four types has its own associated keywords and input values.

For additional information involving the superimposed geometry TMESH tally see Section 5.4.4.

DESCRIPTION OF GENERAL TMESH INPUT CARDS	
Card Mnemonic	**Description**
TMESH	Block Initiation Card
CORA	Data Card for Mesh Coordinate Direction #1
CORB	Data Card for Mesh Coordinate Direction #2
CORC	Data Card for Mesh Coordinate Direction #3
ERGSH	Mesh Tally Energy or Time Boundary Card
MSHMF	Response Function
RMESH	Rectangular Mesh Control Card
CMESH	Cylindrical Mesh Control Card
SMESH	Spherical Mesh Control Card
ENDMD	Block Termination Card

3.3.5.24.1 SETTING UP THE TMESH TALLY IN THE INP FILE

All of the input for TMESH tallies must be in a dedicated block of cards in the INP file data card section. This block must start with a card containing the word TMESH in the first five columns and end with a card containing the word ENDMD in the first five columns. For each requested mesh tally (a maximum of 20 TMESH tallies are permitted), a minimum of four cards must exist between the TMESH and ENDMD cards: an RMESH, CMESH, or SMESH control card, and CORA, CORB, and CORC cards. Optional cards within the mesh-tally block include ERGSH and MSHMF. An FM tally multiplier card may be specified only for Type 1 mesh tallies (Section 3.3.5.24.2); *however, if an* FM *card is associated with a Type 1 mesh tally, it must appear outside of the* TMESH/ENDMD *card block*. Each of these cards is described in the discussion that follows.

The basic structure of the desired mesh as well as what quantities are to be stored to the mesh tally are determined by a mesh control card (RMESH, CMESH, or SMESH). The general form of the control cards follow:

```
RMESHn:<pl>    KEYWORD=value(s) ...
CMESHn:<pl>    KEYWORD=value(s) ...
SMESHn:<pl>    KEYWORD=value(s) ...
```

where

RMESH specifies a rectangular mesh;

CMESH specifies a cylindrical mesh;

SMESH specifies a spherical mesh;

<pl> is the particle type to be tallied—this parameter may or may not be required, depending on the mesh-tally type;

n is a user-defined mesh-tally number for which the last digit of *n* , defines the type (1, 2, 3, or 4) of mesh tally and, consequently, the type of information to be stored in the mesh; and

KEYWORD options vary depending on the mesh-tally type.

The notation (R/C/S)MESH will be used in subsequent sections to indicate any of the three mesh geometries. Input keywords for the four mesh-tally types are described in sections that follow. Note that the chosen mesh-tally number must be different from all other tallies in the problem. For example, an F1:N tally will conflict with a RMESH1:N tally.

In addition to the (R/C/S)MESH control card, the following set of cards provides details about the TMESH mesh characteristics and must be present for each requested mesh tally:

```
CORAn    corra_n,1  corra_n,2 ...
CORBn    corrb_n,1  corrb_n,2 ...
CORCn    corrc_n,1  corrc_n,2 ...
```

where *n* is the same user-defined mesh-tally number as that on the associated (R/C/S)MESH control card. The mesh tally number must end in 1, 2, 3, or 4 corresponding to the mesh tally type. The entries on the CORA, CORB, and CORC cards describe a mesh in three coordinate directions as defined by the mesh type (rectangular, cylindrical, or spherical), prior to any transformation. (Each tally type supports an optional TRANS keyword to allow the application of a coordinate transformation to the mesh.)

To describe a rectangular mesh, the entries on the CORA card represent planes perpendicular to the *x*-axis, CORB entries are planes perpendicular to the *y*-axis, and CORC entries are planes perpendicular to the *z*-axis. Bins do not have to be equally spaced.

To describe a cylindrical mesh, the middle coordinate, CORB, is the untransformed *z*-axis, which is the symmetry axis of the cylinder, with radial meshes defined on the CORA input line. The first smallest radius must be equal to zero. The values following CORB define planes perpendicular to the untransformed *z*-axis. The values following CORC are positive angles relative to a counter-clockwise rotation about the untransformed *z*-axis. These angles, in degrees, are measured from the positive *x*-axis and must have at least one entry of 360, which is also required to be the last entry. The lower limit of zero degrees is implicit and never appears on the CORC card.

For spherical meshes, scoring will happen within a spherical volume, and can also be further defined to fall within a conical section defined by a polar angle (relative to the +*z*-axis) and azimuthal angle. The CORA card entries are sphere radii; inner and outer radii are required. The CORB entries define the polar angle meshing in which the polar angle ranges from 0 to 180 degrees, the 1st bin must be greater than 0 degrees, and the last bin must be 180. The CORC entries are the same as in the cylindrical case, with the 1st bin greater than 0 degrees and the last bin equal to 360. It is helpful in setting up spherical problems to think of the longitude-latitude coordinates on a globe.

The "I" data-input notation (Section 2.8.1) is allowed, enabling a large number of regularly spaced mesh points to be defined with a minimum of entries on the coordinate lines. All of the coordinate entries must be monotonically increasing for the tally mesh features to work properly, but do not need to be equally spaced. It should be noted that the size of these meshes scales with the product of the number of entries for the three coordinates. Machine memory could become a problem for very large meshes with fine spacing.

Additional cards that can be used with TMESH mesh tallies include the following:

ERGSH*n*	e_1 e_2	,
MSHMF*m*	e_1 f_1 e_2 f_2 ... e_i f_i	, and
FM*n*	...	,

where positive values on the ERGSH card, e_1 and e_2, are the lower and upper energy limits for information to be stored to mesh tally *n*. On the other hand, negative values of e_1 and e_2 represent lower and upper time limits (in shakes) for information to be stored to mesh tally *n*. The default is to consider all energies and all times. The value of *m* on the MSHMF card does *not* refer to a corresponding mesh tally; instead, *m* is an arbitrary user-assigned value between 1 and 9. The entries on the MSHMF card, e_i and f_i, are pairs of energies and the corresponding response functions; as many pairs as needed can be designated. Use of the FM card is limited to Type 1 mesh tallies (Section 3.3.5.24.2) and the card must *not* appear inside the TMESH card block..

Note that the type 1 (particle track) and type 3 (energy deposition) mesh tallies work with heavy ions although there is no capability to separate out contributions from particular heavy ion species. Also, in void regions, electron mesh tallies will generate zeros; to circumvent this issue, a material of very low density (but ≥1E-15 g/cm^3) may be specified in these regions.

For additional examples involving the mesh tally see Section 5.4.4.

3.3.5.24.2 TRACK-AVERAGED TMESH MESH TALLY (TYPE 1)

The first TMESH mesh type scores track averaged data: flux, fluence, or current. The values can be weighted by an MSHMF card, through a dose conversion-coefficient function, or for energy deposition.

Form: (R/C/S)MESH*n*:<*pl*> KEYWORD=*value*(*s*) ...

where *n*= 1, 11, 21, 31, ..., and <*pl*> is the particle type. (See Table 2-2.) (Note: The mesh tally number, *n*, must not duplicate one used for an F1 tally.) There is no default. The allowed keywords for the Type 1 TMESH are presented in Table 3-107.

Table 3-107. Track-Averaged TMESH Mesh Tally (Type 1)

Keyword	Description
TRAKS	If TRAKS appears on the input line, tally the number of tracks through each mesh volume. No values accompany the keyword.
FLUX	If FLUX appears on the input line, then the average fluence is particle weight times track length divided by volume in units of number/cm^2. If the source is considered to be steady state in particles per second, then the value becomes flux in number/cm^2/second. No values accompany the keyword. (DEFAULT)
DOSE	Causes the average flux to be modified by an energy-dependent dose function. The DOSE keyword may be followed by up to four entries, where If the first entry is 1 to 9, an energy-dependent dose function must be supplied by the user on an MSHMF card. If the first entry is 10, 20, 31–35, 40, or 99, the dose function is an ANSI standard dose as on the DF card. The next three optional entries define additional standard dose options: *int*, *iu*, and *fac*. See the dose conversion coefficients discussion below and Section 3.3.5.8—DF card. If no entries follow the DOSE keyword, the default entries are 10, 1, 1, and 1.0, which form inputs into the dose conversion-coefficient function. Results are in rem/hour/source_particle. These functions are described in Table 3-108.
POPUL	If POPUL appears on the input line, tally the population (i.e., weight times the track length) in each volume.

Keyword	Description
PEDEP	**If PEDEP appears on the input line, scores the average energy deposition per unit volume (MeV/cm^3/source_particle) for the particle type <*pl*>. In contrast to the 3rd type of mesh tally, energy deposition can be obtained in this option for any particular particle.** **This option allows one to score the equivalent of an F6:<*pl*> (see Section 3.3.5.1.1) heating tally for the particle type <*pl*>. Note, the mesh is independent of problem geometry, and a mesh cell may cover regions of several different masses. Therefore the normalization of the PEDEP option is per mesh cell volume, not per unit mass.**
MFACT	**Can have from one to four numerical entries following it.** **The value of the first entry, *m*, is an arbitrary number that refers to an energy-dependent response function given on an MSHMF*m* card. If *m*=-1, then it is followed by a single value that is used as a constant multiplier. (No default)** **The second entry is 1 for linear interpolation and 2 for logarithmic interpolation. (DEFAULT=1)** **If the third entry is 0, the response is a function of the current particle energy; if the third entry is 1, the response is a function of the energy deposited (only valid with the PEDEP option). (DEFAULT=0)** **The fourth entry is a constant multiplier and is the only floating-point entry allowed. (DEFAULT=1.0)** **If any of the last three entries are used, the entries preceding it must be present so that the order of the entries is preserved. Only one MFACT keyword may be used per tally.**
TRANS	**Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card. (See Note 1.)**

Note 1: If a TR card is used with a mesh tally, it must appear outside of the mesh data block between the TMESH and ENDMD cards.

It is possible to use the FM tally multiplier card (Section 3.3.5.7) to calculate reaction rates in a type 1 mesh tally if both of the following criteria hold:

- the FM card must *not* appear within the mesh data block between the TMESH and ENDMD cards; and
- if the multiplier involves a MT reaction identifier, the FM card must be included in an equivalent F4 tally specification.

Dose Conversion Coefficients for TMESH Type 1 Mesh Tallies

MCNP6 contains a number of standard dose conversion coefficients that are accessed through the DOSE keyword of the Type 1 TMESH mesh tally.

Form: `DOSE` *`ic int iu fac`*

where each of the parameters is described in Table 3-108.

Table 3-108. DOSE Parameter Descriptions for Type 1 Mesh Tallies

Parameter	Description
ic	**Choice of conversion coefficient.** **Note: The 10 and 20 options are *dose equivalent* (H), i.e., absorbed dose at a point in tissue weighted by a distribution of quality factors (Q) related to the LET distribution of radiation at that point.** **The 30 options *are equivalent dose* (H_t) based on an average absorbed dose in the tissue or organ (D_t), weighted by the radiation weighting factor (w_r), summed over all component radiations.** **Neutrons:** **If *ic*=10 ⇒ ICRP-21 1971 (DEFAULT)** **If *ic*=20 ⇒ NCRP-38 1971, ANSI/ANS 6.1.1—1977** **If *ic*=31 ⇒ ANSI/ANS 6.1.1—1991 (AP anterior-posterior)** **If *ic*=32 ⇒ ANSI/ANS 6.1.1—1991 (PA posterior-anterior)** **If *ic*=33 ⇒ ANSI/ANS 6.1.1—1991 (LAT side exposure)** **If *ic*=34 ⇒ ANSI/ANS 6.1.1—1991 (ROT normal to length & rotationally symmetric)** **If *ic*=40 ⇒ ICRP-74 1996 ambient dose equivalent** **Photons** **If *ic*=10 ⇒ ICRP-21 1971 (DEFAULT)** **If *ic*=20 ⇒ Claiborne & Trubey, ANSI/ANS 6.1.1-1977** **If *ic*=31 ⇒ ANSI/ANS 6.1.1—1991 (AP anterior-posterior)** **If *ic*=32 ⇒ ANSI/ANS 6.1.1—1991 (PA posterior-anterior)** **If *ic*=33 ⇒ ANSI/ANS 6.1.1—1991 (LAT side exposure)** **If *ic*=34 ⇒ ANSI/ANS 6.1.1—1991 (ROT normal to length & rotationally symmetric)** **If *ic*=35 ⇒ ANSI/ANS 6.1.1—1991 (ISO isotropic)** **Special Dose Function** **If *ic*=99 ⇒ ICRP-60 (effective-dose conversion function for energy deposition tallies; see Table 3-91 for more information)**
int	**Interpolation method** **If *int*=1, then use logarithmic interpolation in energy, linear in function. (DEFAULT)** **If *int*=2, then use linear interpolation in energy and function.** **If *int*=3, then use recommended analytic parameterization (not available for *ic*=10).**

Parameter	Description
Iu	**Units of the result.** **If *iu*=1, units will be (rem/h)/(particles). (DEFAULT)** **If *iu*=2, units will be (sieverts/h)/(particles).**
Fac	**Normalization factor for dose.** **If *fac*≥0.0, then the dose conversion-coefficient function result will be multiplied by this value. (For example, *fac*=1.0 means no change.) The value must be a real number. (DEFAULT: *fac*=1.0)** **Certain special options are also available.** **If *fac*=-1.0, then normalize dose conversion results to Q=20 by dividing out the parametric form of Q, which equals 5.0+17.0*exp(-(ln(2E))/*2/6) from ICRP60 (1990), paragraph A12 (i.e., normalize results to Q=20).** **If *fac*=-2.0, then apply LANSCE albatross response function.** **If *fac*=-3.0, then use quality factors based on the stopping powers (see IC=99/**

3.3.5.24.3 SOURCE TMESH MESH TALLY (TYPE 2)

The second type of mesh tally scores source-point data, in which the weight of the source particles <*pl*>$_1$, <*pl*>$_2$, <*pl*>$_3$, ..., and <*pl*>$_n$ are scored in mesh arrays 1, 2, 3, ..., *n*. A separate mesh tally grid will be produced for each particle chosen.

The usefulness of this method involves locating the source of particles entering a certain volume, or crossing a certain surface. The user asks the question, "If particles of a certain type are present, where did they originally come from?" In shielding problems, the user can then try to shield the particles at their source.

This mesh tally is normalized as number of particles per SDEF source particle.

Form: (R/C/S)MESH*n* <*pl*>$_1$ <*pl*>$_2$ ... KEYWORD=*value*

where *n*= 2, 12, 22, 32, …. (Note: Number must not duplicate one used for an F2 tally.). The allowed keywords for the Type 2 TMESH are presented in Table 3-109.

Table 3-109. Source Mesh Tally (Type 2)

Input Parameter	Description
<*pl*>$_i$	**Particle designators, i.e., N, P, E, etc. (See Table 2-2.)** **Restriction: *i*≤10** **Source particles are considered to be those that come directly from the source defined by the user and those new particles created during nuclear interactions. One should be aware that storage requirements can get very large, very fast, depending on the dimensions of the mesh, because a separate histogram is created for each particle chosen. If there are no entries on this card, the information for neutrons is scored by default.**

Keyword	Description
TRANS	**Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card.**

3.3.5.24.4 ENERGY DEPOSITION TMESH MESH TALLY (TYPE 3)

The third type of mesh tally scores energy deposition data in which the energy deposited per unit volume from *all particles* is included. This can be due to the slowing of a charged particle, the recoil of a nucleus, energy deposited locally for particles born but not tracked, etc. The results are similar to the scoring of an +F6 tally as described in Section 3.3.5.1.1.

Note that in MCNP6 the option to track energy deposition from one type of particle alone in a problem is included in the first mesh tally type. (See Table 3-107, keyword PEDEP.) The energy deposition mesh tally described here gives results for all particles tracked in the problem, and has no option to specify a particular particle.

Because the mesh is independent of problem geometry, a mesh cell may cover regions of several different masses. Therefore the normalization of the output is per unit volume (MeV/cm^3/source_particle), not per unit mass.

Form: (R/C/S)MESH*n* KEYWORD=*value*(*s*) ...

where *n*= 3, 13, 23, 33, ... The allowed keywords for the Type 3 TMESH are presented in Table 3-110.

Table 3-110. Energy Deposition Mesh Tally (Type 3)

Keyword	Description
TOTAL	**If TOTAL appears on the input line, score energy deposited from any source. No values accompany the keyword. (DEFAULT)**
DE/DX	**If DE/DX appears on the input line, score ionization from charged particles. No values accompany the keyword.**
RECOL	**If RECOL appears on the input line, score energy transferred to recoil nuclei above tabular limits. No values accompany the keyword.**
TLEST	**If TLEST appears on the input line, score track length folded with tabular heating numbers. No values accompany the keyword.**
EDLCT	**If EDLCT appears on the input line, score non-tracked particles assumed to deposit energy locally. This allows the user to ascertain the potential error in the problem caused by allowing energy from non-tracked particles to be deposited locally. This can be a serious problem in neglecting the tracking of high-energy photons or electrons. No values accompany the keyword.**

Keyword	Description
MFACT	**Can have from one to four numerical entries following it.** **The value of the first entry, *m*, is an arbitrary number that refers to an energy-dependent response function given on an MSHMF*m* card. If *m*=-1, then it is followed by a single value that is used as a constant multiplier. (No default)** **The second entry is 1 for linear interpolation, and 2 for logarithmic interpolation. (DEFAULT=1)** **If the third entry is 0, the response is a function of the current particle energy; if the third entry is 1, the response is a function of the energy deposited. (DEFAULT=0)** **The fourth entry is a constant multiplier and is the only floating-point entry allowed (DEFAULT=1.0).** **If any of the last three entries are used, the entries preceding it must be present so that the order of the entries is preserved. Only one MFACT keyword may be used per tally.**
TRANS	**Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card.**

3.3.5.24.5 DXTRAN TMESH MESH TALLY (TYPE 4)

The fourth type of mesh tally scores the tracks contributing to all detectors defined in the input file for the <*pl*> particle type. If this mesh card is preceded by an asterisk (*), tracks contributing to DXTRAN spheres (see Section 3.3.6.10) are recorded. Obviously, a point detector or DXTRAN sphere must already be defined in the problem, and the tally will record tracks corresponding to all such defined items in the problem. The user should limit the geometrical boundaries of the grid to focus on a specific detector or DXTRAN sphere in order to prevent confusion with multiple detectors (although the convergence of the particle tracks should help in the interpretation).This tally is an analytical tool useful in determining the behavior of detectors and how they may be effectively placed in the problem.

Form: (R/C/S)MESH*n*:<*pl*> KEYWORD=*value*

where *n*= 4,14, 24, 34, ..., and <*pl*> is a particle type [neutron (N) or photon (P)]. (Note: Number must not duplicate one used for an F4 tally.) There is no default. The allowed keywords for the Type 4 TMESH are presented in Table 3-111.

Table 3-111. DXTRAN Mesh Tally (Type 4)

Keyword	Description
TRANS	**Must be followed by a single reference to a TR card number that can be used to translate and/or rotate the entire mesh. Only one TR card reference is permitted with a mesh card.**

3.3.5.24.6 PROCESSING THE TMESH MESH TALLY RESULTS

The values of the coordinates, the tally quantity within each mesh bin, and the relative errors are all written by MCNP6 to the RUNTPE file, the optional MCTAL file, and an unformatted binary file named MDATA.

The mesh tallies may be plotted with the MCNP6 geometry plotter either during the course of a run (by placing an `MPLOT` card in the input file or by using the TTY interrupt capability to invoke MCPLOT) or after a run using the RUNTPE file and the MCNP6 geometry plotter. These plots are superimposed over 2D views of the problem geometry. Note that the geometry plotter must be accessed via the tally plotter. For example,

```
MCNP6 Z
MCPLOT>RUNTPE=<filename>
MCPLOT>PLOT
PLOT>py 4 ex 40 or 0 4 0 la 0 1 tal12 color on la 0 0 con 0 100 %
```

After the `PLOT` command, the MCNP6 interactive geometry plotter appears. If the `Plot>` button (bottom center) is clicked, then the above command after the `PLOT>` prompt can be entered. Alternatively, the mesh tally superimposed on the geometry can be viewed by clicking buttons (`tal`, etc.) of the interactive tally plot. Note that the command `tal12` has no space between `tal` and `12` and that the cell labels (`la 0 1 tal12`) must be turned on to set the color (`color on`) and then be turned off (`la 0 0`).

The second mesh tally processing option is to use the MCNP6 tally plotter (MCPLOT) after a run with the optional MCTAL file (see `PRDMP` card). For example,

```
MCNP6 Z
MCPLOT>RMCTAL=<filename>
tal 12 free ik
```

Note that there is a space between `tal` and `12` and that the mesh tally dimensionality (`i`,`j`,`k`) corresponding to `CORA`, `CORB`, and `CORC`) must be specified.

The third mesh tally processing option is to post-process the MDATA (or MCTAL) file with GRIDCONV and then use an external graphics package.

The GRIDCONV program is a post-processing code used with the MDATA output file. It can also be used with the MCTAL output file from the radiography tally as described in Section 3.3.5.1.2. GRIDCONV converts the data arrays in MDATA to forms compatible with various external graphics packages. Those supported in MCNP6 include the following:

PAW	PAW (Physics Analysis Workstation) is distributed through the CERN Program Library. (`http://wwwasd.web.cern.ch.wwwasd/paw/index.html`)

IDL	IDL (Interactive Data Language) is a product of ITT Visual Information Solutions, 4990 Pearl East Circle, Boulder, CO 80301 (`http://www.ittvis.com/idl/index.asp`)
Tecplot	Tecplot is a product of Amtec Engineering, Inc., 13920 SE Eastgate Way, Ste. 220, Bellevue, WA 98005 (`http://www.amtec.com`)
GNUPLOT	Freeware. (`http://www.gnuplot.info`). Only 1D and 2D plots supported.

Like MCNP6, GRIDCONV will compile on several platforms. However, currently the PAW part of the code will not compile on the Linux operating system, since some of the PAW subroutines needed by the code are not Linux compatible. GRIDCONV may be compiled with a '`NOPAW`' option.

After GRIDCONV is compiled, one need type only the word '`GRIDCONV`' to execute the code. The code will then prompt the user for information that is required such as file type, file names, etc. In most cases the default value is used and a return is all that is necessary.

Once the header information from MDATA has been read from the file, GRIDCONV can either produce an ASCII file from a binary or generate the required graphics input files as requested by the user. (Note that the ASCII file contains raw data not normalized to the number of source particles.) The reason for the option to write an ASCII file is that sometimes users will want to look at the numbers in the MDATA file before doing any plotting, or check the numerical results for a test case. The ASCII option is also very useful for porting the MDATA file to another computer platform, and for reading the data into graphics packages not currently supported by GRIDCONV.

GRIDCONV is currently set up to generate one-, two-, or three-dimensional graphics input files with any combination of binning choices. Once the input file has been generated, GRIDCONV gives the user the option of producing another file from the currently selected mesh tally, selecting a different mesh tally available on this MDATA file, or reading information from a different file. Of course there is always the option to exit the program.

The capabilities of GRIDCONV have recently been expanded so that any and all tallies written to MCTAL can be processed. The code is still interactive, but now shows all tallies in the problem, from which any may be selected. The user has the option of generating one- or two-dimensional output. The user is then told about the bin structure so the one or two free variables may be selected. The energy is the default independent variable in the one-dimensional case. There is no default for the two-dimensional case. The order in which the two-dimensional bin variables are selected does not make any difference to the output, in that the order of the processing will be as it appears on the MCTAL file.

For additional information involving superimposed geometry mesh tallies, see Section 5.4.4.

3.3.5.25 FMESH SUPERIMPOSED MESH TALLY B

The FMESH card allows the user to define a mesh tally superimposed over the problem geometry. Results are written to a separate output file with the default name MESHTAL. By default, the mesh tally calculates the track length estimate of the particle flux averaged over a mesh cell in units of particles/cm^2. If an asterisk precedes the FMESH card, energy times particle weight will be tallied in units of MeV/cm^2. Other mesh-tally types include source points and isotopic reaction rates.

FMESH mesh tallies can be used in combination with the DE, DF, FC, FM, and TR cards. FMESH mesh tallies can be used in combination with the surface (SF) and cell (CF) flagging tally cards. However, unlike the regular tallies, only one mesh tally, the flagged tally, is created. A separate mesh tally will need to be provided for un-flagged tally results.

Form: FMESH*n*:<*pl*> KEYWORD=*value*(*s*)

where *n* is a tally number ending in the numeral 4 (only type 4 volume flux tallies are permitted) and <*pl*>=N or P or E. The allowed FMESH keywords are presented in Table 3-112.

Table 3-65. Superimposed FMESH Mesh Tally

Keyword	Description
GEOM	**Mesh geometry, either Cartesian (XYZ or REC) or cylindrical (RZT or CYL) coordinates. (DEFAULT: GEOM=XYZ)**
ORIGIN	**Coordinates *x,y,z* of the origin of the mesh in terms of MCNP6 cell geometry. This position is the bottom center for cylindrical coordinates or the bottom, left, behind for rectangular coordinates. (DEFAULT: ORIGIN=0.,0.,0.) (See Note 1.)**
AXS	**Vector giving the direction of the axis of the cylindrical mesh. (DEFAULT: AXS=0.,0.,1.) (See Note 2.)**
VEC	**Vector defining, along with AXS, the plane for θ=0. (DEFAULT: VEC=1.,0.,0.) (See Note 2.)**
IMESH	**Locations of the coarse mesh points in the *x* direction for rectangular geometry or in the *r* direction for cylindrical geometry. (DEFAULT: none) (See Note 3.)**
IINTS	**Number of fine mesh points within each corresponding coarse mesh in the *x* direction for rectangular geometry or in the *r* direction for cylindrical geometry. (DEFAULT: IINTS=1)**
JMESH	**Locations of the coarse mesh points in the *y* direction for rectangular geometry or in the *z* direction for cylindrical geometry. (DEFAULT: none) (See Note 3.)**
JINTS	**Number of fine mesh points within each corresponding coarse mesh in the *y* direction for rectangular geometry or in the *z* direction for cylindrical geometry. (DEFAULT: JINTS=1)**

Keyword	Description
KMESH	**Locations of the coarse mesh points in the *z* direction for rectangular geometry or in the θ direction (in revolutions) for cylindrical geometry. (DEFAULT: none) (See Note 3.)**
KINTS	**Number of fine mesh points within each corresponding coarse mesh in the *z* direction for rectangular geometry or in the θ direction for cylindrical geometry. (DEFAULT: KINTS=1)**
EMESH	**Values of the coarse mesh points in energy in MeV. (DEFAULT: EMESH=0.,$E_{pl,max}$)**
EINTS	**Number of fine mesh points within each corresponding coarse mesh in energy. (DEFAULT: EINTS=1)**
ENORM	**If ENORM=NO, then the tally results are not divided by energy bin width. If ENORM=YES, then provides the tally results per unit energy (MeV^{-1}). (DEFAULT: ENORM=NO)**
TMESH	**Values of the coarse mesh points in time in shakes. (DEFAULT: TMESH=-∞,T_{max}) (See Note 4.)**
TINTS	**Number of fine mesh points within each corresponding coarse mesh in time. (DEFAULT: TINTS=1)**
TNORM	**If TNORM=NO, then the tally results are not divided by time bin width. If TNORM=YES, then provides the tally results per shake (sh^{-1}). (DEFAULT: TNORM=NO)**
FACTOR	**Multiplicative factor for each mesh. (DEFAULT: FACTOR=1.)**
OUT	**Output format, either in column format or as a series of 2D matrices. If OUT=COL, a columnar output format is provided, listing the coordinates of the center of the bin, the tally results, and associated relative error. (DEFAULT) If OUT=CF, a columnar output format is provided, listing the coordinates of the center of the bin, the tally results, and associated relative error. In addition, the volume and the tally results multiplied by the volume are also printed. If OUT=IJ or IK or JK, tally results are printed as a series of two 2D matrices, with I=*x* or *r*, J=*y* or *z*, and K=*z* or θ, depending on the coordinate system chosen. The first matrix contains the tally results, and the second matrix the relative errors. The rows and columns are labeled by the mid-points of the corresponding mesh bins. These pairs of matrices will be printed for each mesh bin in the third coordinate. If OUT=NONE, no MESHTAL file is printed. (See Note 5.)**
TR	**Number of the transformation to be applied to the mesh. (DEFAULT: none) (See Note 6.)**

Keyword	Description
INC c_L c_U	**Defines a range of collisions that will contribute to the FMESH tally.** **For a particle track undergoing n collisions, the track will contribute to the FMESH tally if $c_L \le n \le c_U$. The specification of c_U is optional. If only c_L is specified, then a particle track undergoing exactly n collisions will contribute to the FMESH tally if $n=c_L$. The keyword entry "INFINITE" can be used for c_U to represent an infinite number of collisions.** **(DEFAULT: c_L=0; c_U=INFINITE)**
TYPE	**Allows users to specify the quantity being tallied.** **If TYPE=FLUX, neutron volume fluxes are tallied. (DEFAULT) (See F4 type tally, Section 3.3.5.1.1.)** **If TYPE=SOURCE, neutron source points are tallied.**
KCLEAR	**Used in KCODE calculations for generating visualizations of cycle wise quantities. Zeros out the mesh tally every n KCODE cycles, where n is specified with KCLEAR=n. If n is non-zero, then tallies are accumulated both during active and inactive cycles; consequently, the output should only be used for visualizations and not as actual results. If n is zero, then the mesh tally behaves normally and mesh tally results are never cleared. (DEFAULT: KCLEAR=0)**

Use: Optional

Note 1: The location of the n^{th} coarse mesh in the u direction (r_{un} in what follows) is given in terms of the most positive surface in the u direction. For a rectangular mesh, the coarse mesh locations r_{xn}, r_{yn}, r_{zn}, are given as planes perpendicular to the x-, y-, and z-axis, respectively, in the MCNP6 cell geometry coordinate system. Thus the ORIGIN point (x_0, y_0, z_0) is the most negative point of the mesh tally. For a cylindrical mesh, ORIGIN defines the bottom center point of the mesh. The z-coordinate is then measured from the cylindrical mesh origin. For both types of geometry, the lowest energy value is 0 MeV. The coarse mesh locations and energy values must increase monotonically (beginning with the ORIGIN point). The fine meshes are evenly distributed within the n^{th} coarse mesh in the u direction.

Note 2: For a cylindrical mesh, the AXS and VEC vectors need not be orthogonal but they must not be parallel; the one half-plane that contains them and the ORIGIN point will define θ=0. The AXS vector will remain fixed. The length of the AXS or VEC vectors must not be zero. The z-coordinate is specified in the cylinder geometry coordinate system. The θ coarse mesh locations are given in revolutions and the last one must be 1.

Note 3: At least one coarse mesh per coordinate direction must be specified using IMESH, JMESH, and KMESH keywords. The code uses a default value of 1 fine mesh per coarse mesh if the IINTS, JINTS, or KINTS keywords are omitted. If the IINTS, JINTS, or KINTS keywords are present, the number of entries must match the number of entries on the IMESH, JMESH, and KMESH keywords, respectively. Entries on the IINTS, JINTS, and KINTS keywords must be greater than zero.

Note 4: Because the lower time bound is minus infinity, users are encouraged to specify the first bin as a dummy bin with the smallest time of interest (usually zero shakes). The user should then ignore the first time bin when plotting.

Note 5: If the FMESH card is present in a continue-run, only the OUT keyword is permitted.

Note 6: Any FMESH mesh can be transformed using the TR keyword followed by a transformation number. The transformation is defined on the associated TR card. (See Section 3.3.1.3.)

Special Cases of the FM Tally Multiplier Used in Conjunction with the FMESH Mesh Tally

Default Materials: When the FMESH capability is associated with a tally multiplier (FM) card, then the material number specified on the FM card determines the cross sections that are used to calculate the mesh bin values. That is, the cross sections of the specified material are used for the entire mesh, even if the mesh covers several different materials. If instead, a "0" is entered as the material number on the FM card, then MCNP6 will use the reaction data of the material through which the particle travels to calculate the bin values. Thus, material-dependent quantities that are computed with the use of the FM card (e.g., neutron heating) can be calculated using mesh tallies that cover more than one material.

Example 1:

```
FC4   Mesh tally energy deposition (in MeV/cm^3)
FMESH4:n    GEOM=xyz    ORIGIN= -5 -5 -5
            IMESH=  5   IINTS=100
            JMESH=  5   JINTS=  1
            KMESH=  5   KINTS=100
FM4        -1  0  -5
```

This example describes an energy-deposition rectangular-mesh tally covering a 10 cm × 10 cm × 10 cm box centered on the origin. The tally is divided into 100 bins in both the x and z directions and one bin in the y direction.

Isotopic Reaction Rate Tallies: Individual isotopic reaction rates can be obtained throughout the mesh tally geometry. To invoke this capability, define a new dummy material card containing only the isotope(s) of interest. This dummy material card should be specified in exactly the same way as a standard Mm card; however, the dummy material number should not appear in the problem geometry—instead the material number is used exclusively by the FM card. Note that for these dummy materials, the isotopic densities are *not* used by MCNP6 but values must be provided as placeholders. Instead, the required isotopic atom fractions will be extracted from the appropriate material data used during transport.

To specify a reaction-rate mesh tally based on isotopic fractions, place a "+" symbol in front of the FM card associated with the mesh tally. The rest of the FM card is set up the regular way, with a multiplicative constant followed by the dummy material number and the ENDF reaction numbers of interest.

When calculating the mesh tally, MCNP6 will multiply the particle flux times the cross sections for the isotopes defined on the material card. This value is then multiplied by the atom fraction of the dummy material isotope(s) which are present in the material in which the particle is traveling to calculate the isotopic reaction rate. The units of the results will be (number of reactions/cm^3) *c (atoms/b-cm) (multiplicative constant) or (number or reactions/cm^3/shake) *c (atoms/b-cm) depending on the units of the source. Recall that placing a minus sign in front of the multiplicative constant will multiply the results by the atom density of the cell. Therefore using c=-1 will return units of (number of reactions/cm^3) or (number of reactions/cm^3/shake) for the specific isotopes. For isotopic reaction rate tallies, multiplication by this factor usually is undesired.

Example 2:

```
FMESH4:n     GEOM=CYL   ORIGIN= –100 0 0
             IMESH=   5  10   IINTS= 5 2
             JMESH= 100 200   JINTS 10 5
             KMESH  0.5   1   KINTS= 1 2
             AXS= 1 0 0  VEC=0 1 0  OUT=IJ
```

This example describes a cylindrical mesh tally along the *x*-axis, with base at *x*=-100 and θ=0 along the +*y*-axis. The tally is divided into five bins from *r*=0 to *r*=5, two bins from *r*=5 to *r*=10, ten bins from *z*=0 to 100, five bins from *z*=100 to *z*=200, one bin from θ=0° to θ=180°, and two bins from θ=180° to 360°.

Special Case of Leakage Tallies using the FMESH Mesh Tally

All normal applications of the FMESH tallies make use of pathlength estimates of flux, dose, or reaction rates over each mesh element volume. For these normal applications, the FMESH tally number must end in the numeral 4, e.g., Fmesh74:n.

As a very special and limited extension of the FMESH mesh tallies, FMESH cards with a tally number ending in the two numerals 01 can be used to obtain the outgoing leakage (or outgoing partial current) across each of the 6 faces of each mesh element.

- Outgoing partial current FMESH tallies defined in the problem input **must** end in "01"
- Specifying Fmesh901:n in the problem input will result in the following FMESH tallies being created internally:

- Fmesh911:n - outgoing partial current in the +x or +r direction
- Fmesh921:n - outgoing partial current in the -x or -r direction
- Fmesh931:n - outgoing partial current in the +y or +z direction
- Fmesh941:n - outgoing partial current in the -y or -z direction
- Fmesh951:n - outgoing partial current in the +z or +t direction
- Fmesh961:n - outgoing partial current in the -z or -t direction

All 6 of the partial current tallies will have the same specifications that are supplied for Fmesh901:n. The specific tally Fmesh901:n will not actually be stored or be available for referencing with FM, DE/DF, SC, or SF cards.

- These tallies are **not** divided by volume or area. They produce the total particle weight crossing each surface of a mesh cell in the outward direction, normalized to be per unit source particle.

- The incoming partial currents to a mesh element can be obtained from the outgoing partial currents of neighboring elements. Since the partial current FMESH tally only tallies outward currents for each mesh element, it is necessary to specify the mesh to include a "halo" of inactive elements surrounding the active problem domain in order to properly capture incoming current at the boundary of the problem domain.

- Use of the "*" prefix, as in *Fmesh901:n, is permitted. This will result in the FMESH partial current tallies providing the energy crossing each mesh element surface in the outward direction.

- The tally modifier cards, such as FM, DE/DF, CF, or SF may be used with the partial current tallies (although most modifiers don't make physical sense). To do so, however, the tally number for only the first of the created FMESH tallies must be used. For example, if Fmesh901:n is specified, then tally number 911 should be used on any FM, DE/DF, CF, or SF cards. Those cards will be also be applied to the Fmesh912:n, …, Fmesh916:n partial current mesh tallies. Note that using DE/DF cards, for example, is not appropriate with these tallies, since "flux-to-dose" conversion factors are not the same as "current-to-dose" factors. Similarly, FM modifiers that are typically used with flux tallies may not be appropriate with partial currents.

- The partial current tallies can be plotted, using the tally numbers for the 6 created mesh tallies. For example, in the plotter one can specify "fmesh 911" for the example above.

- The tallies appear in the standard format in the *meshtal* file, with the 6 names of tallies created, e.g., Fmesh911, and can be combined using merge_meshtal

- There can be as many FMESH "01" tallies as desired.

The FMESH partial current tallies are deliberately limited in scope and usage. They are provided primarily so that users can obtain a complete particle balance for individual mesh elements. That is, using FMESH4 tallies for particle production and particle capture, the FMESH01 tallies provide the leakage across mesh element surfaces.

3.3.5.26 SPDTL LATTICE SPEED TALLY ENHANCEMENT

The `SPDTL` card allows the user to force or prevent the use of the lattice speed tally enhancement. [GOO04] This feature allows the user to run a short test case with and without the enhancements to verify they are appropriate by comparing the tally results of the two runs.

Form: `SPDTL KEYWORD`

Table 3-113. Lattice Speed Tally Enhancement (SPDTL)

Keyword	Description
FORCE	**Force the use of the lattice speed tally enhancement feature. No values accompany the keyword.* (See Note 1.)**
OFF	**Prevent the use of the lattice speed tally enhancement feature. No values accompany the keyword.***

* Only one keyword may be specified for `SPDTL`.

Default: Lattice speed tally enhancement is enabled by default if strict criteria are met.

Use: Optional.

Note 1: Using `SPDTL FORCE` also causes comments to be printed about lattice speed tally enhancement conflicts with other cards.

Conditions Required for Lattice Speed Tally Enhancements:

The lattice speed tally enhancements greatly reduce the runtime of certain problems, namely large lattices used for voxel phantoms. This enhancement will only work under certain conditions, which MCNP6 will try to detect. If any of the following criteria are not met, then the lattice speed tally enhancement will not be used unless the `SPDTL FORCE` card is used. Using the `SPDTL FORCE` card to run the lattice speed tally enhancement is discouraged, since it may result in a program crash, tally values that are all zeros, or silent wrong answers.

Criteria that must be met for MCNP6 to automatically (and appropriately) use the lattice speed tally enhancement include the following:

a. A hexagonal lattice must be present in the geometry.
b. All F4 tallies contain a hexahedral lattice.
c. None of the following cards are used: DXT, DXC, F1, F2, *F4, F6, F7, F8, +F8, PERT, WWG, WWGE, WWGT.
d. None of the following cards are used to modify an F4 tally: FT, E, EM, T, TM, CF, SF, FS, C.
e. All F4 tallies have an associated FM4 card that contains only a single digit multiplier.
f. All F4 tallies have associated DE/DF cards.

The following criteria are not checked by MCNP6. The user must verify that the input deck meets these criteria:

g. Nested lattices are not tallied over.
h. The entries for a cell's FILL card do not include that cell's own universe number.
i. The full lattice index range is given on every lattice on each F4 tally card.

For more information, see GOO04.

.

3.3.6 Data Cards Related to Variance Reduction

Many of these variance-reduction cards require knowledge of both the Monte Carlo method and the particular variance reduction technique employed. The MCNP5 Theory Manual[X-503a] and its references are a good place to start learning more about these topics.

INDEX OF VARIANCE REDUCTION INPUT INFORMATION		
Mnemonic	**Description**	**Section**
IMP	Cell Importance	3.3.6.1
VAR	Variance Reduction Control	3.3.6.2
WWE	Weight-Window Energies	3.3.6.3.1
WWT	Weight-Window Times	3.3.6.3.2
WWN	Cell-Based Weight-Window Bounds	3.3.6.3.3
WWP	Weight-Window Parameter	3.3.6.3.4
WWG	Weight-Window Generation	3.3.6.4.1
WWGE	Weight-Window Generation Energies	3.3.6.4.2
WWGT	Weight-Window Generation Times	3.3.6.4.3

INDEX OF VARIANCE REDUCTION INPUT INFORMATION		
Mnemonic	**Description**	**Section**
MESH	Superimposed Importance Mesh for Mesh-Based Weight-Window Generator	3.3.6.4.4
ESPLT	Energy Splitting and Roulette	3.3.6.5
TSPLT	Time Splitting and Roulette	3.3.6.6
EXT	Exponential Transform	3.3.6.7
VECT	Vector Input	3.3.6.8
FCL	Forced Collision	3.3.6.9
DXT	DXTRAN Sphere	3.3.6.10
DD	Detector Diagnostics	3.3.6.11
PD	Detector Contribution	3.3.6.12
DXC	DXTRAN Contribution	3.3.6.13
BBREM	Bremsstrahlung Biasing	3.3.6.14
PIKMT	Photon-Production Biasing	3.3.6.15
SPABI	Secondary Particle Biasing	3.3.6.16
PWT	Photon Weight	3.3.6.17

Only two variance reduction games in MCNP6 are set "on" by default: implicit capture/weight cutoff and Russian roulette for point detectors and DXTRAN spheres. All other variance reduction games must be applied explicitly and therefore are considered optional. In spite of this statement, the code does require that either (1) the `IMP` card be present in the data-card section of the INP file (or, equivalently, an `IMP` parameter be specified on each cell card) or (2) weight windows be supplied through `WWN` cards (or, equivalently, read from a WWINP file). Otherwise, a fatal error will occur during the input-checking process.

Some variance reduction cards (e.g., `IMP`) in the data section require the number of entries to equal the number of cells or surfaces in the problem; otherwise, a fatal error results. For other cards (e.g., `EXT`) no fatal error results if the number of entries does not equal the number of cells or surfaces, but a warning may be issued. The order of the cells or surfaces on these cards correspond in order to the cell or surface cards that appear in the INP file. The *n*`R` repeat or *n*`J` jump features may help in supplying the desired values. Note that the *n*`J` feature relies on the presence of a default value. Users should refer to the individual cards to learn about their defaults.

3.3.6.1 IMP CELL IMPORTANCE

A cell's importance is used (1) to terminate the particle's history when a particle enters a cell with importance zero, (2) for playing geometry splitting and Russian roulette as a means to control the particle population upon entering a cell, and (3) for scaling the cutoffs in the weight cutoff game.

An importance assigned to a cell that is in a universe is interpreted as a multiplier of the importance of the filled cell.

Form 1 (cell card entry): `IMP:`*<pl>*`=`*x*

Form 2 (data card): `IMP:`*<pl>* x_1 x_2 ... x_j ...

Table 3-114. Cell Importance Card (IMP:*<pl>*)

Input Parameter	Description
<pl>	**Any particle symbol from Table 2-2. May also be a list of particle symbols separated by commas as long as the importance are the same for the desired importance are the same for the different listed particle types.**
x	**Cell importance. One entry must appear on each cell card for each particle type that has non-default values.**
x_j	**Importance of cell *j*. Number of entries must equal number of cells in the problem.**

Default: Default `IMP` values are variable and depend on the presence or absence of other cards as illustrated below. For this reason, it is highly recommended that the user explicitly specify `IMP` values for all particle types or verify from `print table 60` the values used in the calculation are those intended.

If no `WWN` card is present: `IMP` values are explicitly required for one of the requested particle types on the `MODE` card, otherwise a fatal error occurs. Additionally, if (1) one particle is explicitly assigned `IMP` values and (2) `IMP` values are not supplied for the other particle types, then the default `IMP` values for the remaining particles are `1` where the explicitly assigned importance are greater than `0` and `0` where the explicitly assigned importance are `0`.

If a `WWN` card is present: `IMP` values are not required when using cell-based weight windows. However, one set of `IMP` values is required when using mesh-based weight windows. The default `IMP` values for the particle(s) on the `WWN` card are set to `1` where the weight-window lower bounds are not `-1`, otherwise they are set to `0`. `IMP` values for all other particles not having a `WWN` card are set to `0`. If `IMP` values are explicitly provided along with the `WWN` card(s), they are retained and `IMP` values not explicitly provided for any other particles are set to `1` where the explicitly set `IMP` values are not `0`; otherwise, they are set to `0`.

If a cell importance is set to `0` for any particle, all particle importance for that cell will be set to `0` (default implicit value) unless specified otherwise. However, if the *n*`J` feature is used to specify importance, the values jumped over are given a default importance value of `0`. Particles entering a cell with an importance value of `0` are immediately terminated as are contributions to detectors and DXTRAN spheres. The outside world cell (surrounding the geometry of interest) should be such a cell; problems without such a cell will experience lost particles.

Use: Use IMP when weight windows are not desired. See details in the default discussion above.

Different particle types can be split differently by having separate IMP:<*pl*> cards. When using the data card entry format, it is a fatal error if the number of entries on any IMP:<*pl*> card is not equal to the number of cells in the problem. Similarly, if an IMP:<*pl*> parameter appears on one cell card, a fatal error occurs if a comparable entry does not appear on all cell cards. The *n*R repeat and *n*M multiply features are especially useful with this card in the data-card section. Be careful when using these shorthand notations together—R does not duplicate the M, but rather the value that the M notation creates..

A track will neither be split nor rouletted when it enters a void cell even if the importance ratio of the adjacent cells would normally call for a split or roulette. However, the importance of the non-void cell that a particle exits is remembered and splitting or Russian roulette will be played when the particle next enters a non-void cell. As an example of the benefit of not splitting into a void, consider a long cylindrical void (or pipe) surrounded by a material like concrete where the importance are decreasing radially away from the pipe. Considerable computer time can be wasted by tracks bouncing back and forth across the pipe and doing nothing but splitting, then immediately undergoing roulette. Splitting into a void increases the time per history but has no counterbalancing effect on the expected history variance. Thus, the figure of merit (FOM) is reduced by the increased time per history.

If a superimposed weight-window mesh is used, the IMP card is required. Cell importance are only used for the weight cutoff game in zero-window meshes.

Example:

```
IMP:N    1  2  2M  0  1  20R
```

The neutron importance of cell 1 is 1, cell 2 is 2, cell 3 is 4, and cell 4 is 0. The importance for cells 5 through 25 are 1. A track will be split 2 for 1 going from cell 2 into cell 3, each new track having half the weight of the original track before splitting. A track moving in the opposite direction will be terminated in half the cases (that is, with probability=0.5), but it will be followed in the remaining cases with twice the weight.

3.3.6.2 VAR VARIANCE REDUCTION CONTROL

The VAR card is used to control variance-reduction methods across several variance-reduction techniques. In particular, it allows the roulette game for weight windows and cell/energy/time importance to be turned off. Turning off roulette can be helpful for F8 tallies using variance reduction. (See Note 1.)

Form: `VAR` `KEYWORD=value`

where, if the keyword `RR` is set to either `OFF` or `NO` (`RR=OFF` or `RR=NO`), then the roulette game for weight windows and cell/energy/time importance is turned off.

Default: No modifications of variance reduction methods.

Use: Optional

Note 1: For a pulse-height tally (that uses the de-branching method), Russian rouletting a particle produces zero tallies for all collections of particles that include the rouletted particle. This procedure results in no bias, but adds computational effort. In this circumstance, roulette is contraindicated.

3.3.6.3 WEIGHT-WINDOW CARDS

Weight windows can be either cell-based or mesh-based. Mesh-based windows eliminate the need to subdivide geometries finely enough for importance functions.

Weight windows provide an alternative means to importance (`IMP` values), energy splitting (`ESPLT` cards), and time splitting (`TSPLT` cards) for specifying space-, energy-, and time-dependent importance functions. The advantages of weight windows are that they 1) provide an importance function in space, time, space-energy, space-time, or space-energy-time; 2) attempt to control particle weights; 3) are more compatible with other variance-reduction features such as the exponential transform (`EXT` card); 4) can be applied at surface crossings, collisions, or both; 5) control the severity of splitting or Russian roulette; 6) can be turned off in selected space, time, or energy regions; and 7) can be automatically generated by the weight-window generator. The disadvantages are that 1) weight windows are not as straightforward as importance and 2) when the source weight is changed, the weight windows may have to be renormalized (see the 7th entry on the WWP card, Section 3.3.6.3.4). (The novice user is strongly advised to read the section on weight windows in the MCNP5 Theory Manual[X-503a].)

In repeated structures, an additional difference between cell importance and weight windows exists. For cell importance (`IMP` card), an importance in a cell that is in a universe is interpreted as a multiplier of the importance of the filled cell (see Section 3.3.6.1) and action (i.e., splitting or roulette) is taken based on the ratio of importance. The weight-window bounds are absolute bounds, not multipliers. The lower window bound in cell j and energy bin k is unaffected by the repeated structures. Mesh based windows are recommended for use with repeated structures.

A cell-based weight-window lower bound of a cell that is in a universe is interpreted as a multiplier of the weight-window lower bound of the filled cell.

3.3.6.3.1 WWE WEIGHT-WINDOW ENERGIES (OR TIMES[1])

The `WWE` card defines the energy (or time) intervals for which weight-window bounds will be specified on the `WWN` card. The minimum energy is not entered on the `WWE` card, but is defined to be zero. Similarly, the minimum time is -∞. Whether energy or time is specified is determined by the 6th entry on the `WWP` card. (See Section 3.3.6.3.4.) For time-dependent weight windows, the `WWT` card is now recommended. (See Section 3.3.6.3.2.)

Form: `WWE:`<*pl*> e_1 e_2 ... e_i ...

where $i \leq 99$.

Table 3-115 Weight-Window Energies (or Times) Card (WWE)

Input Parameter	Description
<*pl*>	**Particle designator.**
e_i	**Upper energy (or time) bound of *i*th window.** **Restriction: 1≤*i*≤99** **(Note: Parameter e_i accepts time entries to allow backward compatibility. See `WWT` card for time-dependent weight windows.)**
e_{i-1}	**Lower energy (or time) bound of *i*th window.**

Default: If the `WWE` card is omitted and weight windows are used, one energy (or time) interval is established corresponding to the energy (or time) limits of the problem.

Use: Optional. Use only with `WWN` card. See the `WWGE` card for use with the weight-window generator

3.3.6.3.2 WWT WEIGHT-WINDOW TIMES

The `WWT` card defines the time intervals in shakes for which weight-window bounds will be specified on the `WWN` card. The minimum time is not entered on the `WWT` card, but is defined to be -∞.

Form: `WWT:`<*pl*> t_1 t_2 ... t_i ...

where $i \leq 99$.

[1] Times are allowed on the `WWE` card to preserve backward compatibility. The user is directed now to use the `WWT` card for time-dependent weight windows.

Table 3-66. Weight-Window Times Card (WWT)

Input Parameter	Description
<pl>	**Particle designator.**
t_i	**Upper time bound of i^{th} window.** **Restriction: $1 \le i \le 99$**
t_{i-1}	**Lower time bound of i^{th} window.**

Default: One weight-window time interval.

Use: Optional. Use only with `WWN` card. See `WWGT` card for use with the weight-window generator.

3.3.6.3.3 WWN CELL-BASED WEIGHT-WINDOW BOUNDS

The `WWN` card specifies the lower weight bound of the space-, time-, and energy-dependent weight windows in cells. It must be used with the `WWP` card and, if the weight windows are energy and/or time dependent, with the `WWE` and/or `WWT` card. For a particular particle type, both `IMP` and `WWN` cards should not be used with one exception: mesh-based weight windows require the presence of `IMP` cards (see the `IMP` card default value discussion). The weight-window game turns off the `IMP` card game unless the weight-window phase-space region has a lower bound of 0—then the weight cutoff game, which uses the `IMP` values to scale the cutoff values, is played.

In terms of the weight window, particle weight bounds are always absolute and not relative; the user must explicitly account for weight changes from any other variance reduction techniques such as source biasing. The user must specify one lower weight bound per cell per energy per time interval. There must be no holes in the specification; that is, if `WWN`*i* is specified, `WWN`*k* for $1<k<i$ must also be specified.

Form 1 (cell card entry): `WWN`*i*`:`<*pl*>`=`w_{ij}

Form 2 (data card): `WWN`*i*`:`<*pl*> w_{i1} w_{i2} ... w_{ij} ...

Table 3-117. Cell-Based Weight-Window Bounds Card (WWN*i*)

Input Parameter	Description
<pl>	**Particle designator.**
i	**Energy or time index.**
w_i	**If $w_i>0$, then value is the lower weight bound in the cell for energy (or time) interval $e_{i-1}<e<e_i$, where $e_0=0$, or time interval $t_{i-1}<t<t_i$, where $t_0=-\infty$. If no `WWE` or `WWT` card is included in INP file, then $i=1$. (See Note 1.)** **If $w_i=0$, then no weight-window game is played. (See Note 2.)** **If $w_i=-1$, then any particle entering the cell is killed (equivalent to zero importance). (See Note 3.)**

w_{ij}	**If w_{ij}>0, then value is the lower weight bound in cell j for energy (or time) interval e_{i-1}<e<e_i, where e_0=0, or time interval t_{i-1}<t<t_i, where t_0=-∞. If no WWE or WWT card is included in INP file, then i=1. (See Note 1.)** **If w_{ij}=0 then no weight-window game is played. (See Note 2.)** **If w_{ij}=-1, then any particle entering cell j is killed (equivalent to zero importance). (See Note 3.)** **Note: The number of entries equals the number of cells in the problem.**

Default: None.

Use: Either cell importance (Section 3.3.6.1) or weight windows (3.3.6.3.3) must be supplied to MCNP6.

Note 1: If w_{ij}>0, particles entering or colliding in the cell are split or rouletted based on the conditions setup by the WWP card parameters. (See Section 3.3.6.3.4.)

Note 2: If w_{ij}=0, the weight-window game is turned off in cell j for energy or time bin i and the weight cutoff game is turned on with a 1-for-2 roulette limit. Sometimes it is useful to specify the weight cutoffs on the CUT card as the lowest permissible weights desired in the problem. Otherwise, too many particles entering cells with w_{ij}=0 may be killed by the weight cutoff. Usually, the 1-for-2 roulette limitation is sufficient to use the default weight cutoffs, but caution is needed and the problem output file should be examined carefully. The capability to turn the weight-window game off in various phase-space regions is useful when these regions cannot be characterized by a single importance function or set of weight-window bounds.

Note 3: Caution should be exercised when one energy (or time) group out of many groups is set to -1. If the intent is to kill only low-energy particles, this may be okay; otherwise, it may be better to set all groups to -1.

Example 1:

WWE:N e_1 e_2 e_3
WWN1:N w_{11} w_{12} w_{13} w_{14}
WWN2:N w_{21} w_{22} w_{23} w_{24}
WWN3:N w_{31} w_{32} w_{33} w_{34}

These cards define three energy intervals and the weight-window bounds for a four-cell neutron problem.

Example 2:

WWN1:P w_{11} w_{12} w_{13}

This card, without an accompanying WWE card, defines an energy- or time-independent photon weight window for a three-cell problem.

3.3.6.3.4 WWP WEIGHT-WINDOW PARAMETER

The `WWP` card contains parameters that control various aspects of the weight-window game

Form:
`WWP:<pl> wupn wsurvn mxspln mwhere switchn mtime wnorm etsplt wu`

Table 3-118. Weight-Window Parameter Card (WWP)

Input Parameter	Description
<pl>	**Particle designator.**
wupn	**Multiplier to define the weight window upper limit. If the particle weight goes above *wupn* times the lower weight bound, the particle will be split. (DEFAULT: *wupn*=5)** **Restriction: *wupn*≥2**
wsurvn	**Multiplier to define the maximum Russian roulette survival weight within the window. If the particle survives the Russian roulette game, its weight becomes MIN(*wsurvn* times the lower weight bound, WGT×*mxspln*).** **DEFAULT: *wsurvn*=0.6×*wupn*, 3 times the lower bound))** **Restriction: 1<*wsurvn*<*wupn***
mxspln	**Maximum number of integer splits. No particle will ever be split more than *mxspln*-for-one or be rouletted more harshly than one-in-*mxspln*. (DEFAULT: *mxspln*=5)** **Restriction: *mxspln*>1**
mwhere	**Controls where to check a particle's weight.** **If *mwhere*=-1, check the weight at collisions only.** **If *mwhere*=0, check the weight at surfaces and collisions. (DEFAULT)** **If *mwhere*=1, check the weight at surfaces only.**
switchn	**Controls where to get the lower weight-window bounds.** **If *switchn*<0, get the lower weight-window bounds from an external WWINP file containing either cell- or mesh-based lower weight-window bounds. Requires an IMP card. (See Note 1.)** **If *switchn*=0, get the lower weight-window bounds from WWN*i* cards present in the INP file. (DEFAULT) (See Note 2.)** **If *switchn*>0, set the lower weight-window bounds equal to *switchn* divided by the cell importance from the IMP card. (See Note 3.)**
mtime	**If *mtime*=0, energy-dependent windows are provided on the WWE card. (DEFAULT)** **If *mtime*=1, time-dependent windows are provided on the WWE card.** **(Note: Parameter *mtime* remains to allow backward compatibility. See WWT card for time-dependent weight windows.)**
wnorm	**Weight-window normalization factor. If *wnorm*>0, *wnorm* is a multiplicative constant for all lower weight-window bounds on WWN*i*:<*pl*> cards or values in the WWINP file. Applies to particle type <*pl*> specified by this WWP card. (DEFAULT: *wnorm*=1)**

Input Parameter	Description
etsplt	**If *etsplt*=0, then any entries on the ESPLT and TSPLT cards are used solely to scale the weight window. (DEFAULT)** **If *etsplt*=1, then any entries on the ESPLT and TSPLT cards are used to split/roulette particles as well as scale the weight windows. (See the ESPLT and TSPLT cards in Sections3.3.6.5 and 3.3.6.6, respectively.)**
wu	**Limits the maximum lower weight-window bound for any particle, energy, or time to wu. If wu=0, there is no limit.(see Note 4.) (DEFAULT: wu=0)**
nmfp	**Number of mfp's to travel before checking mesh-based weight windows for neutron & photon problems only. (DEFAULT: *nmfp*=1)**

Default: *wupn*=5; *wsurvn*=3; *mxspln*=5; *mwhere*=0; *switchn*=0; *mtime*=0; *wnorm*=1.0; *etsplt*=0; *wu*=0; nmfp=1

Use: Weight windows are required unless importance are used.

Note 1: If *switchn*<0, an external WWINP file with either cell- or mesh-based lower weight-window bounds must exist and an IMP card is required. The WWINP file is a weight-window generator output file, either WWOUT or WWONE, that has been renamed in the local file space or equivalenced on the execution line using WWINP=*filename*. The different formats of the WWINP file will indicate to the code whether the weight windows are cell or mesh based. For mesh-based weight windows, the mesh geometry will also be read from the WWINP file. (See Appendix B.)

Note 2: If *switchn* is zero, the lower weight-window bounds must be specified with the WWN cards present in the INP file.

Note 3: An energy-independent weight window can be specified using existing importance from the IMP card and setting the fifth entry (*switchn*) on the WWP card to a positive constant C. If this option is selected, the lower weight bounds for the cells become C/I, where I is the cell importance. A suggested value for C is one in which source particles start within the weight window, such as 0.25 times the source weight. If that is not possible, the window is probably too narrow or the source should be re-specified. Having *switchn*>0 and also having WWN*i* cards is a fatal error.

Note 4: Unreasonably high weight-window bounds can be generated if 1) tracks that pass through a cell score only rarely or score very low, or 2) adjoint Monte Carlo is used. When weight windows with very high bounds are used in a subsequent run, the ultra-high windows will roulette nearly all particles in those phase-space regions. This results in no future estimate in these regions by the weight-window generator and potentially biased results. Use the 9th entry, *wu*, to limit the maximum lower weight-window bound. A good value of *wu* is often 1–10 times the maximum source weight.

3.3.6.4 WEIGHT-WINDOW GENERATION CARDS

The weight-window generator estimates the importance of the space-energy-time regions of phase space specified by the user. The space-energy-time weight-window lower bounds are then calculated inversely proportional to the importance.

The cell–based generator estimates the average importance of a phase-space cell. Inadequately sized (i.e., large) geometry cells often lead to inappropriate weight windows because of a large variation in the importance inside the cell. An appropriate user action is to refine the cell definitions or use the mesh-based weight window. Inadequate geometry specification for weight-window purposes also results when there are large importance differences between adjacent cells. Fortunately, the code provides information about whether the geometry specification is adequate for sampling purposes by printing to the OUTP file a list of neighboring cells that differ by a factor of 4 or more. If geometries are inadequately subdivided by the geometry cells, mesh-based weight windows should be used.

The user is advised to become familiar with the section on the weight windows in The MCNP5 Theory Manual[X-503a], before trying to use the weight-window generator.

3.3.6.4.1 WWG WEIGHT-WINDOW GENERATION

The `WWG` card allows the code to generate an importance function for a user-specified tally (input parameter i_t). In many cases, a window using the adjoint function will not be too far from optimal.

For the cell-based weight-window generator, the code creates `WWE` and `WWN`*i* cards that are printed, evaluated, and summarized in the OUTP file and written to the weight-window generator output file WWOUT.

For the mesh-based weight-window generator, the code writes the weight-window lower bounds and a mesh description only to the WWOUT file. (The format of the mesh-based WWOUT file is provided in Appendix B.)

In either case, the generated weight-window information can be easily used in subsequent runs using *switchn*<0 on the `WWP` card. For many problems, the weight-window generator results are superior to anything an experienced user can guess and then input on an `IMP` card. To generate energy- and/or time-dependent weight windows, use the `WWGE` and/or `WWGT` cards described below.

Form: `WWG` i_t i_c w_g J J J J i_E

Table 3-119. Weight-Window Generator Card (WWG)

Input Parameter	Description
i_t	**Problem tally number (n of the `Fn` card). The particular tally bin for which the weight-window generator is optimized is defined by the `TFn` card. (See Note 1.)**
i_c	**Invokes cell- or mesh-based weight-window generator.** **If i_c>0, then invoke the cell-based weight-window generator with i_c as the reference cell (typically a source cell).** **If i_c=0, then invoke the mesh-based weight-window generator. (`MESH` card required.) (See Note 2.)**
w_g	**Value of the generated lower weight-window bound for cell i_c or for the reference mesh. (See `MESH` card.) (See Note 3.)** **If w_g=0, then the lower bound will be half the average source weight.**
J J J J	**Unused placeholders.**
i_E	**Toggles energy- or time-dependent weight windows.** **If i_E=0, then interpret `WWGE` card entries as energy bins.** **If i_E=1, then interpret `WWGE` card entries as time bins.** **(Note: Parameter i_E remains to allow backward compatibility. See `WWGT` card for time-dependent weight windows.)**

Default: No weight-window values are generated.

Use: Optional.

Note 1: Weight-window generation relies on scores being made by the primary source particle to or near (so secondary particles can score) the reference tally, i_t. The primary source particle is typically specified by PAR on the SDEF card. If PAR is a distribution or unspecified, then the primary source particle is the particle with the lowest number on the MODE card.

Note 2: For mesh-based weight windows, a reference point (REF) is required instead of a cell number. (See MESH card, Section 3.3.6.4.4.)

Note 3: The value w_g of the lower weight-window bound for reference cell i_c or reference mesh location is chosen so that the source weight will start within the weight window, when possible. The reference cell i_c is often chosen as the source cell and the reference mesh location is often chosen in or near the source cell.

3.3.6.4.2 WWGE WEIGHT-WINDOW GENERATION ENERGIES (OR TIMES[1])

If the WWGE card is present, energy- (or time-) dependent weight windows are generated and written to the WWOUT file and, for cell-based weight windows, to the OUTP file. In addition, single-group energy- (or time-) independent weight windows are written to a separate output file, WWONE. Energy- (or time-) independent weight windows are sometimes useful for trouble-shooting the energy- (or time-) dependent weight windows on the WWOUT file. The WWONE file format is the same as that of the WWOUT file (see Appendix B). The selection of energy- or time-dependent weight windows is made with the 8th entry on the WWG card (see Section 3.3.6.4.1).

Form: WWGE:<*pl*> e_1 e_2 ... e_j

where $j \le 15$.

Table 3-120. Weight-Window Generation Energies (or Times) Card (WWGE)

Input Parameter	Description
<*pl*>	**Particle designator.**
e_i	**Upper energy (or time) bound for weight-window group to be generated, $e_{i+1}>e_i$.** **Restriction: $i \le 15$** **(Note: Parameter e_i accepts entries of time bounds to allow backward compatibility. See the WWGT card for time-dependent weight-window generation.)**

Default: If the WWGE card is omitted and the weight window is used, a single energy (time) interval will be established corresponding to the energy (time) limits of the problem being run. If the card is present but has no entries, ten energy (time) bins will be generated with energies (times) of $e_i=10^{i-8}$ MeV (or shakes), for i=1,2,...,10. Both the single energy (time) and the energy- (time-) dependent windows are generated.

Use: Optional.

3.3.6.4.3 WWGT WEIGHT-WINDOW GENERATION TIMES

If the WWGT card is present, time-dependent weight windows are generated and written to the WWOUT file and, for cell-based weight windows, to the OUTP file. In addition, single-group time-independent weight windows are written to a separate output file, WWONE. Time-independent weight windows are sometimes useful for trouble-shooting the time-dependent weight windows on the WWOUT file. The WWONE file format is the same as that of the WWOUT file (see Appendix B).

[1] Although the WWGE card will accept time bins so to be compatible with previous versions of MCNP, it is recommended that the user use the WWGT card for time-dependent weight-window generation.

Form: WWGT:<*pl*> t_1 t_2 ... t_j

where $j \le 15$.

Table 3-121. Weight-Window Generation Times Card (WWGT)

Input Parameter	Description
<*pl*>	Particle designator.
t_i	Upper time bound for weight-window group to be generated, $t_{i+1} > t_i$. Units in shakes. Restriction: $i \le 15$

Default: If the WWGT card is omitted and the weight window is used, a single time interval will be established corresponding to the time limits of the problem being run. If the card is present but has no entries, ten time bins will be generated with times of $t_i = 10^{i-8}$ shakes, for i=1,2,...,10. Both the single time and the time-dependent windows are generated.

Use: Optional.

Example:

```
WWG       111   45  0.25
WWGE:p    1  100
WWGT:p    1  100  1.e20
```

The cell-based windows generated from the above cards would look like:

```
WWP:p  5  3  5
WWE:p  1  100
WWT:p  1  100  1.e20
WWN1:p  w1  w2  w3 ...   $ energy 1 time 1
WWN2:p  w1  w2  w3 ...   $ energy 2 time 1
WWN3:p  w1  w2  w3 ...   $ energy 1 time 2
WWN4:p  w1  w2  w3 ...   $ energy 2 time 2
WWN5:p  w1  w2  w3 ...   $ energy 1 time 3
WWN6:p  w1  w2  w3 ...   $ energy 2 time 3
```

This example generates a 2-energy group, 3-time group weight window. In particular, the WWG card would generate weight windows to optimize tally 111. The lowest weight-window bound in any energy-time bin group in cell 45 (the reference cell) would be 0.25. The WWGE and WWGT cards would generate two energy bins and three time bins for photons.

3.3.6.4.4 MESH SUPERIMPOSED IMPORTANCE MESH FOR MESH-BASED WEIGHT-WINDOW GENERATOR

Form: MESH KEYWORD=*value(s)* ...

Table 3-122. Superimposed Mesh Variables (MESH)

Keyword	Description
GEOM	**Controls mesh geometry type. If GEOM=XYZ or GEOM=REC, mesh geometry is Cartesian. If GEOM=RZT or GEOM=CYL, mesh geometry is cylindrical. If GEOM=RPT or GEOM=SPH, mesh geometry is spherical. (DEFAULT: GEOM=XYZ)**
REF	***x*-, *y*-, and *z*-coordinates of the reference point; used to create the normalization constant for the mesh-based weight-window generator. (DEFAULT: none) Restriction: Required.**
ORIGIN	***x*-, *y*-, and *z*-coordinates, in MCNP6 cell geometry, of the origin (bottom, left, rear for rectangular; bottom center for cylindrical; center for spherical) of the superimposed mesh. (DEFAULT: ORIGIN=0. 0. 0.)**
AXS	**Vector giving the direction of the (polar) axis of the cylindrical (see Note 1) or spherical mesh (DEFAULT: AXS=0. 0. 1.)**
VEC	**Vector defining, in conjunction with AXS, the plane for θ=0. For spherical geometry, VEC must be orthogonal to φ. (DEFAULT: VEC=1. 0. 0.)**
IMESH	**Locations of the coarse meshes in the *x* direction for rectangular geometry or in the *r* direction for cylindrical or spherical geometry. (See Notes 2, 3, and 4.) (DEFAULT: none)**
IINTS	**Number of fine meshes within corresponding coarse meshes in the *x* direction for rectangular geometry or in the *r* direction for cylindrical or spherical geometry. (See Notes 6 and 7.) (DEFAULT: IINTS=1 fine mesh in each coarse mesh)**
JMESH	**Locations of the coarse meshes in the *y* direction for rectangular geometry, in the *z* direction for cylindrical geometry, or the phi (φ) polar angle bounds for spherical geometry. (See Notes 2, 3, 4, and 5.) (DEFAULT: none)**
JINTS	**Number of fine meshes within corresponding coarse meshes in the *y* direction for rectangular geometry, in the *z* direction for cylindrical geometry, or in the φ direction for spherical geometry. (See Notes 6 and 7.) (DEFAULT: JINTS=1 fine mesh in each coarse mesh)**
KMESH	**Locations of the coarse meshes in the *z* direction for rectangular geometry or in the θ direction for cylindrical or spherical geometry. (See Notes 2, 3, 4, and 5.) (DEFAULT: none)**
KINTS	**Number of fine meshes within corresponding coarse meshes in the *z* direction for rectangular geometry or in the θ direction for cylindrical or spherical geometry. (See Notes 6 and 7.) (DEFAULT: KINTS=1 fine mesh in each coarse mesh)**

Use: Required to generate mesh-based weight windows; not required to use without weight-window generation. This card is also used to generate a structured discrete-ordinates-style geometry file..

Note 1: For a cylindrical mesh, the AXS and VEC vectors need not be orthogonal but they *must* not be parallel; the one half-plane that contains them and the ORIGIN point will define θ=0. The AXS vector will remain fixed. The length of the AXS or VEC vectors must not be zero.

Note 2: For both the cylindrical and spherical meshes, the lower radial and angular mesh bounds (R-φ-θ) are implicitly zero.

Note 3: The location of the n^{th} coarse mesh in the u direction (ru_n in what follows) is given in terms of the most positive surface in the u direction. For a rectangular mesh, the coarse mesh locations rx_n, ry_n, and rz_n are given as planes perpendicular to the x-, y-, and z-axes, respectively, in the MCNP6 cell coordinate system; thus, the ORIGIN point (x_0,y_0,z_0) is the most negative point of the mesh. For a cylindrical mesh, ORIGIN (r_0,z_0,θ_0) corresponds to the bottom center point and, for a spherical mesh, ORIGIN (r_0,φ_0,θ_0) corresponds the sphere center. The coarse mesh locations must increase monotonically.

Note 4: In the XYZ (REC) mesh, the IMESH, JMESH, and KMESH are the actual x,y,z coordinates. In the RZT (CYL) mesh, IMESH (radius) and JMESH (height) are relative to ORIGIN and KMESH (θ) is relative to VEC. In the RPT (SPH) mesh, IMESH (radius) is relative to ORIGIN, JMESH (φ) is relative to AXS, and KMESH (θ) is relative to VEC.

Note 5: Polar and azimuthal angles may be specified in revolutions (0≤φ≤0.5 and 0≤θ≤1), radians, or degrees. MCNP6 recognizes the appropriate units by looking for 0.5, 3.14, or 180 for the last spherical geometry JMESH entry and for 1, 6.28, or 360 for the last spherical or cylindrical KMESH entry.

Note 6: The fine meshes are evenly distributed within the n^{th} coarse mesh in the u direction. The mesh in which the reference point lies becomes the reference mesh cell for the mesh-based weight-window generator; this reference mesh cell is analogous to the reference cell used by the cell-based weight-window generator. The mesh cell containing the REF point will have its (over energy) weight-window lower bound equal to the third entry on the WWG card.

Note 7: The code uses a default value of 1 fine mesh per coarse mesh if IINTS, JINTS, or KINTS keywords are omitted. If IINTS, JINTS, or KINTS keywords are present, the number of entries must match the number of entries on the IMESH, JMESH, and KMESH keywords, respectively. Entries on the IINTS, JINTS, and KINTS keywords must be greater than zero.

Using an Existing Superimposed Mesh

A second method of providing a superimposed mesh is to use one that already exists, written either to the WWOUT file or to the WWONE file. To implement this method, use the WWG card with i_c=0 in conjunction with the MESH card where the only keyword is REF. The reference point must be within the superimposed mesh and must be provided because there is no reference point in either WWOUT or WWONE. If the mesh-based weight-window generator is invoked by this method, MCNP6 expects to read a file called WWINP. The WWINP file is a weight-window generator output file, either WWOUT or WWONE, that has been renamed in the local file space or equivalenced on the execution line using WWINP=*filename*. (See Appendix B.)

It is not necessary to use mesh-based weight windows from the WWINP file in order to use the mesh from that file. Furthermore, previously generated mesh-based weight windows can be used (WWP card with *switchn*<0 and WWINP file in mesh format) while the mesh-based weight-window generator is simultaneously generating weight windows for a different mesh (input on the MESH card). However, it is not possible to read mesh-based weight windows from one file and a weight-window generation mesh from a different file.

Hints and Guidelines Regarding Superimposed Mesh Creation:

The superimposed mesh should fully cover the problem geometry; i.e., the outer boundaries of the mesh should lie outside the outer boundaries of the geometry, rather than being coincident with them. This requirement guarantees that particles remain within the weight-window mesh. A line or surface source should not be made coincident with a mesh surface. A point source should never be coincident with the intersection of mesh surfaces. In particular, a line or point source should never lie on the axis of a cylindrical mesh. These guidelines also apply to the WWG reference point specified using the REF keyword.

If a particle does escape the weight-window mesh, the code prints a warning message giving the coordinate direction and surface number (in that direction) from which the particle escaped. The code prints the total number of particles escaping the mesh (if any) after the tally fluctuation charts in the standard output file. If a track starts outside the mesh, the code prints a warning message giving the coordinate direction that was missed and which side of the mesh the particle started on. The code prints the total number of particles starting outside the mesh (if any) after the tally fluctuation charts in the standard output file.

Specifying i_c=0 on the WWG card with no MESH card is a fatal error. If AXS or VEC keywords are present and the mesh is rectangular, a warning message is printed and the keyword is ignored. If there are fatal errors and the FATAL option is on, weight-window generation is disabled.

Example 1:

```
MESH   GEOM=CYL  REF=1e-6 1e-7 0  ORIGIN=1  2  3
       IMESH   2.55 66.34
       IINTS   2 15  $ 2 fine bins from 0 to 2.55, 15 from 2.55 to 66.34
       JMESH   33.1  42.1  53.4  139.7
       JINTS   6     3     4     13
       KMESH   0.5     1
       KINTS   5     5
```

Example 2:

```
MESH   GEOM=REC  REF=1e-6 1e-7 0  ORIGIN=-66.34 -38.11 -60
       IMESH   -16.5  3.8  53.66
       IINTS    10   3    8    $ 10 fine bins from -66.34 to -16.5, etc.
```

Example 3:

```
MESH  GEOM sph  ORIGIN 7 -9 -12  REF -23 39 -10  AXS 0.4 -0.5 0.2
       VEC   0.1 -0.2 -0.7
       IMESH     60.                 IINTS  3
       JMESH    0.1   0.35   0.5      JINTS  1 1 1
       KMESH    0.2   0.85   1        KINTS  1 1 1
```

In this example a spherical mesh is located at `ORIGIN=7 -9 -12`. The reference location in the XYZ coordinate system of the problem is at `REF=-23 39 -10`. The weight-window generator lower weight-window bound will be `W` for whatever mesh cell contains this location, where `W` is half the source weight by default or whatever is the 3rd entry on the `WWG` weight-window generator card. The polar (φ) axis of the spherical mesh (as in latitude on the globe) is `AXS=0.4 -0.5 0.2`, which MCNP6 will normalize to a unit vector. The azimuthal planes (as in longitude on a globe, or cylindrical mesh theta bins) are measured relative to the azimuthal vector, theta (θ), `VEC=0.1 -0.2 -0.7`. `VEC` will also be renormalized by MCNP6 and must be orthogonal to φ. The radial mesh bins have three interpolates between 0 and 60—that is, the mesh bounds are at 0, 20, 30, and 60 cm. The polar angles (φ) are at 0.1, 0.35, and 0.5 revolutions from the `AXS` vector. The azimuthal angles (θ) are at 0.2, 0.85, and 1 revolutions from the `VEC` vector. Note that $0 \leq \varphi \leq 0.5$ and $0 \leq \theta \leq 1$ are always required.

For examples that show how to plot superimposed weight-window meshes see Section 5.4.8.

3.3.6.5 ESPLT ENERGY SPLITTING AND ROULETTE

The `ESPLT` card allows problem-wide splitting and Russian roulette of particles in energy, similar to how the `IMP` card allows splitting and Russian roulette as a function of geometry. The `ESPLT` card can be used in all problems except multigroup problems. The changes to a particle's weight caused by the `ESPLT` card will create compensating weight adjustments to the weight cutoff and weight-window values.

Form: `ESPLT:<pl>` r_1 e_1 ... r_{20} e_{20}

Table 3-123. Energy Splitting and Roulette Card (ESPLT)

Input Parameter	Description
<pl>	**Particle designator.**

r_i	**Provides splitting/roulette ratios at each energy boundary, e_i, for decreasing energy. The meanings of the r_i differ depending on whether or not there is a weight window present for the particle type <pl>. These splitting/roulette ratios are internally converted in the code to an absolute importance function with an $r_0=1$ inserted to set the importance to unity for energies greater than the maximum of the e_i.**
	
	When weight windows are not used:
	If the energy of a particle of type <pl> falls below e_i (decreasing energy), then
	If $r_i>1$, then r_i is the number of tracks into which a particle will be split.
	If $0<r_i<1$, then r_i is the probability of Russian roulette.
	If, $r_i=1$, then there is no action.
	If the energy of a particle of type <pl> increases in energy above e_i, then
	If $1/r_i>1$, then $1/r_i$ is the number of tracks into which a particle will be split.
	If $0<1/r_i<1$, then $1/r_i$ is the probability of Russian roulette.
	Exception: If the first $r_1<0$, then no game is played on energy increases.
	
	When weight windows are specified, then the energy splitting is accomplished solely with the weight windows (see Note 1). The r_i in this case are energy importance modifications to the weight window:
	If the energy of a particle of type <pl> falls below e_i, then the existing weight windows will be adjusted by dividing the windows by r_i.
	If the energy of a particle of type <pl> increases above e_i, then the weight windows are multiplied by r_i.
	If more than one energy boundary is crossed, the windows are adjusted by the product of the r_i values.
	Restriction: $1 \le i \le 20$

e_i	**Energy (MeV) at which particles are to undergo splitting or Russian roulette. Values must be monotonic.** **Restriction: $1 \le i \le 20$**

Default: Omission of this card means that energy splitting will not take place for those particles for which the card is omitted.

Use: Optional. Cannot be used in multigroup calculations.

Caution: The ESPLT card is intended to be used with a time-dependent weight window. The ESPLT card is not recommended for an energy-dependent weight window as these two cards may interfere with one another (see the discussion in the table above). However, the code does not prevent the user from invoking both at the same time. Instead of a single-range weight window and an ESPLT card, consider using an energy-dependent weight window.

Note 1: If the eighth entry on the WWP card is 1 (0 is the default), then in addition to the weight-window adjustment, the particle will be explicitly split or rouletted upon crossing e_i, just as is the case without a weight window. It is anticipated that the default will be appropriate for almost all problems.

Additional Information Regarding ESPLT:

The entries on the ESPLT card consist of pairs of energy-importance ratio parameters, r_i and e_i, with a maximum of twenty pairs allowed. A warning message is issued if the e_i are not monotonic. The value of r_i can be non-integer and also can be between 0 and 1. For an energy decrease below an e_i with an associated r_i greater than 1, particle splitting will occur. For a value of r_i between 0 and 1, r_i becomes the survival probability in the Russian roulette game. For an energy increase above an e_i with an associated $1/r_i$ greater than 1, particle splitting will occur. For a value of $1/r_i$ between 0 and 1, $1/r_i$ becomes the survival probability in the Russian roulette game. If a particle's energy becomes less than e_i, the specified splitting or roulette is sampled. If more than one energy boundary is passed during a particle trajectory, the product of the r_i values is used to determine the outcome.

If the particle's energy falls below e_i, the specified splitting or roulette always occurs. If the particle's energy increases above e_i, the inverse game is normally played (unless r_1 has been specified as less than zero). For example, suppose roulette is specified at 0.1 MeV with a survival probability of 0.5; if a particle's energy increases above 0.1 MeV, it is split 2-for-1.

A neutron's energy may increase by fission or from thermal up-scattering. There are cases when it may not be desirable to have the splitting or roulette game played on energy increases (particularly in a fission-dominated problem). If $r_1<0$, then splitting or roulette will be played only for energy decreases and not for energy increases.

Example 1:

```
ESPLT:N    2  0.1   2  0.01   0.25  0.001
```

This example specifies a 2 for 1 split when the neutron energy falls below 0.1 MeV, another 2 for 1 split when the energy falls below 0.01 MeV, and Russian roulette when the energy falls below 0.001 MeV with a 25% chance of surviving. Thus, a neutron that enters a collision at 0.5 MeV and exits at 0.005 MeV will be split 4 to 1.

Example 2:

```
ESPLT:N    2  0.1   2  0.01   0.25  0.001
WWP:N      5  3  5  0  0  0  J  J
```

This example divides the weight windows by 2 when the energy falls below 0.1 MeV, divides by 2 again when the energy falls below 0.01 MeV, and divides by 0.25 when the energy falls below 0.001 MeV.

Example 3:

```
ESPLT:N    2  0.1   2  0.01   0.25  0.001
WWP:N      5  3  5  0  0  0  J  1
```

This example is similar to Example 2 except that the eighth entry on the WWP card (*etsplt*) is set to 1. Consequently, in addition to the weight-window adjustment, the particle will be explicitly split or rouletted upon crossing e_i. For this example, the weight windows will be divided by 2 when the energy falls below 0.1 MeV, divided by 2 again when the energy falls below 0.01 MeV, and divided by 0.25 when the energy falls below 0.001 MeV. In addition, a 2-for-1 split will occur when the neutron energy falls below 0.1 MeV, another 2-for-1 split will happen when the neutron energy falls below 0.01 MeV, and Russian roulette with a survival probability of 0.25 will be played when the neutron energy falls below 0.001 MeV.

3.3.6.6 TSPLT TIME SPLITTING AND ROULETTE

The TSPLT card allows problem-wide splitting and Russian roulette of particles in time, like the IMP card allows splitting and Russian roulette as a function of geometry. The TSPLT card can be used in all problems except multigroup problems. The changes to a particle's weight caused by the TSPLT card will create compensating weight adjustments to the weight cutoff and weight-window values.

Form: TSPLT:<*pl*> r_1 t_1 ... r_{20} t_{20}

Table 3-124. Time Splitting and Roulette Card (TSPLT)

Input Parameter	Description
<*pl*>	**Particle designator. (See Note 1.)**

r_i	**Provides splitting/roulette ratios at each time boundary, t_i, for increasing time. These splitting/roulette ratios are internally converted in the code to an absolute importance function with an r_0=1 inserted to set the importance to unity for times less than the minimum of the t_i.** **When weight windows are not used:** **If r_i>1, then r_i is the number of tracks into which a particle will be split.** **If 0<r_i<1, then r_i is the probability of Russian roulette.** **If r_i=1, then there is no action.** **When weight windows are specified, then the time splitting/roulette is accomplished solely with the weight windows (see Note 2): The r_i in this case are time importance modifications to the weight window.** **If the particle crosses t_i, the existing weight windows will be adjusted by dividing the windows by r_i.** **If more than one time boundary is crossed, the windows are divided by the product of the r_i values.** **Restriction: $1 \le i \le 20$**
t_i	**Times (shakes) at which particles are to undergo splitting or Russian roulette. Values must be monotonic.** **Restriction: $1 \le i \le 20$**

Default: Omission of this card means that time splitting will not take place for those particles for which the card is omitted.

Use: Optional. Cannot be used in multigroup calculations.

Caution: The TSPLT card is intended to be used with an energy-dependent weight window. The TSPLT card is not recommended for a time-dependent weight window as these two cards may interfere with one another. However, the code does not prevent the user from invoking both at the same time. Instead of a single-range weight window and a TSPLT card, consider using a time-dependent weight window.

Note 1: Normally in a coupled mode problem (e.g., MODE N P), if particle type <*pl*> is important late in time, then all particles producing particle type <*pl*> will also be important late in time. For these reasons, it is suggested that the user have a TSPLT card for each relevant particle type. Thus in a MODE N P problem, if a TSPLT:P card is specified then a TSPLT:N card would normally be specified as well.

Note 2: If the eighth entry on the WWP card is 1 (0 is the default), then in addition to the weight-window adjustment, the particle will be explicitly time-split or rouletted upon crossing t_i, just as is the case without a weight window. It is anticipated that the default will be appropriate for almost all problems.

Additional Information Regarding TSPLT:

The entries on the `TSPLT` card consist of pairs of time-importance ratio parameters, r_i and t_i, with a maximum of twenty pairs allowed. A warning message is issued if the t_i are not monotonic. The value of r_i can be non-integer and also can be between `0` and `1`. For an r_i greater than `1`, particle splitting will occur. For a value of r_i between `0` and `1`, r_i becomes the survival probability in the Russian roulette game. If a particle's time becomes greater than t_i, the specified splitting or roulette is sampled. If more than one time boundary is passed during a particle trajectory, the product of the r_i values is used to determine the outcome. The t_i are in units of shakes.

Example 1:

```
TSPLT:N    2 100  2 1000  0.2 10000
```

This example specifies a-2 for-1 split when the neutron time exceeds 100 shakes, another 2-for-1 split when the time exceeds 1000 shakes, and Russian roulette with a survival probability of 0.2 when the time exceeds 10000 shakes. A neutron that crosses both 1000 and 10000 shakes will have a survival probability of 0.4.

Example 2:

```
TSPLT:N    2 100  2 1000  0.2 10000
WWP:N      5  3  5  0  0  0  J  J
```

This example divides the weight windows by 2 when the neutron time exceeds 100 shakes, divides by 2 again when the time exceeds 1000 shakes, and divides by 0.2 when the time exceeds 10000 shakes. Thus the weight window will be divided by a factor of 4 for a particle whose time at the start of the transport step was 90 shakes and whose time at the end of the transport step was 1010 shakes.

Example 3:

```
TSPLT:N    2 100  2 1000  0.2 10000
WWP:N      5  3  5  0  0  0  J  1
```

This example is similar to Example 2 except that the eighth entry on the `WWP` card (*`etsplt`*) is set to 1. Consequently, in addition to the weight-window adjustment, the particle will be explicitly split or rouletted when it exceeds t_i. For this example the weight windows will be divided by 2 when the neutron time exceeds 100 shakes, divided by 2 again when the time exceeds 1000 shakes, and divided by 0.2 when the time exceeds 10000 shakes. In addition, this example specifies a 2-for-1 split when the neutron time exceeds 100 shakes, another 2-for-1 split when the time exceeds 1000 shakes, and a Russian roulette survival probability of 0.2 when the time exceeds 10000 shakes.

3.3.6.7 EXT EXPONENTIAL TRANSFORM

The exponential transform method stretches the path length between collisions in a preferred direction by adjusting the total cross section.

Form 1 (cell card entry): EXT:<*pl*>=*a*

Form 2 (data card): EXT:<*pl*> a_1 a_2 ... a_j ...

Table 3-125. Exponential Transform Card (EXT)

Input Parameter	Description
<*pl*>	**Particle designator.**
A	**Each entry *a* is of the form *a*=QV*m*, where Q describes the amount of stretching and V*m* defines the stretching direction for the cell. (See Table 3-126 of Example 1.)**
a_j	**Each entry a_j is of the form a_j=QV*m*, where Q describes the amount of stretching and V*m* defines the stretching direction for cell *j*. (See Table 3-126 of Example 1.) The number of entries need not equal the number of cells in the problem, but a warning message is printed if they are not equal..**

Default: No transform, a_j=0.

Use: Optional. Use cautiously. Weight windows are strongly recommended. A warning message is given if weight windows are not present when the exponential transform is used. The exponential transform should not be used in the same cell as forced collisions or without good weight control. The transform works best when the particle flux has an exponential attenuation, such as in problems with highly absorbing media.

Additional Information Regarding the Exponential Transform:

The exponential transform method stretches the path length between collisions in a preferred direction by adjusting the total cross section as follows:

$$\Sigma_t^* = \Sigma_t(1 - p\mu)$$

where Σ_t^* is the artificially adjusted total cross section,
Σ_t is the true total cross section,
p is the stretching parameter, and
μ is the cosine of the angle between the particle direction and the stretching direction.

The stretching parameter, *p*, can be specified by the stretching entry, Q, in three ways:

If p=0, then Q=0 and the exponential transform is not used.
If 0<p<1, then Q=p and a constant stretching parameter is specified.
If $p=\Sigma_c/\Sigma_t$, then Q=S where Σ_c is the capture cross section (as defined by nuclear engineers).

Letting $p=\Sigma_c/\Sigma_t$ can be used for implicit capture along a flight path, as described in the MCNP5 Theory Manual[X-503a].

The stretching direction is defined by the V*m* part of each a_j entry on the `EXT` card with three available options:

1. If the V*m* part of the a_j entry is omitted (i.e., a_j=Q for a given cell), then the stretching is in the particle direction (μ=1), independent of the particle direction (and therefore independent of any direction). This is not recommended unless you want to do implicit capture along a flight path, in which case a_j=Q=`S` and the distance to scatter rather than the distance to collision is sampled.
2. The stretching direction may be specified as V*m*, where *m* is a unique integer that is associated with the vector entry provided on the `VECT` card (Section 3.3.6.8). The stretching direction is defined as the line from the collision point to the point (x_m,y_m,z_m), where (x_m,y_m,z_m) is provided on the `VECT` card. The direction cosine μ is now the cosine of the angle between the particle direction and the line drawn from the collision point to point (x_m,y_m,z_m). The sign of a_j governs whether stretching is toward or away from (x_m,y_m,z_m).
3. The stretching direction may also be specified as V*m*=`X` or `Y` or `Z`, so the direction cosine μ is the cosine of the angle between the particle direction and the *x*–, *y*–, or *z*–axis, respectively. The sign of a_j governs whether stretching is toward or away from the *x*–, *y*–, or *z*–axis.

Example 1:

```
EXT:N    0  0  0.7V2  S  -SV2  -0.6V9  0  0.5V9  SZ  -0.4X
VECT     V9  0  0  0    V2  1  1  1
```

The 10 entries are for the 10 cells in this problem. Path length stretching is not turned on for photons or for cells `1`, `2`, and `7`. Table 3-126 is a summary of path length stretching in the other cells.

Table 3-126 Exponential Transform Stretching Parameter

Cell	a_i	Q	V*m*	Stretching Parameter	Stretching Direction
3	0.7V2	0.7	V2	$p = 0.7$	Toward point (1,1,1)
4	S	S		$p = \Sigma_c/\Sigma_t$	Particle direction
5	-SV2	S	-V2	$p = \Sigma_c/\Sigma_t$	Away from point (1,1,1)
6	-0.6V9	0.6	-V9	$p = 0.6$	Away from origin
8	0.5V9	0.5	V9	$p = 0.5$	Toward origin
9	SZ	S	Z	$p = \Sigma_c/\Sigma_t$	Along +*z*-axis
10	-0.4X	0.4	-X	$p = 0.4$	Along -*x*-axis

3.3.6.8 VECT VECTOR INPUT

The entries on the VECT card are quadruplets that may define any number of vectors for either the exponential transform or user patches. See the EXT card (Section 3.3.6.7) for a usage example

Form: VECT V*m* x_m y_m z_m . . . V*n* x_n y_n z_n . . .

Table 3-127. Vector Input Card (VECT)

Input Parameter	Description
m, *n*	Any number to uniquely identify vectors V*m*, V*n*, . . .
x_m y_m z_m	Coordinate triplets to define vector V*m*.

Default: None.

Use: Optional.

3.3.6.9 FCL FORCED COLLISION

The FCL card controls the forcing of neutron or photon collisions in each cell. This is particularly useful for generating contributions to point detectors or DXTRAN spheres. The weight-window game at surfaces is not played when entering forced-collision cells.

Because the forced-collision variance reduction method can produce several very low-weight particles, the weight cutoff game is turned on by default when using pulse-height tallies and forced collisions together. Any of the default settings can be overridden by explicitly setting the weight cutoffs on the CUT card (see Section 3.3.3.4.1).

Form 1 (cell card entry): FCL:<*pl*>=*x*

Form 2 (data card): FCL:<*pl*> x_1 x_2 . . . x_j . . .

Table 3-128. Forced-Collision Card (FCL)

Input Parameter	Description
<*pl*>	Particle designator. Restriction: Only neutrons (N) and photons (P) are permitted.
x	Forced-collision control for cell. (See Notes 1, 2 and 3.) Restriction: $-1 \le x \le 1$ If $x>0$, forced collision applies to particles entering the cell and to those surviving weight cutoff/weight-window games in the cell. (See Note 4.) If $x<0$, forced collision applies only to particles entering the cell. (See Note 5.) If $x=0$, no forced collision in the cell. (DEFAULT)

x_j	**Forced-collision control for cell j. (See Notes 1, 2 and 3.)** **Restriction: $-1 \le x_j \le 1$** **If $x_j>0$, forced collision applies to particles entering the cell j and to those surviving weight cutoff/weight-window games in the cell. (See Note 4.)** **If $x_j<0$, forced collision applies only to particles entering the cell j. (See Note 5.)** **If $x_j=0$, no forced collision in the cell j. (DEFAULT)** **The number of entries need not equal the number of cells in the problem, but a warning message is printed if they are not equal.**

Default: $x_j=0$, no forced collisions.

Use: Optional. Exercise caution.

Note 1: If $x_j \neq 0$, all particles entering cell j are split into collided and un-collided parts with the appropriate weight adjustment. If $|x_j|<1$, Russian roulette is played on the collided parts with survival probability $|x_j|$ to keep the number of collided histories from getting too large. Fractional x_j entries, rather than values of -1 or 1, are recommended if a number of forced-collision cells are adjacent to each other.

Note 2: When cell-based weight-window bounds bracket the typical weight entering the cell, choose $x_j>0$. When cell-based weight-window bounds bracket the weight typical of forced-collision particles, choose $x_j<0$. For mesh-based windows, $x_j>0$ usually is recommended. When using importance, $x_j>0$ because $x_j<0$ turns off the weight cutoff game.

Note 3: Let $x_j=1$ or -1 unless a number of forced collision cells are adjacent to each other or the number of forced collision particles produced is higher than desired. Then fractional values are usually needed.

Note 4: If $x_j>0$, the forced collision process applies both to particles entering cell j and to the collided particles surviving the weight cutoff or weight-window games. Particles will continue to be split into un-collided and (with probability $|x_i|$) collided parts until killed by either weight cutoff or weight windows.

Note 5: If $x_j<0$, the forced collision process applies only to particles entering the cell. After the forced collision, the weight cutoff is ignored and all subsequent collisions are handled in the usual analog manner. Weight windows are not ignored and are applied after contributions are made to detectors and DXTRAN spheres.

3.3.6.10 DXT DXTRAN SPHERE

DXTRAN (deterministic transport) spheres are used to improve the particle sampling in a given region of phase-space, a type of angle biasing, or, conversely, to block high-weight particles from reaching a given region. Primarily, the DXT card specifies the spheres needed to define a spherical phase-space region and the special weight-cutoff game that applies inside the spheres, depending upon the presence or absence of other variance reduction games specified in the problem. See the MCNP5 Theory Manual[X-503a] for more details about this method.

Form: `DXT:`*<pl>* x_1 y_1 z_1 ri_1 ro_1 x_2 y_2 z_2 ri_2 ro_2 ... dwc_1 dwc_2 *dpwt*

Table 3-129. DXTRAN Card (DXT)

Input Parameter	Description
<pl>	**Particle designator.** **Restriction: Only allowed particles are neutrons (`N`) and photons (`P`).**
x_i y_i z_i	**Coordinates of the point at the center of the i^{th} pair of spheres. (See Notes 1 and 2.)** **Restriction: $i \le 10$**
ri_i	**Radius of the i^{th} inner sphere in cm. (See Note 3.)** **Note: The inner sphere is only used to bias placement of the DXTRAN particles on the outer sphere by modifying the probability density function into a two-step histogram. (See the MCNP6 Theory Manual [X-503a] for more details.) All particles start on the outer sphere.** **Restriction: $i \le 10$**
ro_i	**Radius of the i^{th} outer sphere in cm.** **Restriction: $i \le 10$**
dwc_1	**Upper weight cutoff in the spheres for the DXTRAN weight-cutoff game inside the sphere. (DEFAULT: dwc_1=0)**
dwc_2	**Lower weight cutoff in the spheres for the DXTRAN weight-cutoff game inside the sphere.. (DEFAULT: dwc_2=0)**
dpwt	**Minimum photon weight. Entered on `DXT:N` card only. (See Note 4.) (DEFAULT: *dpwt*=0)**

Defaults: Zero for dwc_1, dwc_2, and *dpwt*. No defaults for locations or radii.

Use: Optional. Consider using `DXC:`*<pl>* or `DD` cards when using `DXT`.

Note 1: There can be up to 10 sets of *x*, *y*, *z*, *ri*, and *ro* per particle type. There is only one set of dwc_1 and dwc_2 entries for each particle type. The *dwc* pair is entered after conclusion of the other data and (with `DXT:N`) before the one value of *dpwt*. The weight cutoffs apply to DXTRAN particle tracks inside the outer radii and have default values of zero. The DXTRAN photon weight cutoffs have no effect unless the simple physics is used, with one exception: upon leaving the sphere, track weights (regardless of what physics is used) are checked against the cutoffs of the `CUT:P` card. The DXTRAN weight cutoffs dwc_1 and dwc_2 are ignored when mesh-based weight windows are used, but are active for cell-based weight windows because the weight-window game is turned off inside the spheres.

Note 2: DXTRAN spheres can be nested inside one another. [BOO09] The allowed nesting is reasonably general: more than one DXTRAN sphere may be nested inside a larger DXTRAN sphere and the centers of the nested DXTRAN spheres need not be concentric. Also, the spherical surfaces must not intersect. This nesting mitigates weight fluctuation problems as the particles approach the region(s) of interest.

Note 3: When the DXTRAN method is used as a means to produce a higher particle population near a tally, the inner radius *ri* should be at least as large as the tally region. The purpose of the inner sphere is for biasing placement of DXTRAN particles on the outer sphere; there is no problem making the two radii the same.

Note 4: The minimum photon weight limit *dpwt* on the DXT:N card parallels almost exactly the minimum photon weight entries on the PWT card. One slight difference is that in Russian roulette during photon production inside DXTRAN spheres, the factor for relating current cell importance to source cell importance is not applied. Thus, the user must have some knowledge of the weight distribution of the DXTRAN particles (from a short run with the DD card, for example) inside the DXTRAN sphere, so the lower weight limit for photon production may be specified intelligently. As in the case of the PWT entries, a negative entry will make the minimum photon weight relative to the source particle starting weight. The default value is zero, which means photon production will occur at each neutron DXTRAN particle collision in a material with non-zero photon production cross section inside the DXTRAN sphere.

Additional Information Regarding DXTRAN Spheres:

One use of DXTRAN is to improve the particle sample in the vicinity of a tally (see the MCNP6 Theory Manual[X-503a]. It should not be misconstrued as a tally itself, such as a point detector; it is used in conjunction with tallies as a variance reduction technique. DXTRAN spheres must not overlap. The spheres should normally cover the tally region if possible. Specifying a tally cell or surface partly inside and partly outside a DXTRAN sphere usually will make the mean of the tally erratic and the variance huge.

The technique is most effective when the geometry inside the spheres is very simple and can be costly if the inside geometry is complicated, involving several surfaces. However, the nested DXTRAN treatment should alleviate some of these complicated geometry issues. The inner sphere is intended to surround the region of interest. The outer sphere should surround neighboring regions that may scatter into the region of interest. In MCNP6, the relative importance of the two regions is five. That is, the probability density for scattering toward the inner sphere region is five times as high as the probability density for scattering between the inner and outer spheres. This position biasing is only one of several factors that affect the weights of the DXTRAN particles; see the MCNP5 Theory Manual[X-503a] on this topic for more information.

All collisions producing neutrons and photons contribute to DXTRAN, including model physics interactions. When the secondary neutron/photon angular scattering distribution function is unknown, isotropic scattering, which may be a poor approximation, is assumed. Although the extension to higher energies often is approximate, a tally with an appropriate energy structure can provide the user with insight regarding the contributions at these energies. This approximation is superior to neglecting charged-particle and high-energy neutron collisions altogether.

As mentioned above, DXTRAN uses an assumption of isotropic scatter for contributions from collisions within the model regime. These estimators require the angular distribution data for particles produced in an interaction to predict scattering toward the sphere(s). Information on these distributions is available in tabular form in the libraries; however, this information is not available in the required form from physics models used to produce secondary particles above the tabular region.

DXTRAN can be used in a problem with the $S(\alpha,\beta)$ thermal treatment, but contributions to the DXTRAN spheres are approximate. DXTRAN should not be used with reflecting surfaces, white boundaries, or periodic boundaries (see the MCNP6 Theory Manual[X-503a]). DXTRAN can be used with mono-direction sources, but the user should understand that no contributions from sources occur unless the source is directed at the DXTRAN sphere.

DXTRAN spheres can be used around point detectors (F5 tallies), but the combination may be very sensitive to reliable sampling.

If more than one set of DXTRAN spheres is used in the same problem, they can "talk" to each other in the sense that collisions of DXTRAN particles in one set of spheres cause contributions to another set of spheres. The contributions to the second set have, in general, extremely low weights but can be numerous with an associated large increase in computer time. In this case the DXTRAN weight cutoffs probably will be required to kill the very-low-weight particles, provided mesh-based weight windows are not used. The DD card (Section 3.3.6.11) can give you an indication of the weight distribution of DXTRAN particles.

Remember that the DD card roulette game is on by default and the reference weight is a moving average for the first dmmp histories unless this Russian roulette game is turned off or a fixed level is input (as a $-k_i$ on the DD card). It is highly recommended that the user make a short exploratory run to establish a value to input; a value that is 10% of the average contributed weight to the sphere is a good place to start. See Section 3.3.6.11 for the DD card input requirements and more details regarding the number of histories used to find the average contribution. If the user were to rely on the default behavior, then running a single history after the first dmmp histories (perhaps for the sake of debugging or dealing with a lost particle) will not yield the same result as before.

3.3.6.11 DD DETECTOR DIAGNOSTICS

The DD card (1) can speed up calculations significantly by using a Russian roulette game to limit small contributions that are less than some fraction k of the average contribution per history to detectors or DXTRAN spheres and (2) can provide more information about the origin of large contributions or the lack of a sufficient number of collisions close to the detector or DXTRAN sphere. The information provided about large contributions can be useful for setting cell importance or source-biasing parameters.

The DD card eliminates *tracks* to DXTRAN spheres, and *contributions* to detectors.

Form: DD*n* k_1 m_1 k_2 m_2 ...

Table 3-130. Detector Diagnostics Card (DD)

Input Parameter	Description
N	If *n*=0 or blank, diagnostic parameters apply to all detector tallies and DXTRAN spheres unless overridden with a separate DD*n* card. If *n*=1, provide detector diagnostics for neutron DXTRAN spheres. If *n*=2, provide detector diagnostics for photon DXTRAN spheres. If *n* ends in the numeral 5, then *n* is the tally number for a specific detector tally.
k_i	Criterion for playing Russian roulette for DXTRAN sphere *i* or detector *i* in tally *n*. Let A_i be the average score per history for either the sphere or detector. (See Note 1.) Then, If $k_i<0$, DXTRAN or detector scores $>\|k_i\|$ will always be made and contributions $<\|k_i\|$ are subject to Russian roulette; or If $0<k_i\leq 1$, all DXTRAN sphere or detector contributions are made for the first *dmmp* histories. Thereafter, any contribution to the detector or sphere $>k_iA_i$ will always be made, but any contribution $<k_iA_i$ is subject to Russian roulette (See Note 2.); or If $k_i=0$, no Russian roulette is played on small DXTRAN or detector scores.
m_i	Criterion for printing diagnostics for large contributions for DXTRAN sphere *i* or detector *i* of tally *n*. Let A_i be the average score per history for either the sphere or detector. (See Note 1.) Then, If $m_i=0$, no diagnostic print. If $m_i>0$ and $k_i\geq 0$, then no diagnostic print made for the first *dmmp* histories. Thereafter, the first 100 contributions larger than m_iA_i, will be printed. (See Note 2.) If $m_i>0$ and $k_i<0$, then the first 100 contributions larger than $m_i\|k_i\|$ will be printed.

Default: If k_i is not specified on a DD*n* card, k_i on the DD card is used. If that is not specified, k_i=0.1 is used. A similar sequence of defaults defines m_i, with a final default of m_i=1000.

Use: Optional. Remember that Russian roulette will be played for detectors and DXTRAN unless specifically turned off by use of the DD card. The value of k_i=0.5 is suitable for most problems; the non-zero default value, k_i=0.1, means that the game is always played unless explicitly turned off by the user. Consider also using the PD (Section 3.3.6.12) or DXC (Section 3.3.6.13) cards.

Note 1: The average contribution per history, A, to a particular DXTRAN sphere or detector is calculated from all contributions to the detector or sphere made by particle histories until the first tally fluctuation chart (TFC) interval is reached (see the *dmmp* entry on the PRDMP card). (See Section 3.3.7.2.3.) The default is 1000 particles per interval for fixed-source problems or one KCODE cycle. The average is then updated at all subsequent tally fluctuation chart intervals.

Note 2: Remember that when k_i is positive, the Russian roulette game is played on the basis of the estimated average contribution per history, A_i. Because the estimate improves from time to time, the game is based on different values for different histories. This can make debugging a problem more complicated, and the variance estimate does not quite obey the Central Limit Theorem.

A procedure worth considering is to determine the average contribution per history in a preliminary run and then use some fraction of the negative of this value in subsequent longer runs. The Russian roulette game is played without regard to particle time or energy; thus time and energy bins for which the ultimate tally is small may lose a disproportionate share of scores by the roulette game.

Example 1:

```
DXT:N    x1  y1  z1   ri1  ro1
         x2  y2  z2   ri2  ro2
         x3  y3  z3   ri3  ro3
DXT:P    x4  y4  z4   ri4  ro4
F15X:P   a1  r1  R1
         a2  r2  R2
DD        0.2   100  0.15  2000
DD1   -1.1E25  3000     J     J    J  3000
DD15      0.4   10
```

This input results in the following interpretation for the DD parameters for the detectors and DXTRAN spheres:

	k	*m*
sphere 1	-1.1E25	3000
sphere 2	0.15	2000
sphere 3	0.2	3000
sphere 4	0.2	100
detector 1	0.4	10
detector 2	0.15	2000

3.3.6.12 PD DETECTOR CONTRIBUTION

The PD card reduces the number of contributions to point detector tallies (F5) from selected cells that are relatively unimportant to a given detector, thus saving computing time. At each collision in cell j, the point detector tallies are made with probability p_j ($0 \le p_j \le 1$); that is, a Russian roulette game is played in which the survival probability is p_j to determine if the contribution should take place. When the contribution survives the roulette game, the tally is then increased by the factor $1/p_j$ to obtain unbiased results for all cells except those where p_j=0. This enables the user to decrease the problem runtime by setting p_j<1 for cells many mean free paths from the detectors. It also selectively eliminates detector contributions from cells by setting the p_j values for those cells to zero. This card is analogous to the DXC card (Section 3.3.6.13), but is used for contributions to point detector tallies (F5).

Form 1 (cell card entry): PD*n*=*p*

Form 2 (data card): PD*n* p_1 p_2 ... p_j ...

Table 3-131. Detector Contribution Card (PD)

Input Parameter	Description
N	**Tally number. (See Note 1.)** **Restriction: *n*≤9999**
P	**Probability of contribution to detector *n* from cell. (DEFAULT: *p*=1)**
p_j	**Probability of contribution to detector *n* from cell *j*. (DEFAULT: p_j=1) Number of entries is equal to the number of cells in the problem.**

Default: p_j=1

Use: Optional. Consider also using the DD card, Section 3.3.6.11.

Note 1 A default set of probabilities can be established for all tallies by use of a PD0 card. These default values will be overridden for a specific tally *n* by values entered on a PD card.

3.3.6.13 DXC DXTRAN CONTRIBUTION

The DXC card is analogous to the PD card for detector contributions except it is used for contributions to DXTRAN spheres.

Form 1 (cell card entry): DXC*m*:<*pl*>=*p*

Form 2 (data card): DXC*m*:<*pl*> p_1 p_2 ... p_j ...

Table 3-132. DXTRAN Contribution Card (DXC)

Input Parameter	Description
M	**Indicates to which DXTRAN sphere, *m*, the DXC card applies. If *m*=0 or absent, the DXC card applies to all the DXTRAN spheres in the problem. (DEFAULT: *m*=0)**
<*pl*>	**Particle designator.** **Restriction: Only allowed particles are neutrons (N) and photons (P).**
P	**Probability of contribution to DXTRAN sphere *m* from cell. (DEFAULT: *p*=1)**
p_j	**Probability of contribution to DXTRAN sphere *m* from cell *j*. (DEFAULT: p_j=1) Number of entries equals number of cells in the problem.**

Use: Optional. Consider also using the DD card, Section 3.3.6.11.

3.3.6.14 BBREM BREMSSTRAHLUNG BIASING

The bremsstrahlung process generates many low-energy photons, but the higher-energy photons are often of more interest. One way to generate more high-energy photon tracks is to bias each sampling of a bremsstrahlung photon toward a larger fraction of the available electron energy. Use the BBREM card to specify this biasing toward higher-energy photons.

Form: BBREM b_1 b_2 b_3 ... b_{49} m_1 m_2 ... m_n

Table 3-133. Bremsstrahlung Biasing Card (BBREM)

Input Parameter	Description
b_1	**Any positive value (currently unused).**
b_2 ... b_{49}	**Bias factors for the bremsstrahlung energy spectrum.**
m_1 ... m_n	**List of *n* materials for which the biasing is invoked.**

Default: None.

Use: Optional.

Example 1/Discussion:

```
BBREM     1.  1.  46I  10.  888  999
```

This specification will create a gradually increasing enhancement (from the lowest to the highest fraction of the electron energy available to a given event) of the probability that the sampled bremsstrahlung photon will carry a particular fraction of the electron energy. This biasing would apply to each instance of the sampling of a bremsstrahlung photon in materials 888 and 999. The sampling in other materials would remain unbiased. The bias factors are normalized by the code in a manner that depends both on material and on electron energy, so that although the ratios of the photon weight adjustments among the different groups are known, the actual number of photons produced in any group is not easily predictable. For the EL03 treatment, there are more than 49 relative photon energy ratios so the lower energy bins have a linear interpolation between b_1 and b_2 for their values.

In most problems the above prescription will increase the total number of bremsstrahlung photons produced because there will be more photon tracks generated at higher energies. The secondary electrons created by these photons will tend to have higher energies as well, and will therefore be able to create more bremsstrahlung tracks than they would at lower energies. This increase in the population of the electron-photon cascade will make the problem run more slowly. The benefits of better sampling of the high-energy domain must be balanced against this increase in run time.

3.3.6.15 PIKMT PHOTON-PRODUCTION BIASING

Photon-Production Biasing

For several classes of coupled neutron-photon calculations, the desired result is the intensity of a small subset of the entire photon energy spectrum. Two examples are discrete-energy (line) photons and the high-energy tail of a continuum spectrum. In such cases, it may be beneficial to bias the spectrum of neutron-induced photons to produce only those that are of interest.

Be careful. Use of the `PIKMT` card can cause non-zero probability events to be excluded completely, resulting in a biasing game that may not be fair. While neutron tallies will be unaffected (within statistics), the only reliable photon tallies will be those with energy bins immediately around the energies of the discrete photons produced.

To use this feature, users will likely need information about the MT identifiers of the reactions that produce discrete energy photons. The user is encouraged to consult Appendix B of the ENDF-6 Formats Manual (CSEWG Document ENDF-102, Report BNL-90365-2009) for a list of all MT identifiers and look through Chapters 12 and 13 (i.e., Files 12 and 13) for a better understanding of ENDF neutron-induced photon production.

This photon-production biasing feature is also useful for biasing the neutron-induced photon spectrum to produce very high-energy photons (for example, $E_\gamma \geq 10$ MeV). Without biasing, these high-energy photons are produced very infrequently; therefore, it is difficult to extract reliable statistical information about them. An energy cutoff can be used to terminate a track when it falls below the energy range of interest.[1]

[1] LANL users interested in using the `PIKMT` card for this application should contact XCP-3 regarding an internal code (NIPE) that is useful for optimizing such problems.

Form: `PIKMT` $zaid_1$ $ipik_1$ $mt_{1,1}$ $pmt_{1,1}$ ... $mt_{1,ipik_1}$ $pmt_{1,ipik_1}$
$zaid_n$ $ipik_n$ $mt_{n,1}$ $pmt_{n,1}$ ... $mt_{n,ipik_n}$ $pmt_{n,ipik_n}$

Table 3-134. Photon Production Bias (PIKMT)

Input Parameter	Description
$zaid_i$	**Nuclide identifier of the i^{th} entry. Full or partial identifiers can be specified; that is, `29000` is equivalent to `29000.50`.**
$ipik_i$	**Controls the biasing for $zaid_i$.** **If $ipik_i$=`0`, no photon-production biasing is done for $zaid_i$. That is, photons from $zaid_i$ are produced with the normal sampling technique.** **If $ipik_i$=`-1`, no photons are produced from $zaid_i$.** **If $ipik_i$>`0`, photon-production is biased for $zaid_i$. The value of $ipik_i$ is the number of partial photon-production reactions to be sampled.**
$mt_{i,j}$	**MT reaction identifiers for the partial photon-production reactions to be sampled. Note: Only required for $zaid_i$s that have $ipik_i$>`0`, then must provide appropriate $mt_{i,j}/pmt_{i,j}$ pairs.**
$pmt_{i,j}$	**Controls, to a certain extent, the frequency with which the specified MT reactions are sampled. Note: Only required for $zaid_i$s that have $ipik_i$>`0`, then must provide appropriate $mt_{i,j}/pmt_{i,j}$ pairs. See Note 1.**

Default: If the `PIKMT` card is absent, no biasing of neutron-induced photons occurs. If the `PIKMT` card is present, any ZAID not listed has a default value of *ipik*=`-1`, **and no photons are produced for these unlisted ZAID identifiers**.

Use: Only useful for biasing photon production. Only available for neutron libraries.

Note 1: Entries on the *mt* and *pmt* pairs need not be normalized. For a ZAID with a positive value of *ipik*, any reaction that is not identified with its *mt* on the `PIKMT` card will not be sampled.

Example:

```
PIKMT     26000.55  1  102001  1            7014  0
          29000     2    3001  2  3002  1
           8016    -1
```

This example results in normal sampling of all photon-production reactions for ^{14}N. All photons from neutron collisions with Fe are from the reaction with MT identifier 102001. Two photon-production reactions with Cu are allowed. Because of the *pmt* parameters, the reaction with MT identifier 3001 is sampled twice as frequently relative to the reaction with MT identifier 3002 than otherwise would be the case. No photons are produced from ^{16}O or from any other isotopes in the problem that are not listed on the `PIKMT` card.

3.3.6.16 SPABI SECONDARY PARTICLE BIASING

Secondary particle biasing allows the user to adjust the number and weight of secondary particles produced at the time of their creation. Multiple `SPABI` cards for different secondary particles are allowed.

Form: `SPABI:<pl> xxx... e1 s1 e2 s2 ... ei si ...`

Table 3-135. Secondary Particle-Biasing Argument Descriptions (SPABI)

Input Parameter	Description
<pl>	Secondary particle designator. (See Table 2-2.)
xxx	List of primary particles to be considered. For example, `NPHE` represents reactions of neutrons, photons, protons, and electrons. No spaces are allowed. If all particles are to be considered, the entry should be `ALL`.
e_i	The i^{th} upper energy bin limit of secondary particles. The lower bin limit is considered to be zero.
s_i	Use splitting for secondary particles in the i^{th} bin if $s_i>1$. Use roulette if for secondary particles in the i^{th} bin $0\leq s_i \leq 1$.

Example 1:

```
SPABI:N   NHE   1  0.1  5  1  10  2  20  4
```

This example specifies that neutron secondaries produced by neutron, proton, and electron primaries will be biased in the following manner: Below 1 MeV, the secondary neutrons will be rouletted by a factor of 0.1. At energies, 1 to 5 MeV, no biasing is performed. At energies from 5 to 10 MeV, the secondary neutrons will be split 2-for-1, and from 10 to 20 MeV, the secondary neutrons will be split 4-for-1 (with a corresponding reduction in particle weights).

3.3.6.17 PWT PHOTON WEIGHT

The `PWT` card is used in `MODE N P` or `MODE N P E` problems. Its purpose is to control the number and weight of neutron-induced photons produced at neutron collisions. By default, only prompt photons are produced from neutron collisions. Delayed gammas can be produced and biased using the ACT card.

Form 1 (cell card entry): `PWT=w`

Form 2 (data card): `PWT w1 w2 ... wi ...`

Table 3-136. Photon Weight Card (PWT)

Variable	Description
w	**Relative threshold weight of photons produced at neutron collisions in cell. (See Notes 1 and 2.)** **If w>0, only neutron-induced photons with weights greater than $w \times I_s / I_i$ are produced, where I_s and I_i are the neutron importance of the collision and source cells, respectively. Russian roulette is played to determine if a neutron-induced photon with weight below this value survives.** **If w<0, only neutron-induced photons with weights greater than $-w \times w_s \times I_s / I_i$ are produced, where w_s is the starting weight of the neutron for the history being followed, and I_s and I_i are the neutron importance of the collision and source cells, respectively. Russian roulette is played to determine if a neutron-induced photon with weight below this value survives.** **If w=0, exactly one photon will be generated at each neutron collision in the cell, provided that photon production is possible.** **If w=-1.0E6, photon production in the cell is turned off.**
w_i	**Relative threshold weight of photons produced at neutron collisions in cell i. (See Notes 1 and 2.) Number of entries is equal to number of cells in the problem.** **If w_i>0, only neutron-induced photons with weights greater than $w_i \times I_s / I_i$ are produced, where I_s and I_i are the neutron importance of the collision and source cells, respectively. Russian roulette is played to determine if a neutron-induced photon with weight below this value survives.** **If w_i<0, only neutron-induced photons with weights greater than $-w_i \times w_s \times I_s / I_i$ are produced, where w_s is the starting weight of the neutron for the history being followed, and I_s and I_i are the neutron importance of the collision and source cells, respectively. Russian roulette is played to determine if a neutron-induced photon with weight below this value survives.** **If w_i=0, exactly one photon will be generated at each neutron collision in cell i, provided that photon production is possible.** **If w_i-1.0E6, photon production in cell j is turned off.**

Default: w_j=-1 if neutrons and photons appear on the MODE card.

Use: Recommended for MODE N P and MODE N P E problems without weight windows.

Note 1: For problems using photon cell importance (IMP:P), rather than photon weight windows (WWNn:P), a good first guess for PWT card entries is either the default value, w_i=−1, or set w_i in every cell to the average source weight.

Note 2: For problems with photon weight windows (i.e., WWP:P exists), the PWT card is ignored and the correct numbers of photons are produced within the weight windows.

The PWT card controls the production of neutron-induced photons by comparing the total weight of photons produced with a relative threshold weight specified on the PWT card. This threshold weight is relative to the neutron cell importance and, if w_i<0, to the source neutron weight. If more neutron-induced photons are desired, the absolute value of w_i should be lowered to reduce the weight and therefore increase the number of photons. If fewer neutron-induced photons are desired, the absolute value of w_i should be increased.

3.3.7 Problem Termination, Output Control, and Miscellaneous Data

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Mnemonic	**Description**	**Section**
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CTME	Computer Time Cutoff	3.3.7.1.2
STOP	Precision Cutoff	3.3.7.1.3
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3.3.7.1 PROBLEM TERMINATION

Six normal ways to terminate an MCNP6 calculation are the NPS card, the CTME card, the STOP card, the job time limit, the end of a surface source file, and the number of cycles on a KCODE card. If more than one is in effect, the one encountered first will control termination of the MCNP6 calculation.

3.3.7.1.1 NPS HISTORY CUTOFF

Terminates the MCNP6 calculation after a requested number of histories have been transported, unless the calculation is terminated earlier for some other reason (such as the computer time cutoff, `CTME`).

Form: `NPS` *npp* *npsmg*

Table 3-137. History Cutoff Card (NPS)

Input Parameter	Description
Npp	**The total number of histories to be run in the problem. An 8-byte integer is permitted for *npp*. (See Notes 1 and 2.)**
Npsmg	**Number of histories for which direct source contributions are to be made to the pixels of an `FIR` radiography image grid. An 8-byte integer is permitted for *npsmg*. (See Note 3.) (See Section 3.3.5.1.2.)**

Default: Infinite.

Use: As needed to terminate the calculation. In a criticality calculation, the `NPS` card has no meaning and a warning error message is issued if it is used. Highly recommended for use in multiprocessor computations.

Note 1: In a continue-run, the `NPS` input values are the total number of particles including runs before the continue-run; they are cumulative. A negative *npp* entry means to print an output file at the time of the last history run and then stop.

Note 2: In a surface source problem, either more or fewer than all of the particle histories on the RSSA surface source file will be run, depending on the value of *npp* entered on the `NPS` card. Let NP1 represent the number of original histories. If *npp*<NP1, Russian roulette with weight adjustment will be played with each history in the file using a survival probability of *npp*/NP1. If *npp*>NP1, the histories will be split *npp*/NP1-to-1 with the fractional part is taken care of by sampling. This can be done equally well for non-spherical sources by cell importance splitting. With a spherical source, each multiple occurrence of the history is sampled for a different starting location on the source sphere, possibly improving the spatial statistics of the results. In either case, the use of the `NPS` card will not provide additional information about the original source distributions or the transport to the recording surface crossing.

Note 3: When the number of source histories exceeds *npsmg*, the time-consuming process of determining the attenuation of the `FIR` direct contribution is avoided by adding the average of the previous direct contributions into each of the appropriate tally bins. Depending on the computer time required to calculate the direct image in a particular problem, *npsmg* can save from a few seconds to upward of ten minutes per history in some cases. For example, a mono-energetic isotropic point source or a mono-energetic mono-directional surface source requires only one history to determine completely the direct image. For this case, `npsmg=1` is adequate.

3.3.7.1.2 CTME COMPUTER TIME CUTOFF

Allows the user to specify minutes of computer time after which MCNP6 will terminate the calculation. MCNP6 checks the computer time remaining in a running problem and will terminate the job itself, allowing enough time to wrap up and terminate gracefully.

Form: `CTME tme`

where *tme*=maximum amount of computer time (in minutes) to be spent in the Monte Carlo calculation. (See Notes 1 and 2.)

Default: Infinite.

Use: As needed.

Note 1: For a continue-run job the time on the `CTME` card is the time relative to the start of the continue-run; it is not cumulative.

Note 2: For multiprocessor runs, it is highly recommended that the `NPS` card (Section 3.3.7.1.1) be used to limit the run time.

3.3.7.1.3 STOP PRECISION CUTOFF

Enables termination of calculations based on the number of particle histories run, the computer time expended, or the desired precision for a specified tally.

Form: `STOP KEYWORD=value(s) ...`

Table 3-138. Precision Cutoff (STOP)

Keyword	Description
NPS *npp* [*npsmg*]	**Stop calculation after *npp* particle histories. (See Note 1.) (See NPS card, Section 3.3.7.1.1.)**
CTME *tme*	**Stop calculation after *m* minutes of computer time. (See Note 2.) (See CTME card, Section 3.3.7.1.2.)**
F*k* *e*	**Stop calculation when the tally fluctuation chart of tally *k* has a relative error less than *e*. (See Note 3.)**

Use: If values for any (or all) of the keywords are supplied, MCNP6 will terminate the problem at the first met criteria.

Note 1: For radiography problems, a second `NPS` keyword entry, *`npsmg`*, may be provided to specify how many histories are used for direct radiography tally contributions.

Note 2: For multitasking calculations, `CTME` will be checked only at rendezvous points, where all tasks rendezvous for tally fluctuations and other activities.

Note 3: The tally precision stop will be checked only at rendezvous points for the tally bin of the tally fluctuation charts. Thus, the calculation usually will proceed for a short time after the desired error is achieved. (See `TF` card, Section 3.3.5.19.)

Example 1:

```
STOP   F111   0.05
```

MCNP6 will stop at the first rendezvous for which the relative error of the tally bin for the tally fluctuation chart of tally `F111` is less than 0.05. MCNP6 may stop at error=0.048 or other value slightly less than 0.05.

3.3.7.2 OUTPUT CONTROL

3.3.7.2.1 PRINT OUTPUT PRINT TABLES

Allows selective printing or suppression of optional output tables.

Form: `PRINT` [x_1 x_2 ... x_i ...]

Table 3-139. Output Print Tables (PRINT)

Input Parameter	Description
x_i	**List of optional and default table numbers to be included in or excluded from the output file.** **If there are no entries for x_i, the full output print is provided.** **If x_i>0 for all i, the tables specified by each positive x_i are provided in addition to the "basic" output tables.** **If x_i<0 for any i, the full output applicable to the problem is printed with the exception of those tables identified by negative x_i values.**

Default: Absence of a `PRINT` card in the INP file or a `PRINT` option on the MCNP6 execution line will result in a reduced output print comprised only of the tables in Table 3-140 marked "basic," "default," and "shorten."

Use: Optional. To get all optional print tables applicable to your problem use the `PRINT` card without entries in the INP file or the `PRINT` option on the execution line. The execution line takes precedence over the input card. Entries on the `PRINT` card can be in any order; however, no entries may follow the `PRINT` option on the MCNP6 execution line.

Table 3-140. MCNP6 Output Tables

Table Number	Type	Table Description
10	optional	Source coefficients and distribution.
20	optional	Weight-window information.
30	optional	Tally description.
32	optional	Mesh tally description.
35	optional	Coincident detectors.
38	optional	Fission multiplicity data; controlled by table 30.
40	optional	Material composition.
41	default	LAHET physics options.
44	optional	Activities of the materials in an SDEF=SP problem.
50	optional	Cell volumes and masses, surface areas.
55	default	Burnup results.
60	Basic	Cell importance.
62	Basic	Forced collision and exponential transform.
70	optional	Surface coefficients.
72	Basic	Cell temperatures.
80	optional	ESPLT/TSPLT importance ratios.
85	optional	Charged-particle stopping powers and straggling. Multigroup: flux values for biasing adjoint calculations.
86	optional	Electron bremsstrahlung and secondary production.
87	optional*	Secondary heavy ion stopping powers and straggling.
90	optional	KCODE source data.
95	default	GENXS tally input.
98	optional	Physical constant and compile options.
100	Basic	Cross-section tables.
102	optional	Assignment of $S(\alpha, \beta)$ data to nuclides.
110	optional	First 50 starting histories.
115	default	Fission multiplicity summary.
117	default	Spontaneous and induced fission multiplicities and moments.
118	default	Neutron captures, moments & multiplicity distributions.
120	optional	Analysis of the quality of your importance function.
126	Basic	Particle activity in each cell.
128	optional	Universe map.
130	optional	Neutron/photon/electron weight balance.
140	optional	Neutron/photon nuclide activity.

Table Number	Type	Table Description
150	**optional**	**DXTRAN diagnostics.**
160	**default**	**TFC bin tally analysis.**
161	**default**	***f*(*x*) tally density plot.**
162	**default**	**Cumulative *f*(*x*) and tally density plot.**
163	**optional**	**Receiver-Operator Characterization (ROC) curve data.**
170	**optional**	**Source distribution frequency tables, surface source.**
175	**shorten**	**Estimated k_{eff} results by cycle.**
178	**optional**	**Estimated k_{eff} results by batch size.**
180	**optional**	**Weight-window generator bookkeeping summary controlled by WWG(7), not print card.**
190	**basic**	**Weight-window generator summary.**
198	**optional**	**Weight windows from multigroup fluxes.**
200	**basic**	**Weight-window-generated windows.**
210	**default**	**Burnup summary table.**
220	**default**	**Burnup summary table summed over all materials.**

* The printing of table 87 does not follow the standard default convention. To print table 87, specify the table number on the PRINT card.

The following output will be printed automatically, as applicable:

- a listing of the input file,
- the problem summary of particle creation and loss,
- KCODE cycle summaries,
- tallies,
- tally fluctuation charts,
- the tables listed in Table 3-140 as basic, and
- the tables listed in Table 3-140 as default, provided they are not turned off explicitly with the PRINT card.

In an MCNP6 output file, a table number appears in the upper right-hand corner of each table, providing a convenient pattern when scanning the output file with an editor. The pattern is "print table *n*," where *n*, the table number, is always preceded by one space and is a two- or three-digit number. The table numbers, titles, and type are summarized in Table 3-140 above. "Basic" tables cannot be controlled by the PRINT card." "Default" tables are automatically printed but can be turned off. "Optional" tables with can be turned off and on with the PRINT card or option.

With one exception, the PRINT control can be used in a continue-run to recover all or any applicable print tables, even if they were not requested in the original run. The following continue-run input file:

```
CONTINUE
NPS        -1
PRINT
```

will create the output file for the initial run starting with the Problem Summary (located after `print table 110`). However, note that `print table 128` can never be printed if it was not requested in the original run.

Several of the output tables listed in Table 3-140 have additional restrictions:

a) If you turn off table 160, tables 161 and 162 will not appear either. If table 160 is printed, they will all be printed. All three tables are automatically printed if there is no `PRINT` card or if there is a blank `PRINT` card. If a `PRINT` card has a positive entry, tables 160, 161, and 162 will not appear unless table 160 is explicitly requested. If the entry is negative, they will appear unless table 160 is explicitly turned off.

b) Table 175 cannot be turned off completely, but the output can be greatly shortened to every 100 cycles plus the last five cycles. The specification `PRINT −175` and `PRINT 110` both will produce the short version of table 175.

c) Table 128, the repeated structure universe map, is special. If table 128 is not turned on in an initial run, it *cannot* be turned on in a subsequent continue-run because the (often large) storage arrays have not been set up. Table 128 is the only print table that affects storage. The information in the other tables is always stored, whether or not it is printed. A warning will be printed in a repeated structures problem if you do not request the universe map/lattice activity table in the original run.

d) Be aware that `print table 87` does not follow the standard default convention of most other MCNP6 print tables because stopping powers for all 100 elements for each material would result in huge output files. To print table 87, the user must specify the table number on the `PRINT` card.

Example 1:

```
PRINT    110   40   150
```

The output file will contain the "basic" tables plus tables `40`, `110`, `150`, and the shortened version of 175, but not 55, 117, 118, 160, 161, 162, 210, 220 (the "default" tables).

Example 2:

```
PRINT     -170   -70   -110
```

The output file will contain all the "basic" tables, all the "default" tables, the long version of table `175`, and all the optional tables applicable to your problem, except tables `70`, `110`, and `170`.

Example 3:

```
PRINT    -1   87
```

Prints all output including `print table 87`.

3.3.7.2.2 TALNP NEGATE PRINTING OF TALLIES

Controls the printing of bin prints for specified tally numbers.

Form: `TALNP` [tal_1 tal_2 ... tal_i]

Table 3-141. Tally No Print (TALNP)

Input Parameter	Description
tal_i	**List of tally numbers to be excluded from output file. (See Note 1.)** **If there are no tal_i entries, then turn off the bin prints for all tallies in the problem.** **If there are tal_i entries, then turn off the bin prints for the tally numbers that are listed.**

Default: If card is present without entries, then no bin prints are provided for tallies. If card is absent, bin prints are provided for all tallies.

Note 1: If, after the run is completed, one would like to see these numbers, the printing of the bin values can be restored with the `TALNP` card in an INP file used in a continue-run. To accomplish this, the tally numbers tal_i must be entered on the `TALNP` card as negative numbers. A single entry of zero in a continue-run restores the prints of all tally bins.

3.3.7.2.3 PRDMP PRINT AND DUMP CYCLE

The `PRDMP` card allows the user to control the interval at which tallies are printed to the OUTP file and information is dumped to the RUNTPE file.

Form: `PRDMP` *ndp ndm mct ndmp dmmp*

Table 3-142. Print & Dump Cycle Card (PRDMP)

Input Parameter	Description
ndp	**Increment for printing tallies.** **If *ndp*>0, the problem summary and tallies are printed to the output file after every *ndp* histories (or cycles for a KCODE problem). (See Note 1.)** **If *ndp*<0, the problem summary and tallies are printed to the output file after every *ndp* minutes of computer time.** **An 8-byte integer is permitted for *ndp*.**
ndm	**Increment for dumping to RUNTPE file.** **If *ndm*>0, a dump is written to the RUNTPE file after every *ndm* histories (or cycles for a KCODE problem). (See Note 1.)** **If *ndm*<0, a dump is written to the RUNTPE file after every *ndm* minutes of computer time.** **An 8-byte integer is permitted for *ndm*.**
mct	**Controls printing of MCTAL file. (See Note 2.)** **If *mct*>0, write MCTAL file at problem completion.** **If *mct*=0, do not write MCTAL file.** **If *mct*=-1, MCTAL file is written at problem completion, but references to code name, version number, problem ID, figure of merit, and anything else having to do with running time are omitted from MCTAL and OUTP. This ensures tracking runs (using identical random walks) yield identical MCTAL and OUTP files.** **If *mct*=-2, MCTAL file is written at problem completion, but additional prints in OUTP are turned off to assist in comparing multitasking output.**
ndmp	**Maximum number of dumps on RUNTPE file. (See Note 3.)**
dmmp	**Controls how frequently tally fluctuation chart (TFC) entries and rendezvous occur. (See Notes 4 and 5.)** **If *dmmp*<0, write charts every 1000 particles for non-KCODE problems or every |*dmmp*| cycles for KCODE problems..** **If *dmmp*=0, write charts every 1000 particles or, if multiprocessing, 10 times total during the run.** **If *dmmp*>0, write charts every *dmmp* particles for non-KCODE problems or every |*dmmp*| cycles for KCODE problems.** **An 8-byte integer is permitted for *dmmp*.**

Default: Print only after the calculation has successfully ended. Dump to RUNTPE every 60 minutes and at the end of the problem. Do not write a MCTAL file. Write all dumps to the RUNTPE file. Write charts and rendezvous for fixed-source problems every 1000 particles or, if multiprocessing, 10 times total during the run (*dmmp*=0); for KCODE problems, write charts and rendezvous at the end of each cycle.

Use: Recommended, especially for complex problems. For multiprocessor problems, it is recommended that the *ndp*, *ndm*, and *dmmp* entries be provided in number of histories.

Note 1: If *ndp* or *ndm* is set to time on a parallel job, it will be time used by one processor, approximately elapsed wall time. The scheduled print or dump will be delayed to the next rendezvous or cycle to assure consistent data. For parallel (i.e., multiprocessor) runs, is highly recommended that the *ndp* and *ndm* values be set in terms of particles or cycles, instead of minutes,

Note 2: The MCTAL file is an ASCII file of tallies that can be subsequently plotted with the MCNP6 MCPLOT option. The MCTAL file is also a convenient way to store tally information in a format that is stable for use in the user's own auxiliary programs. For example, if the user is on a system that cannot use the MCNP6 MCPLOT option, the MCTAL file can be manipulated into whatever format is required by the user's own local plotting algorithms.

Note 3: Using the parameter *ndmp*, the `PRDMP` card allows the user to control the size of the RUNTPE file. The RUNTPE file will contain the last *ndmp* dumps that were written. For example, if *ndmp*=4, after dump 20 is written only dumps 17, 18, 19, and 20 will be on the RUNTPE file. In all cases, the fixed data and cross-section data at the front of the RUNTPE file are preserved.

Note 4: The fifth entry *dmmp* has several possible meanings. For sequential non-KCODE MCNP6, a value of *dmmp*≤`0` results in TFC entries every 1000 particles initially. This value doubles to 2000 after 20 TFC entries. A positive value of *dmmp* produces TFC entries every *dmmp* particles initially. For non-KCODE distributed memory multiprocessing, *dmmp*<`0` produces TFC entries and task rendezvous every 1000 particles initially, the same as does the sequential version. The default value, *dmmp*=`0`, produces ten TFC entries and task rendezvous, rounded to the nearest 1000 particles, based on other cutoffs such as `NPS`, `CTME`, etc. This selection optimizes speedup in conjunction with TFC entries. If detectors/DXTRAN are used with default Russian roulette criteria (`DD` card default), the *dmmp*=`0` entry is changed by MCNP6 to *dmmp*<`0`, ensuring tracking with the sequential version (i.e., TFC entries and rendezvous every 1000 particles). As with the sequential non-KCODE version, *dmmp*>`0` produces TFC entries and task rendezvous every *dmmp* particles, even with detectors/DXTRAN with default Russian roulette criteria. Setting *dmmp* to a large positive number minimizes communication time and maximizes speedup. However, the TFC may not have many entries, possibly only one, if *dmmp*=*npp*.

Note 5: The rendezvous frequency of a multiprocessor run is the minimum interval of parameters or *ndp*, *ndm*, and *dmmp*.

3.3.7.2.4 PTRAC PARTICLE TRACK OUTPUT

The `PTRAC` card generates an output file, default name PTRAC, of user-filtered particle events. (See Appendix E.) The file name PTRAC can be changed on the execution line or within the message block.

Form: `PTRAC KEYWORD=`*`value(s)`* `...`

Default: See Table 3-143. Using the `PTRAC` card without any keywords causes all particle events to be written to the PTRAC file. *Caution*: If all particle events are written to the PTRAC file, an extremely large file likely will be created unless `NPS` is small.

Use: Optional.

Table 3-67. Particle Track Output (`PTRAC`)

Output Control Keyword	Description
BUFFER	**Determines the amount of storage available for filtered events. A small value results in increased I/O and a decrease in required memory; a large value minimizes I/O and increases memory requirements. Single integer entry. (DEFAULT: `BUFFER=100`)** **Restriction: `BUFFER>0`**
FILE	**Controls file type.** **If `FILE=ASC`, generates an ASCII output file.** **If `FILE=BIN`, generates a binary output file. (DEFAULT)** **If `FILE=AOV`, generates an ASCII output file by overwriting an existing ASCII PTRAC file to a named pipe on UNIX systems. Requires a PTRAC file to exist prior to execution.** **If `FILE=BOV`, generates a binary output file by overwriting an existing binary PTRAC file to a named pipe on UNIX systems. Requires a PTRAC file to exist prior to execution.**
MAX	**Sets the maximum number of events to write to the PTRAC file. Single integer entry. (DEFAULT: `MAX=10000`)** **If `MAX>0`, write `MAX` events to PTRAC.** **If `MAX<0`, MCNP6 is terminated when `|MAX|` events have been written to PTRAC.** **Note: An 8-byte integer is permitted for keyword `MAX`.** **Restriction: `MAX≠0`**
MEPH	**Determines the maximum number of events per history to write to the PTRAC file. Single integer entry. (DEFAULT: write all events)** **Restriction: `MEPH>0`**

`WRITE`	**Controls what particle parameters are written to the PTRAC file. (See Note 1.)** **If `WRITE=POS`, write only the x, y, z location of the particle with related cell and material numbers. (DEFAULT)** **If `WRITE=ALL`, write the x, y, z location of the particle with related cell and material numbers and the u, v, w direction cosines, as well as particle energy, weight, and time.**
`COINC`	**Activates a PTRAC file format specifically for coincidence tally scoring. Used in conjunction with `TALLY` keyword. (See Note 2.)** **If `COINC=COL`, a full printing of all specified tally scores is produced, even if the tally scores were zero. The output is column-based. (DEFAULT)** **If `COINC=LIN`, tally score pairs are printed for non-zero scores only.**
Event Filter Keyword	**Description**
`EVENT`	**Specifies the type of events written to the PTRAC file. Up to six mnemonic entries can be specified:** **If `EVENT=SRC`, write initial source events.** **If `EVENT=BNK`, write bank events. These include secondary sources (e.g., photons produced by neutrons, as well as particles created by variance-reduction techniques such as DXTRAN and energy splitting). See Appendix E for a complete list.** **If `EVENT=SUR`, write surface events.** **If `EVENT=COL`, write collision events.** **If `EVENT=TER`, write termination events.** **If `EVENT=CAP`, write coincident capture events. (See Note 3.)** **(DEFAULT: write all events)**
`FILTER`	**Specifies additional MCNP6 variables for filtering. The parameter values consist of one or two numerical entries and a variable mnemonic that corresponds to a variable in the PBL derived structure. (See Table 3-144 for available mnemonics.) A single numerical entry requires an exact value; two numerical entries represent a range. When a range is specified, the first entry must be less than or equal to the second. Multiple sets of numerical entries and mnemonics are allowed. (DEFAULT: no additional filtering)** **Example: `FILTER=2,ICL` writes only those events that occur in cell `2`.** **Example: `FILTER=0,10,X` writes only those events in which the particle's *x*-coordinate is between `0` and `10` cm.** **Example: `FILTER=0.0,10.0,X 0,1,U 1.0,2,ERG` writes only those events in which the particle's *x*-coordinate is between `0` and `10` cm *and* the particle's *x*-axis cosine is between `0` and `1` *and* the particle's energy is between `1` and `2` MeV.**
`TYPE`	**Filters events based on one or more particle types. May specify filtering of a single particle or multiple particles, where <pl_i> is a particle identifier specified in Table 2-2: `TYPE=`<pl_1>,<pl_2>, . . .** **(DEFAULT: Write events for all particles.)**

History Filter Keyword	Description
`NPS`	Sets the range of particle histories for which events will be output. A single value produces filtered events only for the specified history. Two entries indicate a range and will produce filtered events for all histories within that range. The first entry must be less than or equal to the second. (DEFAULT: Events for all histories) Example: `NPS=10` write events only for particle number 10. Example: `NPS=10,20` writes events for particles 10 through 20. Note: An 8-byte integer is permitted for keyword `NPS`. Restriction: `NPS>0`
`CELL`	List of cell numbers to be used for filtering. If any track enters the listed cell(s), all filtered events for the history are written to the PTRAC file. Example: `CELL=1,2` writes all filtered events for those histories that enter cell `1` or `2`. Note: Number of entries is unlimited Restriction: `CELL>0` (DEFAULT: No filtering based on cell entrance.)
`SURFACE`	List of surface numbers to be used for filtering. If any track crosses the listed surface(s), all filtered events for the history are written to the PTRAC file. Note: Number of entries is unlimited. Restriction: `SURFACE>0` (DEFAULT: No filtering based on surface crossing.)
`TALLY`	List of tally numbers to be used for filtering. If any track contributes to the TFC bin of listed tallies, all filtered events for the history are written to the PTRAC file. (See `TF`*n* card in Section 3.3.5.19 for specification of the TFC bin for tally *n*.) Example: `TALLY=4` writes all filtered events for those histories that contribute to tally `4`. (See `VALUE` keyword for filter criteria.) Note: A negative `TALLY` entry indicates that the corresponding `VALUE` entry (below) is a multiplier rather than an absolute value. Note: Number of entries is unlimited. Restriction: `TALLY≠0` (DEFAULT: No filtering based on tally contribution.)

VALUE	**Specifies the tally cutoff above which history events will be written. The number of entries must equal the number of entries on the TALLY keyword. A negative TALLY value indicates that the corresponding VALUE entry is a multiplier.** **Example: TALLY=4 VALUE=2.0 writes all filtered events of any history that contributes 2.0 or more to the TFC bin of tally 4.** **Example: TALLY=-4 VALUE=2.0 writes all filtered events of any history that contributes more than 2.0 × T_a to tally 4, where T_a is the average tally of the TFC bin. The values for T_a are updated every *dmmp* histories (see PRDMP card, Section 3.3.7.2.3).** **Example: TALLY=4 VALUE=0.0 writes all filtered events of every history that scores to tally 4.** **Note: Filtering based on the T_a values will occur only when they become non-zero. Thus, when using a multiplier, PTRAC events may not be written for several thousand particles, or at all, if scores are seldom or never made to the TFC bin of the specified tally. In such cases, it is best to enter an absolute value.** **Note: Number of entries is unlimited.** **(DEFAULT: VALUE=10 for each tally associated with the TALLY keyword)**

Table 3-144. Mnemonic Values for the FILTER Keyword

Mnemonic	MCNP6 Variable	Description
X	PBL%R%X	*X*-coordinate of particle position (cm)
Y	PBL%R%Y	*Y*-coordinate of particle position (cm)
Z	PBL%R%Z	*Z*-coordinate of particle position (cm)
U	PBL%R%U	Particle *x*-axis direction cosine
V	PBL%R%V	Particle *y*-axis direction cosine
W	PBL%R%W	Particle *z*-axis direction cosine
ERG	PBL%R%ERG	Particle energy (MeV)
WGT	PBL%R%WGT	Particle weight
TME	PBL%R%TME	Time at the particle position (shakes)
VEL	PBL%R%VEL	Speed of the particle (cm/shake)
IMP1	PBL%R%FIML(1)	Neutron cell importance
IMP2	PBL%R%FIML(2)	Photon cell importance
IMP3	PBL%R%FIML(3)	Electron cell importance
SPARE1	PBL%R%SPARE(1)	Spare banked variable
SPARE2	PBL%R%SPARE(2)	Spare banked variable
SPARE3	PBL%R%SPARE(3)	Spare banked variable
ICL	PBL%I%ICL	Problem number of current cell
JSU	PBL%I%JSU	Problem number of current surface

IDX	**PBL%I%IDX**	**Number of current DXTRAN sphere**
NCP	**PBL%I%NCP**	**Count of collisions for current branch**
LEV	**PBL%I%LEV**	**Geometry level of particle location**
III	**PBL%I%III**	**1st lattice index of particle location**
JJJ	**PBL%I%JJJ**	**2nd lattice index of particle location**
KKK	**PBL%I%KKK**	**3rd lattice index of particle location**

Use: The output formats for PTRAC and event logs limit the printing of cell, surface, and material numbers to a maximum of five characters. Users intending to use PTRAC or event logs should avoid the use of cell, surface, or material numbers greater than 99,999.

Note 1: If the size of the PTRAC file is a concern and the additional parameters are not needed, the default value of WRITE=POS is recommended.

Note 2: The COINC feature only supports the TALLY and VALUE keywords as filter options. When used in conjunction with the COINC keyword, TALLY entries must be positive. The existing VALUE keyword can be used to set threshold scores for the tallies itemized on the TALLY keyword. All scores below that threshold are treated as zero. The COINC keyword will force ASCII file output format (FILE=ASC or FILE=AOV).

Note 3: For EVENT=CAP, most of the standard PTRAC capabilities are bypassed (for speed) and the data written to each line (or record) of the PTRAC file are very different from the usual PTRAC data. For binary files, the entries on each PTRAC line include the particle history number ("NPS"), the time from source event to analog capture in any FT8 CAP tally ("Time"), and the cell number in which the analog capture occurred ("Cell"). Additionally, for ASCII files, a fourth column, "Source," provides the source particle number of a given history. The 5th column of output provides the ZAID identifier of the spontaneous fission nuclide. A value of 0 appears if the source is not spontaneous fission, i.e., PAR=SF. The 6th column contains the ZAID of the first induced fission; the 7th, that of the second induced fission; the 8th, that of the third induced fission; and the 9th, that of the last fission before capture, either induced or spontaneous.

Use of one or more keywords listed in Table 3-143 will reduce significantly the PTRAC file size. In Table 3-143 the keywords are arranged into three categories: output-control keywords, event-filter keywords, and history-filter keywords. The output-control keywords provide user control of the PTRAC file and I/O. The event-filter keywords filter particle events on an event-by-event basis. That is, if the history meets the filter criteria, all filtered events for that history are written to file PTRAC. The PTRAC card keywords can be entered in any order and, in most cases, the corresponding parameter values can appear in any order. The PTRAC card is not allowed in a continue-run input file because a change in the PTRAC input would require a readjustment in dynamically allocated storage.

The PTRAC file will contain the heavy ion particles and their track information, but *not* individual heavy ion identities (ZZZAAAs).

Example:

```
PTRAC  FILTER=8,9,ERG  EVENT=SUR  NPS=1,50  TYPE=E  CELL=3,4
```

When multiple keywords are entered on the PTRAC card, the filter criteria for each keyword must be satisfied to obtain an output event. This input line will write only surface crossing events for 8–9-MeV electrons generated by histories 1–50 that have entered cells 3 or 4.

3.3.7.2.5 MPLOT PLOT TALLY WHILE PROBLEM IS RUNNING

The MPLOT card specifies a plot of intermediate tally results that is to be produced periodically during the run.

Form: MPLOT KEYWORD=*value*(*s*)

Default: None.

Use: Optional. The specification of 8-byte integer values is allowed for FREQ.

The entries on the MPLOT card are MCPLOT commands (see Table 5-5) for one picture. During the run, as determined by the FREQ *n* keyword entry, MCRUN will call MCPLOT to display the current status of one or more of the tallies in the problem. If a FREQ *n* command is not included on the MPLOT card, *n* will be set to 5000. The following MCPLOT commands cannot appear on the MPLOT card: RMCTAL, RUNTPE, DUMP, and END. All of the commands on the MPLOT card are executed for each displayed picture, so coplots of more than one bin or tally are possible. No output is sent to a COMOUT file. MCPLOT will not take plot requests from the terminal; it returns to MCRUN after each plot is displayed. See Section 5.3.2 for a complete list of MCPLOT commands available.

A second way to plot intermediate tally results is to use the TTY interrupt <ctrl-c>MCPLOT or <ctrl-c>M that allows interactive plotting during the run. At the end of the history that is running when the interrupt occurs, MCRUN will call MCPLOT, which will take plot requests from the terminal. No output is sent to the COMOUT file. The following commands can not be used: RMCTAL, RUNTPE, DUMP, and END.

3.3.7.2.6 HISTP CREATE LAHET-COMPATIBLE FILES

To produce LAHET-compatible HISTP files, the `HISTP` card must be added to the INP file. This card controls the writing of information to an external file for analysis by the HTAPE3X[1] program.

Form: `HISTP [-lhist] [icl1 icl2 ...]`

Table 3-145. HISTP Card

Input Parameter	Description
-lhist	**Controls the number of words written to a HISTP file. Once this limit is exceeded, a new file will be written with the name HISTPA and the incrementing of the name will continue until all particles are run. Entered as a negative number, *lhist* may appear anywhere on the card. (DEFAULT: *-lhist*=-500000000)**
icl_i	**List of cell numbers: Only events occurring within these cells will be written to HISTP file. If no *icl_i* values are provided, all events will be written to HISTP.**

Default: `-lhist=-500000000`; all events written to HISTP file

No heavy ion transport information is written to the HISTP file aside from the usual recoils from which the heavy ions are started.

Writing HISTP files during multiprocessing is still under development.

Example 1:

```
HISTP   -100000  5  6  3  10
```

Each HISTP file will contain a maximum of 100,000 words. Only events within cells `3`, `5`, `6`, and `10` will be written to the HISTP file.

Example 2:

```
HISTP
```

Each HISTP file will contain a maximum of 500,000,000 words (which virtually ensures that only one file will be written). All events in all cells will be written to the file.

[1] The HTAPE3X program is not packaged with MCNP6. However, the MCNPX version should be able to read and process most of the output files from MCNP6.

3.3.7.3 MISCELLANEOUS DATA

3.3.7.3.1 RAND RANDOM NUMBER GENERATION

Form: `RAND KEYWORD=`*`value(s)`* `...` (See Notes 1 and 2.)

Table 3-146. Random Number Generation (RAND)

Keyword	Description
GEN	**Type of pseudorandom number generator to be used by MCNP6.** **If GEN=1, then use MCNP6 Lehmer 48-bit congruential generator, which has a period of 7.0×10^{13} numbers. (DEFAULT)** **If GEN=2, then use L'Ecuyer 63-bit generator number 1, which has a period of 9.2×10^{18} numbers.** **If GEN=3, then use L'Ecuyer 63-bit generator number 2, which has a period of 9.2×10^{18} numbers.** **If GEN=4, then use L'Ecuyer 63-bit generator number 3, which has a period of 9.2×10^{18} numbers.** **(See Note 3.)**
SEED	**Random number generator seed for starting the transport of the first particle history in a run. (DEFAULT: SEED=19073486328125)** **Restriction: Must end with an odd digit. Note: An 8-byte integer is permitted for keyword SEED. (See Note 4.)**
STRIDE	**Number of random numbers between source particles. Note: An 8-byte integer is permitted for keyword STRIDE. (DEFAULT: STRIDE=152917)**
HIST	**If HIST=*n*, then causes the starting pseudorandom number of the problem to be that which would normally start the *n*th history. That is, causes the *n*th history to be the first history of a problem for debugging purposes. Setting HIST=*n* can also be used to select a random number sequence different from that in an identical problem to compare statistical convergence. Note: An 8-byte integer is permitted for keyword HIST. (See Note 4.) (DEFAULT: HIST=1)**

Note 1: `RAND` entries take precedence over `DBCN(1)`, `DBCN(8)`, `DBCN(13)`, and `DBCN(14)`. See Section 3.3.7.3.2.

Note 2: The `RAND` card may be used to change the problem random number seed in a continue-run. This capability provides a work-around for avoiding a troublesome particle history. This procedure is not recommended, but is permitted. Be aware that repeatability is very difficult to achieve if this feature is used.

Note 3: Random number generators will not repeat when the period is exceeded, but longer periods are preferred.

Note 4: The i^{th} source particle always starts with the same random number; this correlated source sampling enables faster evaluation of small problem differences where the problems have identical source distributions. *Caution*: When trying to duplicate a particle history by setting the starting random number with either `SEED` or `HIST`, the random number sequence may be altered by a default Russian roulette game on contributions to detectors or DXTRAN spheres. If a problem has detectors or DXTRAN, the only ways to reproduce histories with `SEED` or `HIST` are a) to turn off the Russian roulette game on the `DD` card by setting k_i=0; b) to play the roulette game with a fixed criterion by setting k_i<0 on the `DD` card; or c) to reproduce a particle history that occurs before the first TFC interval.

3.3.7.3.2 DBCN DEBUG INFORMATION

Caution: Former MCNPX users need to be aware that several `DBCN` inputs may be required to invoke MCNPX default behavior. In particular, please see `DBCN` parameters x_{38}, x_{39}, and x_{60}.

The entries on this card are used primarily for debugging problems and the code itself. The first 12 entries can be changed in a continue-run, which is useful for diagnosing troubles that occur late in a long-running problem.

Form: `DBCN` x_1 x_2 ...

Table 3-147. Debug Information Card (DBCN)

Input Parameter	Description
x_1	**Obsolete. The pseudorandom number used for starting the transport of the first particle history in a run. [DEFAULT: x_1=(5^{19})] Recommended: Use the `RAND` card with the `SEED` keyword. (See Notes 1 and 2.)**
x_2	**Debug print interval. Print out information about every x_2th particle. The information consists of a) the particle history number, b) the total number of collisions, c) the total number of random numbers generated, and d) the random number at the beginning of the history. This information is printed at the beginning of the history and is preceded by the letters `DBCN` in the output to aid in a pattern search. (DEFAULT: x_2=0)**
x_3 and x_4	**History number limits for event-log printing. Event-log printing is done for histories x_3 through x_4, inclusively. The information includes a step-by-step account of each history, such as where and how a particle is born, which surface it crosses and which cell it enters, what happens to it in a cell, etc. (Note: The output formats for event logs limit the printing of cell, surface, and material numbers to a maximum of five characters (i.e., identifying numbers ≤99,999). See x_{11}. (DEFAULT: x_3=0 and x_4=0)**
x_5	**Maximum number of events per history in the event log. (DEFAULT: x_5=600)**

Input Parameter	Description
x_6	**Detector/DXTRAN underflow limit. (See Note 3.) (DEFAULT: x_6=`80.0`)** **Restriction: `50`≤x_6≤`200`** **If the attenuation factor, λ, to the detector or DXTRAN sphere is >x_6, then the score is terminated as "`underflow in transmission`."**
x_7	**If x_7=`0`, no print from the volume and surface area calculations is produced. (DEFAULT)** **If x_7≠`0`, a detailed print from the volume and surface area calculations is produced.** **Useful only to MCNP6 code developers.**
x_8	**Obsolete. Causes the starting pseudorandom number of the problem to be that which would normally start the x_8th history. That is, causes the x_8th history to be the first history of a problem for debugging purposes; can also be used to select a random number sequence different from that in an identical problem to compare statistical convergence. (DEFAULT: x_8=`1`)** **Recommended: Use the `RAND` card with the `HIST` keyword. (See Notes 1 and 2.)**
x_9	**Defines the distance allowed between coincident repeated-structures surfaces for them still to be considered coincident. (DEFAULT: x_9=`1.0E-4`) A value of 1.0E-30 reproduces the earlier treatment where coincident repeated structure surfaces were not allowed. The parameter x_9 should not have to be changed unless geometries have dimensions greater than 1.0E5 or unless surfaces at different levels are intended to be closer than 2.0E-4.**
x_{10}	**Specifies the half-life threshold for stable nuclides (DEFAULT: 1.5768e16 s)**
x_{11}	**If x_{11}=`0`, collision events are not printed in event logs for lost particles. (DEFAULT)** **If x_{11}≠`0`, the collision lines in the lost-particle event log are printed.**
x_{12}	**Expected number of random numbers for this calculation. Entering x_{12} will cause the last line of the output file to print x_{12} and the actual number of random numbers used so that a quick comparison can be made to see if two problems tracked each other. DEFAULT: x_{12}=`0`, i.e., test ignored)**
x_{13}	**Obsolete. Random number stride. (DEFAULT: x_{13}=`152917`)** **Note: The period of the default random number generator is 2^{46}=7.037E13. Therefore, the number of histories beyond which the period is exceeded is 460 million.** **Recommended: Use the `RAND` card with the `STRIDE` keyword. (See Note 1.)**
x_{14}	**Obsolete. Random number multiplier. (DEFAULT: x_{14}=`1`)** **Recommended: Use the `RAND` card with the `GEN` keyword. (See Note 1.)**

Input Parameter	Description
x_{15}	If x_{15}=0, the usual selection of statistical quantities is printed (DEFAULT) If $x_{15}\neq$0, the shifted confidence interval and the variance of the variance for all tally bins are printed. An extra line of tally output is created for each tally that contains non-zero information. The shifted confidence interval center is followed by the estimated VOV. If the tally mean and relative error (RE) are all zeros, the VOV line is not printed because it is all zero also. Changing x_{15} from non-zero to zero in a continue-run will cause the VOV information not to be printed. The parameter x_{15} cannot be changed from zero to non-zero in a continue-run.
x_{16}	Scale the history score grid for the accumulation of the empirical $f(x)$ in `print table 161` and `162`. MCNP6 uses a logarithmically spaced history score grid in `print table 161` for $f(x)$, producing a straight line for $f(x)$ on a log-log plot for $1/x^n$ behavior, covering 60 decades of unnormalized tally magnitudes from 1E-30 to 1E30. This range can be multiplied by the x_{16} entry when the range is not sufficient. A negative entry means that negative history scores will be accrued in the score grid $f(-x)$ and the absolute value of x_{16} will be used as the score grid multiplier. Positive history scores will then be lumped into the lowest bin with this option. This scaling can be done only in the original problem, not in a continue-run. (DEFAULT: x_{16}=1.0)
x_{17}	If x_{17}=0, use default angular treatment for partial sub steps to generation sites of secondary particles. This treatment accounts for the probability of the delta function first, then interpolates in the cosine of the deflection angle. It does not preserve the plane in which the deflection angle will lie at the end of the full sub step. (DEFAULT) If x_{17}>0, use alternate angular treatment for secondary generation. The cosine of the electron angle is interpolated and the end-of-sub step plane is preserved, but the changing probability of the delta function along the sub step is ignored. This option is preserved for further testing of angular algorithms because results have been known to be sensitive to these details. If x_{17}<0, use MCNP4A treatment of electron angles at secondary generation sites. Use by developers only.
x_{18}	Controls the energy-indexing algorithm for electron transport related to bin interpolation. If x_{18}=0, use "MCNP-style" energy-indexing algorithm; also called the "bin-centered" treatment. (Used by MCNPX.) If x_{18}=1, use Integrated Tiger Series (ITS)-style energy-indexing algorithm; also called the "nearest group boundary" treatment. If x_{18}=2, use detailed Landau straggling sampling logic, also called the "energy- and step-specific" treatment. Required for single-event electron transport. (DEFAULT)
x_{19}	In use by MCNP6 developer(s) to study quadratic polynomial interpolation. [DEFAULT (x_{19}=0) provides current model.]
x_{20}	Unused.

Input Parameter	Description
x_{21}	**Unused.**
x_{22}	**Unused.**
x_{23}	**If x_{23}=0, use pulse-height tally variance reduction trees if variance reduction is present, otherwise do not use PHT VR trees. (DEFAULT)** **If x_{23}=1, force pulse-height tally variance reduction trees whether they are needed or not.** **If x_{23}=-1, do no use pulse-height tally variance reduction trees.**
x_{24}	**Controls grazing contribution cut-off for surface flux tallies.** **If x_{24}=0, $\|mu_{cut}\|$ = 0.001. (DEFAULT)** **If $x_{24}\neq$0, $\|mu_{cut}\|$ = x_{24}**
x_{25}–x_{26}	**Unused.**
x_{27}	**Controls antiparticle promotion.** **If x_{27}=0, do not promote antiparticles. (DEFAULT)** **If x_{27}=1, promote antiparticles (affects MODE card and certain tallies); lumps particle and antiparticle pairs under one particle type. (Used in MCNPX.) (Certain restrictions may apply.)**
x_{28}	**Bank size. (DEFAULTs vary by application: x_{28}=2048 for most fixed-source problems, x_{28}=128 for criticality problems, x_{28}=16384 for high-energy problems)**
x_{29}–x_{31}	**Unused.**
x_{32}	**If x_{32}=0, normal GENXS behavior. (DEFAULT)** **If $x_{32}\neq$0, use internal bremsstrahlung spectrum generation with CEM and LAQGSM models for GENXS.**
x_{33}	**If x_{33}=0, do not apply an additional interpolation/smoothing method to stopping powers for heavy ions. (DEFAULT)** **If $x_{33}\neq$0, apply an additional interpolation/smoothing method to stopping powers for heavy ions.**
x_{34}	**For developers use to reproduce a bug in μ^--induced gammas. [DEFAULT (x_{34}=0) is to use the corrected code.]**
x_{35}	**If x_{35}=0, causes slight (arbitrary) spreading of nuclear excitation during μ^- capture. (DEFAULT)** **If $x_{35}\neq$0, turns off slight (arbitrary) spreading of nuclear excitation during μ^- capture.**
x_{36}	**If x_{36}=0, use user-provided data for μ^--induced gamma rays, if available. (DEFAULT)** **If $x_{36}\neq$0, use older data (literature or MUON/RURP) previously hard-coded in MCNPX.**
x_{37}	**Set minimum of internal bremsstrahlung spectrum for CEM and LAQGSM in GENXS when $x_{32}\neq$0. (DEFAULT: x_{37}=30 MeV)**
x_{38}	**If x_{38}=0, use Barashenkov/Polanski data file BARPOL2001.dat. (DEFAULT)** **If $x_{38}\neq$0, use older BARPOL.dat data file from 1996.**

Input Parameter	Description
x_{39}	**Controls the default $S(\alpha,\beta)$ smoothing behavior, which was present in MCNPX but not in MCNP5. If x_{39}=0, use default $S(\alpha,\beta)$ sampling treatment, as in MCNP5 (DEFAULT). If $x_{39}\neq$0, use MacFarlane/Little sampling, as in MCNPX.**
x_{40}	**For developers: controls writing of MCPLIB and XSDIR lines**
x_{41}	**For developers: for printing photon/electron data**
x_{42}	**If x_{42}=0, use default method for model cross sections. (DEFAULT) If x_{42}>0, use original MCNPX model cross-section method. If x_{42}<0, use earlier MCNP6 method (MARS coding).**
x_{43}	**For developers: to control photon form-factor interpolation. If x_{43}=0, use linear form-factor interpolation. (Used by MCNPX.) If x_{43}=2, use best method for form-factor interpolation. (DEFAULT) Currently the best method is logarithmic inversion or log-log.**
x_{44}	**For developers: to study coherent scattering in isolation. (DEFAULT: x_{44}=0, all processes)**
x_{45}	**If x_{45}=0, use MCNP6 elastic scattering method. (DEFAULT) If $x_{45}\neq$0, use earlier MCNPX elastic scattering method.**
x_{46}	**If x_{46}=0, use default CEM-to-LAQGSM photonuclear energy boundary. If x46>0, set x_{46} as CEM-to-LAQGSM energy boundary.**
x_{47}	**If x_{47}=0, use CLEM model for cosmic-ray spectra.(DEFAULT) If $x_{47}\neq$0, use Lal model for cosmic-ray spectra.**
x_{48}	**If x_{48}=0, allow MCNP6 to forbid threading when not suitable. (DEFAULT) If $x_{48}\neq$0, insit on threading if requested.**
x_{49}	**If x_{49}=0, perform normal input checking. (DEFAULT) If x_{49}>0, expert user option to skip some lattice input checking for very large problems to save time in initialization.**
x_{50}	**Modifies printing the tally fluctuation chart (TFC). Controls printing of the FSD and the VOV. If x_{50}=0, do traditional printing of tally fluctuation charts. (DEFAULT) If $x_{50}\neq$0, provide FSD and VOV in scientific notation and decrease printing of three TFCs side-by-side to two TFCs side-by-side.**
x_{51}	**Used by developers to turn off all photon-induced fluorescence. (Default is to have photon-induced fluorescence active.)**
x_{52}	**Used by developers to turn off Compton-induced relaxation. Applies to fluorescence and Auger electrons. (Default is have Compton-induced relaxation active.) Set x_{52}=1, to invoke MCNPX functionality in emission of Auger electrons.**

Input Parameter	Description
x_{53}	**If x_{53}=0, use new ENDF photoelectric relaxation data, if available. (DEFAULT) If $x_{53}\neq$0, use traditional photoelectric fluorescence; i.e., use limited pre-ENDF/B VI.8 treatment. Applies to fluorescence and Auger electrons.**
x_{54}	**Controls sampling method for ENDF Law 9. If x_{54}=0, use traditional sampling for first 10^8 tries but then use new, improved sampling method. (DEFAULT) If $x_{54}\neq$1, use new, improved sampling method.**
x_{55}	**Spontaneous decay integration time. Default is 20 s which includes ~20 decay levels, or ~1 s per decay level. Complex decay chains may require an increase in this parameter. See Note 12 in Section 3.3.4.1**
x_{56}–x_{59}	**Unused.**
x_{60}	**If x_{60}=0, print number of calls to each high-energy model. DEFAULT If $x_{60}\neq$0, also include successes for each model.**
x_{61}	**For developers: models of knock-on electron angles. (DEFAULT=0)**
x_{62}	**For developers: to debug single-event electrons excitation energy loss. (DEFAULT=0)**
x_{63}	**Unused.**
x_{64}	**For developers: to debug single-event electrons angular deflection for knock-on electrons. (DEFAULT=0)**
x_{65}	**For developers: to debug single-event ionization and treat deflection for incident particles. (DEFAULT=0)**
x_{66}	**For developers: to control single-event bremsstrahlung photon angles. (DEFAULT=0)**
x_{67}	**Controls number of particle histories (*nps*) for first calculation of the average contribution per history for point detectors and DXTRAN spheres for Russian roulette game. If x_{67}=0, use TFC value of NPS for first calculation of detector or DXTRAN average contribution. (DEFAULT) If x_{67}>0, use the first x_{67} particles to determine the average contribution per history for point detectors and DXTRAN spheres for Russian roulette game.**
x_{68}	**Unused.**
x_{69}	**Used to increase the LJA array size, which stores the surfaces bounding the cells. Only needed when a fatal error occurs and MCNP6 advises the user to increase the value of the initial allocation, *mlja1*.**
x_{70}	**For developers: debug choice of some interaction models. (DEFAULT=0)**
x_{71}	**If x_{71}=0, allow model photonuclear capability. (DEFAULT) If $x_{71}\neq$0, prohibit model photonuclear capability.**

Input Parameter	Description
x_{72}	**If x_{72}=0, explicit log-log interpolation in ELXS_MOD. (DEFAULT) If $x_{72}\neq$0,random linear interpolation.**
x_{73}-x_{74}	**Unused.**
x_{75}	**If $x_{75}\neq$0, print extra info for F-matrix calculations.**
x_{76}	**If $x_{76}\neq$0, print array storage info after setup.**
x_{77}	**If $x_{77}\neq$0, specify number of bins for hash-based cross-section searches. DEFAULT is 8192.**
x_{78}	**For developers: 0 for old 6.1 S(A,B) method, 1 for new.**
x_{79}	**If x_{79}=0, use MT=101 for PTRAC absorption and MT=18 for fission. If $x_{79}\neq$0, use MT=2 for absorption and fission.**
x_{80}	**Unused.**
x_{81-82}	**For developers: 0 uses linear interpolation of electron elastic scatter and 1 uses log-log interpolation.**
x_{83}	**For developers: 0 uses linear interpolation for electron partial x-s and 1 uses log-log interpolation.**
x_{84-85}	**For developers: 0 uses linear interpolation for electron bremsstrahlung energy and 1 uses log-log interpolation.**
x_{86}	**For developers: 0 uses linear interpolation for electron excitation energy and 1 uses log-log interpolation.**
x_{87-88}	**For developers: 0 uses linear interpolation for electron knock-on energy and 1 uses log-log interpolation.**
x_{89}	**For developers: 0 uses linear interpolation for electron ionization x-s and 1 uses log-log interpolation.**
x_{90}	**If $x_{90}\neq$0, set maximum number of terms for Goudsmit-Saunderson distribution. DEFAULT is 240.**
x_{91}	**If x_{91}>0, set the minimum ROC curve count value to x_{91}.**
x_{92}	**If x_{92}>0, set the maximum ROC curve count value to x_{92}.**
x_{93-99}	**Unused.**
x_{100}	**0 uses new coincident-surface method and 1 uses old method.**

Use: Optional. All DBCN parameters allow 8-byte entries.

Note 1: Settings for the random-number-generator parameters are now accomplished using the RAND card. The DBCN(1), DBCN(8), DBCN(13), and DBCN(14) parameters are provided for backward compatibility only.

Note 2: When trying to duplicate a particle history by setting the starting random number with either x_1 or x_8, the random number sequence may be altered by a default Russian roulette game on contributions to detectors or DXTRAN spheres. If a problem has detectors or DXTRAN, the only ways to reproduce histories with x_1 or x_8 are (a) to turn off the Russian roulette game on the `DD` card by setting k=`0`; (b) to play the roulette game with a fixed criterion by setting k<`0` on the `DD` card; or (c) to reproduce a history that occurs before the first TFC interval.

Note 3: *Caution*: The contributions neglected because of underflow are typically insignificant to the final answer. However, in some cases, the underflow contribution is significant and necessary. When DXTRAN spheres for point detectors are used to get tally contributions for generating weight windows, sometimes these underflow contributions cannot be neglected. If DXTRAN or detector underflow is significant in the calculation, generally there are serious problems, such as not sampling enough collisions near the detector. Changing the underflow limit should be done only with extreme caution.

3.3.7.3.3 LOST LOST PARTICLE CONTROL

The `LOST` card allows the user to increase the number of lost particles the code will allow before terminating.

Form: `LOST` *`lost1`* *`lost2`*

Table 3-148. Lost Particle Card (LOST)

Input Parameter	Description
`lost1`	**Number of particles which can be lost before the job terminates with `BAD TROUBLE`. (DEFAULT: *`lost1`*=`10`)**
`lost2`	**Maximum number of debug prints that will be made for lost particles. (DEFAULT: *`lost2`*=`10`)**

Defaults: 10 lost particles and 10 debug prints.

Use: Discouraged. Losing more than 10 particles is rarely justifiable.

The word "lost" means that a particle gets to an ill-defined section of the geometry and does not know where to go next. This card should be used cautiously: the user should know why the particles are being lost and the number lost should be statistically insignificant out of the total sample. Even if only one of many particles gets lost, there could be something seriously wrong with the geometry specification. Geometry plots in the area where the particles are being lost can be extremely useful in isolating the reason that particles are being lost.

3.3.7.3.4 IDUM INTEGER ARRAY

The IDUM integer array is in the MCNP_DEBUG.F90 module and is available to the users. IDUM is included in the dumps on the RUNTPE file and therefore can be used for any purpose, including accumulating information over the entire course of a problem through several continue-runs.

Form: `IDUM` i_1 ... i_n

where $1 \le n \le 2000$ and i_i is an integer.

Default: All array values zero.

Use: Useful only in user-modified versions of MCNP6.

Note: Up to 2000 entries can be provided to fill the IDUM array with integer numbers. If floating-point numbers are entered, they will be truncated and converted to integers.

3.3.7.3.5 RDUM FLOATING-POINT ARRAY

The RDUM floating-point array is in the MCNP_DEBUG.F90 module and is available to the users. RDUM is included in the dumps on the RUNTPE file and therefore can be used for any purpose, including accumulating information over the entire course of a problem through several continue-runs.

Form: `RDUM` r_1 ... r_n

where $1 \le n \le 2000$ and r_i is a real number.

Default: All array values zero.

Use: Useful only in user-modified versions of MCNP6.

Note: Up to 2000 entries can be provided to fill the RDUM array with floating-point (real) numbers.

3.3.7.3.6 ZA, ZB, ZC, AND ZD DEVELOPERS CARD PLACEHOLDERS

The `ZA`, `ZB`, `ZC`, and `ZD` cards are made available to advanced user-developers who wish to construct their own input cards in MCNP6. Similar to the use of `IDUM` and `RDUM`, source code that is modified by users to create a modified version of MCNP6 no longer carries the extensive validation and verification the original LANL-created source and executables do. Users <u>must</u> perform their own verification and validation to ensure their modifications have not had adverse effects on existing capabilities.

3.3.7.3.7 FILES FILE CREATION

Form: `FILES` *unit_no. filename access form record_length ...*

(See Note 1.)

Table 3-149. File Creation Card (FILES)

Variable	Description
unit_no.	**Recommendation: *unit_no.* ≥ 100. (DEFAULT: none)**
filename	**Name of the file. (DEFAULT: none)**
access	**Options are SEQUENTIAL or DIRECT access. (DEFAULT: SEQUENTIAL)**
form	**Options are FORMATTED or UNFORMATTED. (DEFAULT: FORMATTED if SEQUENTIAL access has been specified, UNFORMATTED if DIRECT access has been specified.)**
record_length	**Record length in direct access file. (DEFAULT: not required if SEQUENTIAL access has been specified, no default if DIRECT access has been specified..)**

Use: When a user-modified version of MCNP6 needs files whose characteristics may vary from run to run. Not allowed in continue-run.

Note 1: If this card is present, the first two entries are required and must not conflict with existing MCNP6 units and files. Setting ***unit_no.*** greater than 100 will prevent any conflicts with MCNP6 unit numbers. The words SEQUENTIAL, DIRECT, FORMATTED, and UNFORMATTED can be abbreviated. The maximum number of files allowed is six, unless the second dimension of the KUFIL array in FIXCOM.F90 is increased.

Caution: The names of any user files in a continue-run will be the same as in the initial run. The names are not automatically sequenced if a file of the same name already exists; therefore, a second output file from a continue-run will overwrite and replace the content of an existing file of the same name. If you are using the FILES card for an input file and do a continue-run, you will have to provide the coding for keeping track of the record number and then positioning the correct starting location on the file when you continue or MCNP6 will start reading the file at the beginning.

Example 1:

```
FILES    21  ANDY  S  F  0    22  MIKE  D  U  512
```

Example 2:

```
FILES    17  DUMN1
MCNP6  INP=TEST3  DUMN1=POST3
```

If the file name is DUMN1 or DUMN2, the user can optionally use the execution line message to designate a file whose name might be different from run to run, for instance in a continue-run.

3.4 SUMMARY OF MCNP6 INPUT CARDS

The following table lists the various input cards and when they are required. Two kinds of defaults are involved in the following table: (1) if a particular entry on a given card has a default value, that value is listed in the appropriate location on the card; and (2) the omission of a card from the input file sometimes has a default meaning, and if so, the default description is preceded by an asterisk.

Table 3-150. Summary of MCNP6 Input Cards

Use	Card	Defaults	Section
General Categories			
optional	**Message block plus blank terminator**		**2.4**
required	**Problem title card**		**2.5**
optional	**C Comment card**		**2.6**
required	**Cell cards plus blank terminator**		**2.8**
required	**Surface cards plus blank terminator**		**2.8**
required	**Data cards plus blank terminator**		**2.8.1**
optional	`READ`	`ECHO`	**3.1**
Cell and Surface Cards			**Section 3.2**
required	**Cell cards plus blank terminator**		**3.2.1**
required	**Surface cards plus blank terminator**		**3.2.2**
Geometry Cards			**Section 3.3.1**
optional	`VOL`	**Use MCNP6-calculated volumes**	**3.3.1.1**
optional	`AREA`	**Use MCNP6-calculated surface areas**	**3.3.1.2**
Optional	`TR`	`0 0 0  1 0 0  0 1 0  0 0 1  1`	**3.3.1.3**
Optional	`TRCL`	`TRCL=0` **or** `0 0 0  1 0 0  0 1 0  0 0 1  1`	**3.3.1.4**
Optional	`U`	`U=0` **("real world" universe)**	**3.3.1.5.1**

Use	Card	Defaults	Section
Optional	LAT	LAT=0 (not a lattice)	3.3.1.5.2
Optional	FILL	FILL=0 (lattice element does not exist)	3.3.1.5.3
Optional	URAN	None	3.3.1.5.4
required for LNK3DNT creation	DAWWG	POINTS=1	3.3.1.6.1
required to embed geometry	EMBED	FILETYPE=ASCII, LENGTH=1	3.3.1.6.2
Optional	EMBEE	ENERGY=1, TIME=1	3.3.1.6.2
Optional	EMBEB	One energy bin with boundary set to the maximum energy limit for the particle type.	3.3.1.6.2
Optional	EMBEM	m_i=1	3.3.1.6.2
Optional	EMBTB	One time bin with boundary set to the maximum time limit for the particle type.	3.3.1.6.2
Optional	EMBTM	m_i=1	3.3.1.6.2
Optional	EMBDE	One energy bin with boundary set to the maximum energy limit for the particle type.	3.3.1.6.2
Optional	EMBDF	m_i=1	3.3.1.6.2
Material Specification Cards			**Section 3.3.2**
optional	M	No ZAID or ZAID fraction default; GAS=0; ESTEP set internally; HSTEP set internally; NLIB, PLIB, PNLIB, ELIB, and HLIB=first match in XSDIR; COND=0	3.3.2.1
(d)	MT	None	3.3.2.2
Optional	MX	None	3.3.2.3
Optional	OTFDB	None	3.3.2.5
(d)	TOTNU	*Total $\bar{\nu}$ if card absent or has no entry.	3.3.2.6
(d)	NONU	*Fission treated as real fission if card not used (a_j=1). If card is used without an entry, fission is treated like capture with gammas produced (a_j=0).	3.3.2.7
Optional	AWTAB	*Atomic weight ratios from cross-section tables if card not used.	3.3.2.8
Optional	XS	None	3.3.2.9
Optional	VOID	*Use problem materials if card is not present.	3.3.2.10

Use	Card	Defaults	Section
optional	MGOPT	*Fully continuous if card not used. If card is used, *iplt*=0, *isb*=0, *icw*=0, *fnw*=1, and *rim*=1000.	3.3.2.11
(d)	DRXS	*Continuous-energy cross-section treatment if card absent. If the DRXS card is present but has no entries, discrete cross sections will be used for every nuclide, if available.	3.3.2.12
Physics Cards			Section 3.3.3
(a)	MODE	*If card absent, MODE N assumed.	3.3.3.1
Optional	PHYS:N	*100 0 0 J J J 0 -1 J J J 0 0;	3.3.3.2.1
Optional	PHYS:P	*100 0 0 0 0 J 0	3.3.3.2.2
Optional	PHYS:E	*100 (if no PHYS:N card or *emax* from PHYS:N card) 0 0 0 0 1 1 1 1 0 0 J J 0.917 0.001	3.3.3.2.3
Optional	PHYS:H	*100 (or *emax* from PHYS:N card) 0 -1 J 0 J 0 3J 0 0 0 0.917	3.3.3.2.4
Optional	PHYS:<*pl*>	*Non-Muons: 100 (or *emax* from PHYS:N card) 3J 0 5J 0 0 0 0.917 Muons: 100 (or *emax* from PHYS:N card) 3J 0 J 1 0.65 2J 0 0 0 0.917	3.3.3.2.5
Optional	ACT	FISSION=N; NONFISS=NONE; DN=LIBRARY; DG=NONE; THRESH=0.95; analog calculation	3.3.3.3
Optional	CUT:<*pl*>	*Neutron: *t*=very large; *e*=0.0; wc_1=-0.5; wc_2=-0.25; *swtm*=minimum source weight if the general source is used. *Photon: *t*=neutron cutoff; *e*=0.001; wc_1=-0.5; wc_2=-0.25; *swtm*=minimum source weight if the general source is used. If there are pulse-height tallies, wc_1=wc_2=0, unless forced collisions are also used. If pulse height tallies are used with forced collisions, wc_1=-0.5 and wc_2=-0.25. *Electron: *t*=neutron cutoff; *e*=0.001; wc_1=0; wc_2=0; *swtm*=minimum source weight if the general source is used. If there are pulse-height tallies, wc_1=wc_2=0, unless forced collisions are also used. If pulse height tallies are used with forced collisions, wc_1=-0.5 and wc_2=-0.25.	3.3.3.4.1
Optional	ELPT	CUT card energy cutoff.	3.3.3.4.2
(d)	TMP	2.53e-8, room temperature	3-91
(d)	THTME	0, no time dependence	3.3.3.6

Use	Card	Defaults	Section
Optional	MPHYS	MPHYS OFF for MODE N, P, and/or E; MPHYS ON if any particle on MODE card other than N, P, E.	3.3.3.7.1
Optional	LCA	2 1 1 0023 1 1 0 1 1 0 unless *icem*=2, then 2 1 0 0023 1 1 0 1 1 0	3.3.3.7.2
Optional	LCB	3500 3500 2500 2500 800 800 -1.0 -1.0	3.3.3.7.3
Optional	LCC	1 45	3.3.3.7.4
Optional	LEA	1 4 1 0 1 0 0 1	3.3.3.7.5
Optional	LEB	1.5 8.0 1.5 10.0 for *ievap*=0 and for *ievap*=1	3.3.3.7.6
Optional	FMULT	See print table 38; METHOD=0, DATA=0, and SHIFT=0 if no METHOD, DATA, or SHIFT keywords are specified; if any of these keywords appear, METHOD=3, DATA=3, SHIFT=1	3.3.3.8
Optional	TROPT	MCSCAT=FNAL1; ELOSS=STRAG1; NREACT=ON; NESCAT=ON; if GENXS keyword absent, standard transport; if GENXS present but without file name, read from file named INXC.	3.3.3.9
Optional	UNC	*j_i=1, secondaries considered as un-collided for all cells.	3.3.3.10
Optional	COSYP	*axsh*=1, *axsv*=2, *emap*$_i$=the energy of the i^{th} COSY map	3.3.3.11.1
Optional	COSY	No map is assigned to the cell.	3.3.3.11.1
Optional	BFLD	VEC=0 0 1, MXDEFLC=10, MAXSTEP=100; For quadrupole fields: AXS=0 0 1; REFPNT=0 0 0	3.3.3.11.2
Optional	BFLCL	No magnetic filed assigned to the cell.	3.3.3.11.2
Optional	FIELD	None	3.3.3.12
Source Specification Cards			Section 3.3.4
Optional	SDEF	CEL=determined from position of particle; SUR=0; ERG=14; TME=0; DIR=isotropic for volume source, cosine distribution for surface source; VEC=vector normal to surface for surface source; NRM=+1; POS=0,0,0; RAD=0; EXT=0; X=0; Y=0; Z=0; WGT=1; EFF=0.01; PAR=N if no MODE card or =lowest IPT number represented on MODE card; LOC(*alt*)=65.0 km	3.3.4.1
Optional	SI	H i_1 ... i_k	3.3.4.2
optional	SP	D p_1 ... p_k	3.3.4.3

Use	Card	Defaults	Section
optional	SB	D b_1 ... b_k	3.3.4.4
optional	DS	H j_1 ... j_k	3.3.4.5
optional	SC	No comment.	3.3.4.6
optional	SSW	SYM=0; record all tracks for all particle types if PTY keyword absent	3.3.4.7
Optional	SSR	OLD=all surfaces in original run; CEL=all cells in original run; NEW=surfaces in the OLD list; PTY=read all tracks for all particle types; COL=0; WGT=1; TR=no transformation; AXS=no axis; EXT=no position bias; POA=0; BCW=no cylindrical window	3.3.4.8
(b)	KCODE	1000 1.0 30 130 max(4500,2×*nsrck*) 0 6500 1	3.3.4.9
(c)	KSRC	None	3.3.4.10
(c)	KOPTS	BLOCKSIZE=10; KINETICS=NO; PRECURSOR=NO; KSENTAL=MCTAL	3.3.4.11
(c)	HSRC	None	3.3.4.12
(c)	BURN	TIME=1; PFRAC=1; POWER=1; MAT=all materials; AFMIN=1.0E-10 1.0E-10; BOPT=1.0 1 -1	3.3.4.13
Optional	SOURCE/SRCDX	None	3.3.4.14
Tally Specification Cards			Section 3.3.5
Optional	F	None	3.3.5.1
Optional	FIP/FIR/FIC	For FIP, f_1=0; for FIR and FIC, f_2=0	3.3.5.1.2
Optional	FC	No comment	3.3.5.2
Optional	E	*One bin over all energies	3.3.5.3
Optional	T	*One bin over all times; CBEG=0; CSUB=1	3.3.5.4
Optional	C	*One bin over all angles	3.3.5.5
Optional	FQ	*F D U S M C E T	3.3.5.6
Optional	FM	None	3.3.5.7
Optional	DE/DF	Logarithmic interpolation of energy and dose; IU=2; FAC=1; IC=10; *int*=LOG for IC=10 and IC=40; recommended analytic parameterization for IC=20, 31–39	3.3.5.8
Optional	EM	None	3.3.5.9
Optional	TM	None	3.3.5.10
Optional	CM	None	3.3.5.11
Optional	CF	None	3.3.5.12
Optional	SF	None	3.3.5.13

Use	Card	Defaults	Section
Optional	FS	**No segmenting**	**3.3.5.14**
Optional	SD	**None**	**3.3.5.15**
Optional	FU	**If FU card is absent, subroutine TALLYX is not called.**	**3.3.5.16**
Optional	TALLYX	**None**	**3.3.5.17**
Optional	FT	**If FT card is absent, there is no special treatment for tally.**	**3.3.5.18**
Optional	TF	1 1 *last last* 1 *last last last*	**3.3.5.19**
Optional	NOTRN	**None.**	**3.3.5.20**
Optional	PERT	**METHOD=+1; ERG=all energies; RXN=1 for neutrons and multigroup, RXN=-5 for photons**	**3.3.5.21**
(c)	KPERT	**ISO=all isotopes; RXN=all reactions; ERG=all energies; LINEAR=NO**	**3.3.5.22**
(c)	KSEN	**XS; ISO=all data tables; RXN=total cross section without $S(\alpha,\beta)$; ERG=all energies; EIN=all energies; COS=all angles; CONTRAIN=YES**	**3.3.5.23**
Optional	TMESH	**Type 1: FLUX; linear interpolation; response is a function of the current particle energy; constant multiplier=1.0** **Type 2: Neutrons scored** **Type 3: Score energy deposited from any source, linear interpolation; response is a function of the energy deposited; constant multiplier=1.0** **Type 4: None**	**3.3.5.24**
Optional	FMESH	**GEOM=XYZ; ORIGIN=0,0,0; AXS=0,0,1; VEC=1,0,0; IINTS=1; JINTS=1; KINTS=1; EMESH=0.,$E_{pl,max}$; EINTS=1; ENORM=NO; TMESH=-∞,T_{max}; TINTS=1; TNORM=NO; FACTOR=1; OUT=COL; INC 0 INFINITE; TYPE=FLUX; KCLEAR=0**	**3.3.5.25**
Optional	SPDTL	***Enabled by default if strict criteria are met.**	**3.3.5.26**
Variance-Reduction Cards			**Section 3.3.6**
required unless WWs used	IMP	**Dependent on presence or absence of other cards.**	**3.3.6.1**
Optional	VAR	**No modifications of variance reduction methods.**	**3.3.6.2**
Optional	WWE	**If the WWE card is omitted and weight windows are used, one weight-window energy (or time) interval for entire problem.**	**3.3.6.3.1**
optional	WWT	**One weight-window time interval for entire problem.**	**3.3.6.3.2**

Use	Card	Defaults	Section
required unless importance or mesh-based WWs are used.	`WWN`	**None.**	**3.3.6.3.3**
optional (If present, WWs required unless importance used)	`WWP`	`5 3 5 0 0 0 1 0 0`.	**3.3.6.3.4**
optional	`WWG`	**No weight windows generated.**	**3.3.6.4.1**
optional	`WWGE`	**If card omitted, single energy (or time) interval; if card with no entries, 10 energy (or time) bins generated**	**3.3.6.4.2**
optional	`WWGT`	**If card omitted and the weight window is used, single time interval; if card with no entries, 10 time bins generated**	**3.3.6.4.3**
optional (required if mesh-based WWs are used or generated) (required for LNK3DNT creation)	`MESH`	`GEOM=XYZ`; `ORIGIN=0 0 0`; `AXS=0 0 1`; `VEC=1 0 0`; `IINTS`, `JINTS`, `KINTS=10`	**3.3.6.4.4**
optional	`ESPLT`	***No energy splitting or roulette if card not used.**	**3.3.6.5**
optional	`TSPLT`	***No time splitting or roulette if card not used.**	**3.3.6.6**
optional	`EXT`	a_j=`0`, **no transform**	**3.3.6.7**
optional	`VECT`	**None**	**3.3.6.8**
optional	`FCL`	x_j=`0`; **no forced collisions**	**3.3.6.9**
optional	`DXT`	dwc_1, dwc_2, **and** *dpwt*=`0`	**3.3.6.10**
optional	`DD`	**If** *n* **of** `DD`*n* **card is** `0` **or blank, apply diagnostic parameters to all detector tallies and DXTRAN spheres unless overridden;** k_i=`0.1`; m_i=`1000`	**3.3.6.11**
optional	`PD`	p_j=`1`	**3.3.6.12**
optional	`DXC`	*m*=`0`, p_j=`1`	**3.3.6.13**
optional	`BBREM`	**None.**	**3.3.6.14**
optional	`PIKMT`	***No neutron-induced photon-production biasing if card not used. If card used, any ZAID not listed has** $ipik_i$=`-1`.	**3.3.6.15**

Use	Card	Defaults	Section
Optional	`SPABI`	**None.**	**3.3.6.16**
Optional	`PWT`	w_j**=-1 when both neutrons and photons appear on the `MODE` card.**	**3.3.6.17**
Problem Termination, Output Control, and Miscellaneous Cards			**Section 3.3.7**
Optional	`NPS`	**Infinite**	**3.3.7.1.1**
Optional	`CTME`	**Infinite**	**3.3.7.1.2**
Optional	`STOP`	**None**	**3.3.7.1.3**
Optional	`PRINT`	***Absence of card causes "basic," "default," and "shorten" tables to be printed. Presence of card with no inputs provides all optional tables applicable to your problem as well as the default print.**	**3.3.7.2.1**
Optional	`TALNP`	**If card without entries, no bin prints for tallies. If card present, bin prints for all tallies provided.**	**3.3.7.2.2**
Optional	`PRDMP`	**Print tallies at end; dump to RUNTPE every 15 minutes and at end; do not write MCTAL file; write all dumps to RUNTPE; for fixed-source problems, write tally fluctuation charts and rendezvous every 1000 particles or, if multiprocessing, 10 times during the run; for KCODE problems, write charts and rendezvous at end of each cycle**	**3.3.7.2.3**
Optional	`PTRAC`	**`BUFFER=100`; `FILE=BIN`; `MAX=10000`; `MEPH=` write all events; `WRITE=POS`; `COINC=COL`; `EVENT=`write all events; `FILTER=`no additional filtering; `TYPE=`all particle types; `NPS=`events for all histories; no filtering based on cell entrance; no filtering based on surface crossing; no filtering based on tally contribution; `VALUE=10`**	**3.3.7.2.4**
Optional	`MPLOT`	**None**	**3.3.7.2.5**
Optional	`HISTP`	***lhist*`=500000000`; all events written to HISTP**	**3.3.7.2.6**
Optional	`RAND`	**`GEN=1`; `SEED=19073486328125`; `HIST=1`; `STRIDE=152917`**	**3.3.7.3.1**

Use	Card	Defaults	Section
optional	DBCN	x_1=5[19]; x_2=0; x_3=0; x_4=0; x_5=600; x_6=80; x_7=0; x_8=1; x_9=1.0E-4; x_{10}=1.5768e16; x_{11}=0; x_{12}=0; x_{13}=152917; x_{14}=1; x_{15}=0; x_{16}=1.0; x_{17}=0; x_{18}=2; x_{19}=0; x_{23}=0; x_{24}=0.001; x_{27}=0; x_{28}=2048 for fixed-source problems below ~150 MeV, x_{28}=16384 for fixed-source problems above ~150 MeV, x_{28}=128 for criticality problems; x_{32}=0; x_{33}=0; x_{34}=0; x_{35}=0; x_{36}=0; x_{37}=30; x_{38}=0; x_{39}=0; x_{42}=0; x_{43}=2; x_{44}=0; x_{45}=0; x_{46}=0; x_{47}=0; x_{48}=0; x_{49}=0; x_{50}=0; x_{53}=0; x_{54}=0; x_{55}=20; x_{60}=0 x_{61}=0; x_{62}=0; x_{64}=0; x_{65}=0; x_{66}=0; x_{67}=0; x_{70}=0; x_{71}=0; x_{72}=0; x_{75}=0; x_{76}=0; x_{77}=0; x_{78}=0; x_{79}=0; x_{81}=0; x_{82}=0; x_{83}=0; x_{84}=0; x_{85}=0; x_{86}=0; x_{87}=0; x_{88}=0; x_{89}=0; x_{90}=240; x_{91}=0; x_{92}=0; x_{100}=0	3.3.7.3.2
optional	LOST	10 10	3.3.7.3.3
optional	IDUM	All array values 0	3.3.7.3.4
optional	RDUM	All array values 0.0	3.3.7.3.5
optional	ZA,ZB,ZC,ZD	None	3.3.7.3.6
optional	FILES	*access*=SEQUENTIAL; *form*=FORMATTED if *access*=SEQUENTIAL, *form*=UNFORMATTED if *access*=DIRECT; *record_length*=not required if *access*=SEQUENTIAL, no default if *access*=DIRECT	3.3.7.3.7

(a) Required for all but MODE N
(b) Neutron criticality problems only.
(c) KCODE only
(d) Neutron problems only

4 EXAMPLES

Instructive examples of several topics are included in this section. Some of the examples are simplistic while others illustrate more complex features of the MCNP6 code. They should be studied in conjunction with the theory, instructions, and previous examples provided in Sections 1, 2, and 3 of this manual.

Following the simple geometry specification examples are related geometry examples that exercise coordinate transformations, repeated structure and lattice geometries, and embedded meshes. After the geometry-related examples are those related to tally options, including the `FM`, `FMESH`, `FS`, and `FT` cards as well as the TALLYX subroutine for user-defined tallies using the `FU` card. Next are source specification examples for the generalized source, beam sources, and a burnup case followed by example SOURCE and SRCDX subroutines for point detectors and/or DXTRAN spheres. Finally, a materials example of table and model-data mix-and-match and a physics model example complete the section.

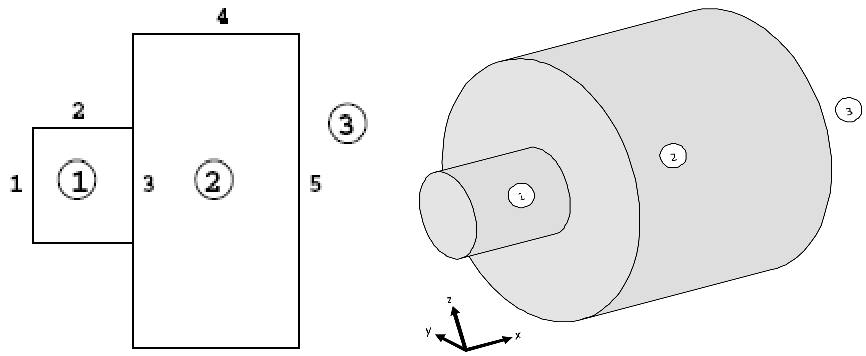
4.1 GEOMETRY EXAMPLES

The geometry discussions in Sections 1 and 2 must be understood before studying the following examples. The concept of combining regions of space bounded by surfaces to make a cell must be fully appreciated; the following examples should help solidify this concept. The use of macrobodies will simplify many geometry definition situations.

4.1.1 Geometry Specification

Several examples of the union and complement operators follow. These should help you better understand how cells are defined. In the illustrations, cell numbers will be circled; surface numbers will not be circled but will appear next to the surface they represent. For simplicity, all cells are void of material.

The next several examples become progressively more difficult and usually take advantage of what you learned in the preceding ones. Remember that unless altered by parentheses, the hierarchy of operations is that intersections are performed first and then unions.



Example 1:

Figure 4-1 below, surfaces 2 and 4 are cylinders and the others are planes with their positive sides to the right. The figure includes a perspective view to make it clearer what is being defined. The surfaces used in this example are:

```
    1  PX  0  $ plane perpendicular to the X axis at x=0
    2  CX  2  $ cylinder on the X axis of radius 2
    3  PX  2  $ plane perpendicular to the X axis at x=2
    4  CX  3  $ cylinder on the X axis of radius 3
    5  PX  6  $ plane perpendicular to the X axis at x=6
```

Cells 1 and 2 are easy to specify:

```
    1  0 −2 1 −3 $ inside cylinder 2, right of plane 1, left of plane 3
    2  0 −4 3 −5 $ inside cylinder 4, right of plane 3, left of plane 5
```

Cell 3 is more complex: There are multiple ways it can be defined. Here are some definitions of cell 3, each of which is described in more detail below:

```
    3  0   (2  3): 1:4:5   $ parentheses used for clarity; not required
    3  0   4: 1:5:(2  3)   $ parentheses not required
    3  0   ( 1:2) (-3:4):5 $ parentheses are require
ed for correctness
    3  0   #1 #2           $ everything that is “not” cell 1 or 2
```

It may be helpful to refer to Figure 2-3 of the MCNP5 Theory Manual[X-503a] and its explanation. Remember that a union adds regions and an intersection gives you only the areas that overlap or are common to both regions. In addition, unions take precedence over intersections. Regions can be added together more than once—or duplicated—with the union operator.

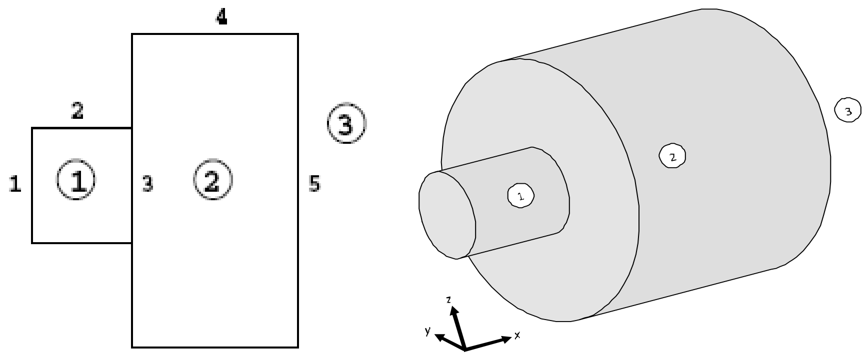


Figure 4-1. Example 1 sample geometry - Two Stacked Cylinders: The XZ cross section (at left) shows the three cells and defining surface indices..

Let us arbitrarily start with the definition of cell 3 at cylindrical surface 2. The expression 2 -3 defines the following region: everything in the world outside surface 2 intersected with everything to the left of plane surface 3. This region is hatched in Figure 4-2. Let us examine in detail how Figure 4-2 was derived. First look at each region separately. The area with a positive sense with respect to surface 2 is shown in Figure 4-3. It includes everything outside surface 2 extending to infinity in all directions. The area with negative sense with respect to surface 2 is undefined so far. The area with negative sense with respect to surface 3 is shown in Figure 4-4. It includes everything to the left of surface 3 extending to infinity, or half the universe. Recall that an intersection of two regions gives only the area common to both regions or the areas that overlap. Superimposing Figure 4-3 and Figure 4-4 results in Figure 4-5. The cross-hatched regions show the space common to both regions. This is the same area hatched in Figure 4-2.

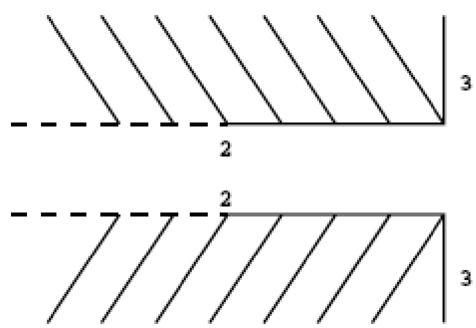


Figure 4-2. Outside (i.e., positive sense) of cylindrical surface 2 intersected with region to left (i.e., negative sense) of plane surface 3.

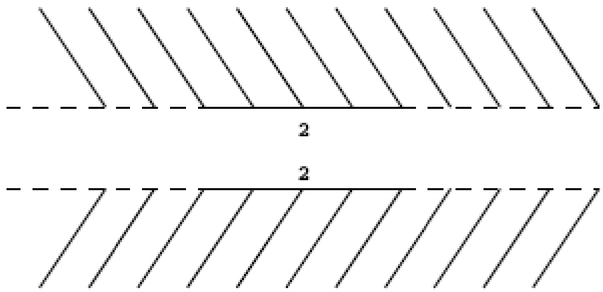


Figure 4-3. Region with positive sense with respect to cylindrical surface 2

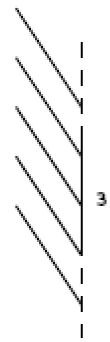


Figure 4-4. Region with negative sense with respect to plane surface 3.

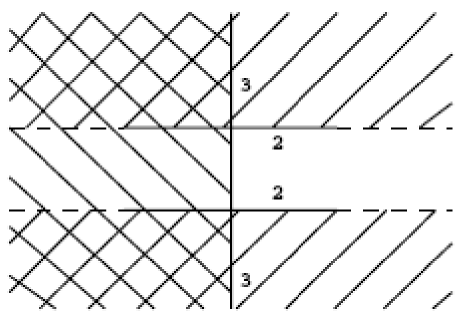


Figure 4-5. Figure 4-3 and Figure 4-4 overlaid creating a cross-hatched region that is identical to the hatched region in Figure 4-2.

Let us now deal with surface `1`. To the quantity `2 -3` we will add everything with a negative sense with respect to plane surface `1` as indicated by the expression `2 -3:-1`, or `(2 -3):-1` if you prefer. First, recall that in the hierarchy of operations, intersections are performed first and then unions. (Consequently, the parentheses are unnecessary in the previous expression.) Second, recall that a union of two regions results in a space containing everything in the first region plus everything in the second region. This union also includes everything common to both regions. Superimposing the region shown in Figure 4-2 and the region to the left of surface `1` results in Figure 4-6. Our geometry now includes everything hatched plus everything crosshatched and has added part of the tunnel that is interior to cylindrical surface `2`.

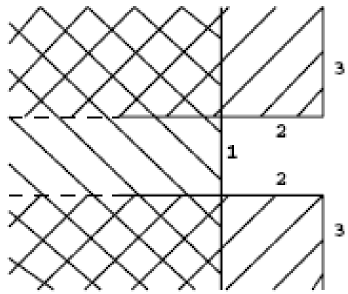


Figure 4-6. Region shown in Figure 4-2 superimposed with region negative with respect to (i.e., left of) plane surface 1.

By the same method we will deal with cylindrical surface 4. To the quantity `2 -3:-1` we will add everything with a positive sense with respect to surface 4, written as `2 -3:-1:4`. Figure 4-7 shows our new geometry. It includes everything in Figure 4-6 plus everything outside surface 4.

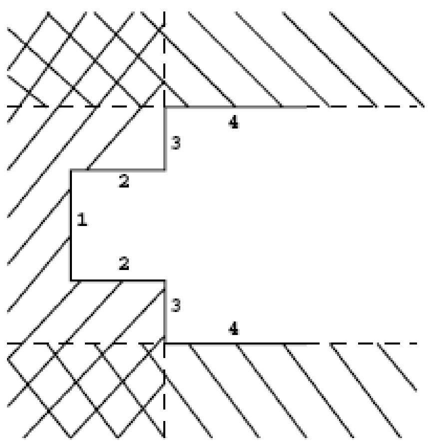
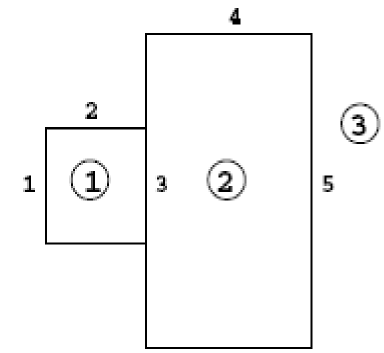


Figure 4-7. Region outside of surface 4 added to the region shown in Figure 4-6.

Our final step is to block off the large tunnel extending to positive infinity (i.e., to the right) by adding the region with a positive sense with respect to plane surface 5 to the region shown



in Figure 4-7. The final expression that defines cell `3` of

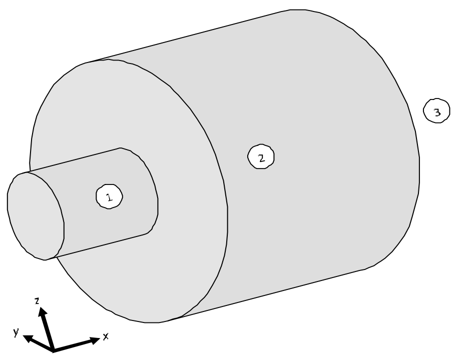


Figure 4-1 is `2 -3:-1:4:5`.

There is more than one way to define cell `3`. Starting with plane surface `1`, we can add the region to the left of `1` to the region outside cylindrical surface `2` or `-1:2`. This newly defined region is illustrated in Figure 4-8. We wish to intersect this space with the space having a negative sense with respect to plane surface `3`. Superimposing Figure 4-8 and the region to the left of surface `3` results in Figure 4-9. The cross-hatched area indicates the area common to both regions and is the result of the intersection. Note that the cross-hatched area of Figure 4-9 is identical to the entire hatched plus crosshatched area of Figure 4-6. Therefore, we have defined the same geometry in both figures but have used two different approaches to the problem. To ensure that the intersection of `-3` is with the quantity `-1:2` as we have illustrated, we must use parentheses giving the expression `(-1:2)` −3. Remember the order in which the operations are performed. Intersections are done before unions unless parentheses alter the order. The final expression is `(-1:2) -3:4:5`.

Another tactic to define cell `3` uses a somewhat different approach. Rather than defining a small region of the geometry as a starting point and adding other regions until we get the final product, we shall start by defining a block of space and adding to or subtracting from that block as necessary. We arbitrarily choose our initial block to be represented by `4: 1:5`, illustrated in Figure 4-10. Notice that the boundaries of this block are the outermost surfaces of our model: cylindrical surface 4 and planar surfaces 1 and 5.

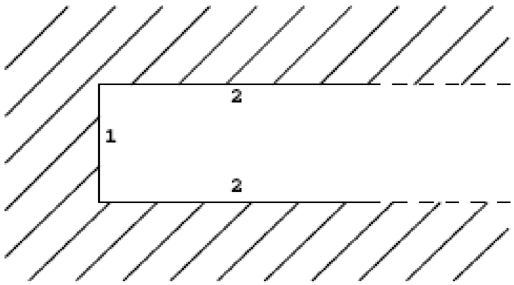


Figure 4-8. Union of regions to the left of surface 1 and outside of surface 2.

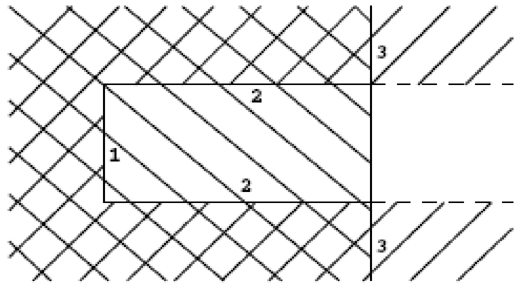


Figure 4-9. Region of Figure 4-8 superimposed with the region to the left of surface 3.

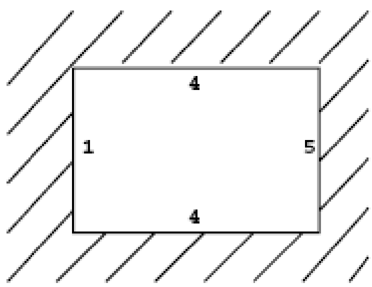


Figure 4-10. A starting point for defining cell 3.

To this block we need to add the space in the upper and lower left corners that belong to cell 3. The expression `2 −3` isolates the space we need to add. Adding `2 -3` to our original block, we have `4:-1:5:(2 -3)`. The parentheses are not required for correctness in this case but help to illustrate the path our reasoning has followed.

Figure 4-11 depicts the union of `2 -3` with the block of space we originally chose.

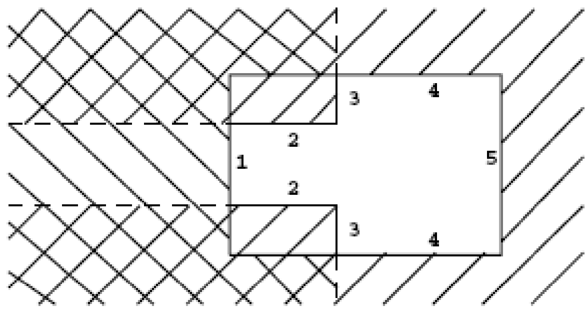


Figure 4-11. Union of the space block defined using outer boundaries of model and the left corner regions.

Now let us arbitrarily choose a different initial block, `4:5:-3`, all the world except cell `2`. From this region we need to subtract cell `1`. If we intersect the region `(2:-1)` with `(4:5:-3)`, as shown in Figure 4-12, we will have introduced an undefined tunnel to the right of surface `5`. To correct this error, define an area `(2:-1:3)` or `(2:-1:5)` and intersect this region with the initial block.

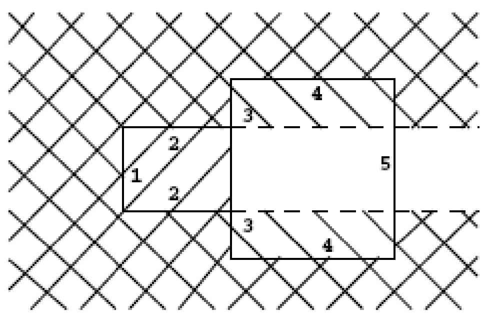


Figure 4-12. Region `(2:−1)` intersected with region `(4:5:−3)`, creating an undefined region.

Yet another approach is to intersect the two regions `-1:2` and `-3:4`, then add that to the region to the right of surface `5` by `(-1:2) (-3:4):5`. In the above paragraph the expression `(4:5:-3) (2:-1:5)` can have the common quantity `5` factored out, also resulting in `(-1:2) (-3:4):5`.

Finally, another approach is to forget about the reality of the geometry and to define cell `3` take the inverse (or complement) of all the cells bounding cell `3`—cells `1` and `2`. This says that cell `3` is the entire world excluding that which has already been defined to be in cells `1` and `2`. The advantage of this method is that cells `1` and `2` are easy to specify and you do not get bogged down in details for cell `3`. Cell `3` thus becomes `(-1:2:3) (-3:4:5)`. Note that the specifications for cells 1 and 2 are reversed. Intersections become unions. Positive senses become negative. Then each piece is intersected with the other. There is a complement operator in MCNP6 that is a shorthand notation for the above expression; it is the symbol #, which can be thought of as meaning "not in." Therefore, cell 3, when specified as #1 #2, is translated as everything in the world that is not in cell 1 and not in cell 2.

Example 2: In this example (Figure 4-13), cell 1 includes everything interior to both surfaces 1 and 2. It is simple enough that the answer is provided without explanation.

```
1  0   -1 : -2
2  0    1    2
```

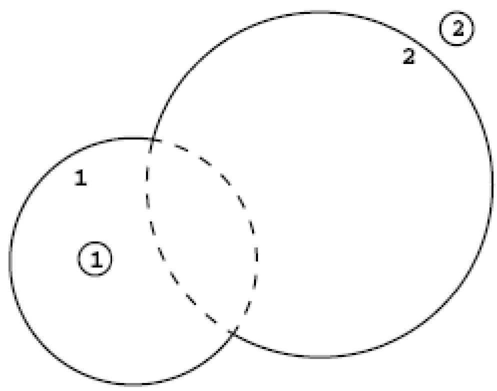


Figure 4-13. Simple two-cell model.

Example 3: In this geometry (Figure 4-14) of four cells defined by three spheres, cell 3 is disconnected, consisting of two disjoint volumes. Cell 3 is the region inside surface 3 but outside surfaces 1 and 2 (-3 1 2) plus the region enclosed between surfaces 1 and 2 (-2 -1):

```
1  0   -1  2
2  0   -2  1
3  0   (-3 1 2):(-2 -1) $ parentheses not required
4  0    3
```

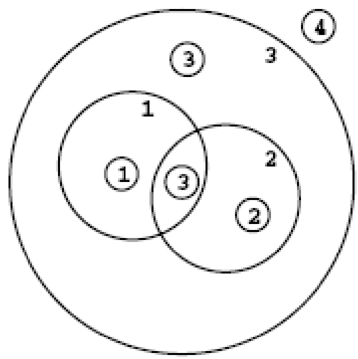


Figure 4-14. Illustration of disconnected cell 3.

Example 4: In this example (Figure 4 15), all vertical lines are planes with their positive sides to the right and all horizontal lines are cylinders. The surface list (with notional dimensions) is:

```
1  PX  -3
2  CX   2
3  PX  -1
4  CX   5
5  PX   1
6  CX   3.5
7  PX   3
8  SO   8
```

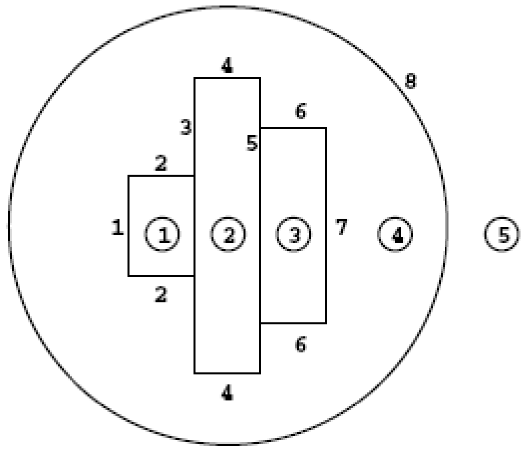


Figure 4-15. Horizontal cylinders internal to a sphere.

Cells 1, 2, and 3 are simple right-circular cylinders. Cell 4 is also simple to define with the complement operator. Cell 5 is also simple, everything in the world with a positive sense with respect to the outer sphere, surface 8.

```
1  0  1 -2 -3
2  0  3 -4 -5
3  0  5 -6 -7
4  0  #1 #2 #3 -8  $ or (-1:4:7:2 -3:5 6) -8
5  0  8            $ everything outside the outer sphere
```

Some users might try defining cell 5 simply as #4 (‘not’ cell 4). However, that would be incorrect. That syntax says cell 5 is everything in the universe not in cell 4, which includes cells 1, 2, and 3. The specification #4 #1 #2 #3 *would* be correct but should not be used because it is computationally inefficient. It tells MCNP6 that cell 5 is bounded by surfaces 1 through 7 in addition to surface 8. The lesson here is that extra, irrelevant surfaces in cell definitions – implicit or explicit – can cause MCNP6 to run significantly more slowly than it should because any time a particle enters a cell or has a collision in it, the intersection of the particle’s trajectory with each bounding surface has to be calculated.

Specifying cell 4 exclusively with the complement operator is very convenient and computationally efficient in this case. However, it will be instructive to set up cell 4 explicitly without complements. There are many different ways to specify cell 4, The following approach should not be considered to be *the* way.

First consider cell 4 to be everything outside the big cylinder of surface 4 that is bounded on each end by surfaces 1 and 7. This is specified by (-1:4:7). The parentheses are not necessary but may add clarity. Now all that remains is to add the corners outside cylinders 2 and 6. The corner outside cylinder 2 is (2 -3), whereas it is (5 6) outside cylinder 6. Again the parentheses are optional. These corners are then added to what we already have outside cylinder 4 to get

```
(−1:4:7):(2 −3):(5 6)
```

The region described so far does not include cells 1, 2, or 3 but extends to infinity in all directions. This region needs to be terminated at the spherical surface 8. In other words, cell 4 is everything we have defined so far that is also common with everything inside surface 8 (that is, everything so far intersected with -8). So as a final result,

```
((−1:4:7):(2 −3):(5 6)) −8
```

The inner parentheses can be removed, but the outer ones are necessary (remember the hierarchy of operations) to give us

```
(−1:4:7:2 −3:5 6) −8
```

If the outer parentheses are removed, the intersection of -8 will occur only with 5 and 6, an event that is clearly incorrect.

Example 5:

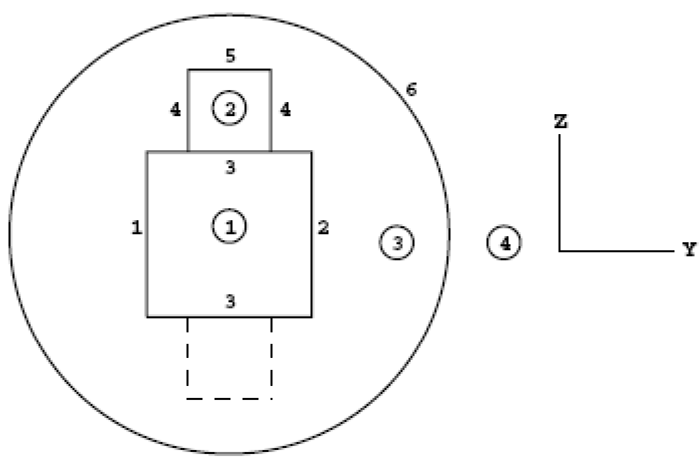


Figure 4-16. Horizontal and vertical cylinders in a sphere.

This example (Figure 4-16) is similar to the previous one except that a vertical cylinder (surface 4) is added to one side of the horizontal cylinder (surface 3).

Cell 1 is (1 -3 -2), cell 3 is #1 #2 #4, and cell 4 is just 6.

Cell `2` is more than might initially meet the eye. The description of cell `2` might appear to be simply `(-5 -4 3)`, but this definition causes two images of cell `2` to be created: one we desire above the *y*-axis and one we do not want below the *y*-axis. This undesired mirror image of cell `2` resides in the bottom half of cell 1 and is depicted by the dashed lines in Figure 4-16. We need to add an ambiguity surface to keep cell `2` above the *y*-axis. Let surface `7` be an ambiguity surface that is a plane at `z=0`. This surface is defined in the MCNP6 input file like any other surface. Then cell `2` becomes `(-5 -4 3 7)` for the final result. You should convince yourself that the region above surface `7` intersected with the region defined by `-5 -4 3` is cell `2`. (Do not even think of surface `7` as an ambiguity surface but just another surface defining some region in space.) The mirror problem can also be avoided by defining cells `1` and `2` as right-circular-cylinder (`RCC`) macrobodies. The necessary cards for defining cells `1` and `2` as macrobodies could be, for example,

```
1  rcc   0 -2  0   0 4 0   4
2  rcc   0  0  0   0 0 7   1
```

In this case cells `1`, `2` and `3` would simply be `(-1)`, `(-2 1)`, and `(1 2 -6)` respectively. Notice that to get the interface between the cylinders correct, macrobody `2` extends into cell `1` and is then truncated by the definition of cell `1`.

Example 6:

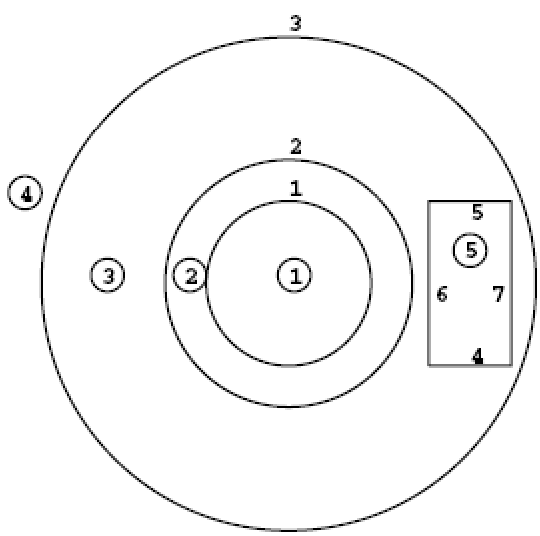


Figure 4-17. A box located within a concentric sphere.

Figure 4-17 contains three concentric spheres with a box cut out of cell `3`. Surface `8` is the front of the box and surface `9` is the back of the box. The cell cards are

```
1  0  −1
2  0  −2  1
```

```
3  0  -3  2 (-4:5:-6:7:8:-9) $ These parentheses are required.
4  0   3
5  0   4 -5  6 -7 -8  9
```

Cell 3 is everything inside surface 3 intersected with everything outside surface 2 but not in cell 5. Therefore, cell 3 could be written as

```
    3  0   -3  2  #(4 -5 6 -7 -8 9)
or  3  0   -3  2  #5
or  3  0   -3  2 (-4:5:-6:7:8:-9)
```

Cell 5 could also be specified using a RPP macrobody. The correct cell and surface cards for this would be

```
5  0   -4                          $ Cell card
4 rrp   2  4    7.5  8.5    -2  2  $ Surface card
```

Example 7:

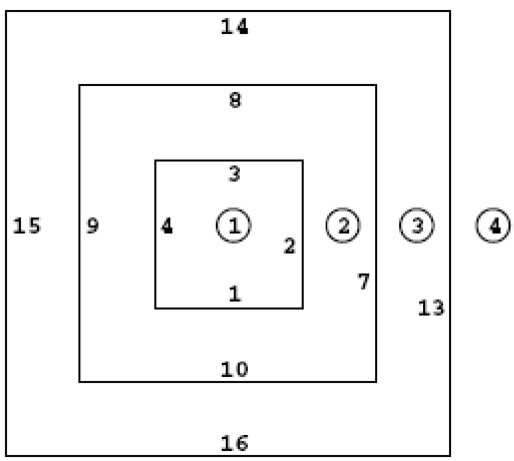


Figure 4-18. Concentric boxes.

Figure 4-18 contains three concentric boxes, a geometry that is very challenging to set up using only intersections, easier with unions, and almost trivial with the BOX macrobody. Surfaces 5, 11, and 17 are the back sides of the boxes (smaller to larger, respectively); 6, 12, and 18 are the fronts:

```
1  0   -2  -3   4   1   5  -6
2  0   -7  -8   9  10  11 -12
       (2 : 3 : -4 :  -1 :  -5 :  6)
3  0  -13 -14  15  16  17 -18
       (7 : 8 : -9 : -10 : -11 : 12)
4  0   13 : 14 : -15: -16 : -17: 18
```

Example 8:

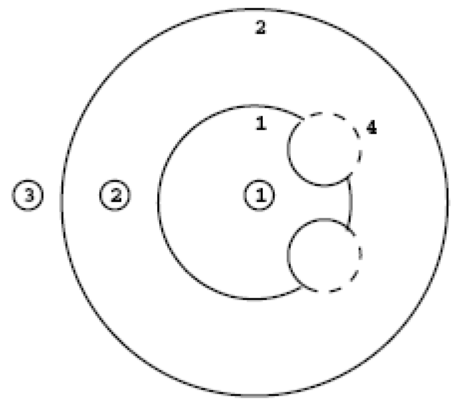


Figure 4-19. Torus attached to a concentric sphere.

Figure 4-19 contains two concentric spheres with a torus attached to cell 2 and cut out of cell 1:

```
1  0   -1  4
2  0   -2 (1 : -4)
3  0    2
```

If the torus were attached to cell 1 and cut out of cell 2, this bug-eyed geometry would be:

```
1  0   -1 : -4
2  0   -2  1  4
3  0    2
```

Example 9:

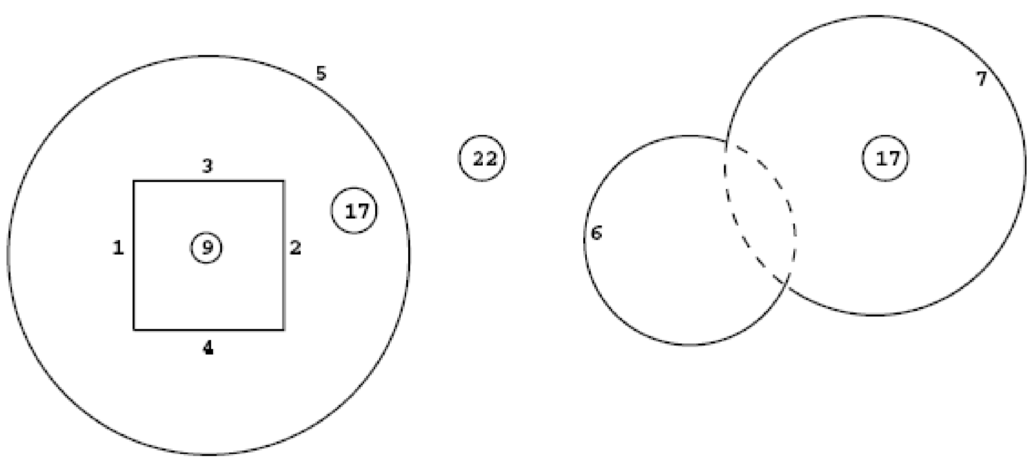


Figure 4-20. Disconnected cell.

Notice that cell 17 is disconnected, having two pieces. Cell 9 in Figure 4-20 is a box cut out of the left part of spherical cell 17; surface 9 is the front of the box and surface 8 is the rear. The right part of cell 17 is the space interior to spheres 6 and 7. An F4 tally in cell 17 would be the average flux in all parts of cell 17. An F2 surface tally on surface 7 would be the flux across only the solid portion of surface 7 in the figure. The cell specifications are:

```
9   0   −3 −2  4  1  8 −9
17  0   −5 (3 : −4 : −1 : 2 : 9 : −8) : −6 : −7
22  0    5  6  7
```

A variation on this problem is for the right portion of cell 17 to be the intersection of the interiors of surfaces 6 and 7 (the region bounded by the dashed lines in Figure 4-20):

```
9   0   −3 −2  4  1  8 −9
17  0   −5 (3 : −4 : −1 : 2 : 9 : −8) : −6 −7
22  0    5 (6 : 7)
```

Example 10:

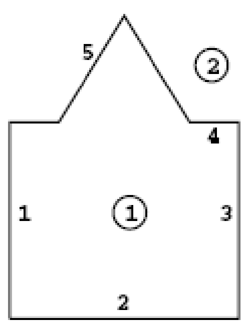


Figure 4-21. Box with an upside-down cone.

Figure 4-21 contains a box with a cone sitting on top of it. Surface 6 is the front of the box and 7 is the rear. You should understand this example before going on to the next one.

```
1  0   1  2 −3 (-4 : −5) −6  7
2  0  −1 : −2 : 3 : 4  5 : 6 : −7
```

This problem could be simplified by replacing surfaces 1–6 with a BOX macrobody. To specify individual macrobody surfaces, the resulting cell and surface definitions must use macrobody facet notation. Typical cell and surface cards would look like

```
c cell cards
1  0   -8:(-5 8.5)
2  0   #1          $ or -8.4:-8.6:8.3:(8.5 5):8.1:-8.2

c surface cards
5  kz     8  0.25  -1
8  box   -2.5 -2.5 0  5 0 0  0 5 0  0 0 5
```

Example 11:

Two views of this example appear in Figure 4-22. Surfaces 15 and 16 are cones, surface 17 is a sphere, and cell 2 is disconnected.

```
1  0    -1   2   3 (-4 : -16) 5 -6 (12 : 13 : -14)
        (10 : -9 : -11 : -7 : 8) 15
2  0   -10   9  11   7  -8  -1 : 2 -12 14 -6 -13 3
3  0   -17  (1 : -2 : -5 : 6 : -3 : -15 : 16 4)
4  0    17
```

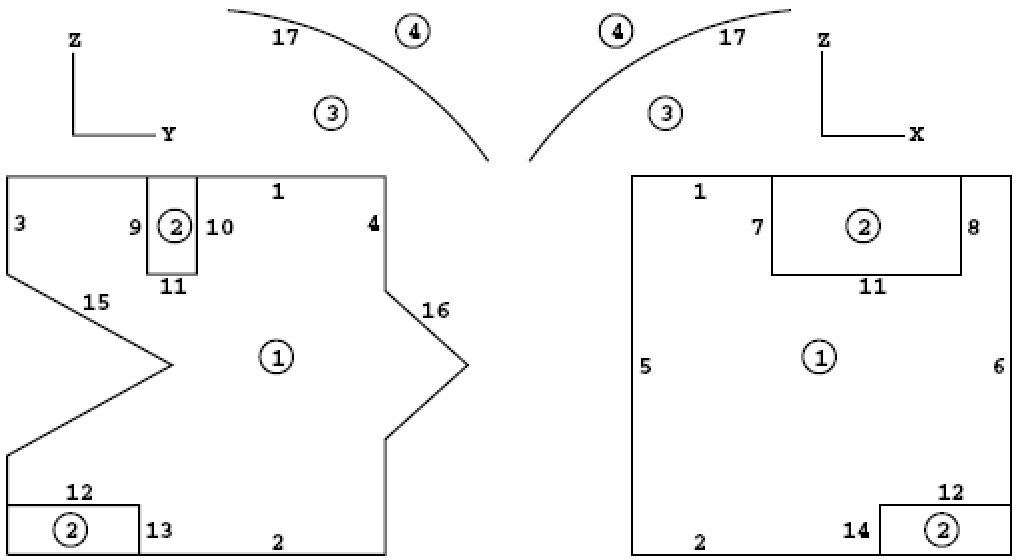


Figure 4-22. Views from two different perspectives of a complicated four-cell model.

Example 12:

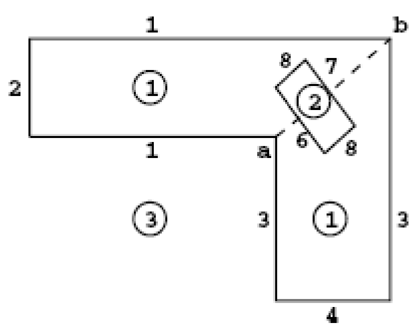


Figure 4-23. Two intersecting cylinders.

In Figure 4-23, cell `1` consists of two cylinders joined at a 45-degree angle. Cell `2` is a disk consisting of a cylinder (surface `8`) bounded by two planes. Surface `5` is a diagonal plane representing the intersection of the two cylinders. The problem is to specify the disk (cell `2`) in one cell formed by the two cylinders (cell `1`). A conflict arises in specifying cell `1` since, from the outside of cell `3`, corner *a* between surfaces `1` and 3 is convex, but on the other side of the cell the same two surfaces form a concave corner at *b*. The dilemma is solved by composing cell `1` of two disconnected cells, each bounded by surface `5` between corners *a* and *b*. Surface `5` must be included in the list of surface cards in the MCNP6 input file. When the two parts are joined to make cell `1`, surface `5` does not appear. Convince yourself by plotting it using an origin of `0 0 24` and basis vectors `0 1 1 0 -1 1`. See Section 5 for an explanation of plotting commands.

```
1  0  (2 −1 −5 (7:8:−6)):(4 −3 5(−6:8:7))
2  0   −8 6 −7
3  0  (−2:1:5) (−4:3:−5)
```

A more efficient expression for cell `1` is

```
1  0  (2 −1 −5:4 −3 5) (−6:8:7)
```

Example 13:

This example (Figure 4-24) has the most complicated geometry so far, but it can be described very simply.

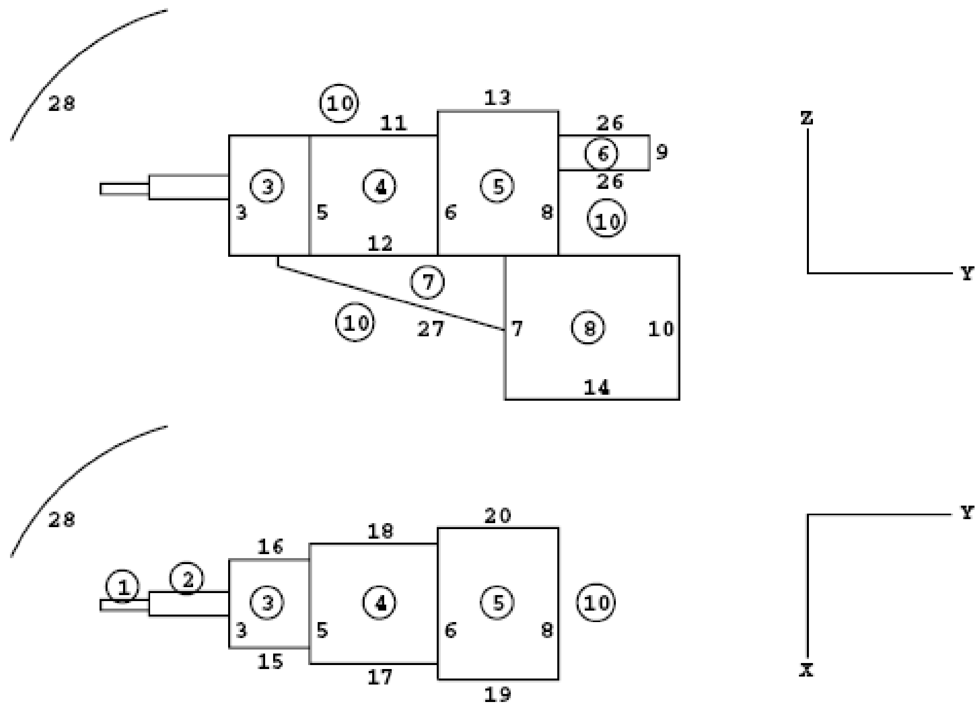


Figure 4-24. More complicated, yet straightforward to define.

You can see that Example 13 is similar to Example 1. There is just a lot more of it. It is possible to set this geometry up by any of the ways mentioned in Example 1. However, going around the outer surfaces of the cells inside cell 10 is tedious. There is a problem of visualization and also the problem of coming up with undefined tunnels going off to infinity as in Example 1.

The way to handle this geometry is by the last method in Example 1. Set up the cell/surface relations for each interior cell, then just take the complement for cell `10`. For the interior cells,

```
1   0    1  -2 -23
2   0   -3  25 -24   2
3   0    3  -5  12 -15  16 -11
4   0    5  -6  12 -17  18 -11
5   0    6  -8  12 -13 -19  20
6   0    8  -9 -26
7   0  -12   4  -7 -27
8   0  -12   7 -10  14 -21  22
9   0    2  -3 -25
```

Cell 10 is surrounded by the spherical surface 28. Considering cell 10 to be everything outside cells 1 through 9 but inside surface 28, one can reverse the senses and replace all intersections with unions to produce

```
10  0  (−1:2:23) (3:−25:24:−2)
       (−3:5:−12:15:−16:11)
       (−5:6:−12:17:−18:11)
       (−6:8:−12:13:19:−20)
       (−8:9:26) (12:−4:7:27)
       (12:−7:10:−14:21:−22)
       (−2:3:25) −28
```

Note how easy cell 10 becomes when the complement operator is used:

```
10  0  #1 #2 #3 #4 #5 #6 #7 #8 #9 −28
```

Once again this example can be greatly simplified by replacing all but cell 7 with macrobodies. However the definition of cell 7 must then be changed to use the facets of the surrounding macrobodies instead of surfaces 12 and 7. The facets of macrobodies can be visualized using the MBODY OFF option of the geometry plotter.

Example 14:

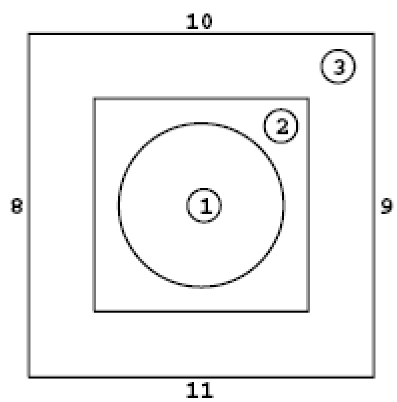


Figure 4-25

Figure 4-25 illustrates some necessary conditions for volume and area calculations. The geometry has three cells, an outer cube, an inner cube, and a sphere at the center. If cell 3 is described as

```
3  0   8 −9 −10 11 −12 13 #2 #1
```

(and #1 must be included to be correct), the volume of cell 3 cannot be calculated. As described, it is not bounded by all planes so it is not a polyhedron, nor is it rotationally symmetric. If cell 3 is described by listing all 12 bounding surfaces explicitly, the volume can be calculated.

4.1.2 Coordinate Transformations

In most problems, the surface transformation feature of the `TR` card will be used with the default setting, *m*=`1`. When *m*=`1` applies, most of the geometry can be set up easily in an (*x*,*y*,*z*) coordinate system and only a small part of the total geometry will be difficult to specify. For example, a box with sides parallel to the (*x*,*y*,*z*) coordinate system is simple to describe, but inside might be a tilted object consisting of a cylinder bounded by two planes. Since the axis of the cylinder is neither parallel to nor on the *x*-, *y*-, or *z*-axis, a general quadratic must be used to describe the surface of the cylinder. The `GQ` surface card has ten entries that are usually difficult to determine. On the other hand, it is simple to specify the entries for the surface card for a cylinder centered on the *y*-axis. Therefore, we define an auxiliary coordinate system (*x*′,*y*′,*z*′) so the axis of the cylinder is one of the primed axes, *y*′ for example. Now we will use the `TR` card to describe the relationship between one coordinate system and the other. The *m*=`1` specification on the `TR` card requires that the coordinates of a vector from the (*x*,*y*,*z*) origin to the (*x*′,*y*′,*z*′) origin be given in terms of (*x*,*y*,*z*).

Only in rare instances will *m*=`-1` be needed. Some unusual circumstances may require that a small item of the geometry be described in a certain system which we will call (*x*,*y*,*z*), and the remainder of the surfaces would be easily described in an auxiliary system (*x*′,*y*′,*z*′). The o_i displacement entries on the `TR` card are then the coordinates of a vector from the (*x*′,*y*′,*z*′) origin to the (*x*,*y*,*z*) origin given in terms of the primed system.

Example 15:

The following example consists of a can whose axis is in the *yz* plane but tilted 30° from the *y*-axis and whose center is at (0,10,15) in the (*x*,*y*,*z*) coordinate system. The can is bounded by two planes and a cylinder, as shown in Figure 4-26.

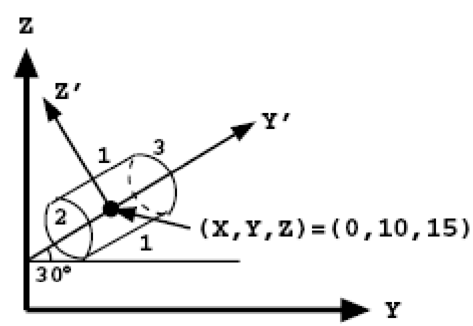


Figure 4-26. Tilted can in the yz plane showing the main and auxiliary coordinate systems.

The surface cards that describe the can in the simple (*x*′,*y*′,*z*′) system are the following:

```
1  1  CY    4
2  1  PY   −7
3  1  PY    7
```

The 1 before the surface mnemonics on the cards is the *n* that identifies to which TR*n* card these surface cards are associated. The TR*n* card indicates the relationship of the primed coordinate system to the basic coordinate system.

We will specify the origin vector as the location of the origin of the (x',y',z') coordinate system with respect to the (x,y,z) system; therefore, *m*=1. Since we wanted the center of the cylinder at (0,10,15), the o_i entries are simply 0 10 15. If, however, we had wanted surface 2 to be located at (x,y,z)=(0,10,15), a different set of surface cards would accomplish it. If surface 2 were at y'=0 and surface 3 at y'=14 the o_i entries would remain the same. The significant fact to remember about the origin vector entries is that they describe one *origin* with respect to the other *origin*. The user must locate the surfaces about the auxiliary origin so that they will be properly located in the main coordinate system.

The rotation matrix entries on the TR*n* card are the cosines of the angles between the axes as listed Section 3.3.1.3. In this example, the *x*-axis is parallel to the x'-axis. Therefore, the cosine of the angle between them is 1. The angle between *y* and x' is 90° with a cosine of 0. The angle between *z* and x', and also between *x* and y', is 90° with a cosine of 0. The angle between *y* and y' is 30° with a cosine of 0.866. The angle between *z* and y' is 60° with 0.5 the cosine. Similarly, 90° is between *x* and z'; 120° is between *y* and z'; and 30° is between *z* and z'. The complete TR*n* card is

```
TR1   0 10 15  1 0 0  0 0.866 0.5  0 −0.5 0.866
```

An asterisk preceding TR*n* indicates that the rotation matrix entries are the angles given in degrees between the appropriate axes. The entries using the *TR*n* mnemonic become

```
∗TR1   0 10 15  0 90 90  90 30 60  90 120 30
```

The default value of 1 for *m*, the thirteenth entry, has been used and is not explicitly specified.

The user need not enter values for all of the rotation matrix entries. As shown in Section 3.3.1.3, the rotation matrix may be specified in any of five patterns. Pattern #1 was used above, but the simplest form for this example is pattern #4 because all the skew surfaces are surfaces of revolution about some axis. The complete input card then becomes

```
∗TR1   0 10 15  3J  90 30 60
```

Example 16:

The following example illustrates another use of the TR*n* card. The first part of the example uses the TR1 card and an *m*=1 transformation; the second part uses the TR2 card and *m*=-1. Both parts and transformations are used in the following input file.

```
EXAMPLE OF SURFACE TRANSFORMATIONS
2  0   -4   3  -5
6  0  -14 -13 : -15 41 -42

3   1  PX   -14
4   1  X    -14 10 0 12 14 10
5   1  PX    14
13  2  SX   -15 70
14  2  CX    30
15  2  Y      75 0 30 16
41  2  PY      0
42  2  PY     75

TR1      20   31  37  0.223954  0.358401  0.906308
TR2    -250 -100 -65  0.675849  0.669131  0.309017
        J J 0.918650     J J  -0.246152    -1
imp:n    1  1
SDEF
PRINT
NPS      50
```

Case 1: `TR1` and *m*=1

Cell `2` is bounded by the plane surfaces `3` and `5` and the spheroid surface `4`, which is a surface of revolution about the skew axis x' in Figure 4-27.

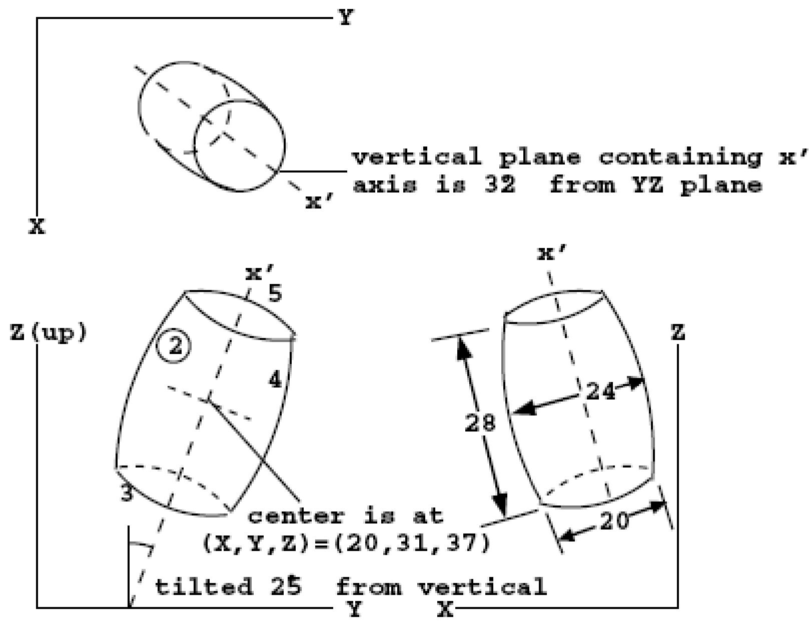


Figure 4-27. A tilted barrel as seen from three views.

To get the coefficients of surfaces 3, 4, and 5, define the *x′*-axis as shown in the drawings. (Because the surfaces are surfaces of revolution about the *x′*-axis, the orientation of the *y′*- and *z′*-axes does not matter.) Then set up cell 2 and its surfaces with coefficients defined in the *x′y′z′* coordinate system.

On the TR1 card, the origin vector is the location of the origin of the *x′y′z′* coordinate system with respect to the main *xyz* system of the problem. The pattern #4 in Section 3.3.1.3 is appropriate since the surfaces are all surfaces of revolution about the *x′*-axis. The components of one vector of the transformation matrix are the cosines of the angles between *x′* and the *x*-, *y*-, and *z*-axes. They are obtained from spherical trigonometry as shown in Figure 4-28.

cos E = cos 58° × sin 25° = 0.223954
cos F = cos 32° × sin 25° = 0.358401
cos G = cos 25° = 0.906308

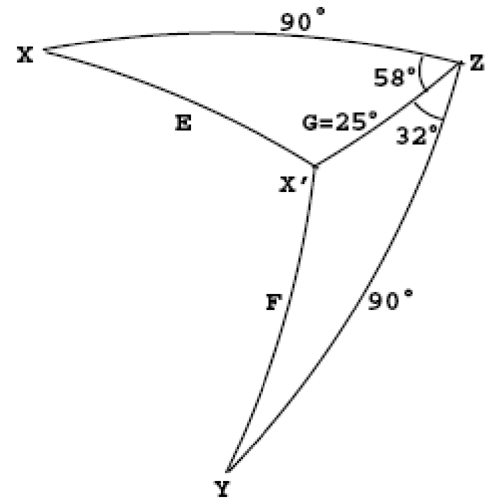


Figure 4-28. Angles between the *x′*-axis and the main *xyz* coordinate system of Case 1.

Case 2: TR2 and *m*=-1

Cell 6 is the union of a can bounded by spherical surface 13 and cylindrical surface 14, and a conical piece bounded by conical surface 15 and ambiguity surfaces 41 and 42, which are planes. (Surface 42 is required because when surface 15 is defined in *x′y′z′* it is as a type Y surface, which becomes a cone of one sheet; when it is transformed into the *xyz* system it becomes a type GQ surface, which in this case is a cone of two sheets. This may seem weird, but that is the way it has to be.) Surfaces 13 and 14 are surfaces of revolution about one axis, and surfaces 15, 41, and 42 are surfaces of revolution about an axis perpendicular to the first axis. Both axes are skewed with respect to the *xyz* coordinate system of the rest of the geometry.

Define the auxiliary *x′y′z′* coordinate system as shown in Figure 4-29. Set up cell 6 with its surfaces specified in the *x′y′z′* coordinate system as part of the input file and add a second transformation card, TR2.

Because the location of the origin of the *xyz* coordinate system is known relative to the *x′y′z′* system (rather than the other way around, as in Case 1), it is necessary to use the reverse mapping. This is indicated by setting *m*=-1. In this reverse mapping the origin vector (-250,-100,-65) is the location of the origin of the *xyz* system with respect to the *x′y′z′* system. For the components of the transformation matrix, pattern #3 out of the four possible choices from Section 3.3.1.3 is most convenient here. The *xyz* components of *z′* and the *x′y′z′* components of *z* are easy to get, while the components of *x* and of *y* are not. The whole transformation matrix is shown here with the components that are obtained from Figure 4-29 written in:

	x	y	z
x'	0.675849	cos 48°=0.669131	cos 72°=0.309017
y'			cos 15° × cos 18°=0.918650
z'			-0.246152

The zz' component is $-$SQRT(1.0$-$0.309107^2$-$0.918650^2)=$-$0.246152, and the xx' component is SQRT(1.0$-$0.669131^2$-$0.309017^2)=0.675849, with the signs determined by inspection of the figure.

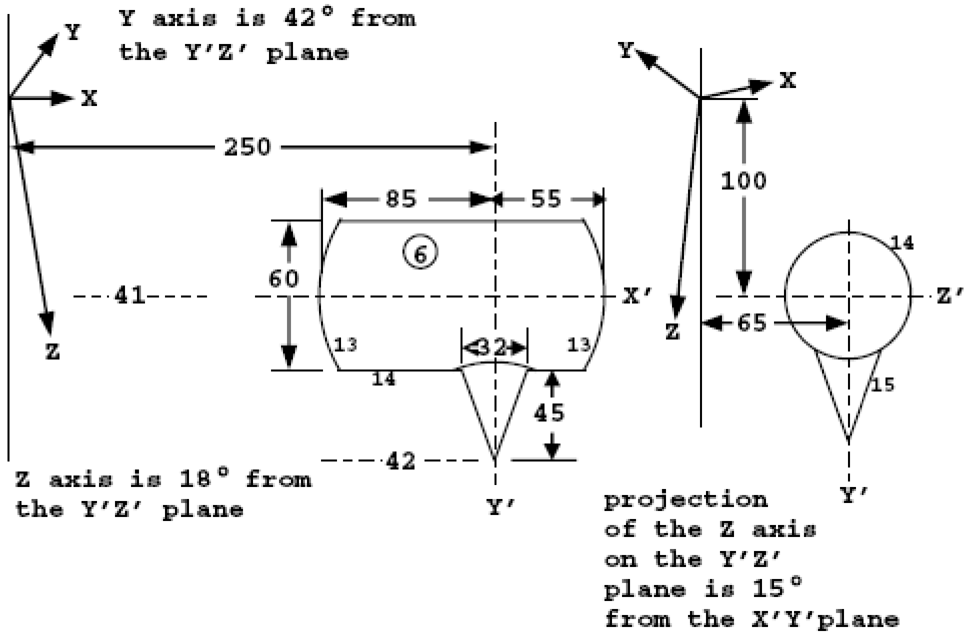


Figure 4-29. Case 2 geometry.

4.1.3 Repeated Structure and Lattice Examples

Example 17:

This example illustrates the use of transformations with simple repeated structures. The geometry consists of a sphere enclosing two boxes that each contains a cylindrical can.

```
simple repeated structures
1  0  -27  #2  #5                          imp:n=1
2  0    1  -2  -3   4  -5   6  fill=1 imp:n=1
3  0  -10 -11  12              u=1    imp:n=1
4  0   #3                      u=1    imp:n=1
```

```
5  like 2 but trcl=3
7  0   27                              imp:n=0

1  px   -3
2  px    3
3  py    3
4  py   -3
5  pz    4.7
6  pz   -4.7
10 cz    1
11 pz    4.5
12 pz   -4.5
27 s     3.5  3.5  0 11

sdef   pos 3.5 3.5 0
f2:n   1
tr3*   7 7 0  40 130 90  50 40 90  90 90 0
nps    10000
```

The geometric structure of this example can be displayed using the plot feature in MCNP6. Specifically, Figure 4-30 can be obtained by launching the plotter:

```
mcnp6 ip i=<input file name>
```

clicking the lower left hand corner of the plot window (“click here or picture or window”) and entering the following three settings:

```
b 1 0 0 0 1 0

ex 11

or 3.5 3.5 0
```

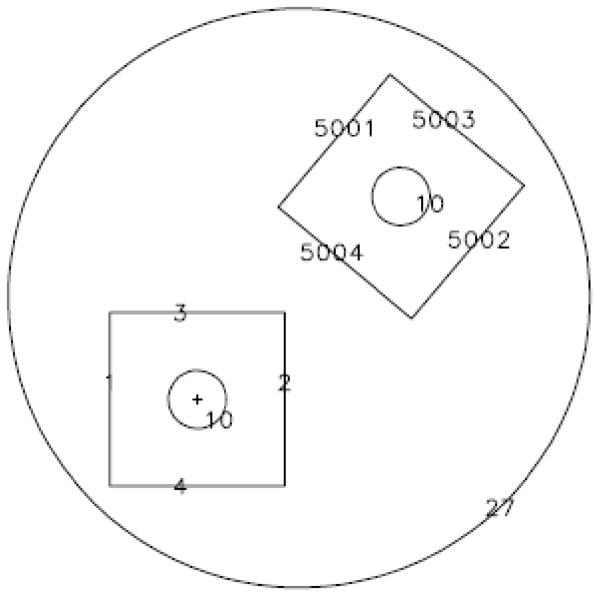


Figure 4-30. Geometry of Example 1: a sphere enclosing two boxes that each contains a cylindrical can.

Cell 2 is filled by universe 1. Two cells are in universe 1—the cylindrical can, cell 3, and the space outside the can, cell 4. Cell 2 is defined and the LIKE *n* BUT card duplicates the structure at another location. The TRCL entry identifies a TR card that defines the displacement and rotational axis transformation for cell 5.

Example 18:

This example illustrates the LIKE *n* BUT construct, the FILL card, the U card, two forms of the TRCL card, and a multiple source cell definition.

```
lattice example 18
1   1 -0.5   -7  #2 #3 #4 #5 #6 imp:n=1
2   0         1 -2 -3 4 5 -6    imp:n=2 trcl=2 fill=1
3   like 2 but trcl=3
4   like 2 but trcl=4
5   like 2 but trcl=5 imp:n=1
6   like 2 but trcl=6
7   0         7           imp:n=0
8   0         8 -9 -10 11 imp:n=1 trcl=(-.9 .9 0) fill=2 u=1
9   like 8 but trcl=(.9 .9 0)
10  like 8 but trcl=(.1 -.9 0)
11  2 -18    #8 #9 #10 imp:n=1 u=1
```

```
12  2 -18   -12 imp:n=1 trcl=(-.3 .3 0) u=2
13  like 12 but trcl=( .3  .3 0)
14  like 12 but trcl=( .3 -.3 0)
15  like 12 but trcl=(-.3 -.3 0)
16  1 -0.5  #12 #13 #14 #15 u=2 imp:n=1

1  px   -2
2  py    2
3  px    2
4  py   -2
5  pz   -2
6  pz    2
7  so   15
8  px   -0.7
9  py    0.7
10 px    0.7
11 py   -0.7
12 cz    0.1

sdef  erg=d1 cel=d2:d3:0 rad=d5 ext=d6 axs=0 0 1 pos=d7
#      si1       sp1      sb1
        1        0        0
        3        0.22     0.05
        4        0.08     0.05
        5        0.25     0.1
        6        0.18     0.1
        7        0.07     0.2
        8        0.1      0.2
        9        0.05     0.1
       11        0.05     0.2
si2  L  2 3 4 5 6
sp2     1 1 1 1 1
si3  L  8  9 10
sp3     1  1  1
si5    0 0.1
sp5   -21  1
si6    -2  2
sp6     0  1
si7 L  0.3 0.3 0  0.3 -0.3 0  -0.3 0.3 0  -0.3 -0.3 0
sp7    1          1            1           1
m1     6000  1
m2    92235  1
drxs
tr2    -6  7  1.2
tr3     7  6  1.1
tr4     8 -5  1.4
```

```
tr5*    -1 -4  1    40 130 90  50 40 90  90 90 0
tr6     -9 -2  1.3
f4:n     2 3 4 5 6 12 13 14 15
e4       1 3 5 7 9 11 13
sd4      5j  1.8849555921  3r
fq       f e
cut:n    1e20  0.1
nps      100000
print
```

Cell 2 could be replaced with an RPP macrobody that can then be replicated and translated identically to cell 2 above.

Figure 4-31 can be displayed by typing:

```
b 1 0 0 0 1 0

ex 21

la 0
```

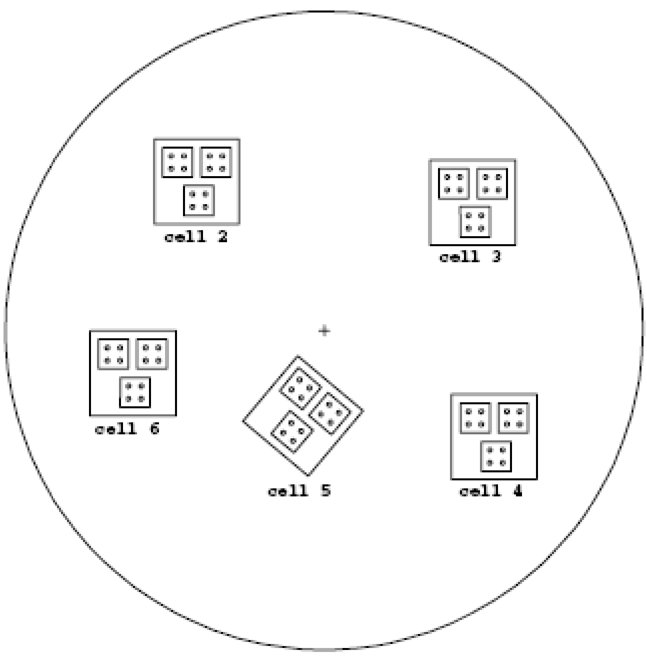


Figure 4-31. Repeated structures located at different positions and orientations.

Figure 4-31 shows five cells, numbers 2 through 6, identical except for their locations. Cell 2 is described fully and the other four are declared to be like cell 2 but in different locations. Cell 2 is defined in an auxiliary coordinate system that is centered in the cell for convenience. That coordinate system is related to the main coordinate system of the problem by transformation number 2, as declared by the TRCL=2 entry and the TR2 card. Cells 2 through 6 are all filled with universe number 1. Because no transformation is indicated for that filling, universe 1 inherits the transformation of each cell that it fills, thereby establishing its origin in the center of each of those five cells.

As shown in Figure 4-32, universe 1 contains three infinitely long square tubes embedded in cell 11, which is unbounded. All four of these infinitely large cells are truncated by the bounding surfaces of each cell that is filled by universe 1, thus making them effectively finite. To illustrate the two possible ways of performing transformations, the transformations that define the locations of cells 8, 9 and 10 are entered directly on the cell cards after the TRCL symbol rather than indirectly through TR cards as was done for cells 2 through 6. Cells 8, 9 and 10 are each filled with universe 2, which consists of five infinite cells truncated by the boundaries of higher level cells. The simplicity and lack of repetition in this example were achieved by careful choice of the auxiliary coordinate systems at all levels. All of the location information is contained in just a few TRCL entries, some direct and some pointing to a few TR cards.

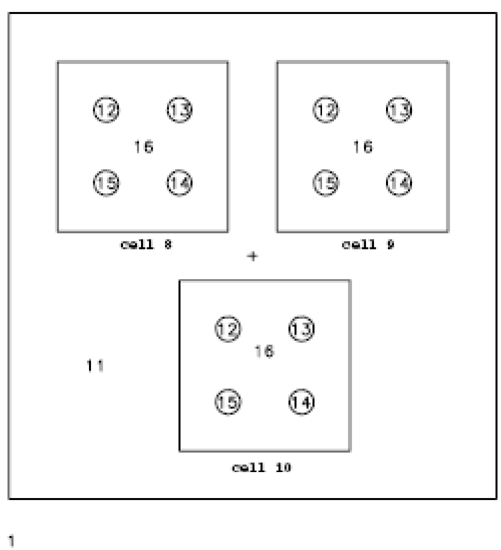


Figure 4-32. Close up of the repeated structure defined by universe 1.

The source definition is given on the SDEF, SI*n*, and SP*n* cards. The source desired is a cylindrical volume distribution, equally probable in all the cylindrical rods. The energies are given by distribution 1. The entry for CEL shows that level 0 cells are given by distribution 2 and level 1 cells by distribution 3. The zero means that cells are searched for at level 2 and also that the sampled position and direction will apply to the universe indicated by the entry just preceding the first entry that is ≤0. In this case the position and direction will be defined in the coordinate system of the cell sampled by distribution 3 at level 1. The SI2 card lists all the cells at level 0 that will contain the source. The SP2 entries indicate equally probable source distributions. The values in SI3 are the cells in level 1, and the positions on the SI7 card are given in the coordinates of this level. A cylindrical volume distribution is specified by RAD, EXT, AXS, and POS. The cylinder is centered about the origin, with a radius of 0.1 (SI5) and a length of 4 (SI6, from -2 to 2). The four sets of entries on the SI7 card are the origins of the four cylinders of cells 12–15. These parameters describe exactly the four cells 12–15.

Example 19:

This simple example illustrates the use of the FILL, U, and LAT cards to create an object within several cells of a lattice. A cylinder contains a square lattice and the cells in the inner 3×3 array of that lattice each contain a small cylinder.

```
simple lattice
1   0    -1  fill=1 imp:n=1
2   0  -301  302 -303  304 lat=1 u=1 imp:n=1
        fill -2:2 -2:2 0:0
        1 1 1 1 1 1 2 2 2 1 1 2 2 2 1 1 2 2 2 1 1 1 1 1 1
3   0   -10  u=2 imp:n=1
4   0    #3  u=2 imp:n=1
5   0     1      imp:n=0

1   cz   45
10  cz    8
301 px   10
302 px  -10
303 py   10
304 py  -10

sdef
mode n
nps 5000
```

The resulting geometry is shown in Figure 4-33. Cell 1 is the interior of the cylinder, and cell 5 is everything outside (all surfaces are infinite in the *z* direction). Cell 1 is filled by universe 1. Cell 2 is defined to be in universe 1. Surfaces 301–304 define the dimensions of the square lattice:

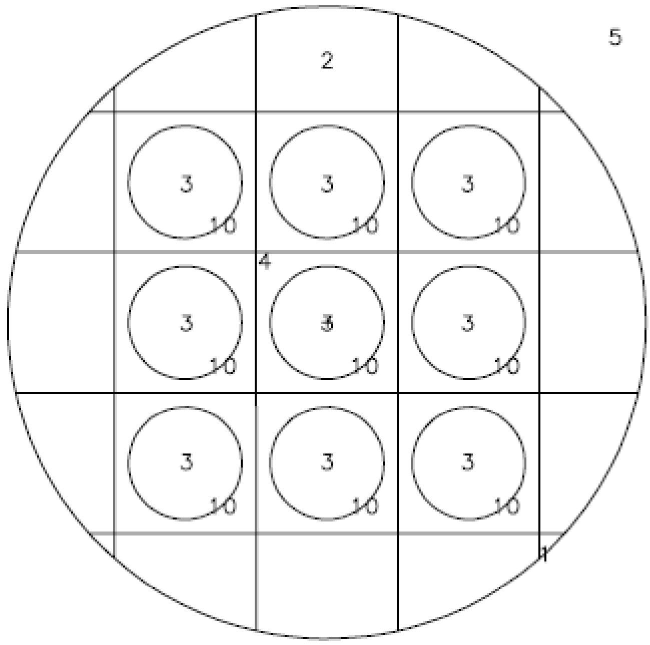


Figure 4-33. The simple lattice defined by Example 3.

When filling the cells of a lattice, all visible cells, even those only partially visible, must be specified by the `FILL` card. In this case, the "window" created by the cylinder reveals portions of 25 cells (5×5 array). A `FILL` card with indices of `-2` to `2` in the *x*- and *y* directions will place the [0,0,0] element at the center of the array. Universe `2`, described by cells `3` and `4`, is the interior and exterior, respectively, of an infinite cylinder of radius 8 cm. The cells in universe `1` not filled by universe `2` are filled by universe `1`, so in effect they are filled by themselves.

Example 20:

This example illustrates a lattice geometry and uses the `FILL` entries followed by transformations, universes, and lattices.

```
Chapter 4 Lattice example 20
1  1 -0.6   -1                                                  imp:n=1
c 2  0         1  2 -4                                          imp:n=1
2  0         1 -2 -4  fill=1 (-6 -6.5 0)                        imp:n=1
3  0         2 -3 -4 *fill=2 (-7 5 0 30  60 90 120 30 90) imp:n=1
4  0         2  3 -4 *fill=2 ( 4 8 0 15 105 90  75 15 90) imp:n=1
5  0         4                                                  imp:n=0
6  0        -5   6  -7   8  -9  10 fill=3 u=1 lat=1       imp:n=1
7  0       -11  12 -13  14 -15  16 fill=5 u=2 lat=1       imp:n=1
```

```
18 3 -2.7  -18                          u=5             imp:n=1
8  2 -0.8  -17  u=3                                     imp:n=1
9  0        17  u=3                                     imp:n=1
10 0       -18  u=4                                     imp:n=1

1  sy  -5 3
2  py   0
3  px   0
4  so  15
5  px   1.5
6  px  -1.5
7  py   1
8  py  -1
9  pz   3
10 pz  -3
11 p    1 -0.5 0  1.3
12 p    1 -0.5 0 -1.3
13 py   0.5
14 py  -0.5
15 pz   3
16 pz  -3
17 sq   1  2  0  0  0  0  -1  0.2  0  0
18 so  10

sdef   pos 0 -5 0  erg d1  rad d2
si1    0 10
sp1    0  1
si2    3
sp2   -21
e0     1 2 3 4 5 6 7 8 9 10 11 12
f2:n   3
sd2    1
f4:n   8 9
sd4    1 1
m1      4009  1
m2      6000  1
m3     13027  1
nps    100000
print
dbcn     0 0 1 4
```

The geometry for this example is shown in Figure 4-34.

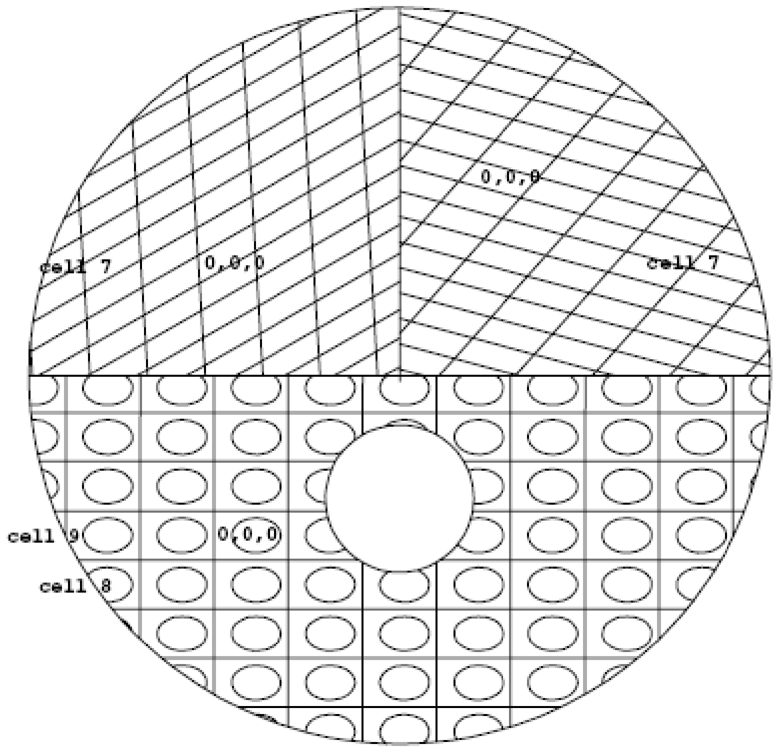


Figure 4-34. Lattices with universes and coordinate transformation.

Cell 2 is the bottom half of the large sphere outside the small sphere (cell 1) and is filled by universe 1. The transformation between the filled cell and the filling universe immediately follows in parentheses.

Cell 6 describes a hexahedral lattice cell (LAT=1) and, by the order of specification of its surfaces, also describes the order of the lattice elements. The (0,0,0) element has its center at (-6,-6.5,0), according to the transformation information on the card for cell 2. Element (1,0,0) is beyond surface 5, element (–1,0,0) is beyond surface 6, element (0,1,0) is beyond surface 7, etc. Cell 6 is filled by universe 3, which consists of two cells: cell 8 inside the ellipsoid and cell 9 outside it.

Alternatively, cell 6 could have been defined using a macrobody, either RPP or BOX. When a lattice cell is defined with a macrobody, some of the lattice-element indexing is predetermined. For example, the first, third and fifth facets are used to define the direction of increasing indices. For the RPP, the second index increases in the positive *y* direction and the third index increases in the positive *z* direction. For the BOX, the order of defining the three vectors will determine the axis each index will increase in a positive direction.

Cell 3 is the top left-hand quarter of the sphere; cell 4 is the top right-hand quarter. Both are filled by universe 2. Both FILL entries are followed by a transformation. The inter-origin vector portion of the transformation is between the origin of the filled cell and the origin of the filling universe, with the universe considered to be in the auxiliary coordinate system. The (0,0,0) lattice element is located around the auxiliary origin and the lattice elements are identified by the ordering of the surfaces describing cell 7. The skewed appearance is caused by the rotation part of the transformation.

The source is centered at (0,–5,0) (i.e., at the center of cell 1). It is a volumetric source filling cell 1, and the probability of a particle being emitted at a given radius is given by the power law function. For RAD the exponent defaults to 2, so the probability increases as the square of the radius, resulting in a uniform volumetric distribution.

Example 21:

This example illustrates a more complicated lattice geometry and uses the FILL card followed by the array specification. It builds on the expertise from Example 20.

```
Lattice Example 21
1  1 -0.6   -5 imp:n=1
2  0        -1  2 -3  4  5 -22 23 imp:n=1 fill=1
3  0         1:-2: 3:-4:22:-23    imp:n=0
4  2 -0.8   -6  7 -8  9           imp:n=1 lat=1 u=1
            fill=-2:2 -4:4 0:0 1 1 1 1 1 1 1 1 2(3) 1 1 3 1 1 1
                  1 2 3 2 1 1 1 1 1 1 1 4(2) 2 1 1 1 1 3 4(1) 1
                  1 2 3 1 1 1 1 1 1 1
5  3 -0.5  -11  10  12     imp:n=1 u=2
6  4 -0.4   11:-10:-12     imp:n=1 u=2
7  0       -13             imp:n=1 u=3 fill=5
8  3 -0.5   13             imp:n=1 u=3
9  0       -14  15 -16  17 imp:n=1 u=5 lat=1 fill=6
10 4 -0.4  -24             imp:n=1 u=6
11 3 -0.5  -18  19 -20  21 imp:n=1 u=4
12 4 -0.4   18:-19: 20:-21 imp:n=1 u=4

1  px    15
2  px   -15
3  py    15
4  py   -15
5  s      7 2.1 0  3.5
6  px     4
7  px    -5
8  py     2
9  py    -2
10 p      0.7 -0.7  0  -2.5
11 p      0.6  0.8  0   0.5
```

```
12 py    -1
13 x     -4.5 0 -0.5 1.7 3.5 0
14 px     1.6
15 px    -1.4
16 py     1
17 py    -1.2
18 px     3
19 px    -3
20 py     0.5
21 py    -0.6
22 pz     6
23 pz    -7
24 so    10

sdef   erg d1  pos 7 2 0  cel=1  rad d2
si2    3.6
si1    0 10
sp1    0  1
f4:n   10
e4     1 3 5 7 9 11
m1      4009  1
m2      6000  1
m3     13027  1
m4      1001  2   8016  1
nps    100000
dbcn   0 0 1 4
*tr1   0 0 0  10 80 90  100 10 90
*tr2   1 0 0   2 88 90   92  2 90
tr3    3 0 0
vol    1 11r
print
```

This example has three "main" cells: cell 1 is inside surface 5, cell 3 is the outside world, and cell 2 is the large square (excluding cell 1) that is filled with a lattice, some of whose elements are filled with three different universes. A schematic of the geometry is given in Figure 4-35.

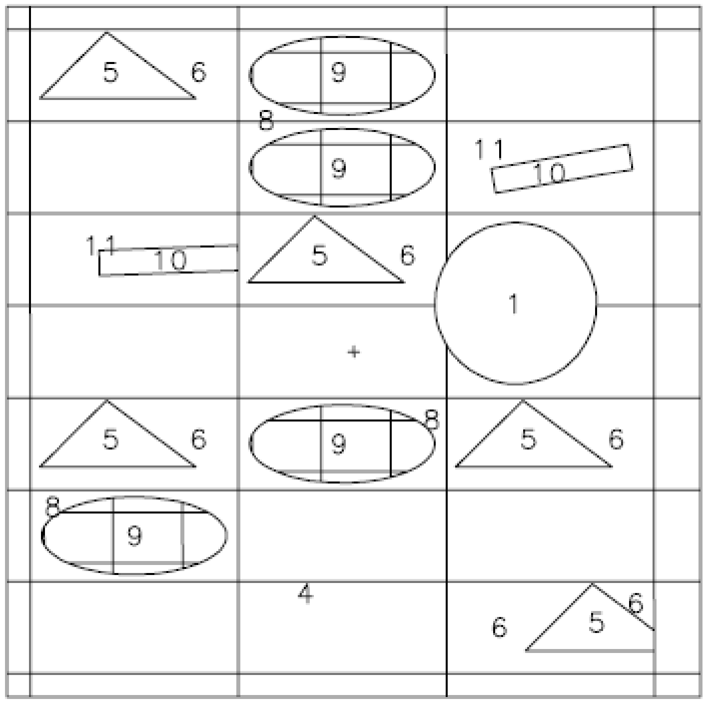


Figure 4-35.

Universe 1 is a hexahedral lattice cell infinite in the *z* direction. Based on the FILL parameters, it can be seen that the lattice has five elements in the first direction numbered from -2 to 2, nine elements in the second direction numbered from -4 to 4, and one element in the third direction. The remaining entries on the card are the array that identifies which universe is in each element, starting in the lower left-hand corner with (-2,-4,0), (-1,-4,0), (0,-4,0), etc. An array entry (in this case 1) that is the same as the number of the universe of the lattice itself means that element is filled by the material specified for the lattice cell. Element (1,-3,0) is filled by universe 2, which is located within the element in accordance with the transformation defined on the TR3 card. Element (-1,-2,0) is filled by universe 3. Cell 7, part of universe 3, is filled by universe 5, which is also a lattice. Note the use of the X parameter to describe surface 13. The quadratic surface, which is symmetric about the *x*-axis, is defined by specifying three coordinate pairs on the surface.

The source is a volumetric source of radius 3.6 cm which is centered in and completely surrounds cell 1. The CEL keyword causes a cell rejection technique to be used to sample uniformly throughout the cell. That is, the source is sampled uniformly in volume and any points outside cell 1 are rejected. The same effect is achieved by using cookie-cutter rejection. The PRINT card results in a full output print, and the VOL card sets the volumes of all the cells to unity.

Example 22:

This example primarily illustrates a fairly complex source description in a lattice geometry. The geometry consists of two "main" cells, each filled with a different lattice.

```
Lattice Example 22
1  0        1:-3:-4:5:6:-7    imp:n=0
2  0       -2  3   4 -5 -6  7 imp:n=1 fill=1 (-25 0 0)
3  0       -1  2   4 -5 -6  7 imp:n=1 fill=2 (0 -20 0)
4  0      -11 12 -14 13 imp:n=1 lat=1 u=1 fill=-1:1 -1:1 0:0 3 8r
5  3 -1.0 -15  2 -18 17       imp:n=1 lat=1 u=2
           fill=0:1 0:3 0:0  4 4 4(5 0 0) 4 0 5 4 4
6  1 -0.9  21:-22:-23:24      imp:n=1 u=3
7  1 -0.9  19                 imp:n=1 u=4
8  2 -18  -21 22 23 -24       imp:n=1 u=3
9  1 -0.9  20(31:-32:-33:34)  imp:n=1 u=5
11 2 -18  -19                 imp:n=1 u=4
13 2 -18  -20                 imp:n=1 u=5
15 2 -18  -31 32 33 -34       imp:n=1 u=5

1  px   50
2  px    0
3  px  -50
4  py  -20
5  py   20
6  pz   60
7  pz  -60
11 px     8.334
12 px    -8.334
13 py    -6.67
14 py     6.67
15 px    25
17 py     0
18 py    10
19 c/z   10  5  3
20 c/z   10  5  3
21 px     4
22 px    -4
23 py    -3
24 py     3
31 px    20
32 px    16
33 py     3
34 py     6

m1    6000 0.4    8016 0.2   11023 0.2   29000 0.2
m2   92238 0.98  92235 0.02
```

```
m3    1001  1
sdef  erg fcel d1   x   fcel d11  y   fcel d13  z   fcel d15  cel d6
      rad fcel d17  ext fcel d19  pos fcel d21  axs fcel d23
ds1     s  d2 d3 d4 d5
sp2        -2  1.2
sp3        -2  1.3
sp4        -2  1.4
sp5        -2  1.42
si6     s  d7    d8   d9   d10
sp6        0.65  0.2  0.1  0.05
si7        l 2:4:8
sp7        1
si8     l  3:5(0 0 0):11  3:5(1 0 0):11  3:5(0 1 0):11  3:5(1 1 0):11
           3:5(0 2 0):11  3:5(0 3 0):11  3:5(1 3 0):11
sp8        1 1 1 1 1 1 1
si9     l  3:5(1 2 0):13
sp9        1
si10    l  3:5(1 2 0):15
sp10       1
ds11    s  d12 0 0 d25
si12       -4  4
sp12        0  1
ds13    s  d14 0 0 d26
si14       -3  3
sp14        0  1
ds15    s  d16 0 0 d16
si16      -60  60
sp16        0   1
ds17    s   0 d18 d18 0
si18        0  3
sp18      -21  1
ds19    s   0 d20 d20 0
si20      -60  60
sp20        0   1
ds21    s   0 d22 d22 0
si22        l 10 5 0
sp22        1
ds23    s   0 d24 d24 0
si24        l 0 0 1
sp24        1
si25        16  20
sp25        0   1
si26        3   6
sp26        0   1
f2:n        1
e2          0.1 1 20
```

```
f6:n        2 4 6 8 3 5 7 9 11 13 15
sd6         1 1 1 1 1 1 1 1  1  1  1
print
nps      5000
```

The geometry for this example is shown in Figure 4-36.

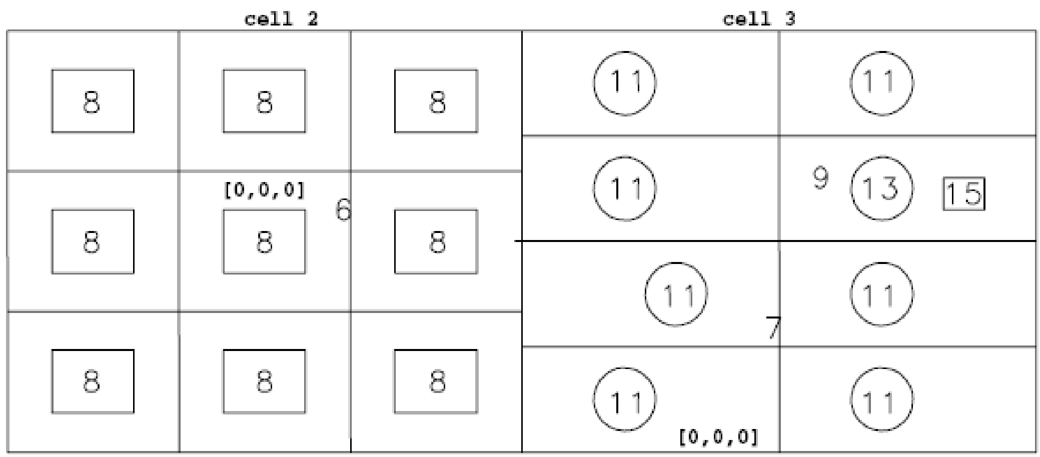


Figure 4-36

Cell 2, the left half of Figure 4-36, is filled with a hexahedral lattice, which is in turn filled with a universe consisting of a rectangular cell and a surrounding cell. The relationship of the origin of the filling universe, universe 1, to the filled cell, cell 2, is given by the transformation in parentheses following `FILL=1`. The right half of Figure 4-36, Cell 3, is filled with a different hexahedral lattice, which in turn is filled by universes 4 and 5. Lattice cells must be completely specified by an expanded `FILL` card if the lattice contains a source (cell 5) or by selecting a coordinate system of a higher level universe (`SI7  1 –2:4:8`). Print table 110 lists the lattice elements that are being sampled.

The reader is cautioned to become familiar with the geometry before continuing with the source description that follows. In this example, a distributed volumetric source located in each of the ten boxes and eight circles (in two dimensions) is desired. The cells involved are given by distribution 6. The `S` on the `SI6` card indicates distribution numbers will follow. The four distributions will describe the cells further. The probabilities for choosing each distribution of cells are given by the `SP6` card.

The `SI7` card shows the entire path from level 0 to level *n* for the nine boxes on the left. The expanded `FILL` notation is used on the cell 4 card to describe which elements of the lattice exist and which universe fills each one. All nine are filled by universe 3. The source information card `SI12` indicates that *x* is sampled from `-4` to `4`; similarly, `SI14` indicates that *y* is sampled from `-3` to `3`. Used together with the expanded `FILL` notation, source points will be sampled from all nine lattice elements. Without the expanded `FILL` notation, only the [0,0,0] element would have source points.

Alternatively, one could use the following input cards:

```
4 0 -11 12 –14 13 imp:n=1 lat=1 u=1 fill=3
si7 l –2:4:8
si12 –46 –4
si14 –17 17
```

The minus sign in front of the second entry on the `SI7` card means that the sampled position and direction will be in the coordinate system of the level preceding that entry. In this case, however, there is no preceding entry, so the position and direction will be in the coordinate system of cell `2`. If a point is chosen that is not is cell `8`, it is rejected and the variable is resampled.

The `SI8` card describes a path from cell `3` through element (0,0,0) of cell `5` to cell `11`, from cell `3` through element (1,0,0) of cell `5` to cell `11`, and so on. Element (1,2,0) is skipped over and will be treated differently. The `SI9` entries provide the path to cell `13`, the circle in element (1,2,0), while `SI10` provides the path to cell `15`, the box in element (1,2,0). All the other source variables are given as a function of the cell and follow explanations given in Section 3.3.4.

Example 23:

This example illustrates a hexagonal prism lattice and shows how the order of specification of the surfaces on a cell card identifies the lattice elements beyond each surface.

```
hexagonal prism lattice
1  0     -11  -19   29              fill=1          imp:n=1
2  0     -10                                    u=3 imp:n=1
3  0   -301  302 -303  305 -304  306 fill=3 lat=2 u=1 imp:n=1
4  0      11:19:-29                                 imp:n=0

11  cz   20
10  so   40
19  pz   31.75
29  pz  -31.75
301 px    1
302 px   -1
303 p     1  1.7320508076  0 2
304 p    -1  1.7320508076  0 2
305 p     1  1.7320508076 0  -2
306 p    -1  1.7320508076 0  -2
```

```
sdef
f1:n      11
nps        2000
```

The geometry for this example is shown in Figure 4-37.

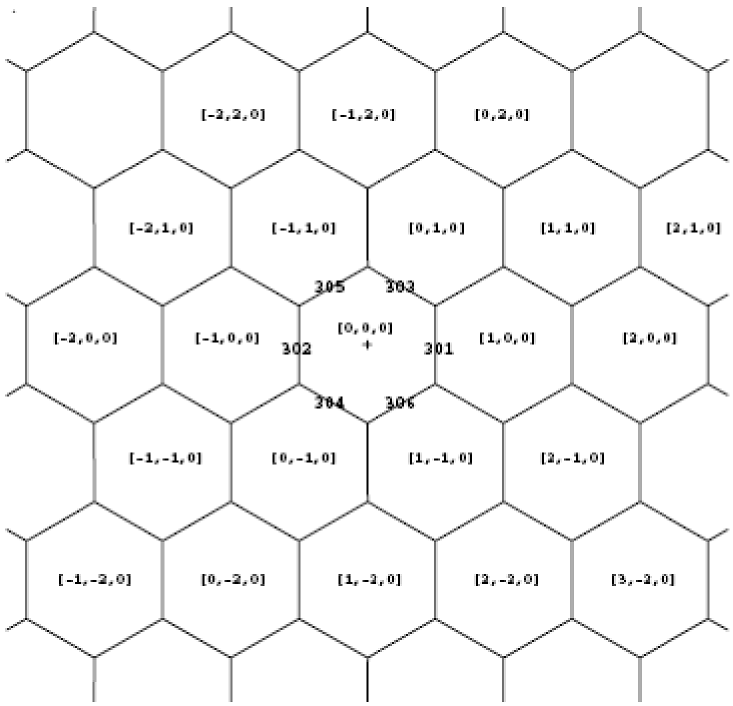


Figure 4-37. Hexagonal prism lattice.

The (0,0,0) element is the space described by the surfaces on the cell card, perhaps influenced by a `TRCL` entry. The user chooses where the (0,0,0) element will be. The user chooses the location of the (1,0,0) element—it is beyond the first surface entered on the cell card. The (-1,0,0) element *must* be in the opposite direction from (1,0,0) and *must* be beyond the second surface listed. The user then chooses where the (0,1,0) element will be—it *must* be adjacent to the (1,0,0) element—and that surface is listed next. The (0,-1,0) element *must* be diagonally opposite from (0,1,0) and is listed fourth. The fifth and sixth elements are defined based on the other four and must be listed in the correct order: (-1,1,0) and (1,-1,0). Pairs can be picked in any order, but once set the pattern must be followed. The example illustrates one pattern that could be selected and shows how the numbering of elements progresses outward from the center.

One of the most powerful uses of macrobodies is for the specification of hexagonal prisms. The example above can be simplified by using the RHP (also called HEX) macrobody as follows:

```
hexagonal prism lattice using macrobodies
C Cell Cards
1  0      -2 fill=1           imp:n=1
2  0     -10              u=3 imp:n=1
3  0      -1 fill=3 lat=2 u=1 imp:n=1
4  0       2                  imp:n=0

C Surface Cards
1  rhp    0 0 -31.75  0 0 63.5  2 0 0
2  rcc    0 0 -31.75  0 0 63.5    20
10 sph    0 0 0 40

sdef
f1:n      2.1
nps       2000
```

Example 24:

This example demonstrates how the LIKE *n* BUT and TRCL cards can be used to create an array of non-identical objects within each cell of a lattice.

```
Lattice/Rotation example of pwrlat
1   0       -1 -19   29            fill=1 imp:n=1
2   2       -1 -301 302 -303 304 lat=1 u=1 imp:n=1 fill=-3:3 -3:3 0:0
       1 1 1 1 1 1 1  1 1 2 2 2 1 1  1 2 2 2 2 2 1  1 2 2 2 2 2 1
       1 2 2 2 2 2 1  1 1 2 2 2 1 1  1 1 1 1 1 1 1
3   1 -18   -10                     u=2 imp:n=1
4   2 -1     #3 #5 #6 #7 #8 #9 #10 #11 #12 #13 #14 #15 #16 #17 #18
             #19 #20 #21 #22 #23 #24 #25 #26 #27 #28   imp:n=1 u=2
5  like 3 but trcl=(-6 6 0)
6  like 3 but trcl=(-3 6 0)
7  like 3 but trcl=(0 6 0)
8  like 3 but trcl=(3 6 0)
9  like 3 but trcl=(6 6 0)
10 like 3 but trcl=(-6 3 0)
11 like 3 but trcl=(0 3 0)
12 like 3 but trcl=(6 3 0)
13 like 3 but trcl=(-6 0 0)
14 like 3 but trcl=(-3 0 0)
15 like 3 but trcl=(3 0 0)
16 like 3 but trcl=(6 0 0)
17 like 3 but trcl=(-6 -3 0)
18 like 3 but trcl=(0 -3 0)
```

```
19 like 3 but trcl=(6 -3 0)
20 like 3 but trcl=(-6 -6 0)
21 like 3 but trcl=(-3 -6 0)
22 like 3 but trcl=(0 -6 0)
23 like 3 but trcl=(3 -6 0)
24 like 3 but trcl=(6 -6 0)
25 like 3 but mat=3 rho=-9 trcl=(-3 3 0)
26 like 25 but trcl=(3 3 0)
27 like 25 but trcl=(-3 -3 0)
28 like 25 but trcl=(3 -3 0)
50  0         1:19:-29         imp:n=0

1   cz    60
10  cz     1.4
19  pz    60
29  pz   -60
301 px    10
302 px   -10
303 py    10
304 py   -10

kcode   1000 1 5 10
ksrc    0 0 0
m1      92235  0.02   92238  0.98
m2       1001  2       8016  1
m3      48000  1
```

A horizontal slice through this configuration is shown in Figure 4-38.

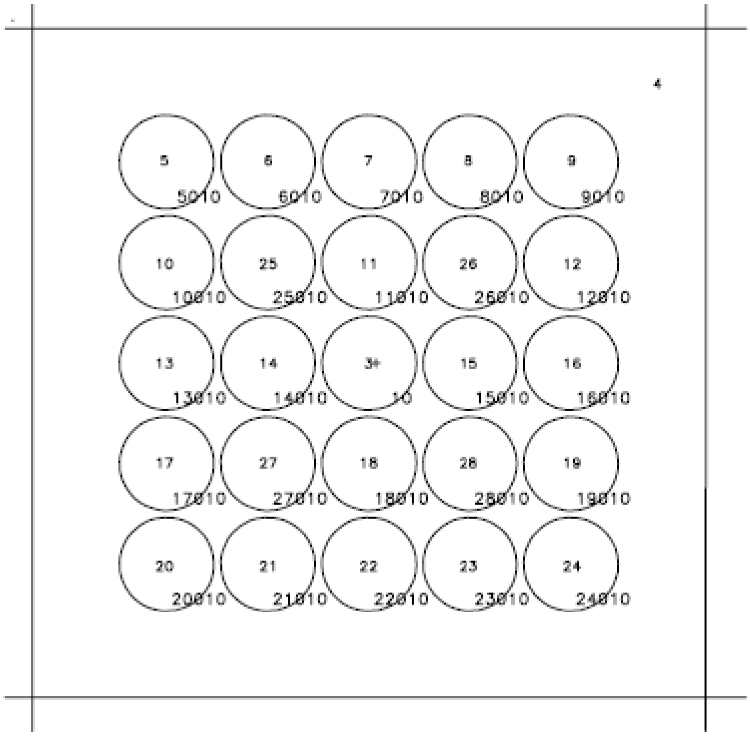


Figure 4-38

Only one lattice element is shown in Figure 4-38. A lattice of hexahedral subassemblies, each holding an array of 25 cylindrical rods, is contained within a cylindrical cell. Cell `1`, the space inside the large cylinder, is filled with universe `1`. Cell `2` is the only cell in universe `1` and is the hexahedral lattice that fills cell `1`. The lattice is a 7×7×1 array, indicated by the array indices on the `FILL` card, and it is filled either by universe `2` or by itself (that is, universe `1`). Cell `3`, a fuel rod, is in universe `2` and is the space inside the cylindrical rod. The other fuel cells, `5`–`24`, are like cell `3` but at different *x,y* locations. The material in these 21 fuel cells is slightly enriched uranium. Cells `25`–`28` are control rods. Cell `25` is like `3` but the material is changed to cadmium, and the density and the *x,y* location are different. Cells `26`–`28` are like cell `25` but at different *x,y* locations. Cell `4` is also in universe `2` and is the space outside all 25 rods. To describe cell `4`, each cell number is complemented. All the surfaces in Figure 4-38 except for the center one have a new predictable surface number equal to 1000×*cell number*+*surface number*. These numbers could be used in the description of cell `4` if desired.

The `KCODE` and `KSRC` cards appear because this example is a criticality calculation. The `KCODE` card specifies that there are 1000 particles per cycle, the initial guess for k_{eff} is 1, 5 cycles are skipped before the tally accumulation begins, and a total of 10 cycles will be run. The `KSRC` indicates that the neutron source for the first cycle will be a point source at the origin.

4.1.4 Embedded Meshes: Structured and Unstructured

In the following example, we first create a structured PARTISN-style geometry mesh and save it in LNK3DNT format. The cylindrical mesh consists of two materials in a checkerboard pattern that appears radially, axially, and azimuthally. After the LNK3DNT-format mesh file is created, we then embed the mesh in a new MCNP6 file.

Example 25 (Part 1):

```
Generate a LNK3DNT rzt mesh w/ multiple materials
c upper-inner
1   1   -18.7         -11  1  2  3   imp:n=1
2   2   -0.001        -11  1 -2  3   imp:n=1
3   1   -18.7         -11 -1 -2  3   imp:n=1
4   2   -0.001        -11 -1  2  3   imp:n=1
c upper-outer
6   2   -0.001     -10 11  1  2  3   imp:n=1
7   1   -18.7      -10 11  1 -2  3   imp:n=1
8   2   -0.001     -10 11 -1 -2  3   imp:n=1
9   1   -18.7      -10 11 -1  2  3   imp:n=1
c lower-inner
11  2   -0.001        -11  1  2 -3   imp:n=1
12  1   -18.7         -11  1 -2 -3   imp:n=1
13  2   -0.001        -11 -1 -2 -3   imp:n=1
14  1   -18.7         -11 -1  2 -3   imp:n=1
c lower-outer
16  1   -18.7      -10 11  1  2 -3   imp:n=1
17  2   -0.001     -10 11  1 -2 -3   imp:n=1
18  1   -18.7      -10 11 -1 -2 -3   imp:n=1
19  2   -0.001     -10 11 -1  2 -3   imp:n=1
c
c outer void
20         0           10            imp:n=0

10  rcc    0. 0. -10.  0. 0. 20.  10.  $ outer rcc
11  rcc    0  0  -10   0  0  20    5   $ inner rcc
1   py     0.0
2   px     0.0
3   pz     0.0

kcode     5000  1.0  50  250
ksrc      0.0 0.0 0.0
m1        92235.69c   1.0
m2         6012       1.0
dm1       92235 92235.50
```

```
mesh  geom cyl
      ref     0.0   0.0   0.0
      origin  0.0   0.0 -10.0  $ bottom center of cylinder
      axs     0.0   0.0   1.0
      vec     1.0   0.0   0.0
      imesh   10  $ cylinder radius
      iints    2  $ 2 radial divisions
      jmesh   20  $ axial (z) length
      jints    2  $ 2 axial divisions
      kmesh    1  $ azimuth-single rotation (0-2pi)
      kints    4  $ 4 azimuthal divisions (0, pi/2, pi, 3pi/2, 2pi)
dawwg   xsec=ndilib  points=10
```

In this example the MESH and DAWWG cards specify a cylindrical geometry with diameter and length of 20 cm. The cylinder mesh has two radial, two axial, and four azimuthal divisions, creating a total of eight mesh elements. The materials in each of the elements alternate, creating a checkerboard-like pattern throughout the cylinder. The use of the MESH keywords ORIGIN, AXS, and VEC ensure that the mesh aligns with the geometry —the bottom center of the mesh at (0,0,-10), the cylinder oriented along the z-axis, and the azimuthal plane along the positive x-axis. To create the LNK3DNT file, run MCNP6 with the M execution-line option using the example file above as the MCNP6 input and assign the LINKOUT file the arbitrary name "cyl.linkout."

Example 25 (Part 2):

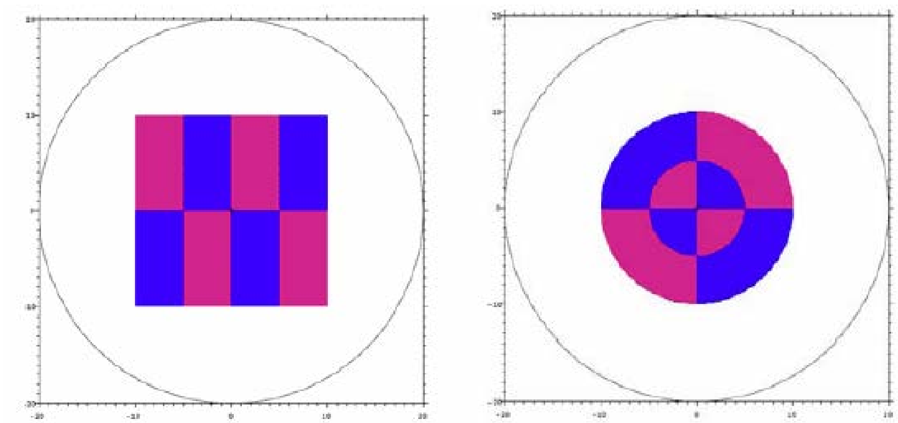
Now we embed the mesh geometry into an MCNP6 input using inferred geometry cells (one for each material in the cyl.linkout file) and one inferred background cell.

```
RZT Test of checkerboard cylinder with lnk3dnt
11  3  -18.7   0         u=e10 imp:n=1  $ inferred geometry cell
12  4  -0.001  0         u=e10 imp:n=1  $ inferred geometry cell
13  0          0         u=e10 imp:n=1  $ inferred background cell
20             0  -1  fill=e10 imp:n=1  $ embedded mesh fill cell
99  0          1               imp:n=0  $ outside world

1  so   20

kcode     500     1.0  50   100
ksrc 1 1  5 1 -1  5 -1 -1  5 -1 1  5
     5 5  5 5 -5  5 -5 -5  5 -5 5  5
     1 1 -5 1 -1 -5 -1 -1 -5 -1 1 -5
     5 5 -5 5 -5 -5 -5 -5 -5 -5 5 -5
m3        92235.69c   1.0
m4        6012 1.0
dm1 92235 92235.50
```

```
embed10 meshgeo=lnk3dnt mgeoin=cyl.linkout debug=echomesh
        matcell= 1 11  2 12
        background=13
```

Note that inferred geometry cell 11 maps to mesh material 1, inferred geometry cell 12 maps to mesh material 2, and the inferred background cell 13 completes the embedded mesh universe by defining the space surrounding the mesh. The embedded mesh universe then fills cell 20 of the MCNP6 model. Recall that the "`e`" is optional for the `U` and `FILL` keywords to denote an embedded mesh.

Figure 4-39 shows two views of the resulting geometry with the embedded geometry shaded by material, which in this case alternates between geometry elements.



YZ Plot XY Plot

Figure 4-39. Two MCNP6 geometry plots of a cylindrical rzθ embedded geometry. In each plot, the remaining axis points toward the reader.

Example 25 (Part3):

Now let's assume we want two copies of this mesh geometry embedded into our MCNP6 model, each having a different placement and orientation. We need to rotate/translate the two mesh geometry universes appropriately as we fill two distinct MCNP6 cells.

```
RZT Test of two checkerboard cylinders with lnk3dnt
11  3  -18.7   0     u=e10 imp:n=1  $ inferred geometry cell
12  4  -0.001  0     u=e10 imp:n=1  $ inferred geometry cell
13  0          0     u=e10 imp:n=1  $ inferred background cell
20  0         -1  fill=e10 (20 0 0) imp:n=1  $ fill cell 1
21  0         -2  fill=e10 (-20 0 0 -1 1 0 1 1 0)imp:n=1  $ fill cell 2
```

For this example, we assume that surfaces 1 and 2 are off-center spheres and the transformations shift the embedded geometry universes to be aligned with the spheres' geometric centers (x=±20 cm). With the addition of a 45° counterclockwise rotation applied to one of the embedded meshes, we get the geometry displayed in Figure 4-40.

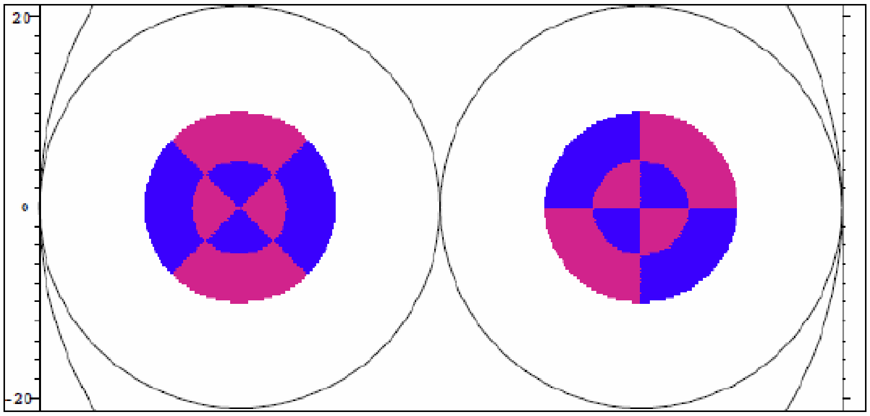


Figure 4-40. (Cropped) MCNP6 geometry plot of an embedded structured mesh placed in two unique containers. The left instance is rotated 45° in addition to being translated 20 cm in the -x direction.

4.2 TALLY EXAMPLES

This section contains examples of the `FM`, `FS`, and `FT` tally cards, a complicated repeated structures/lattice example, and the TALLYX subroutine. Refer also to Section 3.3.5.7 for the `FM` card, Section 3.3.5.14 for the `FS` card, Section 3.3.5.18 for the `FT` card, Section 3.3.5.1.4 for the basic repeated structure/lattice tally, and Section 3.3.5.17 for TALLYX before trying to understand these examples.

4.2.1 FM Examples (Simple Form)

Example 26:

Consider the following input cards.

```
Tally Multiplier (FM)
10  999 -7.0   -1    imp:n=1
11   0          1 -2 imp:n=1
12   0             2 imp:n=0

1 so   5
2 so   6

sdef
f1:n      1
nps       2000
```

```
f4:n      10
fm4       0.04786   999   102
m999      92238.80c  1.0
```

The F4 neutron tally is the track length estimate of the average fluence in cell 10. Material 999 is ^{238}U with an atomic fraction of 100%.

c=	0.04786 normalization factor (such as atom/barn-cm)
m=999	material number for ^{238}U as defined on the material card (with an atom density of 0.04786 atom/barn-cm)
r_1=102	ENDF reaction number for radiative capture cross-section (microscopic)

The average fluence is multiplied by the microscopic (n,γ) cross section of ^{238}U (with an atomic fraction of 1.0) and then by the constant 0.04786 (atom/barn–cm). Thus the tally 4 printout will indicate the number of ^{239}U atoms/cm^3 produced as a result of (n, γ) capture with ^{238}U.

Standard F6 and F7 tallies can be duplicated by F4 tallies with appropriate FM4 cards. The FM4 card to duplicate F6 is

```
FM4    c  m   1  –4
```

where

c	=	10^{-24} × number of atoms per gram	
r_1	=	1	ENDF reaction number for total cross section (barns)
r_2	=	−4	reaction number for average heating number (MeV/collision)

and for F7 it is

```
FM4    c  m  –6  –8
```

where

c	=	10^{-24} × number of atoms per gram	
r_1	=	−6	reaction number for total fission cross section (barns)
r_2	=	−8	reaction number for fission Q (MeV/fission)

This technique applied to F2 tallies can be used to estimate the average heating over a surface rather than over a volume. It provides the surface equivalents of F6 and F7 tallies, which are not available as standard tallies in MCNP6.

Example 27:

Consider a point detector.

```
Point Detector Tally
10  999  -1.0   -1    imp:n=1
11  1001 -5.0    1 -2 imp:n=1
12   0            2 imp:n=0

1 so   5
2 so   6

sdef
f1:n     1
nps      2000
m999     1001.80c 2   8016.80c 1
F25:N    0  0  0  0
FM25     0.00253  1001  -6  -8
M1001    92238.80c  0.9   92235.80c  0.1
```

This `F25` neutron tally is the fission heating per unit volume of material `1001` at the origin. Material `1001` does not actually have to be in a cell at the origin. The `FM25` card constants are:

c	=	0.00253	atoms per barn–cm (atomic density) of material 1001
m	=	1001	material number for material being heated
r_1	=	-6	reaction number for total fission cross section (barn)
r_2	=	-8	reaction number for fission Q (MeV/fission)

More Simple Form Fm Examples:

(Remember c=–1=$\rho\rangle$ for type 4 tally)

F5:N	0 0 0 0	Neutron heating per cm^3 with an atom density
FM5	ρ m 1 -4	of ρ of material m at a point detector
F5Y:P	10 5 0	Photon heating per cm^3 of material m with
FM5	ρ m -5 -6	an atom density ρ at a ring detector
F1:N	1 2 3	Number of neutron tracks crossing surfaces 1,
FM1	1 0	2, and 3 per neutron started
F35:P	0 0 0 0	Number of photon collisions per source particle
FM35	1 0	that contribute to point detector
M99	3007 1	^{7}Li tritium production per cm^3 in cell 10
F4:N	10	
FM4	-1 99 91	
F104:N	8	Number of reactions per cm^3 of type r in cell 8
FM104	ρ m r	of material m of atom density ρ

4.2.2 FM Examples (General Form)

Remember that the hierarchy of operation is multiply first and then add, and that this hierarchy can not be superseded by the use of parentheses.

Example 28:

```
F4:N   1
FM4    (ρ 1 (1 –4)(–2)) (ρ 1 1) $where c=ρ=atomic density (atom/barn-cm)
M1     6012.10   1
```

In this example there are three different tallies, namely

(a) ρ 1 1 -4
(b) ρ 1 -2
(c) ρ 1 1

Thus tally (a) will yield the neutron heating in MeV/cm^3 from ^{12}C in cell `11`. The advantage in performing the multiplication `1 -4` in tally (a) is that the correct statistics are determined for the desired product. This would not be true if tally (a) were to be done as two separate tallies and the product formed by hand after the calculation.

Example 29:

```
Tally Multiplier (FM)
10   999  -1.0     -1    imp:n=1 $ Water
11  1001  -1.       1 -2 imp:n=1 $ Li
12  0                  2 imp:n=0

1 so 5
2 so 6

sdef
nps       2000
M999     1001.80c 2       8016.80c 1
M1001    3006.80  0.0742  3007.80  0.9258
F4:N    11
FM4     (0.04635 1001 (105:91))
```

In this example we obtain the total tritium production per cm^3 from natural lithium (ENDF/B-V evaluation) in cell `1`. The constant *c* on the `FM4` card is the atomic density of natural lithium. A subtle point is that the *r*=105 reaction number contains the reaction data for just the ^{6}Li reaction and *r*=91 contains the reaction data for the ^{7}Li reaction. However, this example uses both sets of reaction data in the `FM4` card to calculate the tritium production in a media composed of both ^{6}Li and ^{7}Li. Thus, four calculations are carried out (two for ^{6}Li using *r*=91,105, and two for ^{7}Li using *r*=91,105). Note that two of these calculations (^{6}Li with *r*=91, and ^{7}Li with *r*=105) will contribute nothing to the total tritium production.

Example 30:

Suppose we have three reactions—r_1, r_2, and r_3—and wish to add r_2 and r_3 and multiply the result by r_1. The following would *not* be valid: `FMn (C m r1 (r2:r3))`. The correct card is: `FMn (C m (r1 r2:r1 r3))`.

4.2.3 FMESH Tally Examples

`FMESH` allows the user to perform mesh tallies for fluxes and material reaction rates on an arbitrary, user-specified mesh that is independent of the actual problem geometry.

Example 31:

```
FMESH tally Example 31
c Cells
900 100 -19.1  -1    imp:n=1 $ Natural Uranium
901 200 -19.1  -2    imp:n=1 $ Depleted Uranium
902 300 -0.001 1 2 -3 imp:n=1 $  air
903  0         3     imp:n=0 $  Void, kill n

c Surfaces
1 sx 4  3
2 sx -4 3
3 so 10

sdef erg=2
mode n
nps 500000
c
c Problem materials
c Natural Uranium
m100   92238  0.992745
       92235  0.007200
c Hypothetical Depleted Uranium
m200   92238  0.9999
       92235  0.0001
c Air
m300 7014 -0.755  8016 -0.231  18000 -0.013
c Dummy materials for FM mesh tallies
m238 92238  1.0
m235 92235  1.0
c
```

```
fmesh04:n  geom=xyz origin -10 -10 -10
           imesh 10  iints 100
           jmesh 10  jints 100
           kmesh 10  kints 100
           out=none
fmesh14:n  geom=xyz origin -10 -10 -10
           imesh 10  iints 100
           jmesh 10  jints 100
           kmesh 10  kints 100
           out=none
fmesh24:n  geom=xyz origin -10 -10 -10
           imesh 10  iints 100
           jmesh 10  jints 100
           kmesh 10  kints 100
           out=none
c Tally multipliers
+fm04  -1  235  -6   $ fission rate per cm3 from U235
+fm14  -1  238  -6   $ fission rate per cm3 from U238
+fm24  -1  100  -6   $ total fission rate from both U235 and U238
```

In this problem, there are two cells, one composed of natural uranium and the other, depleted uranium. To calculate the fission rates for each isotope in both cells, a mesh tally is used. The default units of the results are the number of fissions per cm^3 (or per cm^3 per shake) in each mesh cell. For tally 24, material 200 could be used instead of material 100 because both materials contain the same isotopes.

Example 32:

```
FMESH tally Example 32
c Cells
900 10 -2.5    -1    imp:n=1 $ Concrete
901 11 -7.86   -2    imp:n=1 $ Stainless Steel - 202
902 12 -0.0012 1 2 -3 imp:n=1 $  Void, transport
903  0          3    imp:n=0 $  Void, kill n

c Surfaces
1 sx 6 3
2 sx -6 3
3 so 10

sdef erg=2
mode n
nps 500000
c
c Problem materials
```

```
c Ordinary Concrete (rho = 2.35 g/cc)
m10    1001  -0.00600
       8016  -0.50000
      11023  -0.01700
      13027  -0.04800
      14028  -0.28940
      14029  -0.01518
      14030  -0.01042
      19000  -0.01900
      20000  -0.08300
      26054  -0.00068
      26056  -0.01106
      26057  -0.00026
c Stainless Steel - 202
m11    6000  -0.00075
       7014  -0.00125
      14000  -0.00500
      15031  -0.00030
      16000  -0.00015
      24000  -0.18000
      25055  -0.08750
      26000  -0.67505
      28000  -0.05000
m12   7014 -0.755 8016 -0.232  18000 -0.013
m20   11023   1
m21   26054   1
m22   25055   1
c
fmesh04:n  geom=xyz origin -10 -10 -10
           imesh 10  iints 50
           jmesh 10  jints 50
           kmesh 10  kints 50
           out=none
fmesh14:n  geom=xyz origin -10 -10 -10
           imesh 10  iints 50
           jmesh 10  jints 50
           kmesh 10  kints 50
           out=none
fmesh24:n  geom=xyz origin -10 -10 -10
           imesh 10  iints 50
           jmesh 10  jints 50
           kmesh 10  kints 50
           out=none
c
```

```
C 102 = (n,gamma) reaction
+fm4   -1  20  102   $ Na-24 production (not in material 11)
+fm14  -1  21  102   $ Fe-55 production (2600 in material 11)
+fm24  -1  22  102   $ Mn-56 production (not in material 10)
```

This problem contains a single cell composed of concrete. We want to calculate the production rate of ^{24}Na and ^{55}Fe in the material. The ^{23}Na and ^{54}Fe isotopes are specified on the dummy material cards because an (n,γ) reaction on these isotopes produce ^{24}Na and ^{55}Fe, respectively. The production rate is calculated by multiplying the (n,γ) reaction cross section times the atomic fraction of the isotope in material 10.

4.2.4 FS Examples

The FS card allows you to subdivide your tally into geometry segments, avoiding over-specifying the problem geometry with unnecessary cells.

The entries on the FS card are the names and senses of surfaces that define how to segment any surface or cell tally.

Example 33:

Consider a 1-MeV point isotropic source at the center of a 2-cm cube of carbon. We wish to calculate the flux through a 1-cm^2 window in the center of one face on the cube. The input file calculating the flux across one entire face is shown in Figure 4-41.

```
EXAMPLE 33 SIMPLE CUBE
1  1 -2.22   1  2 -3 -4 -5  6 IMP:N=1
2  0        #1                IMP:N=0

1  PY    0
2  PZ   -1
3  PY    2
4  PZ    1
5  PX    1
6  PX   –1

SDEF     POS = 0 1 0  ERG = 1
M1       6012.60 –1
F2:N     3
```

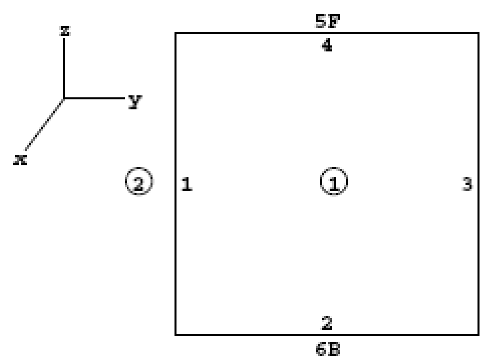


Figure 4-41

The FS card retains the simple cube geometry and four more surface cards are required,

```
7  PX    0.5
8  PX   -0.5
```

```
9  PZ    0.5
10 PZ   -0.5

FS2     7 -10 -8  9
```

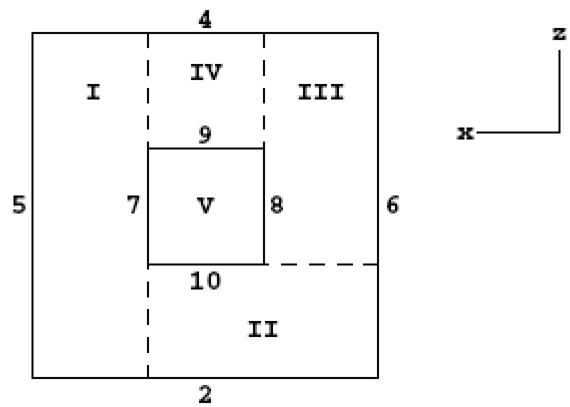


Figure 4-42

The four segmenting surface cards are listed with the other surface cards, but they are not part of the actual geometry and hence do not complicate the cell-surface relationships.

The F2 tally is subdivided into five separate tallies as shown in Figure 4-42: 1) the first is the flux of particles crossing surface 3 but with a positive sense to surface 7; 2) the second is the remaining flux with negative sense to surface 7 crossing surface 3 but with a negative sense to surface 10; 3) the third is the remaining flux (negative sense to 7 and positive sense to 10) crossing 3 but with a negative sense to 8; 4) the remaining flux with positive sense to 9; and 5) everything else. In this example, the desired flux in the window is in the fifth sub-tally—the "everything else" portion.

The FS segmenting card could have been set up other ways. For example:

```
FS2   -10  7   9  -8    and
FS2    -8  9 -10   7
```

Each works, but the order of the sub-tallies is changed. A way to avoid the five sub-tallies and to get only the window of interest is to use the TALLYX subroutine described later.

Example 34:

Consider a source at the center of a 10-cm-radius sphere called cell 1. We want to determine the fission heating in a segment of the sphere defined by the intersection of the 10-cm sphere, an 8-cm inner sphere, and a 20-degree cone whose vertex is at the source and is about the *y*-axis. This is accomplished by using

```
F7:N     1
FS7     -2  -3
```

where surface 2 is the 8-cm sphere and surface 3 is the cone. This breaks the F7 tally up into three portions: 1) the heating inside the 8-cm sphere; 2) the heating outside the 8-cm sphere but within the cone—this is the desired portion; and 3) everything else, which is a 2-cm shell just inside the 10-cm sphere but outside the cone.

4.2.5 FT Examples

Example 35:

Consider the following input cards.

```
F1:N     2
FT1      FRV v1 v2 v3
```

The FT*n* card is the special treatment for tallies card. Various tally treatments are available for certain specific tally requirements. The FT*n* tally with the FRV card used in conjunction with tally type 1 will redefine the vector normal to the tally surface. In this case, the current over surface 2 (tally type 1) uses the vector **V** as its reference vector for getting the cosine for binning.

Example 36:

```
F5:P      4 5 6
FT5       ICD
FU5       1  3
```

In this example the photon flux at detector 5 is being tallied. However, only the contributions to the detector tally from cells 1 and 3 are of interest. The ICD keyword allows the user to create a separate bin for each cell, and only contributions from one of the specified cells are scored. The FU*n* card specifies the cells from which tallies are to be made, but TALLYX is not called.

Example 37:

When keeping track of charged particle current across a surface, it is sometimes desirable to track both positive and negative score contributions, applicable in cases that include charged particles. Consider a photon source that is enclosed in a spherical shell of lead. If a surface current tally is taken over the sphere and it is desirable to tally both the positron and electron current separately, then the special treatment card option is invoked.

```
1  1  −0.001124       −11   imp:e=1 imp:p=1
2  2 −11.0         11 −21   imp:e=1 imp:p=1
3  0               21       imp:e=0 imp:p=0

11 so    30
21 so    32

m1    6012  0.000125   7014  0.6869   8016  0.301248   18040  0.011717
m2   82000  1.
mode   p e
sdef   pos = 0. 0. 0.  erg = 2.5
f1:e   21
ft1    elc  2
```

```
f2:p   21
e2     1e-3 1e-2 0.1 0.5 1.0 1.5 2.0 2.5 C
nps    10000
```

The input deck shown above models a sphere filled with dry air surrounded by a spherical shell of lead. The centrally located source emits 2.5-MeV photons that travel through the air into the lead shell. The F1 surface current tally has been modified with the ELC special tally option. The parameter value of 2 that follows the ELC keyword specifies that positrons and electrons be placed into separate tally user bins. Once this option has been invoked, the user can inspect the output tally bins for the respective scoring of either particle.

The F2 tally scores photon flux crossing surface 21, scored into energy bins defined on the E2 card. The C at the end of the energy bin card indicates that the bins are cumulative. For instance, the bin with an upper limit of 1 MeV would contain scores from particles that cross surface 21 with energy less than or equal to 1 MeV.

Example 38:

Consider the following two point sources, each with a different energy distribution:

```
sdef   pos=d1  erg=fpos d2
si1  L   5 3 6  75 3 6
sp1      0.3    0.7
ds2  S   3 4
si3  H   2 10 14
sp3  D   0  1  2
si4  H   5 2 8
sp4  D   0 3 1
f2:n     2
ft2      scd
fu2      3 4
```

The SCD option causes tallies to be binned according to which source distribution was sampled. The FU*n* card is used to list the distribution numbers of interest. Thus, the tallies in this example are placed in one of two bins, depending on which of the two sources emitted the particle. The two sources may represent two nuclides with different energy distributions. In this case use of the SCD option allows the user to determine each nuclide's contribution to the final tally.

Example 39: Capture Tallies: Interpreting Capture Tally Output

The FT8 CAP coincidence capture tally option produces both a standard tally, which is generally unreadable, and a coincidence capture table, print table 118. An example is provided to help in the interpretation of this table:

```
neutron captures, moments & multiplicity distributions. tally 8         print table 118

 cell:    999

 neutron captures on 3he
                     captures      captures    multiplicity fractions
        histories   by number     by weight    by number    by weight   error

 captures =  0     700       0   0.00000E+00  7.00000E-02  3.25400E-02  0.0364
 captures =  1    2285    2285   1.06220E-01  2.28500E-01  1.06220E-01  0.0184
 captures =  2    3223    6446   2.99647E-01  3.22300E-01  1.49823E-01  0.0145
 captures =  3    2489    7467   3.47109E-01  2.48900E-01  1.15703E-01  0.0174
 captures =  4    1022    4088   1.90033E-01  1.02200E-01  4.75084E-02  0.0296
 captures =  5     209    1045   4.85775E-02  2.09000E-02  9.71551E-03  0.0684
 captures =  6      51     306   1.42246E-02  5.10000E-03  2.37077E-03  0.1397
 captures =  7      12      84   3.90480E-03  1.20000E-03  5.57828E-04  0.2885
 captures >  7       9      73   3.39345E-03  9.00000E-04  4.18371E-04  0.3332

    total        10000   21794   1.01311E+00  1.00000E+00  4.64857E-01  0.0056

     factorial moments             by number              by weight

            3he                 2.17940E+00 0.0056      1.01311E+00 0.0056
       3he(3he-1)/2!            2.01890E+00 0.0128      9.38499E-01 0.0128
    3he(3he-1)(3he-2)/3!        1.06390E+00 0.0291      4.94561E-01 0.0291
  3he(3he-1) .... (3he-3)/4!    3.93800E-01 0.0744      1.83061E-01 0.0744
  3he(3he-1) .... (3he-4)/5!    1.34100E-01 0.1636      6.23373E-02 0.1636
  3he(3he-1) .... (3he-5)/6!    4.43000E-02 0.2666      2.05932E-02 0.2666
  3he(3he-1) .... (3he-6)/7!    1.12000E-02 0.3808      5.20640E-03 0.3808
  3he(3he-1) .... (3he-7)/8!    1.70000E-03 0.5548      7.90257E-04 0.5548
```

The capture tally input for this problem was

```
F8:n      999                 $ input F8 card
FT8 CAP    -8    -8    2003   $ input FT8 CAP card
```

Note that the line "`captures >  7       9      73`" indicates that nine histories had eight or more neutrons captured. This implies that 8 histories had 8×8=64 neutrons captured and 1 history had 1×9 neutrons captured, for a total of 73 neutrons captured. The table of captures evidently was too short, and the problem should have been run with `FT8 CAP  -9  -9` or even more captures and moments. Not specifying enough capture rows affects only the captures >7 lines and the error estimate on the totals capture line; all other information is correct as if more captures and moments were listed.

As an interpretation of the neutron captures on the 3he table, Column 1 is the number of histories according to the number of captures by the designated material (2003=3he) in the designated cell (999). This number sums to the total number of source histories for the problem, nps=10000.

Column 2 is the number of captures by 2003 in cell 999=21794. Because analog capture is the default for `F8` tallies, the total weight captured is also 21794.

Column 3 is the total weight captured divided by the tally normalization. For SDEF PAR=-SF, the tally normalization is the number of source histories=number of spontaneous fissions=10000. For SDEF PAR=-SF, column 3 would be 21794.0/10000= 2.17940. In this problem, SDEF PAR=SF, and the tally normalization is the source particles = spontaneous fission neutrons = 21512. Thus, captures by weight are 21794.0/21512=1.01311.

Column 4 is the multiplicity fraction by number, which is Column 1 divided by the number of source histories. The total is always 1.00000.

Column 5 is the multiplicity fraction by weight, which is the weight of histories undergoing capture divided by the tally normalization. For SDEF PAR=-SF, this fraction would be 10000.0/10000=1.00000. In this problem, SDEF PAR=SF and the multiplicity fraction by weight is 10000.0/21512=0.464857.

The interpretation of the factorial moments table now follows.

The first moment by number is the number of captures divided by the number of source histories=21794/10000=2.17940.

The first moment by weight is the total weight of capture divided by the tally normalization. For SDEF PAR=-SF, this moment would be 21794.0/10000=21794.0. In this problem, SDEF PAR=SF and the first moment by weight is 21794.0/21512=1.01311.

The second moment is N × (N-1)/2, where N is the number of captures. In this problem,

N	N × (N-1)/2		histories		product
1	0	×	2285	=	0
2	1	×	3223	=	3223
3	3	×	2489	=	7467
4	6	×	1022	=	6132
5	10	×	209	=	2090
6	15	×	51	=	765
7	21	×	12	=	252
8	28	×	8	=	224
9	36	×	1	=	36
sum				=	20189

and the second moment by number is divided by the number of histories,

20189 / 10000 = 2.01890 .

Because of analog capture, the second moment weight is 20189.0. The second moment by weight is divided by the tally normalization. For SDEF PAR=-SF, this moment would be 20189.0/10000=2.01890, which is the same as the second moment by number. In this problem, SDEF PAR=SF, and the second moment by weight is

20189.0 / 21512 = 0.938499 .

The seventh moment is

$7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1/7!$	=	1	×	12	=	12
$8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2/7!$	=	8	×	8	=	64
$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3/7!$	=	36	×	1	=	36
sum					=	112

thus, 112/10000=0.0112 .

The eighth moment is

$8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1/8!$	=	1	×	8	=	8
$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2/8!$	=	9	×	1	=	9
sum					=	17

thus, 17/10000=0.0017 .

And the ninth moment is

$$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1/9! = 1 \times 1 = 1$$

thus, 1/10000=0.0001 .

Example 40: Capture Tallies with Time Gating

The coincidence capture tally optionally allows specification of predelay and gate width [SWI04] with the "`GATE`" keyword on the `FT8` card. The "`GATE`" keyword may appear anywhere after the "`CAP`" keyword and is part of the "`CAP`" command. Immediately following, the "`GATE`" keyword must be the predelay time and the total gate width, both in units of shakes (1.0e-8 s).

The addition of the predelay and time gate width changes the capture tally scoring. When a neutron is captured at time t_0 in the specified cell by the specified nuclide (22 and ^{3}He = 2003 in all three tallies below), the gate is "turned on." If the predelay is t_1 and the gate width is t_2, then all captures between $t_0 + t_1$ and $t_0 + t_1 + t_2$ are counted. For a history with no captures, no events are scored. With one capture, 0 events are scored. With two captures, the first turns on the time gate are at time t_0 and scores 0; the second will score one event if it is captured between $t_0 + t_1$ and $t_0 + t_1 + t_2$ or score another 0 if outside the gate.

Other entries after the "`CAP`" keyword may be placed in any order, as shown in the following examples. The negative entries change the allowed number of captures and moments (defaults 21 and 12 are changed to 40 and 40 in `F78` below). The list of capture nuclides (^{3}He = 2003 in all three tallies below) also may be placed anywhere after "`CAP`."

Examples for three capture tallies now follow. The capture tally without gating (`F18`) is shown for reference. An infinite gate (`F38`) results in a very different `print table 118`: the number of captures is the same, but the moments are offset by one. A finite gate (`F78`) has fewer captures, as expected.

Case A: Capture Tally without Gate

Input:

```
f18:n 22
ft18 cap 2003
```

Output:

```
1 neutron captures, moments and multiplicity distributions.  tally  18              print table 118

 weight normalization by source histories =         20000

 cell:    22

 neutron captures on 3he
                        captures    captures       multiplicity fractions
             histories  by number   by weight     by number     by weight     error

 captures =  0  13448        0    0.00000E+00   6.72400E-01   6.72400E-01   0.0049
 captures =  1   5550     5550    2.77500E-01   2.77500E-01   2.77500E-01   0.0114
 captures =  2    588     1176    5.88000E-02   2.94000E-02   2.94000E-02   0.0406
 captures =  3    238      714    3.57000E-02   1.19000E-02   1.19000E-02   0.0644
 captures =  4     94      376    1.88000E-02   4.70000E-03   4.70000E-03   0.1029
 captures =  5     40      200    1.00000E-02   2.00000E-03   2.00000E-03   0.1580
 captures =  6     26      156    7.80000E-03   1.30000E-03   1.30000E-03   0.1960
 captures =  7      8       56    2.80000E-03   4.00000E-04   4.00000E-04   0.3535
 captures =  8      5       40    2.00000E-03   2.50000E-04   2.50000E-04   0.4472
 captures =  9      1        9    4.50000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 12      1       12    6.00000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 16      1       16    8.00000E-04   5.00000E-05   5.00000E-05   1.0000

    total       20000     8305    4.15250E-01   1.00000E+00   1.00000E+00   0.0128

      factorial moments              by number               by weight

             3he                4.15250E-01 0.0128      4.15250E-01 0.0128
        3he(3he-1)/2!           1.59300E-01 0.0651      1.59300E-01 0.0651
     3he(3he-1)(3he-2)/3!       1.47900E-01 0.2165      1.47900E-01 0.2165
  3he(3he-1) .... (3he-3)/4!    1.87750E-01 0.5063      1.87750E-01 0.5063
  3he(3he-1) .... (3he-4)/5!    2.96500E-01 0.7493      2.96500E-01 0.7493
  3he(3he-1) .... (3he-5)/6!    4.61900E-01 0.8727      4.61900E-01 0.8727
  3he(3he-1) .... (3he-6)/7!    6.15800E-01 0.9311      6.15800E-01 0.9311
  3he(3he-1) .... (3he-7)/8!    6.68950E-01 0.9626      6.68950E-01 0.9626
  3he(3he-1) .... (3he-8)/9!    5.83050E-01 0.9812      5.83050E-01 0.9812
  3he(3he-1) .... (3he-9)/10!   4.03700E-01 0.9918      4.03700E-01 0.9918
  3he(3he-1) .... (3he-10)/11!  2.19000E-01 0.9972      2.19000E-01 0.9972
  3he(3he-1) .... (3he-11)/12!  9.10500E-02 0.9994      9.10500E-02 0.9994
```

Case B: Infinite Gate

Input:

```
f38:n 22
ft38 cap 2003 gate 0 1e11
```

Output:

```
1 neutron captures, moments and multiplicity distributions.  tally  38              print table 118

 weight normalization by source histories =         20000

 cell:    22

 neutron captures on 3he

 time gate:  predelay =  0.0000E+00     gate width =  1.0000E+11

     pulses         occurrences  occurrences          pulse fraction
    in gate histogram by number    by weight     by number     by weight    error

 captures =  0   6552       0    0.00000E+00   3.27600E-01   3.27600E-01   0.0101
 captures =  1   1002    1002    5.01000E-02   5.01000E-02   5.01000E-02   0.0308
 captures =  2    414     828    4.14000E-02   2.07000E-02   2.07000E-02   0.0486
 captures =  3    176     528    2.64000E-02   8.80000E-03   8.80000E-03   0.0750
 captures =  4     82     328    1.64000E-02   4.10000E-03   4.10000E-03   0.1102
 captures =  5     42     210    1.05000E-02   2.10000E-03   2.10000E-03   0.1541
 captures =  6     16      96    4.80000E-03   8.00000E-04   8.00000E-04   0.2499
 captures =  7      8      56    2.80000E-03   4.00000E-04   4.00000E-04   0.3535
 captures =  8      3      24    1.20000E-03   1.50000E-04   1.50000E-04   0.5773
 captures =  9      2      18    9.00000E-04   1.00000E-04   1.00000E-04   0.7071
 captures = 10      2      20    1.00000E-03   1.00000E-04   1.00000E-04   0.7071
 captures = 11      2      22    1.10000E-03   1.00000E-04   1.00000E-04   0.7071
 captures = 12      1      12    6.00000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 13      1      13    6.50000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 14      1      14    7.00000E-04   5.00000E-05   5.00000E-05   1.0000
 captures = 15      1      15    7.50000E-04   5.00000E-05   5.00000E-05   1.0000

    total        8305    3186    1.59300E-01   4.15250E-01   4.15250E-01   0.0291

      factorial moments              by number               by weight

              n                 1.59300E-01 0.0651      1.59300E-01 0.0648
          n(n-1)/2!             1.47900E-01 0.2165      1.47900E-01 0.2165
        n(n-1)(n-2)/3!          1.87750E-01 0.5063      1.87750E-01 0.5062
    n(n-1)(n-2) ... (n-3)/4!    2.96500E-01 0.7493      2.96500E-01 0.7492
    n(n-1)(n-2) ... (n-4)/5!    4.61900E-01 0.8727      4.61900E-01 0.8726
    n(n-1)(n-2) ... (n-5)/6!    6.15800E-01 0.9311      6.15800E-01 0.9311
    n(n-1)(n-2) ... (n-6)/7!    6.68950E-01 0.9626      6.68950E-01 0.9626
    n(n-1)(n-2) ... (n-7)/8!    5.83050E-01 0.9812      5.83050E-01 0.9812
    n(n-1)(n-2) ... (n-8)/9!    4.03700E-01 0.9918      4.03700E-01 0.9918
    n(n-1)(n-2) ... (n-9)/10!   2.19000E-01 0.9972      2.19000E-01 0.9972
    n(n-1)(n-2) ... (n-10)/11!  9.10500E-02 0.9994      9.10500E-02 0.9994
    n(n-1)(n-2) ... (n-11)/12!  2.80000E-02 1.0000      2.80000E-02 1.0000
```

Case C: Finite Gate

Input:

```
f78:n 22
ft78 cap gate .5 .4 -40 -40 2003
```

Output:

```
1 neutron captures, moments and multiplicity distributions.  tally  78              print table 118

 weight normalization by source histories =         20000

 cell:    22

 neutron captures on 3he

 time gate:  predelay =  5.0000E-01     gate width =  4.0000E-01

     pulses         occurrences  occurrences           pulse fraction
    in gate histogram by number    by weight     by number     by weight    error

 captures =  0   7837      0     0.00000E+00   3.91850E-01   3.91850E-01   0.0118
 captures =  1    394    394     1.97000E-02   1.97000E-02   1.97000E-02   0.0666
 captures =  2     67    134     6.70000E-03   3.35000E-03   3.35000E-03   0.1542
 captures =  3      6     18     9.00000E-04   3.00000E-04   3.00000E-04   0.4082
 captures =  4      1      4     2.00000E-04   5.00000E-05   5.00000E-05   1.0000

  total          8305    550     2.75000E-02   4.15250E-01   4.15250E-01   0.0624

     factorial moments              by number              by weight

              n                  2.75000E-02 0.0717      2.75000E-02 0.0716
          n(n-1)/2!              4.55000E-03 0.1654      4.55000E-03 0.1654
        n(n-1)(n-2)/3!           5.00000E-04 0.4690      5.00000E-04 0.4690
    n(n-1)(n-2) ... (n-3)/4!    5.00000E-05 1.0000      5.00000E-05 1.0000
```

Scratch space is needed to save capture times during the course of a history. The times are stored temporarily in the capture and moment bins of the tally. If sufficient bins are unavailable, then the number of allowed captures and moments must be increased using the negative entries after the "`CAP`" keyword. The message "`*** warning *** dimension overflow. Some pulses not counted.`" is put in `print table 118` if the space needs to be increased.

Example 41: Residual Nuclei Tally

The following input file models a 1.2-GeV proton source having a single collision with ^{208}Pb.

```
Test of p(1.2GeV)+Pb(208)
1 1 -11. -1 imp:h 1
2 0       1 imp:h 0

1 so .01
```

```
mode h n
sdef par h erg=1200 vec 0 0 1 dir 1
m1 82208 1
phys:h 1300 j 0
phys:n 1300 3j 0
nps 10000
f8:h 1
ft8 res 1 99
fq8 u e
lca   2 1 1 23 1 1 0 -2 0
```

These data are plotted in Figure 4-43, with MCNP6 using the tally plotter and the execute line command

```
MCNP6  Z   ,
```

where the command file, COM91, is

```
rmctal=mctl91
tally 8 free u xlim 81189 8120 ylim .0001 .01   .
```

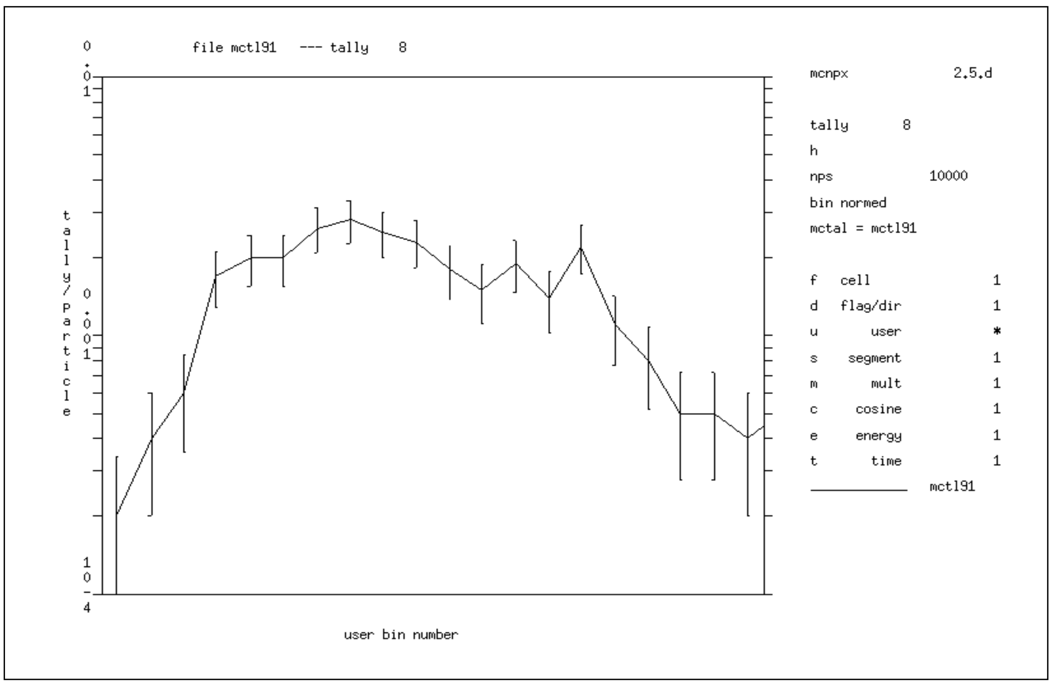


Figure 4-43. Residuals for ^{81}Tl isotopes 189 to 201 from 1.3-GeV protons on $^{208}_{82}\text{Pb}$.

Example 42: ROC Curve Generation

The following input file models a 15-MeV photon source incident on a ^{238}U sphere (10 kg). This source is represented as a single 10 μs pulse of 10^7 photons (S_i). A 1/E background source is specified in the surrounding cube (200 cm each side), and the `FT PHL` option is used to generate a ROC curve from the signal and noise components tallied in a Ge detector for 60 s. The Ge detector is surrounded by 2 cm of Pb. The flux of the background photons was taken as 10 γ/cm^2/min. The background source strength (S_b) to produce this flux is given by A*F/3.7, where A is the surface area of the cube and F is the flux (the factor of 3.7 comes from the shape of the cube—for a sphere this factor is 1.0). This results in S_b=6*200*200*10/3.7, or 648648 photons. The probability of sampling each source component becomes $P_i=S_i/(S_i+S_b)$ and $P_b=S_b/(S_i+S_b)$, or P_i=0.9391 and P_b=0.0609, as seen on the `SP1` card. The *nhb* parameter of the `ROC` option is set to the sum of these sources, or 10648648. In this example, we ran 10 batches to formulate the signal and noise PDFs and the related ROC curve.

```
Generate ROC curve for 15-MeV photons into U-238
1   0          -1  2  7  5  imp:p=1
2   0          -2           imp:p=1
4   1 -5.16    -4           imp:p=1
5   2 -19.0    -5           imp:p=1
6   0          -6           imp:p=1
7   3 -11.3    -7  4  6     imp:p=1
8   0           1           imp:p=0

1 RPP  -100 100 -100 100 -100 100
2 SO   5.0
3 PZ   0.0
4 RCC  20 0 25 0 0 10 4.0
5 SPH  20 0  0 5.0
6 RCC  20 0 20 0 0  5 4.0
7 RCC  20 0 20 0 0 17 6.0

MODE p n
M1     32074.70c 1
M2     92238.70c 1
M3     82208.70c 1
MX2:P  model
CUT:N  60e8
CUT:P  60e8
PHYS:P j 1 j -1 j -101
SDEF PAR=P ERG=D1 X=FERG D2 Y=FERG D3 Z=FERG D4 TME=FERG D7
     VEC=1 0 0 DIR=FERG D8 CEL=1 WGT=1
SI1 S      5      6
SP1    0.9391  0.0609
DS2 S  15  16
```

```
DS3 S  25  26
DS4 S  35  36
DS7 S  45  46
DS8 S  55  56
SI15 L  5.1
SP15      1
SI25 L  0.0
SP25      1
SI35 L  0.0
SP35      1
SI16 -100 100
SP16    0   1
SI26 -100 100
SP26    0   1
SI36 -100 100
SP36    0   1
SI45 0 0.000010e8
SP45 0    1
SI46 0 60e8
SP46 0    1
SI55 L 1
SP55   1
SI56 -1 1
SP56  0 1
SI5 L 15.0
SP5      1
C 1/E for background source
SI6 A .100 1.0  2.0  3.0   4.0   5.0   6.0   7.0   8.0   9.0   10.0
SP6   10.0 1.0  0.5  0.333 0.250 0.200 0.167 0.143 0.125 0.111 0.100
c
f4:p  2
f1:p  4.3
e1    1.0 100.0
t1    0.001e8 60e8
ft1   scx 1 roc 10648648
tf1   1 1 1 1 1 1 2 2   1 1 2 1 1 1 2 2 $ signal bins, noise bins
nps   106486480l
```

The ROC output for Tally 1 is provided in `print table 163`, shown below. The first printed plot is the ROC curve itself, plotting the noise PDF (usually referred to as the probability of false alarm) versus the signal PDF (usually referred to as the probability of detection). The data for the signal and noise PDFs is provided in the subsequent table. The jagged behavior of the ROC curve can be significantly refined by increasing the number of batches (say from 10 to 100, or by running 1064864800 particle histories).

```
1roc curve for tally   1    10 batches, signal mean= 3.489E+01 noise mean= 2.720E+01 nps =   106486480  print table 163

  abscissa           ordinate              plot of probability of detection versus probability of false alarm - 0 to 100 percent
     noise              signal:--------10--------20--------30--------40--------50--------60--------70--------80--------90-------100
     1.000           20.000|         |         x         |         |         |         |         |         |         |         |
     2.000           40.000|         |         |         |         x         |         |         |         |         |         |
     3.000           60.000|         |         |         |         |         |         x         |         |         |         |
     4.000           60.000|         |         |         |         |         |         x         |         |         |         |
     5.000           60.000|         |         |         |         |         |         x         |         |         |         |
     6.000           60.000|         |         |         |         |         |         x         |         |         |         |
     7.000           60.000|         |         |         |         |         |         x         |         |         |         |
     8.000           60.000|         |         |         |         |         |         x         |         |         |         |
     9.000           60.000|         |         |         |         |         |         x         |         |         |         |
    10.000           60.000|         |         |         |         |         |         x         |         |         |         |
    11.000           60.000|         |         |         |         |         |         x         |         |         |         |
    12.000           60.000|         |         |         |         |         |         x         |         |         |         |
    13.000           60.000|         |         |         |         |         |         x         |         |         |         |
    14.000           60.000|         |         |         |         |         |         x         |         |         |         |
    15.000           60.000|         |         |         |         |         |         x         |         |         |         |
    16.000           60.000|         |         |         |         |         |         x         |         |         |         |
    17.000           60.000|         |         |         |         |         |         x         |         |         |         |
    18.000           60.000|         |         |         |         |         |         x         |         |         |         |
    19.000           60.000|         |         |         |         |         |         x         |         |         |         |
    20.000           60.000|         |         |         |         |         |         x         |         |         |         |
    21.000           80.000|         |         |         |         |         |         |         |         x         |         |
    22.000           80.000|         |         |         |         |         |         |         |         x         |         |
    23.000           80.000|         |         |         |         |         |         |         |         x         |         |
    24.000           80.000|         |         |         |         |         |         |         |         x         |         |
    25.000           80.000|         |         |         |         |         |         |         |         x         |         |
    26.000           80.000|         |         |         |         |         |         |         |         x         |         |
    27.000           80.000|         |         |         |         |         |         |         |         x         |         |
    28.000           80.000|         |         |         |         |         |         |         |         x         |         |
    29.000           80.000|         |         |         |         |         |         |         |         x         |         |
    30.000           80.000|         |         |         |         |         |         |         |         x         |         |
    31.000           80.000|         |         |         |         |         |         |         |         x         |         |
    32.000           80.000|         |         |         |         |         |         |         |         x         |         |
    33.000           80.000|         |         |         |         |         |         |         |         x         |         |
    34.000           80.000|         |         |         |         |         |         |         |         x         |         |
    35.000           80.000|         |         |         |         |         |         |         |         x         |         |
    36.000           80.000|         |         |         |         |         |         |         |         x         |         |
    37.000           80.000|         |         |         |         |         |         |         |         x         |         |
    38.000           80.000|         |         |         |         |         |         |         |         x         |         |
    39.000           80.000|         |         |         |         |         |         |         |         x         |         |
    40.000           80.000|         |         |         |         |         |         |         |         x         |         |
    41.000           90.000|         |         |         |         |         |         |         |         |         x         |
    42.000           90.000|         |         |         |         |         |         |         |         |         x         |
    43.000           90.000|         |         |         |         |         |         |         |         |         x         |
    44.000           90.000|         |         |         |         |         |         |         |         |         x         |
    45.000           90.000|         |         |         |         |         |         |         |         |         x         |
    46.000           90.000|         |         |         |         |         |         |         |         |         x         |
    47.000           90.000|         |         |         |         |         |         |         |         |         x         |
    48.000           90.000|         |         |         |         |         |         |         |         |         x         |
    49.000           90.000|         |         |         |         |         |         |         |         |         x         |
    50.000           90.000|         |         |         |         |         |         |         |         |         x         |
    51.000           90.000|         |         |         |         |         |         |         |         |         x         |
    52.000           90.000|         |         |         |         |         |         |         |         |         x         |
    53.000           90.000|         |         |         |         |         |         |         |         |         x         |
    54.000           90.000|         |         |         |         |         |         |         |         |         x         |
    55.000           90.000|         |         |         |         |         |         |         |         |         x         |
    56.000           90.000|         |         |         |         |         |         |         |         |         x         |
    57.000           90.000|         |         |         |         |         |         |         |         |         x         |
    58.000           90.000|         |         |         |         |         |         |         |         |         x         |
    59.000           90.000|         |         |         |         |         |         |         |         |         x         |
    60.000           90.000|         |         |         |         |         |         |         |         |         x         |
```

```
     61.000             90.000|         |         |         |         |         |         |         |         |         x         |
     62.000             90.000|         |         |         |         |         |         |         |         |         x         |
     63.000             90.000|         |         |         |         |         |         |         |         |         x         |
     64.000            100.000|         |         |         |         |         |         |         |         |         |         x
     65.000            100.000|         |         |         |         |         |         |         |         |         |         x
     66.000            100.000|         |         |         |         |         |         |         |         |         |         x
     67.000            100.000|         |         |         |         |         |         |         |         |         |         x
     68.000            100.000|         |         |         |         |         |         |         |         |         |         x
     69.000            100.000|         |         |         |         |         |         |         |         |         |         x
     70.000            100.000|         |         |         |         |         |         |         |         |         |         x
     71.000            100.000|         |         |         |         |         |         |         |         |         |         x
     72.000            100.000|         |         |         |         |         |         |         |         |         |         x
     73.000            100.000|         |         |         |         |         |         |         |         |         |         x
     74.000            100.000|         |         |         |         |         |         |         |         |         |         x
     75.000            100.000|         |         |         |         |         |         |         |         |         |         x
     76.000            100.000|         |         |         |         |         |         |         |         |         |         x
     77.000            100.000|         |         |         |         |         |         |         |         |         |         x
     78.000            100.000|         |         |         |         |         |         |         |         |         |         x
     79.000            100.000|         |         |         |         |         |         |         |         |         |         x
     80.000            100.000|         |         |         |         |         |         |         |         |         |         x
     81.000            100.000|         |         |         |         |         |         |         |         |         |         x
     82.000            100.000|         |         |         |         |         |         |         |         |         |         x
     83.000            100.000|         |         |         |         |         |         |         |         |         |         x
     84.000            100.000|         |         |         |         |         |         |         |         |         |         x
     85.000            100.000|         |         |         |         |         |         |         |         |         |         x
     86.000            100.000|         |         |         |         |         |         |         |         |         |         x
     87.000            100.000|         |         |         |         |         |         |         |         |         |         x
     88.000            100.000|         |         |         |         |         |         |         |         |         |         x
     89.000            100.000|         |         |         |         |         |         |         |         |         |         x
     90.000            100.000|         |         |         |         |         |         |         |         |         |         x
     91.000            100.000|         |         |         |         |         |         |         |         |         |         x
     92.000            100.000|         |         |         |         |         |         |         |         |         |         x
     93.000            100.000|         |         |         |         |         |         |         |         |         |         x
     94.000            100.000|         |         |         |         |         |         |         |         |         |         x
     95.000            100.000|         |         |         |         |         |         |         |         |         |         x
     96.000            100.000|         |         |         |         |         |         |         |         |         |         x
     97.000            100.000|         |         |         |         |         |         |         |         |         |         x
     98.000            100.000|         |         |         |         |         |         |         |         |         |         x
     99.000            100.000|         |         |         |         |         |         |         |         |         |         x
                              |--------10--------20--------30--------40--------50--------60--------70--------80--------90-------100

    tally            signal                  noise
  upper bin      pdf        cum.        pdf        cum.
  1.929E+01  0.000E+00  1.000E+00  1.000E-01  1.000E+00
  1.958E+01  0.000E+00  1.000E+00  0.000E+00  9.000E-01
  1.987E+01  0.000E+00  1.000E+00  0.000E+00  9.000E-01
  2.015E+01  0.000E+00  1.000E+00  1.000E-01  9.000E-01
  2.044E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.073E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.102E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.131E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.160E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.188E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.217E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.246E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.275E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.304E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.333E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.361E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.390E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.419E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.448E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.477E+01  0.000E+00  1.000E+00  0.000E+00  8.000E-01
  2.506E+01  1.000E-01  1.000E+00  2.000E-01  8.000E-01
```

2.535E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.563E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.592E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.621E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.650E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.679E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.708E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.736E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.765E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.794E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.823E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.852E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.881E+01	0.000E+00	9.000E-01	0.000E+00	6.000E-01
2.910E+01	1.000E-01	9.000E-01	2.000E-01	6.000E-01
2.938E+01	0.000E+00	8.000E-01	0.000E+00	4.000E-01
2.967E+01	0.000E+00	8.000E-01	0.000E+00	4.000E-01
2.996E+01	0.000E+00	8.000E-01	0.000E+00	4.000E-01
3.025E+01	0.000E+00	8.000E-01	1.000E-01	4.000E-01
3.054E+01	0.000E+00	8.000E-01	0.000E+00	3.000E-01
3.083E+01	0.000E+00	8.000E-01	0.000E+00	3.000E-01
3.111E+01	2.000E-01	8.000E-01	1.000E-01	3.000E-01
3.140E+01	0.000E+00	6.000E-01	0.000E+00	2.000E-01
3.169E+01	0.000E+00	6.000E-01	0.000E+00	2.000E-01
3.198E+01	0.000E+00	6.000E-01	0.000E+00	2.000E-01
3.227E+01	0.000E+00	6.000E-01	2.000E-01	2.000E-01
3.256E+01	0.000E+00	6.000E-01	0.000E+00	0.000E+00
3.284E+01	0.000E+00	6.000E-01	0.000E+00	0.000E+00
3.313E+01	0.000E+00	6.000E-01	0.000E+00	0.000E+00
3.342E+01	0.000E+00	6.000E-01	0.000E+00	0.000E+00
3.371E+01	0.000E+00	6.000E-01	0.000E+00	0.000E+00
3.400E+01	1.000E-01	6.000E-01	0.000E+00	0.000E+00
3.429E+01	0.000E+00	5.000E-01	0.000E+00	0.000E+00
3.458E+01	0.000E+00	5.000E-01	0.000E+00	0.000E+00
3.486E+01	0.000E+00	5.000E-01	0.000E+00	0.000E+00
3.515E+01	1.000E-01	5.000E-01	0.000E+00	0.000E+00
3.544E+01	0.000E+00	4.000E-01	0.000E+00	0.000E+00
3.573E+01	0.000E+00	4.000E-01	0.000E+00	0.000E+00
3.602E+01	0.000E+00	4.000E-01	0.000E+00	0.000E+00
3.631E+01	0.000E+00	4.000E-01	0.000E+00	0.000E+00
3.659E+01	0.000E+00	4.000E-01	0.000E+00	0.000E+00
3.688E+01	1.000E-01	4.000E-01	0.000E+00	0.000E+00
3.717E+01	0.000E+00	3.000E-01	0.000E+00	0.000E+00
3.746E+01	0.000E+00	3.000E-01	0.000E+00	0.000E+00
3.775E+01	0.000E+00	3.000E-01	0.000E+00	0.000E+00
3.804E+01	0.000E+00	3.000E-01	0.000E+00	0.000E+00
3.832E+01	0.000E+00	3.000E-01	0.000E+00	0.000E+00
3.861E+01	0.000E+00	3.000E-01	0.000E+00	0.000E+00
3.890E+01	1.000E-01	3.000E-01	0.000E+00	0.000E+00
3.919E+01	0.000E+00	2.000E-01	0.000E+00	0.000E+00
3.948E+01	0.000E+00	2.000E-01	0.000E+00	0.000E+00
3.977E+01	0.000E+00	2.000E-01	0.000E+00	0.000E+00
4.006E+01	0.000E+00	2.000E-01	0.000E+00	0.000E+00
4.034E+01	0.000E+00	2.000E-01	0.000E+00	0.000E+00
4.063E+01	0.000E+00	2.000E-01	0.000E+00	0.000E+00
4.092E+01	0.000E+00	2.000E-01	0.000E+00	0.000E+00
4.121E+01	1.000E-01	2.000E-01	0.000E+00	0.000E+00
4.150E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00
4.179E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00
4.207E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00
4.236E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00
4.265E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00
4.294E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00
4.323E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00
4.352E+01	0.000E+00	1.000E-01	0.000E+00	0.000E+00

```
4.380E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.409E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.438E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.467E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.496E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.525E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.554E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.582E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.611E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.640E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.669E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.698E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.727E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.755E+01  0.000E+00  1.000E-01  0.000E+00  0.000E+00
4.784E+01  1.000E-01  1.000E-01  0.000E+00  0.000E+00
```

4.2.6 Repeated Structure/Lattice Tally Example

An explanation of the basic repeated structure/lattice tally format can be found in Section 3.3.5.1.4. The example shown here illustrates more complex uses.

Example 43 - repeated structure lattice tally example

```
1  0         –1 –2   3  13  fill=4
2  0         –1 –2   3 –13  fill=1
3  0         –4  5  –6   7  u=1 lat=1
     fill=–2:2 –2:0 0:0 1 1 3 1 1 1 3 2 3 1 3 2 3 2 3
4  0         –8  9 –10  11  u=2 fill=3 lat=1
5  1 –0.1  –12              u=3
6  0         12             u=3
7  0        –14 –2   3      u=4 fill=3 trcl=(-60 40 0)
8  like 7 but trcl=(-30 40 0)
9  like 7 but trcl=(0 40 0)
10 like 7 but trcl=(30 40 0)
11 like 7 but trcl=(60 40 0)
12 0         #7 #8 #9 #10 #11 u=4
13 0         1:2:-3

1  cz   100
2  pz   100
3  pz  -100
4  px    20
5  px   -20
6  py    20
7  py   -20
8  px    10
9  px   -10
```

```
10 py    10
11 py   -10
12 cz     5
13 py    19.9
14 cz    10

f4:n   5 6 (5 6 3) $ 3 bins
      (5<3) (5<(3[–2:2 –2:0 0:0]))                            $2 bins
      (5<(7 8 9 10 11)) (5<7 8 9 10 11<1) (5<1)               $7 bins
      ((5 6)<3[0 –1 0]) ((5 6)<3[0:0 –1:-1 0:0]) ((5 6)<3[8]) $3 bins
      (5<(4[0 0 0]3[8]))(5<4[0 0 0]<3[8])
           (3<(3[1]3[2]3[4]3[5]3[6]3[10]))                    $3 bins
      (5<u=3)                                                 $12 bins
```

(a)

(b)

(c)

(d)

(e)

(f)

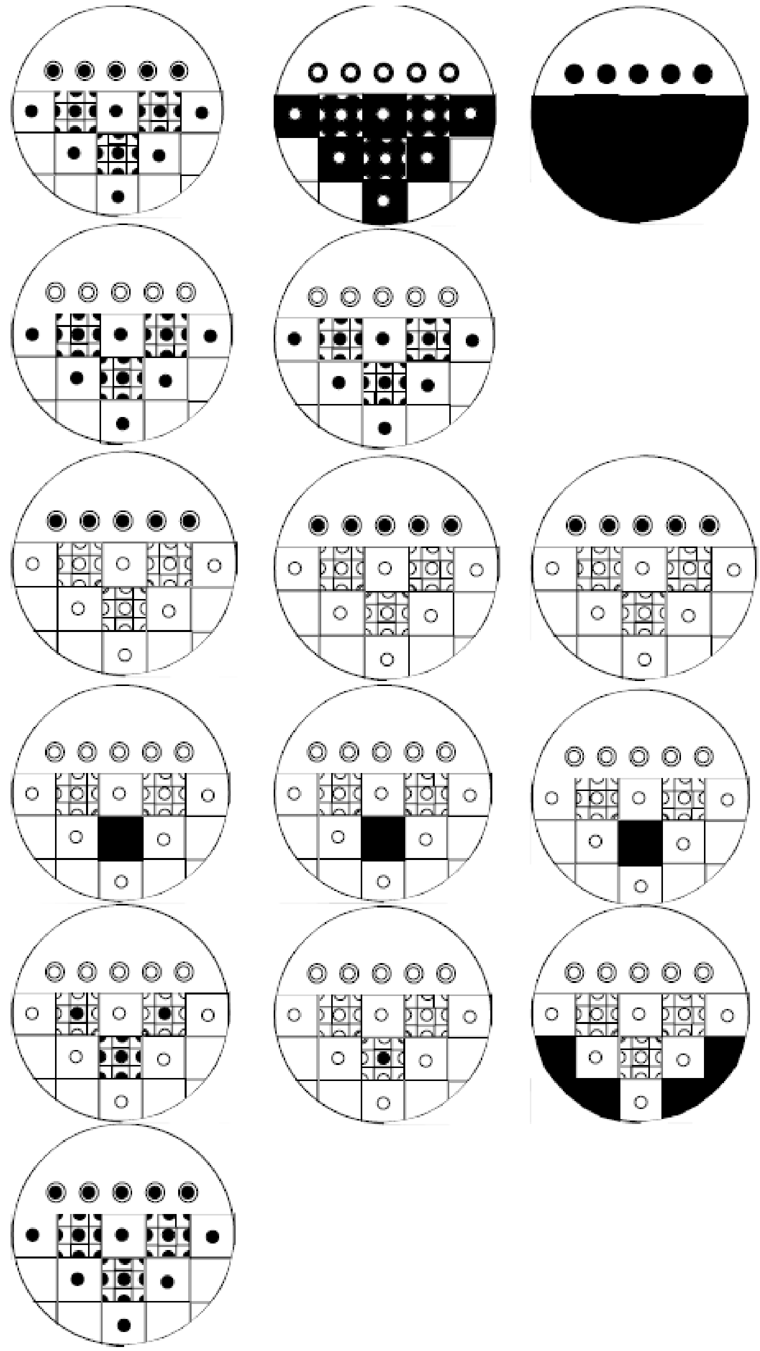


Figure 4-44 (a–f) indicates the tally regions for each tally line. The number of bins generated by MCNP6 is shown at the end of each tally line following the $ in-line comment symbol.

Tally line 1: This first line creates three tally output bins: cell 5, cell 6, and the union of cells 5, 6, and 3, as indicated in Figure 4-44a. Because cell 3 is filled entirely by cells 5 and 6, a tally over cell 5 plus cell 6 is the same as a tally over cell 3. If a particle is tallied in cell 5 and tallied in cell 3, it will be tallied twice in the bin (5 6 3).

Caution: A true union *is* performed when first level cells overlap (or fill) another cell. This is *not* a tally that is normally desired. If an average of cell 3 and region (5 6) outside cell 3 is desired, separate bins must be defined and properly combined using correct volume weighting.

Tally line 2: These two input tally bins result in identical output tallies, as shown in Figure 4-44b. The use of lattice index brackets that include all existing lattice elements makes the two tallies equivalent. The simpler format will execute faster.

Tally line 3: This line illustrates omission of geometry levels and a single output bin versus multiple bins. All three input bins tally cell 5 within cells 7 through 11. The second bin specifies the entire path explicitly. Because the only place cell 5 exists within cell 1 is in cells 7–11, the 7–11 specification can be omitted, as in the third input bin. In the second input bin, the parentheses around cells 7–11 are omitted, creating multiple output bins. Five tally bins are produced: (5<7<1), (5<8<1), (5<9<1), (5<10<1), and (5<11<1). The sum of these five bins should equal the tally in the first and last output bins on this line. The tally regions are shown in Figure 4-44c.

Tally line 4: This line illustrates the union of multiple tally cells, (5 6), and various ways of specifying lattice index data. The three input tally bins create three output tally bins with identical values because the three different lattice descriptions refer to the same lattice element, the eighth entry on the FILL array. If the parentheses around (5 6) were removed, two output bins would be created for each input bin, namely (5<3[0 -1 0]) and (6<3[0 -1 0]), etc. The tally regions are shown in Figure 4-44d.

Tally line 5: This line illustrates tallies in overlapping regions in repeated structures in a lattice and a tally in lattice elements filled with themselves. Three tally output bins are produced. In the first input bin, a particle is tallied only once when it is in cell 5 and in 4[0 0 0] or when it is in cell 5 and in 3[0 -1 0]. Figure 4-44e shows all the cell 5 instances included in this tally bin. This tally is probably more useful than the overlapping regions in tally line 1. Input bin 2 demonstrates a tally for a nested lattice. A tally is made when a particle is in cell 5 and in cell 4, element [0 0 0] and in cell 3, element [0 -1 0]. Note that 3[0 -1 0] is indeed filled with cell 4 (u=2). If that were not true, a zero tally would result in this bin. The final input tally bin demonstrated a tally in lattice elements that are filled with their own universe number. This method is the only way to tally in these elements separate from the rest of cell 3.

Tally line 6: This line illustrates the universe format. The single input bin includes all possible chains involving cell 5. Because u=3 is not within parentheses, the input is expanded into twelve output bins: (5<3[3], etc.). The format 3[3] indicates the third lattice element of cell 3 as entered on the cell 3 FILL array. Note that the third element is filled by universe 3, consisting of cells 5 and 6. The tally regions are shown in Figure 4-44f.

4.2.7 Miscellaneous Tally Examples

4.2.7.1 LIGHT ION RECOIL (RECL)

MCNP6 can produce and track ions created by elastic recoil from neutrons or protons. Neutrons and protons undergoing elastic scatter with light nuclei (H, D, T, ^{3}He, and ^{4}He) can create ions (protons, deuterons, tritons, ^{3}He, and α) that are banked for subsequent transport.

Example 44: Figure 4-45 shows the energy-angle production of alphas created from 15-MeV neutrons striking ^{4}He. Note that in the forward bin, cosine $0.8<\mu<1$, the α energy goes up to the theoretical maximum of 9.6 MeV. The theoretical maxima in the other cosine bins (0.8, 0.6, 0.4, and 0.2) are 6.144, 3.456, 1.536, and 0.384.

The input file for this example is as follows.

```
Test of light ion recoil
1  1  1e-5    -1
2  0           1

1 so      1.e-5

mode      n  a
imp:n,a   1  0
phys:n   6j  1
sdef     erg=15
print   -161 -162
tmp1     1e-20  0
fcl:n     1  0
m1        2004  0.2
cut:a     j  0
nps       1000000
f51:a     1
e51       0.1 100log 20
c51      -0.8  8i  1  t
fq51      e  c
```

The plot commands to produce Figure 4-45 are presented in the following plot command file.

```
rmct lir.m tal 51 xlim .1 15 loglog &
title 1 "Light Ion Recoil: 15 MeV Neutrons on 4He" &
title 2 "Alpha Energy vs Cosine" &
fix c 11 label 1 "cos total" cop fix c 6 label 2 "cos -1-.2" &
cop fix c 7 label 3 "cos .2-.4" cop fix c 8 label 4 "cos .4-.6" &
cop fix c 9 label 5 "cos .6-.8" cop fix c 10 label 6 "cos .8-1."
```

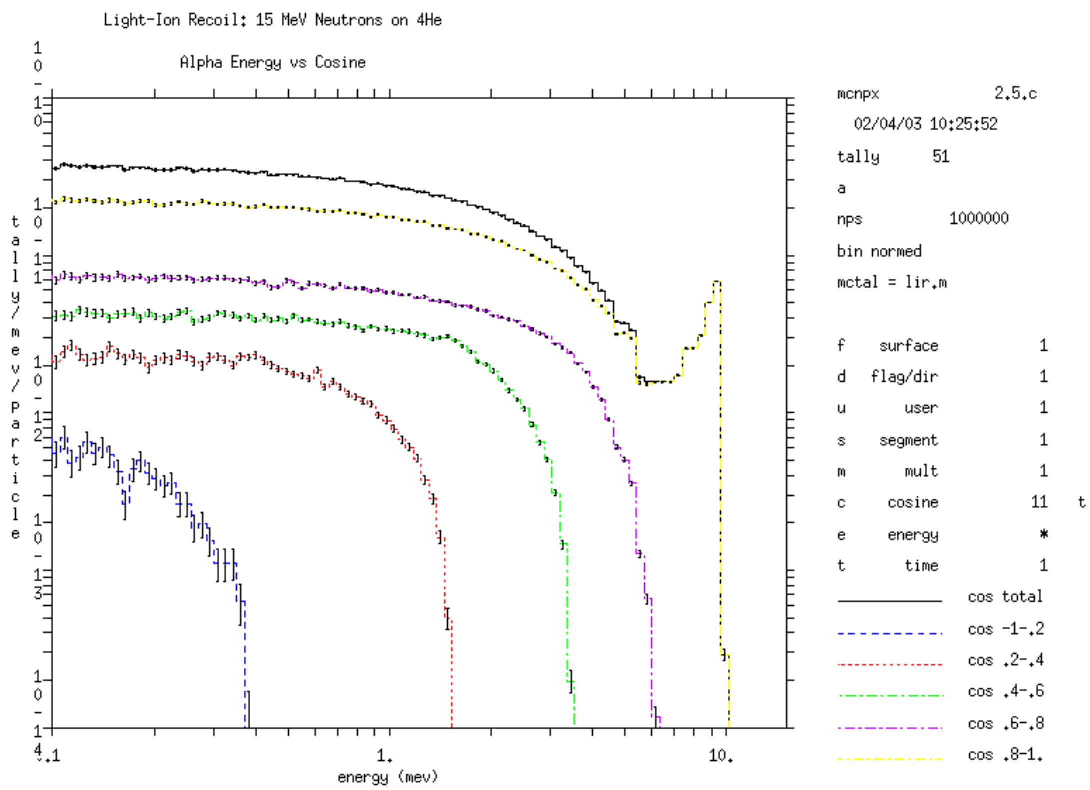


Figure 4-45. Light ion recoil.

4.2.7.2 INLINE GENERATION OF DOUBLE DIFFERENTIAL CROSS SECTIONS AND RESIDUAL NUCLEI

The double differential cross sections and distributions of residual nuclei for a single nuclear interaction thus may be calculated directly in MCNP6. Tallying of the residual nuclei is discussed in the `FT8 RES` tally description (see Section 3.3.5.18). Tallying of the differential cross section can be done with standard `F1` surface tallies, as shown in the following example. The input file models a 1.2-GeV proton source having a single collision with ^{208}Pb.

```
Test of p(1.2GeV)+Pb(208)
1 1 -11. -1 imp:h 1
2 0        1 imp:h 0

1 so .01

mode h n
sdef par h erg=1200 vec 0 0 1 dir 1
```

```
m1 82208 1
phys:h 1300 j 0
phys:n 1300 3j 0
nps 10000
fc1  *** neutron angle spectra tally ***
f1:n  1
ft1  frv 0 0 1
fq1 e c
*c1 167.5 9i 17.5 0 T
e1 1 50log 1300 T
lca   2 1 1 23 1 1 0 -2 0
```

The differential production for neutron production is tallied in the `F1` current tally with energy and time bins. This tally is simply the neutrons that are created from the single proton collision with lead and then escape. These data may be plotted with MCNP6 using the tally plotter and then following execute line command

```
MCNP   Z   ,
```

where the command file, COM91, is

```
rmctal=mctl91
file all loglog xlim 1 1300 ylim 1e-6 1 &
fix c 13 cop fix c 1 cop fix c 6 cop fix c 12
```

In Figure 4-46, the first line (solid black) is the energy spectrum over all angles, the second (blue dashed) is the 180° output, the third (red dotted) is the 100° output, and the fourth (green broken) is the 0° output. Use of the `FM -3` option for Tally 1 in this example will convert these production results into differential cross sections (units of barns).

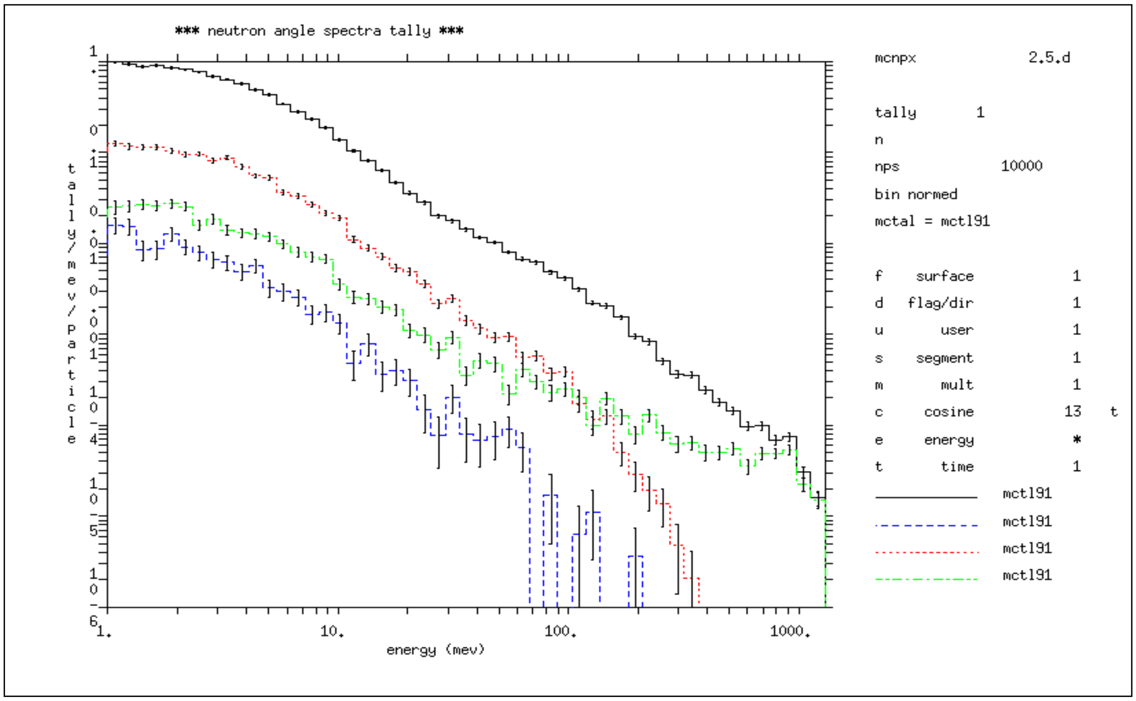


Figure 4-46. Differential production at all angles (black), 180° (blue), 100° (red), 0° (green), for 1.3-GeV protons on $^{208}_{82}\mathrm{Pb}$**.**

4.2.7.3 COMPTON IMAGE TALLY EXAMPLE

This example involves a 2-MeV isotropic photon source located off-center (-5,3,3) at ~4 cm from two 1x5x5 Si panels , with the back panel 3 cm behind the front (front panel is centered at -1,0,0) Figure 4-47. The Si voxels are 2x2x2 cm, making the panels 2x10x10 cm overall in size (see Fig. 3-1 and the input file for INP1). The image plane is coincident with the source location, so it too is ~4 cm from the front panel detector. The size of the image plane is 20 cm in each direction, with 10 grid elements along these "S" and "T" axes. The energy thresholds were set to 0.2 MeV. Figure 4-48 presents the corresponding Compton Image.

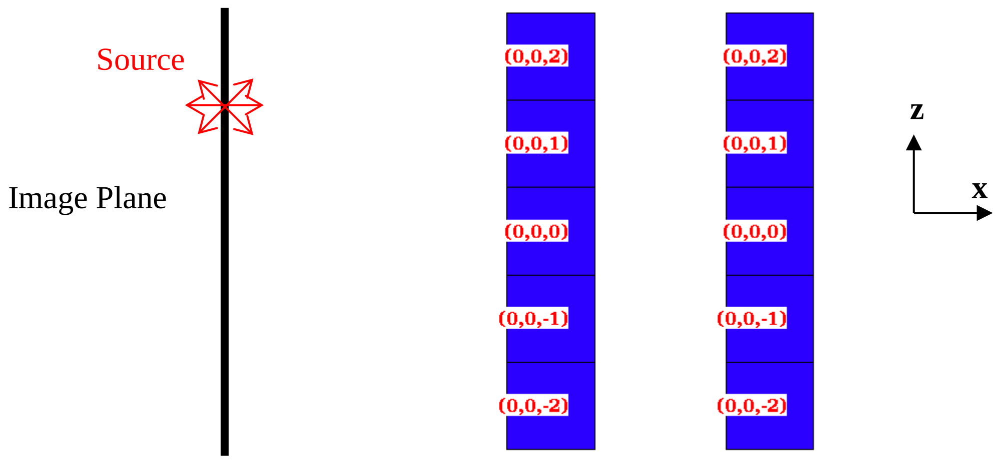


Figure 4-47 Geometry plot of Compton Imaging Tally Example, showing lattice indices for the front and back detector panels.

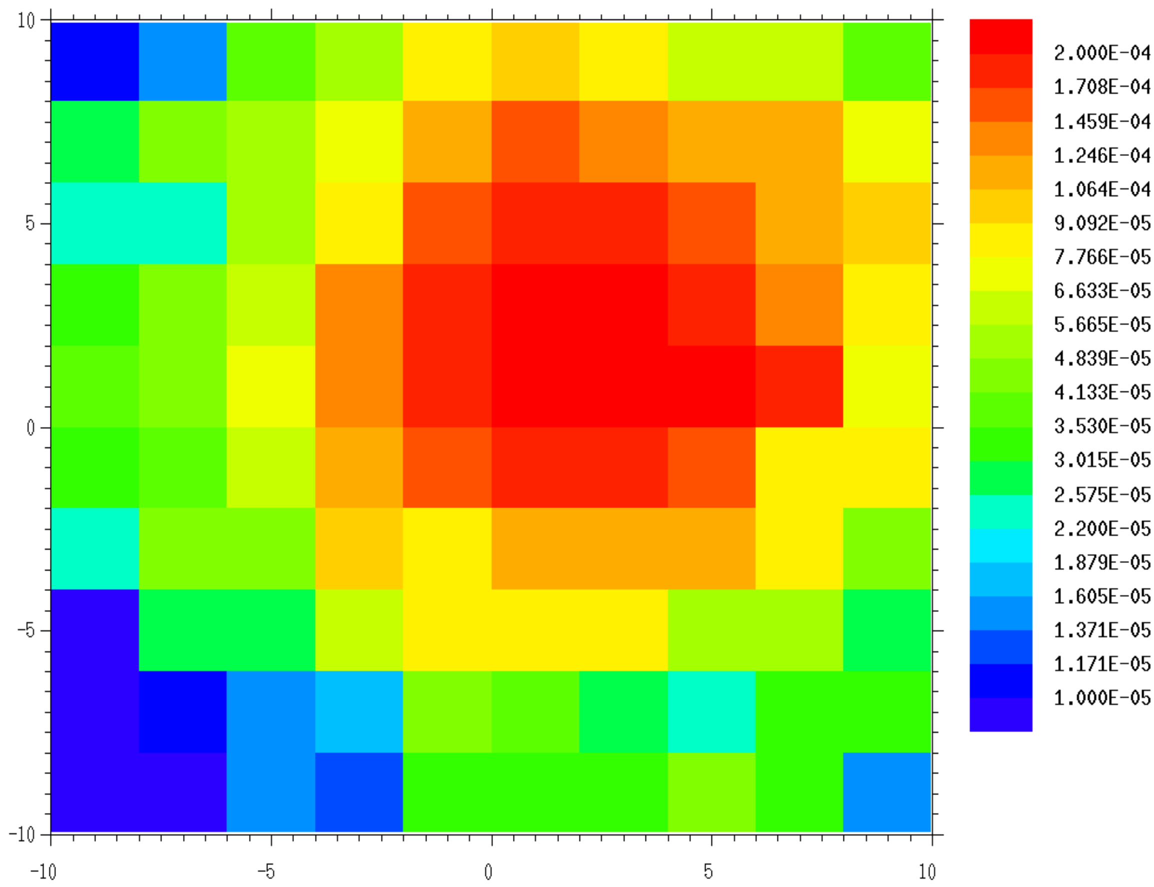


Figure 4-48. Compton image for Compton Imaging Tally Example, using a 20x20 cm image plane with 10x10 grid elements.

Example 45 – INP1

```
2-MeV photons into Si grid
1 1 -2.3 -1 lat=1 u=1       imp:p=1
           fill=0:0 -2:2 -2:2 1 24r
2 1 -2.3 -2 lat=1 u=2       imp:p=1
           fill=0:0 -2:2 -2:2 2 24r
3 0      -3   fill=1        imp:p=1
4 0      -4   fill=2        imp:p=1
5 0      -5 4 3             imp:p=1
6 0       5                 imp:p=0

1 rpp  -1 1  -1 1  -1 1
```

```
2 rpp   4 6  -1 1  -1 1
3 rpp  -1 1  -5 5  -5 5
4 rpp   4 6  -5 5  -5 5
5 sph  0 0 0  100

m1  14028 1
mode p e
cut:p,e 2j 0 0 $ Analog capture
phys:e  2j 1   $ Turn off Brems.
sdef par=p pos=-5 3 3 erg=2
fir5 -5 0 0 0 1 0 0 1 1 1
FS5 -10 9i 10
CS5 -10 9i 10
f16:e (1<1[0:0 -2:2 -2:2]<3)
f26:e (2<2[0:0 -2:2 -2:2]<4)
f8:e  1
ft8   PHL 1 16 0    $ Region 1
          1 26 0    $ Region 2
          0
      COM 5 1
e8   0.2 100 NT
fu8  0.2 100 NT
tf8  j j 2 j j j 2 j
print
nps  500000
prdmp 2j -1
```

4.2.8 TALLYX Subroutine Examples

An explanation of the TALLYX subroutine arguments can be found in Section 3.3.5.17. Only examples illustrating some uses of TALLYX will be found here.

Example 46:

In example 33 of using the FS*n* card (Section 4.2.4) to get the flux through a window on the face of a cube, instead of using the FS2 card which established five sub tallies, TALLYX could have been used to get only the desired window tally. Two input cards are used:

```
FU2      1
RDUM    -0.5 0.5 -0.5 0.5
```

The following subroutine performs the work of extracting the desired window tally. The subroutine is implemented just like a user-provided SOURCE subroutine by replacing the file TALLYX.F90. Note that IB=0 and IBU=1 upon entry into TALLYX.

```
subroutine tallyx(t,ib)
  use mcnp_params
  use mcnp_global
  use pblcom, only: pbl
  use mcnp_debug

  implicit none

  real(dknd), intent(inout) :: t
  integer,    intent(inout) :: ib

  if( (pbl%r%x < rdum(1)) .or. (pbl%r%x > rdum(2)) ) ib=-1
  if( (pbl%r%z < rdum(3)) .or. (pbl%r%z > rdum(4)) ) ib=-1
  return
end subroutine tallyx
```

The subroutine was generalized a bit by using the RDUM input card, although the card could have been avoided by directly encoding the values of the dimensions of the window into TALLYX.

Example 47:

Calculate the number of neutron tracks exiting cell 20 per source neutron. The input cards are

```
F4:N     20
FU4       1
SD4       1
```

and TALLYX becomes

```
subroutine tallyx(t,ib)
  use mcnp_params
  use mcnp_global
  use tskcom, only: pmf
  use pblcom, only: pbl
  use mcnp_debug

  implicit none

  real(dknd), intent(inout) :: t
  integer,    intent(inout) :: ib

  t=1.0_dknd
  if (pmf < pbl%r%dls) ib = -1
  return
end subroutine tallyx
```

The quantity `t=1.0` is scored every time a track exits cell 20. The variables used in this subroutine, PMF (the distance to collision) and DLS (distance to the boundary), are available to TALLYX from the modules TSKCOM and PBLCOM.

Example 48:

Divide the point detector scores into separate tallies (that is, user bins) depending on which of the 20 cells in a problem geometry caused the contributions. The input cards are

```
F5:N    0  0  0  0
FU5     1  18I  20
```

and TALLYX is

```
subroutine tallyx(t,ib)
  use mcnp_params
  use mcnp_global
  use tskcom, only: ibu
  use pblcom, only: pbl
  use mcnp_debug

  implicit none

  real(dknd), intent(inout) :: t
  integer,    intent(inout) :: ib

  ibu=pbl%i%icl
  return
end subroutine tallyx
```

The `FU5` card establishes 20 separate user bins, one for each cell in the problem. Note the use of the "*n*`I`" input format, described in Section 2.8.1, which creates 18 linear interpolates between 1 and 20.

Example 49:

Determine the quantity $\int\varphi(E)\, f(E)\, dE$ in cell `14` where $f(E)=e^{\alpha t}$. The input cards are

```
F4:N    14
FU4      α
```

where α is a numerical value and TALLYX is

```
subroutine tallyx(t,ib)
  use mcnp_params
  use mcnp_global
  use tskcom, only: ital
  use pblcom, only: pbl
  use mcnp_debug
```

```
    implicit none

    real(dknd), intent(inout) :: t
    integer,    intent(inout) :: ib

    t=t*exp(tds(iptal(3,1,ital)+1)*pbl%r%tme)
    return
  end subroutine tallyx
```

The FU4 card establishes a single user bin, and the value of α is stored in TDS(IPTAL(3,1,ITAL)+1) and used for the tally label.

Example 50:

Tally the number of neutrons passing through cell 16 that have had 0, 1, 2, 3, or 4 collisions. The input cards are

```
F4:N    16
FU4      0  1  2  3  4
SD4      1
```

and TALLYX is

```
subroutine tallyx(t,ib)
  use mcnp_params
  use mcnp_global
  use tskcom, only: ibu
  use pblcom, only: pbl
  use mcnp_debug

  implicit none

  real(dknd), intent(inout) :: t
  integer,    intent(inout) :: ib

  ibu = pbl%i%ncp
  if(ibu > 5 ) ib=-1
  t=pbl%r%wgt
  return
end subroutine tallyx
```

If the IF statement in this TALLYX is omitted, a count will be made of the cases of five or more collisions, and in these cases no score will be tallied but a count will be printed of the times that the tally was unable to be made because IBU was a value where no bin existed.

In the five user bins, `t` is the number of neutrons per source neutron passing through cell `16` that have undergone 0, 1, 2, 3, or 4 collisions, respectively. Note that the `FU4` card has five entries to establish the five user bins and provide labels. Note also that in this example, the neutrons are calculated so that `t=t` × renormalization factor (which preserves the weight associated with the tracks), where in TALLYX subroutine Example 3 the neutron tracks are calculated so that `t=1`. Finally, note that if `pbl%i%ncp>5` (six or more collisions) no tally is made because IB is set to be less than zero. If an `E4` card was added, the neutrons would be tallied as a function of energy for each user bin.

4.3 SOURCE EXAMPLES

4.3.1 General Source

Some examples of the general source are given here to illustrate the power and complexity of this feature. Refer to Section 3.3.4 for a more complete explanation and other examples.

The following example is of the general source that illustrates two levels of dependency. Let us assume a duct streaming problem where the source at the duct opening has been obtained from a reactor calculation. Energies above 13.5 MeV have one angular distribution and energies below 13.5 MeV have a different angular distribution. The source has a uniform spatial distribution on a circular disk of radius 37 cm centered at *x*,*y*,*z* on planar surface `1` going into cell `2`.

Example 51:

```
SDEF  ERG = D1  DIR FERG D2  SUR = 1  CEL = 2
      POS = x y z  RAD D5  AXS u v w  VEC u v w
c Source Definition Card.
c In this example, AXS is needed to define a vector which
c defines the source plane of a disk source.
c In this example, POS defines the location of the center
c of the disk.
c VEC is the direction that source particles will be
c travelling once created.
c AXS and VEC can be different.
c For this duct streaming problem, they should be the same.
c
SI1  H  1E-7  1E-5 ... 13.5  14 ...    20
c Source Information 1 (SI1) corresponds to D1.
c H indicates histogram values follow.
c
SP1  D  0    10E-4 ... 10E-2 10E-1 ... 0.3
c Source Probability 1 (SP1) augments SI1.
c D indicates discrete values.
c Probability of each bin on SI1.
c The probability a source particle will be between 10E-7
c and 10E-5 MeV is 10E-4.
```

```
c
DS2  S  3     3 ...    3     4 ...     4
c Dependent Source 2 (Depends as a function of ERG).
c S indicates numbers following are themselves other
c distributions.
c In this example, if a particle has an energy in bin 10E-7 to
c 10E-5, then it will have a direction associated with source
c distribution 3.
c
SI3     0   0.2 ... 1
c Source Information 3 (Second Level)
c Default is histogram values.
c
SP3  D  0  1E-4 ... 0.1
c Source Probability 3 (Second Level).
c Probability of each bin on SI3.
c
SI4     0   0.1 ... 1
c Source Information 4 (Second Level).
c Default is histogram values.
c
SP4  D  0  1E-2 ... 0.1
c Source Probability 4 (Second Level).
c Probability of each bin on SI4.
c
SI5     37
c Source Information 5.
c Default is histogram values.
c There is one bin from 0 to 37.
c When used with the RAD keyword on the SDEF card, it indicates
c a circular distribution from 0 to 37 cm.
c
SP5     -21 1
c Source Probability 5.
c The -21 indicates a sampling scheme based on a power of the
c variable.
c In this case, the sampling is a function of radius^1,
c which results in a uniform spatial distribution over the disk.
c Since a uniform spatial distribution is the default for disk
c sources, this card is optional.
c
```

This example can be expanded by having the source in two ducts instead of one (with the same energy and angular distribution as before). The SI1, SP1, DS2, SI3, SP3, SI4, and SP4 cards remain unchanged, but the SI5 and SP5 cards are no longer valid. The SDEF card is changed as shown below and the other cards are added.

```
SDEF  ERG = D1  DIR FERG D2  SUR = D6  CEL FSUR D7
      POS FSUR D8  RAD FSUR D9  AXS FSUR D10 VEC FSUR D10
SI6  L     1         7
c Source Information 6.
c L indicates discrete values, in this case surface 1 or 7
c
SP6  D     0.6       0.4
c Source Probability 6.
c Probability of each value on SI6.
c
DS7  L     2         8
c Dependent Source 7 (Depends as a function of SUR).
c L indicates discrete value, in this case cell 2 or 8,
c depending on whether surface 1 or 7, respectively, was chosen.
c
DS8  L     x1 y1 z1    x2 y2 z2
c Dependent Source 8 (Depends as a function of SUR).
c L indicates discrete values, in this case the respective centers,
c of two disks, depending on whether surface 1 or 7 was chosen.
c
DS9  S     11        12
c Dependent Source 9 (Depends as a function of SUR).
c S indicates other distributions, in this case the respective radii,
c of two disks, depending on whether surface 1 or 7 was chosen.
c
DS10 L     u1 v1 w1    u2 v2 w2
c Dependent Source 10 (Depends as a function of SUR).
c L indicates discrete values, in this case the vectors that define a
c plane that the disk is on and the vector from which DIR is measured.
c In this streaming problem, AXS=VEC, and both depend on whether
c surface 1 or 7 was chosen.

SI11       0   37
SP11     -21    1
SI12       0   25
SP12     -21    1
c In this problem, the radius of the duct depends on which
c duct was chosen.
```

Example 52:

This example is a two-source-cell problem where the material in one cell is uranium and in the other is thorium. The uranium cell has two isotopes, ^{235}Uand ^{238}U, and the thorium has one, ^{232}Th. Each isotope has many photon lines from radioactive decay. The following input cards describe this source.

```
SDEF  CEL D1  ERG FCEL D2  POS FCEL D3
c
SC1 Source Cells
c Source Comment 1
c
SI1  L  1  2
c Source Information 1
c L indicates discrete values, in this case cell 1 or 2.
c The cell also determines the element in this problem.
c
SP1  D  2  1
c Source Probability 1
c Probability of each value on SI1. Here the cell with
c uranium is twice as likely as the thorium cell.
c Other distributions based on volume or decay rate,
c for example, are also possible.
c
SC2 source "spectra"
DS2  S  4  5
c Dependent Source 2 (Depends as a function of CEL).
c S indicates numbers following are themselves other
c distributions.
c In this example, if a particle starts in cell 1, then the
c ERG is defined by source distribution 4.
c
DS3  L  0 0 0  10.5 0 0
c
SC4 uranium nuclides
SI4  S  6  7
SP4  D  1  3
c Source Distribution and Probability 4.
c Here the specific uranium isotope is chosen, 238U is
c three times more likely than 235U.
c
SC5 thorium nuclide
SI5  S  8
SP5  D  1
c Source Distribution and Probability 5.
c Only one isotope of thorium is possible.
c
SC6 235U photon lines
SI6  L   1.0  2.0 $ E1 ... EI
SP6  D     1    2 $ I1 ... II
SC7 238U photon lines
SI7  L   0.1  0.2 $ E1 ... EI
SP7  D     2    1 $ I1 ... II
```

```
SC8 232Th photon lines
S
  L  0.01 0.02 $ E1 ... EI
SP8  D     1    1 $ I1 ... II
```

Example 53:

```
SDEF  SUR=D1  CEL FSUR D2  ERG FSUR D6
      X FSUR D3  Y FSUR D4  Z FSUR D5
c
SI1  L   11    0
c Source Information 1
c L indicates discrete values, in this case surface 11 or 0
c (meaning the source point is not on a surface).
c
SP1      0.8   0.2
DS2  L   0     88
c Dependent Source 2 (Depends as a function of FSUR).
c L indicates discrete values, in this case cell 0,
c (meaning the point may not be within a cell), or cell 88.
c Note that with Distribution 1, the source point may either be
c on surface 11 (80% probability) or within cell 88
c (20% probability).
c
DS6  S   61    62
SP61     -3   0.98   2.2
SP62     -3   1.05   2.7
c Source Probabilities 61 and 62.
c The -3 indicates the energy is sampled from the Watt Fission
c Spectrum.
c
DS3  S    0    31
SI31     20    30
SP31      0     1
c Source Information and Probabilities for Distribution 3.
c In this case, the 0 on the DS3 card indicates that no
c distribution is given; the default variable will be selected.
c For this case, if surface 11 was selected, the variable
c POS will default to the coordinates 0 0 0.
c If surface 11 was not selected, the source point must be
c within cell 88,and the x coordinate is sampled from a single
c bin histogram with values between 20 and 30.
c Since this value corresponds to a position, the units are cm.
c
DS4  S    0    41
SI41    -17    36
SP41      0     1
```

```
DS5  S    0    51
SI51    -10    10
SP51      0     1
```

Of the particles from this source, 80% start on surface 11, and the rest start in cell 88. When a particle starts in cell 88, its position is sampled, with rejection, in the rectangular polyhedron bounded by x=20 to 30, y=−17 to 36, and z=−10 to 10. When a particle starts on surface 11, its cell is found from its position and direction. The energy spectrum of the particles from surface 11 is different from the energy spectrum of the particles from cell 88. A zero after the S option invokes the default variable value.

The following is an example of using the Q option. The low-energy particles from surface *m* come out with a cosine distribution of direction, but the higher-energy particles have a more nearly radial distribution. The energy values on the DS2 card need not be the same as any of the *ei* on the SI1 card.

Example 54:

```
SDEF  ERG=D1  DIR FERG D2  SUR=m
SI1    e1  e2 ... ek
SP1    0   p2 ... pk
DS2       Q   0.3 21   0.8 22   1.7 23   20. 24
SP21    -21  1
SP22    -21  1.1
SP23    -21  1.3
SP24    -21  1.8
```

4.3.2 Beam Sources

By implementing a general transformation on the SDEF card in one of two forms; TR=*n* or TR=D*n*, a user can point a particle beam in space. In either case a general transformation is applied to a source particle *after* its coordinates and direction cosines have been determined using the other parameters on the SDEF card. Particle coordinates are modified by both rotation and translation; direction cosines are modified by rotation only. This allows the user to rotate the direction of the beam or move the entire beam of particles in space. The TR=D*n* card is particularly powerful because it allows the specification of more than one beam at a time.

Example 55: A Single Beam Source

An example of specifying a Gaussian beam follows:

```
Title
c Cell cards
.
.
.
ccc  0     -nnn     $ cookie cutter cell
```

```
c Surface Cards
.
.
.
nnn  SQ   a-2  b-2  0  0  0  0  -c2  0  0  0    $ cookie cutter surface

c Control Cards
SDEF     DIR=1  VEC=0 0 1  X=D1 Y=D2 Z=0  CCC=ccc  TR=n
SP1      -41  fx  0
SP2      -41  fy  0
TRn       x0 y0 z0   cosϕ -sinϕ 0   sinϕ cosϕ 0   0 0 1
```

The SDEF card sets up an initial beam of particles traveling along the z-axis (DIR=1, VEC=0 0 1). Information on the *x*- and *y*-coordinates of particle position is detailed in the two SP cards. (On the SDEF card, the specifications X=D1 and Y=D2 indicate that MCNP6 must look for distributions 1 and 2, here given by source probability distributions, SP1 and SP2.) The z-coordinate is left unchanged (Z=0).

Because there is no PAR option in this example, the particle generated by this source will be the one with the lowest IPT number in Table 2-2 (i.e., neutron).

The SP cards have three entries. The first entry is -41, which indicates sampling is to be done from a built-in Gaussian distribution. This position Gaussian distribution has the following density function:

$$p(x', y') = \left(\exp - \frac{1}{2}\left(\left(\frac{x'}{a}\right)^2 + \left(\frac{y'}{b}\right)^2 \right) \right) / \left(2\pi ab \left(1 - \exp\frac{\left(-c^2\right)}{2} \right) \right)$$

The parameters a and b are the standard deviations of the Gaussian in x and y.

The second entry (f_x or f_y) on the SP cards is the full-width at half-maximum (FWHM) of the Gaussian in either the *x* or *y* direction. These must be computed from a and b by the user as follows:

$$f_x = (8\ln 2)^{\frac{1}{2}} a = 2.35482a$$

$$f_y = (8\ln 2)^{\frac{1}{2}} b = 2.35482b$$

The third entry on the SP cards represents the centroid of the Gaussian in either the *x*- or *y* direction. We recommend that the user input 0 here, and handle any transformations of the source with a TR card as described below. Using a non-zero value will interfere with the rejection function as specified by the "cookie cutter" option.

Note that in print table 10 in the MCNP6 output file, the definitions of a, b, and c are different from those discussed above; however, FWHM will be the same as the 3rd entry on the `SP` cards. The parameter '*a*' in `Table 10` differs from the parameter '*a*' above by a factor of the square root of two. This is a legacy item from the conversion of the `-41` function from time to space, and will be corrected in a future version.

The user generally does not want the beam Gaussian to extend infinitely in x and y, therefore a cookie cutter option has been included to keep the distribution to a reasonable size. `CCC=`*`ccc`* tells MCNP6 to look at the card labeled *`ccc`* (*`ccc`* is a user-specified cell number) to define the cutoff volume. The first entry on the *`ccc`* card is `0`, which indicates a void cell. The second number, `-`*`nnn`* (*`nnn`* again is a user-specified number), indicates a surface card within which to accept particles. In the example, this is a `SQ` surface (a 2-sheet hyperboloid) that is defined as follows:

$$\left(\frac{x'}{a}\right)^2 + \left(\frac{y'}{b}\right)^2 \le c^2$$

Any particle generated within this cell is accepted; any outside of the cell is rejected. Any well defined surface may be selected, and it is common to use a simple cylinder to represent the extent of a beam pipe.

In this example, a source is generated in an (x',y')-coordinate system with the distribution centered at the origin and the particles traveling in the z′ direction. The particle coordinates can be modified to an (x,y)-coordinate system by translation and rotation according to the following equations, where $0 \le \phi_L \le \pi$:

$$x = x'\sin\phi_L - y'\cos\phi_L + x_0$$
$$y = x's\cos\phi_L + y'\sin\phi_L + y_0$$

Thus the angle ϕ_L is the angle of rotation of the major axis of the source distribution from the positive *y* direction in the laboratory coordinate system. If $\cos\phi_L = 0.0$, the angle is 90° and the major axis lies along the *x*-axis. The `TR`*`n`* card in the example above implements this rotation matrix, however the user should note that ϕ_L in the `TR`*`n`* card is equal to $\phi_L - \frac{\pi}{2}$.

Example 56: Defining Multiple Beams

The opportunity to specify a probability distribution of transformations on the `SDEF` card allows the formation of multiple beams which differ only in orientation and intensity. This feature may have applications in radiography or in the distribution of point sources of arbitrary intensity.

The use of a distribution of transformations is invoked by specifying `TR=D`*`n`* on the `SDEF` card. The cards `SI`, `SP,` and, optionally, `SB` are used as specified for the `SSR` card, which is discussed in Section 3.3.4.8.

```
SIn   L        i1 ... ik
SPn   option   p1 ... pk
SBn   option   b1 ... bk
```

The L option on the SI card is required; input checking ensures this usage for both the SDEF and SSR applications. The "*option*" on the SP and SB cards may be blank, D, or C. The values i_1 ... i_k identify k transformations which must be supplied. The content of the SP and SB cards then follows the general MCNP6 rules.

The following example shows a case of three intersecting Gaussian parallel beams, each defined with the parameters a=0.2 cm, b=0.1 cm and c=2 in the notation previously discussed in Example 1. For each, the beam is normal to the plane of definition.

Beam 1 is centered at (0,0,-2). The major axis of the beam distribution is along the *x*-axis. The beam is emitted in the +*z* direction and has relative intensity 1.

Beam 2 is centered at (-2,0,0). The major axis of the beam distribution is along the *y*-axis. The beam is emitted in the +*x* direction and has relative intensity 2.

Beam 3 is centered at (0,-2,0). The major axis of the beam distribution is along the line defined by *x*=*z*. The beam is emitted in the +*y* direction and has relative intensity 3.

The card SB*n* is used to provide equal sampling from each of the three beams, independent of the relative intensities. The input cards are as follows:

```
Title
c Cell cards
.
.
.
999  0       -999 $ cookie cutter cell

c Surface Cards
.
.
.
999  SQ   25 100 0 0 0 0 -4 0 0 0     $ cookie cutter surface

c Control Cards
SDEF    DIR=1  VEC=0 0 1  X=D1  Y=D2  Z=0  CCC=999  TR=D3
SP1     -41  0.4709640
SP2     -41  0.23584820
SI3    L 1 2 3
SP3      1 2 3
SB3      1 1 1
TR1      0  0 -2 1     0 0     0     1  0     0 0 1
TR2     -2  0  0 0     1 0     0     0  1     1 0 0
TR3      0 -2  0 0.707 0 0.707 0.707 0 -0.707 0 1 0
```

4.3.3 Burning Multiple Materials In a Repeated Structure with Specified Concentration Changes

Example 57:

In the following example, a 4×4 fuel pin array (created using repeated structures) is burned while material concentration changes are made at various time steps. Portions of the input and output files are provided below to illustrate various BURN card features;:

```
burn example
1   1  6.87812e-2  -1         u=2  imp:n=1 vol=192.287 $ fuel
3   2  4.5854e-2    1 -2      u=2  imp:n=1 vol=66.43   $ clad
4   3  7.1594e-2    2         u=2  imp:n=1 vol=370.82  $ water
6   4  6.87812e-2  -1         u=3  imp:n=1 vol=192.287 $ fuel
7   5  4.5854e-2    1 -2      u=3  imp:n=1 vol=66.43   $ clad
8   6  7.1594e-2      2       u=3  imp:n=1 vol=370.82  $ water
10  0              -3  4 -5  6 u=1  imp:n=1 lat=1 fill=0:1 0:1 0:0
                                    2 3 2 3
...

...
BURN  TIME=50,10,500
      MAT=1 4
      POWER=1.0
      PFRAC=1.0 0 0.2
      OMIT= 1,8,6014,7016,8018,9018,90234,91232,95240,95244
            4,8,6014,7016,8018,9018,90234,91232,95240,95244
      BOPT= 1.0, -4
      AFMIN= 1e-32
      MATVOL= 384.57 384.57
      MATMOD= 2
              1
                1  -4  1  94238 1e-6
              2
                2  -1  2  94238 1e-6  94241 1e-6
                   -4  1  94238 1e-6
...
```

A 4×4 lattice contains universes 2 and 3, which are both repeated twice in the lattice. Universe 2 comprises cells 1, 3, and 4, where cell 1 contains material 1; universe 3 comprises cells 6, 7, and 8, where cell 6 contains material 4. The MAT keyword specifies that both materials 1 and 4 will be burned. The combination of the TIME, POWER and PFRAC keywords specify that these materials will be burned first for 50 days at 100% of 1 MW, then decayed for 10 days, and then finally burned for 500 days at 20% of 1 MW.

The BOPT keyword specifies that the following options will be invoked: the Q-value multiplier will be set to a value of 1.0, only Tier 1 fission products will be included, the output will be ordered by ZAID and printed at the end of each KCODE run, and only tabular transport cross sections will be used. Because tabular transport cross sections do not exist for every isotope that is generated, an OMIT card is required to omit these isotopes from the transport process. The transmutation of these isotopes is accounted for by sending a 63-group flux from MCNP6 to be matched to a 63-group cross-section set within CINDER90. These are energy integrated to determine a total collision rate. The OMIT card in the example omits eight isotopes from material 1 and eight isotopes from material 4. The AFMIN card states that only isotopes possessing an atom fraction below 1E-32 will be omitted from the transport calculation.

Because there are repeated structures in the example a MATVOL keyword is required to calculate the track-length-estimated reaction rates in each repeated structure. Because material 1 and 4 are repeated twice and each material possesses a volume of 192.287 cm^3, MATVOL keyword entries of 384.57 (192.287×2) are required for each material being burned.

A MATMOD keyword is used to manually change the concentration of certain isotopes at specified time steps. In this example, manual isotope concentration changes are to be completed at two time steps. At time step 1, material 4 will have the atom density of isotope 94238 changed to 1E-6 atoms/b-cm. At time step 2, the atom densities of isotopes 94238 and 94241 in material 1 both will be revised to 1E-6 atoms/b-cm. Also in step 2, the atom density of isotope 94238 in material 4 will be set to 1E-6 atoms/b-cm.

Print table 210 contains the burnup summary table:

```
1burnup summary table by material                                                 print table 210


 neutronics and burnup data

 step  duration     time       power      keff       flux      ave. nu  ave. q      burnup     source
        (days)     (days)     (MW)                                                  (GWd/MTU)  (nts/sec)
   0  0.000E+00  0.000E+00  1.000E+00  1.54021  7.715E+14    2.452    200.979  0.000E+00  7.616E+16
   1  5.000E+01  5.000E+01  1.000E+00  1.50987  7.945E+14    2.473    201.411  7.183E+00  7.664E+16
   2  1.000E+01  6.000E+01  0.000E+00  1.51150  0.000E+00    2.474    201.448  7.183E+00  0.000E+00
   3  5.000E+02  5.600E+02  2.000E-01  1.43413  1.699E+14    2.510    202.199  2.155E+01  1.550E+16
...
```

The burnup summary table contains information regarding the entire burn system. Each time step is listed with the corresponding time duration and actual specified time. The next six columns list the power used for the flux normalization, k_{eff}, energy integrated system averaged flux, system averaged neutrons per fission and recoverable energy per fission, and burnup. Finally, the production rate is listed in the source column.

Since both materials `1` and `4` were burned in the example, individual burn material burnup information is also available. The available information includes: time step, time duration, actual time, fission power fraction, and individual material burnup:

```
Individual Material Burnup

 Material #:    1

 step  duration     time    power fraction    burnup
        (days)     (days)                    (GWd/MTU)
   0  0.000E+00  0.000E+00    5.015E-01      0.000E+00
   1  5.000E+01  5.000E+01    5.016E-01      7.205E+00
   2  1.000E+01  6.000E+01    5.002E-01      7.205E+00
   3  5.000E+02  5.600E+02    5.002E-01      2.158E+01

 Material #:    4

 step  duration     time    power fraction    burnup
        (days)     (days)                    (GWd/MTU)
   0  0.000E+00  0.000E+00    4.985E-01      0.000E+00
   1  5.000E+01  5.000E+01    4.984E-01      7.161E+00
   2  1.000E+01  6.000E+01    4.998E-01      7.161E+00
   3  5.000E+02  5.600E+02    4.998E-01      2.152E+01
...
```

The fission power fraction is calculated by taking the ratio of the fission power in a particular material to the sum of all burn materials. Fission power fractions are only related to fissions in burn materials.

$$power\ fraction = \frac{\left(\Phi\Sigma_f VQ\right)_i}{\sum_i \left(\Phi\Sigma_f VQ\right)_i}$$

The individual material burnup is calculated by

$$Burnup = Burnup_{previous\ step} + \frac{Power\ Level \times Power\ Fraction \times Time \times PFRAC}{MTU}$$

The time-dependent isotope buildup/depletion is listed after the burnup summary information. The isotope buildup/depletion for each individual material is given at each time step. The information is further subdivided into actinide and non-actinide categories:

```
nuclide data are sorted by increasing zaid for material   1 volume  3.8457E+02 (cm**3)

 actinide inventory for material   1 at end of step  0, time 0.000E+00 (days), power 1.000E+00 (MW)

  no. zaid      mass     activity   spec.act.  atom den.  atom fr.   mass fr.
               (gm)       (Ci)     (Ci/gm)    (a/b-cm)
   1  90231  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   2  90232  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   3  90233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   4  91233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   5  92234  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   6  92235  3.441E+02  0.000E+00  0.000E+00  2.293E-03  1.000E-01  9.886E-02
...
...
 actinide inventory for material   1 at end of step  1, time 5.000E+01 (days), power 1.000E+00 (MW)

  no. zaid      mass     activity   spec.act.  atom den.  atom fr.   mass fr.
               (gm)       (Ci)     (Ci/gm)    (a/b-cm)
   1  90231  1.286E-09  6.837E-04  5.315E+05  8.718E-15  3.832E-13  3.723E-13
   2  90232  2.394E-08  2.625E-15  1.097E-07  1.616E-13  7.100E-12  6.929E-12
   3  90233  1.235E-13  4.468E-06  3.618E+07  8.298E-19  3.647E-17  3.574E-17
   4  91233  1.345E-09  2.792E-05  2.075E+04  9.039E-15  3.973E-13  3.894E-13
...
```

At the end of each subdivision there is an accumulation total of the isotope information for that subdivision. Atom and weight fractions calculations are based on the fractions of that specific subdivision.

```
...
     totals  3.455E+03  2.584E+05  7.479E+01  2.275E-02  1.000E+00  1.000E+00
...
...
 nonactinide inventory for material 1 at end of step  0, time 0.000E+00 (days), power 1.000E+00 (MW)

  no.  zaid     mass     activity   spec.act.  atom den.  atom fr.   mass fr.
               (gm)       (Ci)      (Ci/gm)   (a/b-cm)
   1   6012  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   2   6013  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   3   7014  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   4   7015  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   5   8016  4.684E+02  0.000E+00  0.000E+00  4.585E-02  1.000E+00  1.000E+00
...
```

After isotope information for each individual material is given, `print table 220` lists the total build/up of all actinides and non-actinides from all materials combined at each of the time steps.

```
...
1burnup summary table summed over all materials                                            print table 220

 nuclides with atom fractions below 1.000E-32 for a material are zeroed and deleted from print
tables after t=0

 nuclide data are sorted by increasing zaid summed over all materials volume  7.6914E+02 (cm**3)

 actinide inventory for sum of materials at end of step  0, time 0.000E+00 (days), power 1.000E+00
(MW)

  no.  zaid      mass    activity   spec.act.  atom den.   atom fr.   mass fr.
                 (gm)      (Ci)     (Ci/gm)    (a/b-cm)
   1  90231  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   2  90232  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   3  90233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   4  91233  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   5  92234  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   6  92235  6.883E+02  0.000E+00  0.000E+00  4.585E-03  1.000E-01  9.886E-02
...
```

4.3.4 Source Subroutine

When possible, you should take advantage of the standard sources provided by the code rather than write a source subroutine. When you write your own source subroutine, you lose features such as sampling from multiple distributions, using dependent distributions, and having frequency prints for each tabular distribution. Additionally, if using next-event estimators (F5 tallies) or DXTRAN spheres, subroutine SRCDX is needed.

The standard sources, however, cannot handle all problems. If the general source (`SDEF` card), surface source (`SSR`), or criticality source (`KCODE` card) is unsuitable for a particular application, MCNP6 provides a mechanism to furnish your own source-modeling capability. The absence of `SDEF`, `SSR`, or `KCODE` cards causes MCNP6 to call subroutine SOURCE, which you must supply. Subroutine SOURCE specifies the coordinates, direction, weight, energy, and time of source particles as listed and defined in Section 3.3.4.14. If the value of PBL%I%IPT (particle type) set by STARTP, which calls SOURCE, is not satisfactory, SOURCE must also specify PBL%I%IPT. STARTP sets IPT=1 (neutron) for `MODE N`, `N P`, and `N P E`; sets PBL%I%IPT=2 (photon) for `MODE P` and `P E`; and sets PBL%I%IPT=3 (electron) for `MODE E`. MCNP6 checks the user's source for consistency of cell, surface, direction, and position. If the source direction is anisotropic and there are point detectors or DXTRAN spheres, a SRCDX subroutine is also required (see Section 3.3.4.14).

The following example of a subroutine SOURCE uses `SI`*n*, `SP`*n*, and `SB`*n* cards and demonstrates the use of MCNP6 subroutines SMPSRC, ROTAS, CHKCEL, and the function NAMCHG. The geometry is a 5-cm-long cylinder centered about the *y*-axis, divided into 5 cells by `PY` planes at 1-cm intervals. The 1-MeV mono-energetic source is a biased isotropic distribution that is also biased along the *y*-axis. The input distribution cards are

```
SI1   –1  0  1            $ These 3 cards
```

```
SP1    0  1  1           $ represent a biased
SB1    0  1  2           $ isotropic distribution.
SI2    0  1  2  3  4  5  $ These 3 cards
SP2    0  4  2  2  1  1  $ represent a biased
SB2    0  1  1  2  2  4  $ distribution in y.
RDUM   1                 $ cylindrical radius
IDUM   2  4  6  8  10    $ source cells
```

This problem can be run with the general source by removing the RDUM and IDUM cards and adding:

```
SDEF  ERG=1  VEC=0 1 0  AXS=0 1 0  DIR=D1  EXT=D2  RAD=D3
SI3     0   1 $ represents a covering surface of radius 1
SP3   −21   1 $ samples from the power law with k=1
```

Below is an example source subroutine, which would replace the empty subroutine source provided with the source code.

```
subroutine source
  ! dummy subroutine. aborts job if source subroutine is missing.
  ! if nsr=0, subroutine source must be furnished by the user.
  ! at entrance, a random set of uuu,vvv,www has been defined. the
  ! following variables must be defined within the subroutine:
  ! pbl%r%x, pbl%r%y, pbl%r%z, pbl%r%icl, pbl%r%jsu, pbl%r%erg,
  ! pbl%r%wgt, pbl%r%tme and possibly pbl%i%ipt, pbl%r%u, pbl%r%v,
  ! pbl%r%w.
  ! subroutine srcdx may also be needed.

  use mcnp_params
  use mcnp_global
  use mcnp_interfaces_mod, only: chkcel, namchg, rotas, smpsrc
  use mcnp_debug
  use mcnp_random
  use tskcom, only: uold
  use pblcom, only: pbl

  implicit none

  real(dknd) :: a(3), c, fi, r, th

  ! smpsrc requires an array as the first arguement.
  ! create dummy one dimensional array
  real(dknd) :: array(1)

  integer    :: i, ib, imax, itr, j, lev

  intrinsic cos, sin

  pbl%r%wgt=1.0_dknd
```

```
! rdum(1)--Radius of Source Cylinder
! sample radius uniform in area.

r=rdum(1)*sqrt(rang())

! Y coordinate position, probability and bias are
! defined in distribution 2 by the SI2, SP2, SB2 cards.
! sample for y.
! IB returns the index sampled and FI the interpolated fraction.
! neither is used in this example.

call smpsrc(array,2,ib,fi)
pbl%r%y = array(1)

! Sample for X and Z.

th = 2.0_dknd*pie*rang()
pbl%r%x = -r*sin(th)
pbl%r%z =  r*cos(th)

! Direction is isotropic but biased in cone along Y axis
! Defined as distribution 1 by the SI1, SP1, SB1 cards.
! Sample for cone opening C=cos(NU)
! Rotas samples a direction U,V,W at an angle ARCCOS(C)
! From the reference vector UOLD(3)
! and at an azimuthal angle sampled uniformly.

call smpsrc(array,1,ib,fi)
c = array(1)
uold(1) = 0.0_dknd
uold(2) = 1.0_dknd
uold(3) = 0.0_dknd

call rotas(c,uold,a,lev,itr)
pbl%r%u = a(1)
pbl%r%v = a(2)
pbl%r%w = a(3)

! Cell source - find starting cell.
! IDUM(1) - IDUM(5) -- list of source cells on IDUM card.
pbl%i%jsu=0
j = 1
i = 1
imax = 5
do while ((J /= 0) .and. (i /= imax))
  pbl%i%icl=namchg(1,idum(I))
  call chkcel(pbl%i%icl,2,J)
  i=i+1
enddo
if (j /= 0) call expire(1,'Source', &
```

```
    & 'Source is not in any cells on the idum card.')
  pbl%r%erg = 1.0_dknd
  pbl%r%tme = 0.0_dknd
  return
end subroutine source
```

4.3.5 SRCDX Subroutine

If a user has supplied a subroutine SOURCE that does not emit particles isotropically (uniform emission in all directions) and is using either a detector tally or DXTRAN in the calculations, then subroutine SRCDX must also be supplied to MCNP6. The structure of this subroutine is the same as for subroutine SOURCE, except that usually only a single parameter, PSC, needs to be specified for each detector or set of DXTRAN spheres. PSC as defined in SRCDX is used to calculate the direct contribution from the source to a point detector, to the point selected for the ring detector or DXTRAN sphere. Other parameters may also be specified in SRCDX. For example, if a quantity such as particle energy and/or weight is directionally dependent, its value must be specified in both subroutines SOURCE and SRCDX. When using detectors and a subroutine SOURCE with an anisotropic distribution, check the direct source contribution to the detectors carefully to see if it is close to the expected result.

In general, it is best to have as few directionally dependent parameters as possible in subroutine SOURCE. Directionally dependent parameters must also be dealt with in subroutine SRCDX.

The most general function for emitting a particle from the source in the laboratory system can be expressed as $p(\mu,\varphi)$, where μ is the cosine of the polar angle and φ is the azimuthal angle in the coordinate system of the problem. Most anisotropic sources are azimuthally symmetric and $p(\mu,\varphi)=p(\mu)/2\pi$. The quantity $p(\mu)$ is the probability density function for the μ variable only (that is, $\int p(\mu)\,d\mu=1$, $p(\mu)\geq 0$). PSC is $p(\mu_0)$, where μ_0 is the cosine of the angle between the direction defining the polar angle for the source and the direction to a detector or DXTRAN sphere point in the laboratory system. (MCNP6 includes the 2π in the calculation automatically.) Note that $p(\mu_0)$ and hence PSC may have a value greater than unity and must be non-negative. It is valuable to point out that every source must have a cumulative distribution function based on $p(\mu,\varphi)$ from which to sample angular dependence. The probability density function $p(\mu,\varphi)$ needs only to be considered explicitly for those problems with detectors or DXTRAN.

Table 4-1 gives the equations for PSC for six continuous source probability density functions. More discussion of probability density functions is given in the detector theory section of Section 5.5.4.6 of the MCNP5 Theory Manual [X-503a]. The isotropic case is assumed in MCNP6; therefore SRCDX is required only for the anisotropic case.

Table 4-1. Continuous Source Distributions and Their Associated PSCs

	Source Description	Source Distribution	PSC	Range of μ_0
1	Isotropic	Uniform	0.5	$-1\le\mu_0\le1$
2	Surface Cosine	μ	$2\lvert\mu_0\rvert$ 0	$0\le\mu_0\le1$ (or $-1\le\mu_0\le0$) $-1\le\mu_0<0$ (or $0<\mu_0\le1$)
3	Point Cosine	$\lvert\mu\rvert$	$\lvert\mu_0\rvert$	$-1\le\mu_0\le1$
4	Point Cosine*	$a+b\mu$	$\frac{2(a+b\mu_0)}{2a+b}$ $\frac{2(a+b\mu_0)}{2a-b}$ 0	$0\le\mu_0\le1$ $-1\le\mu_0\le0$ $-1\le\mu_0<0$ (or $0<\mu_0\le1$)
5	Point Cosine*	$a+b\mu$, $a\ne0$	$\frac{a+b\mu_0}{2a}$	$-1\le\mu_0\le1$
6	Point Cosine*	$a+b\lvert\mu\rvert$	$\frac{a+b\lvert\mu_0\rvert}{2a+b}$	$-1\le\mu_0\le1$

* The quantities *a* and *b* must have values such that PSC is always non-negative and finite over the range of μ_0.

As an example of calculating μ_0, consider a spherical surface cosine source (type 2 in Table 4-1) with several point detectors in the problem. Assume that a point on the spherical surface has been selected at which to start a particle. The value of μ_0 for a detector is given by the scalar (or dot) product of the two directions; that is,

$$\mu_0 = uu' + vv' + ww' \tag{5.1}$$

where *u*, *v*, and *w* are the direction cosines of the line from the source point to the point detector location and *u*′, *v*′, and *w*′ are the direction cosines for either the outward normal if the surface source is outward or the inward normal if the source is inward.

If $u=u'$, $v=v'$, and $w=w'$, then $\mu_0=1$, indicating that the point detector lies on the normal line. The value of PSC for the detector point is

$$\begin{aligned} \text{PSC} &= 2\lvert\mu_0\rvert, & \mu_0>0 \quad (\mu_0<0) \\ &= & \mu_0\le0 \quad (\mu_0\ge0) \end{aligned}$$

where the parenthetical values of μ_0 are for the inward-directed cosine distribution.

For $\lvert\mu_0\rvert$ less than 0.25 in case 2 of Table 4-1, PSC is less than 0.5, which is the value for an isotropic source. This means that source emissions for these values of $\lvert\mu_0\rvert$ are less probable than the isotropic case for this source distribution. The converse is also true. Note that if $\lvert\mu_0\rvert$ is greater than 0.5, PSC is greater than one, which is perfectly valid.

An example of a subroutine SRCDX for a surface outward cosine distribution is shown below. This is basically the technique that is used in MCNP6 to calculate PSC for a spherical surface source in a cosine distribution; the only difference is that MCNP6 uses the cosines of the direction from the center of the sphere that selected the source point because this is normal to the spherical surface. The primed direction cosines were calculated in the example below to aid in illustrating this example. The direction cosines *u*, *v*, and *w* as defined in Equation (5.1) have already been calculated in subroutine DDDET when SRCDX is called and are available through COMMON.

```
subroutine srcdx
  ! dummy subroutine for use with user-defined sources

  use mcnp_global
  use mcnp_params
  use tskcom, only: psc
  use pblcom, only: pbl
  use mcnp_debug

  implicit none

  real(dknd) :: up, vp, wp

  ! Calculate PSC for a surface (Sphere) outward cosine distribution.
  ! Find the direction cosines for this example based on the source
  ! point on the sphere (X,Y,Z).

  up=(pbl%r%x-rdum(1))/rdum(4)
  vp=(pbl%r%y-rdum(2))/rdum(4)
  wp=(pbl%r%z-rdum(3))/rdum(4)

  ! (RDUM(1),RDUM(2),RDUM(3)) are the coordinates of the center
  ! of the sphere from the RDUM card. RDUM(4) is the radius.
  ! U,V, and W have been calculated for the current point detector
  ! in subroutine DDDET.

  psc = 2.0_dknd*max(ZERO,pbl%r%u*up + pbl%r%v*vp + pbl%r%w*wp)
  return
end subroutine srcdx
```

For many sources, a discrete probability density function will be used. In this situation, a cumulative distribution function $P(\mu)$ is available and is defined as

$$P(\mu)=\int_{-1}^{\mu} p(\mu')d\mu' \qquad \text{and} \qquad P_{i+1}=\sum_{j=1,i} p_j \Delta\mu_j \quad ,$$

where p_j is an average value of the probability density function in the interval $\Delta\mu_j$. Thus, the probability density function is a constant p_j in the interval $\Delta\mu_j$. For this case, there are N values of P_i with P_1=0, P_{N+1}=1.0 and $P_{i-1}<P_i$. Each value of P_i has an associated value of μ_i. Because PSC is the derivative of $P(\mu_0)$, then

$$\text{PSC} = \frac{P_i - P_{i-1}}{\mu_i - \mu_{i-1}} \ , \qquad \mu_{i-1} \le \mu_0 < \mu_i \ .$$

This is an average PSC between μ_{i-1} and μ_i and is also an average value of $p(\mu)$ in the specified range of μ.

Frequently, the cumulative distribution function is divided into N equally probable intervals. For this case,

$$\text{PSC} = \frac{1}{N}\frac{1}{\mu_i - \mu_{i-1}} \ .$$

This is precisely the form used in MCNP6 for calculating contributions to the point detector for elastic scattering with N=32.

An example of a subroutine SRCDX for a discrete probability density function is given in the example that follows. This subroutine would work with the subroutine SOURCE example in Section 4.3.4, and would calculate PSC=1/2 for the isotropic distribution.

A biased anisotropic distribution can also be represented by

SI*n* SP   0 p_1 ... p_N
SB   0 q_1 ... q_N

A reference vector u',v',w' for this distribution is also needed.

The subroutine SOURCE input cards can be modified for this case by changing the `SI1`, `SP1`, `SB1`, and `RDUM` cards as follows:

```
SI1    -1  0  1    $ These 3 cards
SP1     0  2  1    $ represent a biased
SB1     0  1  2    $ anisotropic distribution.
RDUM    1  0  1  0 $ cylindrical radius and reference vector
```

SOURCE would sample this anisotropic distribution and SRCDX would calculate the appropriate PSC as shown in the following example.

```
subroutine srcdx
  ! dummy subroutine for use with user-defined sources

  use mcnp_params
  use mcnp_global
  use tskcom, only: psc
  use pblcom, only: pbl
  use mcnp_debug

  implicit none
```

```
real(dknd) :: am
integer    :: i

! The variably dimensioned block SPF holds the SI, SP, SB
! Arrays.

! RDUM(2), RDUM(3),RDUM(4) -- Directional cosines
! for the source reference direction.

am = pbl%r%u*rdum(2) + pbl%r%v*rdum(3) + pbl%r%w*rdum(4)

! KSD(4,1) is the length of the distribution.
! KSD(13,1) is the offset into the SPF block.

do i=1,ksd(4,1)-1
  if ( spf(i,ksd(13,1)+1) <= am .and. spf(i+1,ksd(13,1)+1) >= am) then
    psc = (spf(i+1,ksd(13,1)+2)-spf(i,ksd(13,1)+2))/ &
      &   (spf(i+1,ksd(13,1)+1)-spf(i,ksd(13,1)+1))
    psc = psc * spf(i+1,ksd(13,1)+3)
    exit
  else
   psc = ZERO
  endif
enddo

return
end subroutine srcdx
```

It is extremely important to note that the above case applies only when the source is anisotropic with azimuthal symmetry. For the general case,

$$\mathrm{PSC} = 2\pi p(\mu_0, \varphi_0)$$

The 2π factor must be applied by the user because MCNP6 assumes azimuthal symmetry and, in effect, divides the user-defined PSC by 2π.

For a continuous $p(\mu,\varphi)$ function, PSC is calculated as above. In the case of a discrete probability density function,

$$\mathrm{PSC} = 2\pi \cdot \overline{p(\mu_0, \varphi_0)} = \frac{2\pi(P_i - P_{i-1})}{(\mu_\mathrm{i} - \mu_{i-1})(\varphi_i - \varphi_{i-1})} = \frac{2\pi(P_i - P_{i-1})}{\Delta\mu_i \Delta\varphi_i}$$

where $\mu_{i-1} \leq \mu_0 < \mu_i$, $\varphi_{i-1} \leq \varphi_0 < \varphi_i$, and $\overline{p(\mu_o, \varphi_0)}$ is an average probability density function in the specified values of μ_0 and φ_0 and P_i-P_{i-1} is the probability of selecting μ_0 and φ_0 in these intervals. For N equally probable bins and n equally spaced $\Delta\varphi$'s, each $2\pi/n$ wide,

$$\text{PSC} = \frac{n}{N}\frac{1}{\Delta\mu_i} \quad .$$

Another way to view this general case is by considering solid angles on the unit sphere. For an isotropic source, the probability (P_i-P_{i-1}) of being emitted into a specified solid angle is the ratio of the total solid angle (4π) to the specified solid angle ($\Delta\varphi\Delta\mu$). Then, PSC≡0.5. Thus, for the general case (normalized to PSC≡0.5 for an isotropic source)

$$\text{PSC} = \frac{(0.5)(P_i - P_{i-1})4\pi}{\Delta\mu\Delta\varphi_i} = \frac{2\pi(P_i - P_{i-1})}{\Delta\mu_i\Delta\varphi_i}$$

Note that PSC is greater than 0.5 if the specified solid angle $\Delta\mu\Delta\varphi_i$ is less than (P_i−P_{i-1})4π. This is the same as the previous general expression.

Caution: Be extremely careful when using your own subroutine SOURCE with either detectors or DXTRAN. This caution applies to the calculation of the direct contribution from the source to a point detector, point on a ring, or point on a DXTRAN sphere. Not only is there the calculation of the correct value of PSC for an anisotropic source, but there may also be problems with a biased source.

For example, if an isotropic source is biased to start only in a cone of a specified angle (for example, ψ), the starting weight of each particle should be WGT∗(1-cosψ)/2, where WGT is the weight of the unbiased source (that is, WGT is the expected weight from a total source). The weight in SRCDX *must* be changed to the expected weight WGT to calculate the direct contribution to a point detector correctly if PSC is defined to be 0.5.

This example can be viewed in a different way. The probability density function for the above biased source is

$$p(\mu) = \frac{1}{1-\cos\psi} \qquad \text{for} \quad \cos\psi \le \mu \le 1$$

$$= \quad 0 \qquad \text{for} \quad -1 \le \mu < \cos\psi$$

Thus, PSC is this constant everywhere in the cone and zero elsewhere. Multiplying this PSC and biased starting weight gives

$$\text{WGT} * (1-\cos\psi) * 0.5/(1-\cos\psi)$$

or WGT∗0.5, which is the expected result for an isotropic source.

Another source type that requires caution is a user-supplied source that is energy-angle correlated. For example, assume a source has a Gaussian distribution in energy where the mean of the Gaussian is correlated in some manner with μ. In subroutine SRCDX, the μ_0 to a point detector must be calculated and the energy of the starting particle must be sampled from the Gaussian based on this μ_0. This must be done for each point detector in the problem, thus guaranteeing that the direct source contribution to each detector will be from the proper energy spectrum. The original energy of the starting particle as well as all the other starting parameters selected in subroutine SOURCE are automatically restored after the direct source contribution to detectors is made. Thus, the subroutine SOURCE is still sampled correctly.

4.4 MATERIAL EXAMPLES

4.4.1 Table Data/Model Physics Mix and Match

Consider a neutron problem with deuterium and tritium. The available deuterium library contains values valid up to 150 MeV, but the tritium library goes up to only 20 MeV. Previously, either neutron physics models above 20 MeV (neglecting the deuterium table data up to 150 MeV) or nuclear data tables below 150 MeV (using the 20-MeV tritium data throughout the entire 20- to 150-MeV range) had to be used. Using the mix-and-match capability available through the `tabl` parameter of the `PHYS:<pl>` card, the user can specify that deuterium use tables up to 150 MeV and use physics models above 150 MeV and that tritium use data tables up to 20 MeV and use physics models above 20 MeV.

Figure 4-49 shows an example of the energy-matching capability. The 100-MeV neutrons are incident on an 8.433-cm-long, 3.932-cm-radius BGO crystal. The crystal contains 21% bismuth, 16% germanium, and 63% oxygen. Assume no germanium libraries are available. The solid line represents flux in the crystal with the full mix-and-match capability, which uses all libraries up to their energy limits and physics models above those limits and for germanium. The dashed-line calculation uses the old method of substituting arsenic for the missing germanium library, using the libraries up to 20 MeV and using physics models above. The dotted line uses bismuth and oxygen libraries up to their limits of 150 MeV; the arsenic library is used up to its limit of 20 MeV, and then the 20-MeV data are used from 20 to 150 MeV; above 150 MeV, physics models are used for all three nuclides. This last option is least desirable but often was used in past code versions to take advantage of the 150-MeV libraries, even though many data libraries go only to 20 MeV.

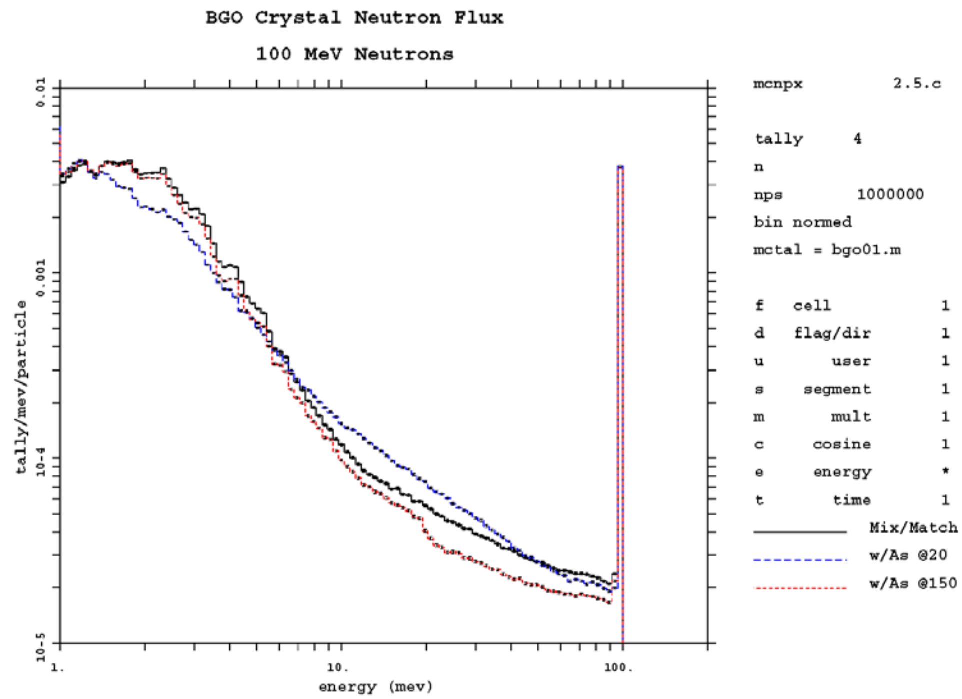


Figure 4-49. Comparison of different germanium library and model options.

4.5 PHYSICS MODELS

4.5.1 Neutron Production from a Spallation Target

One of the fundamental quantities of interest in most spallation target applications is the number of neutrons produced per beam particle incident on target. For targets fed by proton accelerators, this quantity is typically denoted as "n/p". Here, we demonstrate how one goes about calculating this quantity for a simple target geometry using MCNP6.

The geometry consists of a simple right circular cylinder of lead, 10 cm in diameter by 30 cm long. A beam of 1-GeV protons is launched onto the target. The beam has a 7-cm-diameter spot size, with a parabolic spatial profile. (See Figure 4-50.)

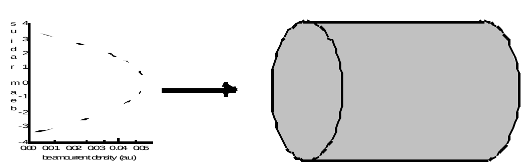


Figure 4-50. Neutron production from a spallation target.

In MCNP6, net neutron production is tallied implicitly and is provided by default in the problem summary for neutrons. The problem summary shows net neutron production resulting from nuclear interactions (the component that accounts for neutron production by all particles transported using INC/Preequilibrium/Evaporation physics) and net production by (*n*,*xn*) reactions (neutrons created in inelastic nuclear interactions by neutrons below the transition energy, using evaluated nuclear data). Net production from nuclear interactions is given by the difference of the neutron weights in the "neutron creation" and "neutron loss" columns. A similar approach is taken to calculate net (*n*,*xn*) production. Net neutron production may also be calculated by realizing that the only loss mechanisms for neutrons are escape and capture. The sum of the weights in the "neutron loss" column under "escape" and "capture" is thus equal to the net neutron production. The values listed in the problem summary are "collision estimators," meaning they are tallied when a collision occurs during transport. Uncertainties are not calculated by MCNP6 for these collision-estimated quantities. A reasonable upper limit on the relative uncertainty would be given by the inverse square root of the number of source particles launched.

We provide here four different variations for the calculation of net neutron production for this simple target geometry. In the "base case" we transport protons, neutrons, and charged pions. The transition energy between LAHET physics and neutron transport using tabular nuclear data is set to the default (`tabl=-1`), which means that "mix and match" (Section 3.3.2.3) will be turned on and the ENDF/B-VI.6 neutron libraries are used. All protons are transported using LAHET physics. Nucleon and pion interactions simulated by LAHET physics use the Bertini intranuclear cascade model. Variations from this base case are outlined in Table 4-2 below. For each case 20,000 source protons were transported. Note that in MCNPX, Bertini INC was the default physics option. In MCNP6, however, the default option is CEM03.03; therefore, we need to specify the following `LCA` card to activate Bertini INC: `LCA 8j 0`. In this example we refer to Bertini INC as the “base case”.

Table 4-2. Neutron Problem Summaries

Case	INC Model	Particles transported	Neutron transition energy (MeV)	Proton transition energy (MeV)
base	**Bertini**	**N H /**	**n/a**	**n/a**
1	**Bertini**	**N H / D T S A**	**n/a**	**n/a**
2	**ISABEL**	**N H /**	**n/a**	**n/a**
3	**CEM**	**N H /**	**n/a**	**n/a**
4	**INCL**	**N H /**	**n/a**	**n/a**

For the sake of brevity, we reproduce here just the neutron problem summaries from the MCNP6 output decks.

Base Case [LCA 8J 0 (invokes Bertini INC physics model)]

```
Sample problem: spallation target
c     neutron production with Bertini physics
c     EJ Pitcher, 1 Nov 99
c     MR James, 31 Oct 2007
C     SG Mashnik, February 27, 2013
c
c --- cell cards ---
c
c     Pb target
     1 1 -11.4   1 -2 -3
c     bounding sphere
     2 0         (-1:2:3) -4
c     outside universe
     3 0         4

c --- surface cards ---
c
     1 pz   0.0
     2 pz  30.0
     3 cz   5.0
     4 so  90.0

c --- material cards ---
c
c     Material #1: Pb without Pb-204
m1    82206 0.255  82207 0.221  82208 0.524 nlib=.66c hlib=.24h
c
c --- data cards ---
mode        n h /
imp:n,h,/   1 1r 0
phys:n      1000. j j
phys:h      1000. j j
c lca         j j j
lca         8j  0
nps         20000
prdmp       j -30 j 1
c
c --- source definition ---
c     1-GeV proton beam, 7-cm-diam, parabolic spatial profile
sdef   sur 1 erg 1000. dir 1 vec 0. 0. 1. rad d1 pos 0. 0. 0. par 9
si1  a   0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
         1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7
         2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5
```

```
sp1      0.00000 0.09992 0.19935 0.29780 0.39478 0.48980 0.58237
         0.67200 0.75820 0.84049 0.91837 0.99135 1.05894 1.12065
         1.17600 1.22449 1.26563 1.29894 1.32392 1.34008 1.34694
         1.34400 1.33078 1.30678 1.27151 1.22449 1.16522 1.09322
         1.00800 0.90906 0.79592 0.66808 0.52506 0.36637 0.19151
         0.00000
```

For the base case, the neutron problem summary follows:

```
     Sample problem: spallation target                                                         probid =  02/27/13 12:30:01
**********************************************************
Calls to event-generator models, counted by particle type.

particle         BERTINI           CEM           INCL          ISABEL         LAQGSM      LAQGSM_H1           HYD

neutron             5506             0              0              0              0              0              0
proton             27269             0              0              0              0              0              0
pi_plus              595             0              0              0              0              0              0

totals             33370             0              0              0              0              0              0


neutron creation    tracks      weight        energy            neutron loss        tracks      weight        energy
                                (per source particle)                                           (per source particle)

source                   0    0.            0.                  escape              347410    1.7355E+01    2.1397E+02
nucl. interaction   292426    1.4621E+01    3.1152E+02          energy cutoff            0    0.            0.
particle decay           0    0.            0.                  time cutoff              0    0.            0.
weight window            0    0.            0.                  weight window            0    0.            0.
cell importance          0    0.            0.                  cell importance          0    0.            0.
weight cutoff            0    0.            0.                  weight cutoff            0    0.            0.
e or t importance        0    0.            0.                  e or t importance        0    0.            0.
dxtran                   0    0.            0.                  dxtran                   0    0.            0.
forced collisions        0    0.            0.                  forced collisions        0    0.            0.
exp. transform           0    0.            0.                  exp. transform           0    0.            0.
upscattering             0    0.            0.                  downscattering           0    0.            9.3802E+00
photonuclear             0    0.            0.                  capture                  0    1.3592E-02    7.2872E-02
(n,xn)               75783    3.7856E+00    1.8490E+01          loss to (n,xn)       24395    1.2182E+00    4.7746E+01
prompt fission           0    0.            0.                  loss to fission          0    0.            0.
delayed fission          0    0.            0.                  nucl. interaction     3587    1.7935E-01    6.0729E+01
prompt photofis          0    0.            0.                  particle decay           0    0.            0.
tabular boundary         0    0.            0.                  tabular boundary         0    0.            0.
tabular sampling      7183    3.5915E-01    1.8827E+00          elastic scatter          0    0.            0.
    total           375392    1.8766E+01    3.3189E+02              total           375392    1.8766E+01    3.3189E+02

  number of neutrons banked                  350997        average time of (shakes)              cutoffs
  neutron tracks per source particle     1.8770E+01          escape            5.7124E+00          tco   1.0000E+33
  neutron collisions per source particle 2.6493E+01          capture           4.6539E-01          eco   0.0000E+00
  total neutron collisions                   529856          capture or escape 5.7083E+00          wc1  -5.0000E-01
  net multiplication              0.0000E+00 0.0000          any termination   5.2838E+00          wc2  -2.5000E-01
```

The two methods for calculating total neutron production give the following results:

net nuclear interactions + net (*n*,*xn*) + tabular sampling:

$$(14.621 - 0.179) + (3.786 - 1.218) + 0.359 = 17.369 \text{ n/p}$$

escapes + captures:

$$17.355 + 0.014 = 17.369 \text{ n/p}$$

Both methods give the same answer. Since "escapes + captures" is easier to calculate, this is the method typically used. A reasonable upper limit on the relative uncertainty of n/p is $(20{,}000^{-1/2})$ ~0.7%.

Case 1

In the first variation we transport not only nucleons (denoted by the symbols `N` and `H` on the `MODE` card) and charged pions (`/`), but also light ions (deuterons, tritons, ^{3}He, and alphas, denoted by `D`, `T`, `S`, and `A`, respectively). The only differences between the two input decks are the following two cards:

Base Case:
```
MODE        N  H /
IMP:N,H,/  1 1R 0
```

Case 1:
```
MODE        N  H / D T S A
IMP:N,H,/,D,T,S,A   1 1R 0
```

Note that nuclear interactions by light ions are simulated using the ISABEL INC model. The problem summary for this case is shown below:

```
     Sample problem: spallation target                                                  probid =  02/27/13 12:22:21
**********************************************************
Calls to event-generator models, counted by particle type.

particle         BERTINI             CEM           INCL          ISABEL         LAQGSM      LAQGSM_H1           HYD

neutron             5475               0              0              0              0              0              0
proton             27334               0              0              0              0              0              0
pi_plus              613               0              0              0              0              0              0
deuteron               0               0              0             28              0              0              0
triton                 0               0              0              1              0              0              0

totals             33422               0              0             29              0              0              0


neutron creation    tracks      weight        energy          neutron loss        tracks      weight        energy
                                (per source particle)                                         (per source particle)

source                   0    0.             0.                escape             347904    1.7379E+01    2.1425E+02
nucl. interaction   293017    1.4651E+01    3.1253E+02         energy cutoff           0    0.            0.
particle decay           0    0.             0.                time cutoff             0    0.            0.
weight window            0    0.             0.                weight window           0    0.            0.
cell importance          0    0.             0.                cell importance         0    0.            0.
weight cutoff            0    0.             0.                weight cutoff           0    0.            0.
e or t importance        0    0.             0.                e or t importance       0    0.            0.
dxtran                   0    0.             0.                dxtran                  0    0.            0.
forced collisions        0    0.             0.                forced collisions       0    0.            0.
exp. transform           0    0.             0.                exp. transform          0    0.            0.
upscattering             0    0.             0.                downscattering          0    0.            9.3846E+00
photonuclear             0    0.             0.                capture                 0    1.3763E-02    7.4677E-02
(n,xn)               76033    3.7980E+00    1.8546E+01         loss to (n,xn)      24518    1.2243E+00    4.7692E+01
prompt fission           0    0.             0.                loss to fission         0    0.            0.
delayed fission          0    0.             0.                nucl. interaction    3623    1.8115E-01    6.1448E+01
prompt photofis          0    0.             0.                particle decay          0    0.            0.
tabular boundary         0    0.             0.                tabular boundary        0    0.            0.
tabular sampling      6995    3.4975E-01    1.7736E+00         elastic scatter         0    0.            0.
    total           376045    1.8799E+01    3.3285E+02             total          376045    1.8799E+01    3.3285E+02

  number of neutrons banked                     351527        average time of (shakes)              cutoffs
  neutron tracks per source particle     1.8802E+01             escape            5.7356E+00          tco   1.0000E+33
  neutron collisions per source particle 2.6633E+01             capture           4.5962E-01          eco   0.0000E+00
  total neutron collisions                      532667          capture or escape 5.7314E+00          wc1  -5.0000E-01
  net multiplication              0.0000E+00 0.0000             any termination   5.3035E+00          wc2  -2.5000E-01
```

Net neutron production for this case is 17.393 n/p, or 0.14% above the base case value. Examination of the net nuclear interactions and net (*n*,*xn*) figures show very similar results to the base case. The implication of this result is that we need not concern ourselves with light ion transport if the quantity with which we are concerned is related solely to neutrons, as neutron production by light ions is small when we start with a proton beam.

Case 2

In the second variation we replace the Bertini INC model used in the base case for the simulation of nucleon and pion interactions with nuclei by the ISABEL INC model (in this example, both INC models utilize the same GCCI level-density model). We invoke the ISABEL INC model by including in the input deck the following card:

Base Case:	`LCA 8J 0`	(Bertini INC)
Case 2:	`LCA 2J 2 5J 0`	(invokes ISABEL physics model)

This changes the value of the variable *`iexisa`* (third value on the `LCA` card) from its default value of 1 to 2. The neutron problem summary for this case follows:

```
     Sample problem: spallation target                                                  probid =  02/27/13 12:18:17
**********************************************************
Calls to event-generator models, counted by particle type.

particle         BERTINI            CEM           INCL          ISABEL         LAQGSM      LAQGSM_H1           HYD

neutron              172              0              0            6138              0              0              0
proton             16436              0              0           12155              0              0              0
pi_plus                0              0              0             706              0              0              0

totals             16608              0              0           18999              0              0              0


neutron creation    tracks      weight        energy           neutron loss        tracks      weight        energy
                                (per source particle)                                          (per source particle)

source                   0    0.            0.                 escape              342730    1.7121E+01    2.1554E+02
nucl. interaction   288164    1.4408E+01    3.1428E+02         energy cutoff            0    0.            0.
particle decay           0    0.            0.                 time cutoff              0    0.            0.
weight window            0    0.            0.                 weight window            0    0.            0.
cell importance          0    0.            0.                 cell importance          0    0.            0.
weight cutoff            0    0.            0.                 weight cutoff            0    0.            0.
e or t importance        0    0.            0.                 e or t importance        0    0.            0.
dxtran                   0    0.            0.                 dxtran                   0    0.            0.
forced collisions        0    0.            0.                 forced collisions        0    0.            0.
exp. transform           0    0.            0.                 exp. transform           0    0.            0.
upscattering             0    0.            0.                 downscattering           0    0.            9.1966E+00
photonuclear             0    0.            0.                 capture                  0    1.3422E-02    7.2094E-02
(n,xn)               74854    3.7392E+00    1.8478E+01         loss to (n,xn)       24008    1.1989E+00    4.7368E+01
prompt fission           0    0.            0.                 loss to fission          0    0.            0.
delayed fission          0    0.            0.                 nucl. interaction     3695    1.8475E-01    6.2501E+01
prompt photofis          0    0.            0.                 particle decay           0    0.            0.
tabular boundary         0    0.            0.                 tabular boundary         0    0.            0.
tabular sampling      7415    3.7075E-01    1.9142E+00         elastic scatter          0    0.            0.
    total           370433    1.8518E+01    3.3468E+02             total           370433    1.8518E+01    3.3468E+02

  number of neutrons banked                     346425       average time of (shakes)              cutoffs
  neutron tracks per source particle     1.8522E+01            escape            5.7255E+00          tco   1.0000E+33
  neutron collisions per source particle 2.6117E+01            capture           4.8478E-01          eco   0.0000E+00
  total neutron collisions                      522349         capture or escape 5.7214E+00          wc1  -5.0000E-01
  net multiplication              0.0000E+00 0.0000            any termination   5.2945E+00          wc2  -2.5000E-01
```

In the MCNP6 summary table, information is provided about the event-generator models used in the calculation. This information assists users to better understand the results and how they were calculated. For this particular case, we specified `LCA 2J 2 5J 0` to invoke ISABEL, yet we see that 16436 proton interactions and 172 neutron interactions were simulated with Bertini INC. The use of Bertini INC occurred because the default maximum energy of incident nucleons to be simulated with ISABEL is 800 MeV. Above this energy simulations were performed with Bertini INC. Note the net neutron production calculated using the ISABEL INC model (in coordination with Bertini INC, as discussed above) is 17.135 n/p, which is 1.35% below the value predicted when invoking the Bertini INC model alone. This result is consistent with other studies that reveal slightly lower neutron production resulting from ISABEL as compared to Bertini.

Case 3

In this variation, we use the CEM03.03 model for neutrons, protons, and pions. CEM is turned on by setting the ninth entry of the `LCA` card to `1`:

Base Case:	`LCA 8J 0`	(Bertini INC)
Case 3:	`LCA 8J 1`	(invokes CEM03.03 physics model, the MCNP6 default)

Because CEM03.03 is the default physics option in MCNP6, no `LCA` card is required to invoke CEM03.03 physics. Unlike the other INC models in the code, CEM03.03 includes its own Modified Preequilibrium Model (MEM) [GUD75, MAS74] and its own extension (see details in [MAS12]) of the Generalized Evaporation Model (GEM) by Furihata [FUR00]. Therefore, the Multistage Pre-equilibrium Model (MPM) by Prael and Bozoian [PRA88] and evaporation model settings used for the Bertini INC and ISABEL models have no effect when CEM03.03 is specified.

The neutron summary table for this case is shown below:

```
     Sample problem: spallation target                                                probid =  02/27/13 12:14:53
**********************************************************
Calls to event-generator models, counted by particle type.
particle         BERTINI            CEM           INCL         ISABEL         LAQGSM      LAQGSM_H1           HYD

neutron                0           3659              0              0              0              0              0
proton                 0          18261              0              0              0              0              0
pi_plus                0            342              0              0              0              0              0

totals                 0          22262              0              0              0              0              0


neutron creation    tracks      weight        energy          neutron loss        tracks      weight        energy
                               (per source particle)                                         (per source particle)

source                   0    0.            0.                escape              366399    1.8303E+01    2.0780E+02
nucl. interaction   317210    1.5861E+01    3.1400E+02        energy cutoff            0    0.            0.
particle decay           0    0.            0.                time cutoff              0    0.            0.
weight window            0    0.            0.                weight window            0    0.            0.
cell importance          0    0.            0.                cell importance          0    0.            0.
weight cutoff            0    0.            0.                weight cutoff            0    0.            0.
e or t importance        0    0.            0.                e or t importance        0    0.            0.
dxtran                   0    0.            0.                dxtran                   0    0.            0.
forced collisions        0    0.            0.                forced collisions        0    0.            0.
exp. transform           0    0.            0.                exp. transform           0    0.            0.
upscattering             0    0.            0.                downscattering           0    0.            1.1305E+01
photonuclear             0    0.            0.                capture                  0    1.4454E-02    8.0582E-02
(n,xn)               72864    3.6393E+00    1.6330E+01        loss to (n,xn)       24684    1.2325E+00    4.3524E+01
prompt fission           0    0.            0.                loss to fission          0    0.            0.
delayed fission          0    0.            0.                nucl. interaction     3659    1.8295E-01    6.8851E+01
prompt photofis          0    0.            0.                particle decay           0    0.            0.
tabular boundary         0    0.            0.                tabular boundary         0    0.            0.
tabular sampling      4668    2.3340E-01    1.2335E+00        elastic scatter          0    0.            0.
    total           394742    1.9733E+01    3.3156E+02            total           394742    1.9733E+01    3.3156E+02

  number of neutrons banked                 370058        average time of (shakes)             cutoffs
  neutron tracks per source particle     1.9737E+01         escape            5.4010E+00          tco   1.0000E+33
  neutron collisions per source particle 2.8016E+01         capture           4.2610E-01          eco   0.0000E+00
  total neutron collisions                  560322          capture or escape 5.3971E+00          wc1  -5.0000E-01
  net multiplication             0.0000E+00 0.0000          any termination   5.0105E+00          wc2  -2.5000E-01
```

Note the net neutron production calculated with the CEM03.03 model is 18.317 n/p, which is 5.38% above the value predicted by the Bertini INC model.

Case 4

In the final variation from the base case we use the INCL model coupled with the ABLA evaporation mode:

Base Case: `LCA 8J 0` (Bertini INC)
Case 4: `LCA 8J 2` (invokes INCL/ABLA physics model)

Note: The ABLA evaporation model is automatically chosen when INCL is specified.

The neutron problem summary for this case is shown below:

```
     Sample problem: spallation target                                                    probid =  02/27/13 12:08:25
**********************************************************
Calls to event-generator models, counted by particle type.

particle          BERTINI           CEM           INCL          ISABEL         LAQGSM      LAQGSM_H1           HYD

neutron                 0             0           8583               0              0              0              0
proton                  0             0          42531               0              0              0              0
pi_plus                 0             0           1080               0              0              0              0

totals                  0             0          52194               0              0              0              0


neutron creation    tracks      weight        energy           neutron loss        tracks      weight        energy
                                (per source particle)                                          (per source particle)

source                   0    0.            0.                 escape              332230    1.6597E+01    2.2404E+02
nucl. interaction   271669    1.3583E+01    3.1917E+02         energy cutoff            0    0.            0.
particle decay           0    0.            0.                 time cutoff              0    0.            0.
weight window            0    0.            0.                 weight window            0    0.            0.
cell importance          0    0.            0.                 cell importance          0    0.            0.
weight cutoff            0    0.            0.                 weight cutoff            0    0.            0.
e or t importance        0    0.            0.                 e or t importance        0    0.            0.
dxtran                   0    0.            0.                 dxtran                   0    0.            0.
forced collisions        0    0.            0.                 forced collisions        0    0.            0.
exp. transform           0    0.            0.                 exp. transform           0    0.            0.
upscattering             0    0.            0.                 downscattering           0    0.            9.2580E+00
photonuclear             0    0.            0.                 capture                  0    1.2528E-02    6.6701E-02
(n,xn)               81138    4.0537E+00    2.0529E+01         loss to (n,xn)       25210    1.2591E+00    5.2600E+01
prompt fission           0    0.            0.                 loss to fission          0    0.            0.
delayed fission          0    0.            0.                 nucl. interaction     3524    1.7620E-01    5.5785E+01
prompt photofis          0    0.            0.                 particle decay           0    0.            0.
tabular boundary         1    5.0000E-05    7.4999E-03         tabular boundary         1    5.0000E-05    7.4999E-03
tabular sampling      8157    4.0785E-01    2.0521E+00         elastic scatter          0    0.            0.
    total           360965    1.8045E+01    3.4176E+02             total           360965    1.8045E+01    3.4176E+02

  number of neutrons banked                     335755        average time of (shakes)              cutoffs
  neutron tracks per source particle     1.8048E+01             escape            5.4378E+00          tco   1.0000E+33
  neutron collisions per source particle 2.4996E+01             capture           4.6562E-01          eco   0.0000E+00
  total neutron collisions                      499914          capture or escape 5.4341E+00          wc1  -5.0000E-01
  net multiplication              0.0000E+00 0.0000             any termination   5.0024E+00          wc2  -2.5000E-01
```

Net neutron production for this case is 16.897 n/p—2.7% less than the base case value.

Summary

Results compiled for each case of this example are shown in Table 4-3. Runtimes were obtained running MCNP6 in a sequential mode using a single processor of a single node of the LANL Moon Light supercomputer (ml-fey). Note the runtime for the case where the ISABEL INC model is used together with the Bertini INC model is about 18% greater than the base case using only the Bertini model. Case 2 also runs a little slower. The CEM03.03 model runs about 22% faster than Bertini INC in this case. The INCL model has a significant speed penalty (about 70%) for this particular example..

Table 4-3. Results Compiled for Summary Cases

Case	Variation from base case	Runtime (minutes)	n/p
Base	**n/a**	**3.41**	**17.369**
1	**light ion transport & nuclear interaction**	**4.01**	**17.393**
2	**ISABEL INC for nucleons and pions**	**3.45**	**17.135**
3	**CEM INC for nucleons and pions**	**2.65**	**18.317**
4	**INCL INC for nucleons and pions; ABLA evaporation model**	**5.80**	**16.897**

This example demonstrates how to calculate neutron production from a spallation target. When the quantity of interest depends only on neutrons and one starts with a proton beam, there is no need to transport any particles other than protons, neutrons, and charged pions, as neutron production by other particles is negligible compared to production by these three particle types[1]. Use of the various physics model options, such as the CEM03.03. Bertini, and INCL modules, within MCNP6 is encouraged—this ability allows the user to test the sensitivity of the quantity of interest to the different physics models. If significant differences are observed, the user should evaluate which physics model is most appropriate for his or her particular application. For example, total neutron production from actinide targets is known to be more accurate if the multi-step preequilibrium model (MPM) is turned off while using Bertini INC and/or ISABEL.

[1] All particles should be included for energy deposition calculations, as discussed in Section 3.3.5.1.1.

5 MCNP GEOMETRY AND TALLY PLOTTING

MCNP6 has two plotting capabilities. The first, PLOT, is used to plot two-dimensional slices of a problem geometry specified in the INP file. The user can perform interactive geometry plotting in two ways: either "point-and-click" mode or "command-prompt" mode. In addition, generation of plot files can be done in batch mode using a command file. The second plotting capability, MCPLOT, plots tally results produced by MCNP6 and cross-section data used by MCNP6. Mesh tallies may be plotted either in MCPLOT from MCTAL files or superimposed over geometry plots in PLOT from RUNTPE files.

Section 5.1 addresses system issues external to MCNP6 related to graphics. Section 5.2 discusses how to invoke the PLOT features, whereas Section 5.3 discusses the MCPLOT features. An explanation of each set of input commands is given. Lines the user will type are shown in `typewriter font`. The <ENTER> key must be pressed after each input line. Although in this section plot options and keywords are shown in `UPPER CASE`, they are usually typed by the user in `lower case`.

5.1 SYSTEM GRAPHICS INFORMATION

X Windows is the only graphics system supported by MCNP6. This graphics library is device-independent in general and gives considerable flexibility in processing graphical output.

The X-window graphics library (`http://www.x.org`) allows the user to send/receive graphics output to/from remote hosts as long as the window manager on the display device supports the X protocol [e.g., OpenLook window manager, MOTIF window manager, Cygwin (PC Windows), etc.]. Before running MCNP6, perform the following steps to use these capabilities. Note that these steps use UNIX C-shell commands. Other shells may require different syntax.

1. On the host that will execute MCNP6, enter:

   `setenv DISPLAY` *`displayhost`*`:0`

   where *`displayhost`* is the name of the host that will receive the graphics. If the *`displayhost`* is the same as the execution host (*`executehost`*), set `DISPLAY` to

   `'localhost:0'` or just `':0'`.

2. If the two hosts are different, in a CONSOLE window of the display host enter:

   `xhost` *`executehost`*

   where *`executehost`* is the name of the host that will execute MCNP6.

With the `setenv` or the `xhost` command, the host IP address can be used in place of the host name. For example,

```
setenv DISPLAY 128.10.1:0
```

This option is useful when one remote system does not recognize the host name of another.

Note to LANL Users: On some systems, including the Los Alamos Integrated Computing Network (ICN) and other LANL local area networks, use of the 'xhost' command is strongly discouraged. This is because it creates a security problem. In place of using the `xhost`, the secure shell (SSH) can be used to log into remote hosts and provide X Windows forwarding. This is considered to be more secure, and it handles setting the `DISPLAY` variable for the user. If SSH is used, do not manually set `DISPLAY` as this will interfere with the secure forwarding. On local systems (where *displayhost* and *executehost* are the same), this warning does not apply.

5.2 THE GEOMETRY PLOTTER, PLOT

The geometry plotter is used to plot two-dimensional slices of a problem geometry specified in the INP file. This feature of MCNP6 is invaluable for debugging geometries. You should first verify your geometry model with the MCNP6 geometry plotter before running the transport part of MCNP6, especially with a complicated geometry in which it is easy to make mistakes. The time that is required to plot the geometry model is small compared with the potential time lost working with an erroneous geometry.

5.2.1 PLOT Input and Execute Line Options

To plot geometries with MCNP6, enter the following command:

```
MCNP6 IP INP=filename KEYWORD[=value(s)]
```

where `IP` stands for initiate and plot. The allowed keywords are explained in Table 5-1. The most common method of plotting is with an interactive graphics terminal. First, MCNP6 will read the input file and perform the normal checks for consistency, then the interactive point-and-click interactive geometry plotting window will appear on the terminal screen.

When X Windows is in use, the plot window supports a variety of interactive features that assist the user in selecting the plot. The interactive options are discussed after the discussion of the command-line plot options.

The four plot options described in Table 5-1 can be entered on the execution line in addition to the standard MCNP6 execution options:

Table 5-1. PLOT Execution Line Keywords

Keyword Options	Description
`NOTEK`	**Suppress plotting at the terminal and send all plots to the graphics metafile, PLOTM. The keyword `NOTEK` is for production and batch situations and is used when the user's terminal has no graphics capability.**
`COM=`*`filename`*	**Use file *`filename`* as the source of plot requests. When an end-of-file (EOF) is read, control is transferred to the terminal. In a production or batch situation, end the file with an `END` command to prevent transfer of control. Never end the COM file with a blank line. If `COM` is absent, the terminal is used as the source of plot requests.**
`PLOTM=`*`filename`*	**Name the graphics metafile *`filename`*. The default name is PLOTM. For some systems this metafile is a standard postscript file and is named PLOTM.PS. When CGS is being used, there can be no more than six characters in *`filename`*. Unique names for the output file, PLOTM, will be chosen by MCNP6 to avoid overwriting existing files.**
`COMOUT=`*`filename`*	**Write all plot requests to file *`filename`*. The default name is COMOUT. PLOT writes the COMOUT file in order to give the user the opportunity to do the same plotting at some later time, using all or part of the old COMOUT file as the COM file in the second run. Unique names for the output file, COMOUT, will be chosen by MCNP6 to avoid overwriting existing files.**

When names are defaulted, unique names for the output files, PLOTM and COMOUT, will be chosen by MCNP6 to avoid overwriting existing files. Unique names are created by changing the last letter of the default name until the next available name is found. For example, if the file PLOTM.PS already exists, MCNP6 tries the name PLOTN.PS, etc., until it finds an available name.

MCNP6 can be run in a batch environment without much difficulty, but the user interaction with the plotter is significantly reduced. When not using an interactive graphics terminal, use the `NOTEK` option on the MCNP6 execution line or set `TERM=0` along with other PLOT commands when first prompted by PLOT. (*Note: For geometry plotting with X Windows, a plot window will appear before the first plot request as the interactive plot window is created. To prevent this, use the* `NOTEK` *option.*) Every view plotted will be put in a postscript file called PLOT*n* where *n* begins at M and goes to the next letter in the alphabet if PLOTM exists. In the interactive mode, plots can be sent to this graphics metafile with the `FILE` keyword. (See the keyword description in Table 5-3 for a complete explanation.) The PLOTN.PS file is a postscript file that can be sent to a postscript printer.

5.2.2 Geometry Plotting Basic Concepts

A plot request consists of a sequence of commands terminated by pressing the <ENTER> key. A command consists of a keyword, usually followed by some parameters. Lines can be continued by typing an & (ampersand) before pressing the <ENTER> key, but each keyword and its parameters must be complete on one line. The & character can be used in the COM file as well as at the plot prompt. Keywords and parameters are blank-delimited. A plot request line cannot have more than128 characters on a single line. Use the & to enter more complex commands. Commas and equal signs are interpreted as blanks. Keywords can be shortened to any degree as long as they are not ambiguous and are spelled correctly. Parameters following the keywords cannot be abbreviated. Numbers can be entered in free-form format and do not require a decimal point for floating point data. Keywords and parameters remain in effect until you change them. ***Note:*** *If a shortened, ambiguous keyword is used, the entire command line will be rejected and a message to that effect will be printed to the terminal. The commands* `OPTIONS`, `HELP`, *and* '?' *display a list of the keywords to help the user recall the correct keyword.*

Before describing the individual plotting commands, it may help to explain the mechanics of two-dimensional (2D) plotting. To obtain a 2D slice of a geometry, you must decide where the slice should be taken and how much of the slice should be viewed on the terminal screen. The slice is actually a 2D plane that may be arbitrarily oriented in space; therefore, the first problem is to decide the plane position and orientation. In an orthogonal three-dimensional coordinate system the three axes are perpendicular to each other. An orthogonal axis system is defined with a set of `BASIS` vectors on the 2D plane used to slice the geometry to determine the plot orientation. The first `BASIS` vector is the horizontal direction on the screen. The second BASIS vector is the vertical direction on the screen. The surface normal for the plane being viewed is perpendicular to the two `BASIS` vectors.

How much of the slice to view is determined next. The center of the view plane is set with the `ORIGIN` command, which serves two purposes. First, for planes not corresponding to simple coordinate planes, it determines the position of the plane being viewed. Second, the origin becomes the center of the cross-sectional slice being viewed. For example, for a *y*-*z* plot, the *x*-coordinate given with the `PX` command determines the location of the `PX` plane. The `ORIGIN` is given as an *x*-, *y*-, and *z*-coordinate and is the center of the plot displayed. Because planes are infinite and only a finite area can be displayed at any given time, you must limit the extent of the cross-sectional plane being displayed with the `EXTENT` command. For instance, a plane defined with `PX=`x_1 at an `ORIGIN` of x_1, y_1, and z_1 would produce a *y*-*z* plane at $x=x_1$, centered at y_1 and z_1 using the default `BASIS` vectors for a `PX` plane of `0 1 0` and `0 0 1`. If the `EXTENT` entered is y_2 and z_2, the plot displayed would have a horizontal extent from y_1-y_2 to y_1+y_2 and a vertical extent of z_1-z_2 to z_1+z_2.

The `BASIS` vectors are arbitrary vectors in space. This may seem confusing to the new user, but the majority of plots are `PX`, `PY`, or `PZ` planes where the `BASIS` vectors are defaulted. For the majority of geometry plots, these simple planes are sufficient and you do not have to enter `BASIS` vectors. The flexibility of the `BASIS` option can also be used to examine the geometry from more obscure views.

The `ORIGIN`, `EXTENT`, and `BASIS` vectors all define a space called the plot *window* (in particular, the window that appears on the terminal screen). The window is a rectangular plane twice the length and width of `EXTENT`, centered about the point defined by `ORIGIN`. The first `BASIS` vector is along the horizontal axis of the plot window and points toward the right side of the window. The second `BASIS` vector is along the vertical axis of the plot window and points toward the top of the window.

The signs are determined by the direction of the vectors; in particular, do the vector components point in the ±*x*, ±*y*, or ±*z* direction? After signs have been fixed, determine the magnitudes of the vector components. Assume the vector is parallel to the *x*-axis. It has no *y*-component and no *z*-component so the vector would be `1 0 0`. If there is no *x*-component but both *y*- and *z*-components, and y and z have equal magnitudes, the vector would be `0 1 1`. The vector does not have to be normalized. If the angle between the vector and the axes is known, the user can use the sine and cosine of the angle to determine the magnitude of the components. A rough approximation will probably be sufficient.

All the plot parameters for the MCNP6 plotter have defaults. If you are in command-line mode, respond to the first MCNP6 prompt with a carriage return to obtain a default plot; if you are in interactive mode, click on the plot area of the interactive screen. The default geometry plot is a `PX` plane centered at `0,0,0` with an extent of `-100` to `+100` on y and `-100` to `+100` on z. The *y*-axis will be the horizontal axis of the plot, and the z-axis will be the vertical axis. Surface labels are printed. In command-prompt mode, this default is the equivalent of entering the command line:

```
ORIGIN 0 0 0  EXTENT 100 100  BASIS 0 1 0  0 0 1  LABEL 1 0
```

By resetting selected plot parameters, you can obtain any desired 2D plot. Most parameters remain set until you change them, either by the same command with new values or by a conflicting command.

Warning: Placing the plot plane exactly on a surface of the geometry is not a good idea. For example, if the input geometry has a `PX` plane at *x*=0, that plane coincides with the default plot plane. Several things can result. Some portion of the geometry may be displayed in dotted lines, which usually indicates a geometry error. Some portion of the geometry may simply not show up at all. Very infrequently the code may crash with an error. To prevent all these un-pleasantries, move the plot plane some tiny amount away from surfaces.

5.2.3 Interactive Geometry Plotting in Point-and-Click Mode

The geometry plotter supports interactive point and click plotting for all systems with X11 graphics. Figure 5-1 shows an example geometry plot window with the interactive controls outlined. The controls are separated into left, right, top, and bottom menus. The plot area itself is also active. An explanation of the point-and-click commands in each control menu is provided in Table 5-2.

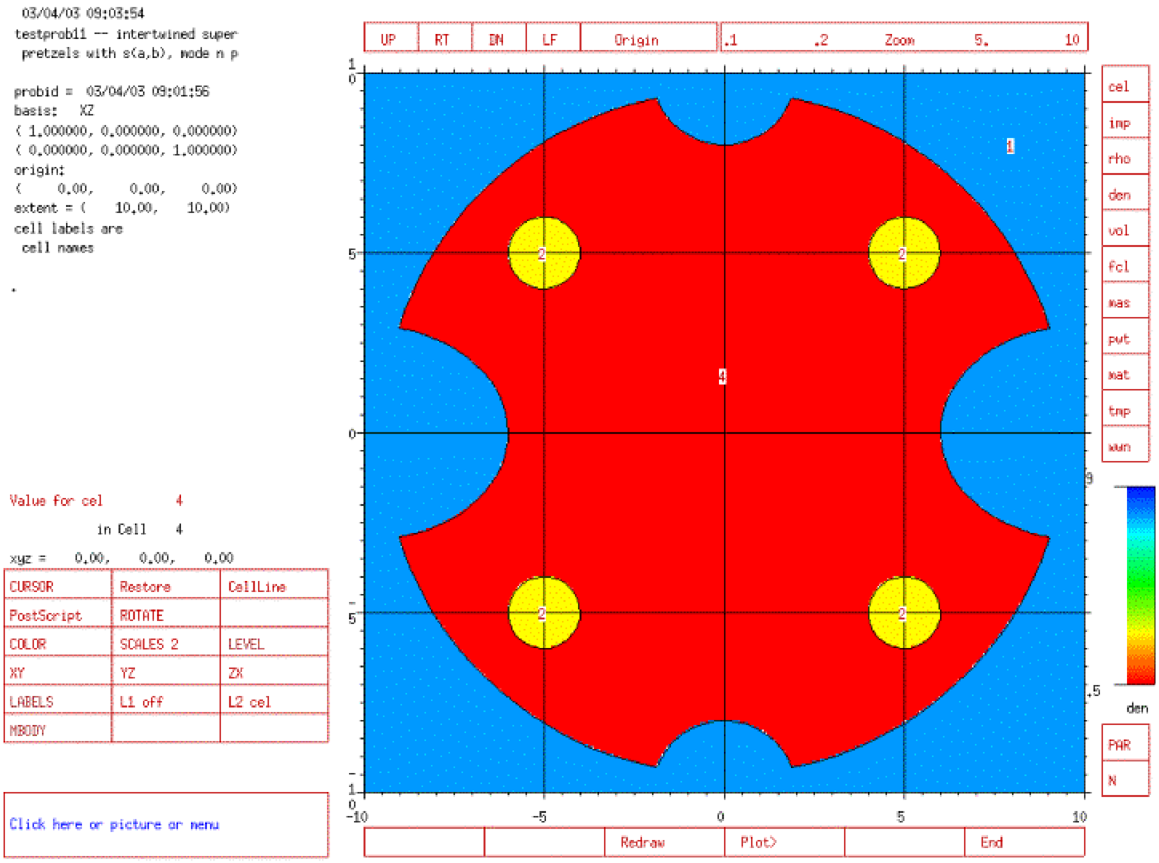


Figure 5-1. Geometry plot window showing interactive plotting controls.

Table 5-2. Point-and-Click Geometry Plotter Commands

Command	Result
Top Margin Menu Commands: Shift and zoom functions	
`UP, RT, DN, LF`	When selected, moves the plot frame one full window upwards (`UP`), to the right (`RT`), downwards (`DN`), or to the left (`LF`), respectively.
`Origin`	After selected, resets the origin to a point selected by a mouse click on the plot.

Command	Result
`.1 .2 Zoom 5 10`	**The zoom command requires a minimum of two mouse clicks: The first click on the zoom scale selects a discrete zoom factor between 0.1 and 10 for the current plot. The selected scale factor is displayed above the "`Click here or picture or menu`" box in the lower left of the plot window. If the first mouse click is followed by a second click in the zoom menu *for the same scale factor value*, the zoom factor is applied using the current origin. If the second click in the zoom menu is *for a different scale factor*, this action is equivalent to a new first click. However, if the second click occurs in the plot, the origin is reset to that point and the zoom occurs about this new origin point. Hint: To effectively cancel a zoom command, reselect the scale factor to 1x (or 1/1x) and then click on the 1x (1/1x) scale position a second time.**
Left Margin Menu Commands: What is plotted and how	
`(Hidden button)`	**A "hidden" button resides in the upper left quadrant of the plot window and triggers a redraw. If your plot window appears blank when exposed, click in the upper left of the screen to refresh it. On some systems, the entire plot window may appear blank if resized or iconified and then restored. Just click in the upper left quadrant to redraw.**
`Edit`	**Provides information for the plot cell number and coordinates at the most recent cursor selection point.**
`CURSOR`	**Selection of this button activates the cursor region selector; the cursor changes shape to appear like the upper left corner of a box. Click in the plot window at a point representing the upper left spatial boundary of the desired plot. The cursor will change shape again; now select the lower right position of the desired plot. The plot will be redrawn using the new boundaries. This is equivalent to an `EXTENT` command and an `ORIGIN` command.**
`SCALES`	**Toggles among three scale modes: If `SCALES` is set to 0, no scale is provided on the plot. If `SCALES` is set to 1, dimensional scales for both horizontal and vertical axes are provided. If `SCALES` is set to 2, dimensional scales for both horizontal and vertical axes with an associated grid are provided. Note: After the scale mode is chosen, select "`Redraw`" from the bottom menu to force the scales to be drawn on the plot.**

Command	Result
CellLine	**Toggles among available line modes:** **CellLine** Plot geometric cells, outlined in black. (DEFAULT) **No Lines** Plot cells not outlined in black. **WW MESH** Plot weight-window superimposed mesh without cell outlines. **WW+Cell** Plot weight-window superimposed mesh and cell outlines. **WWG MESH** Plot weight-window generator mesh. **WWG+Cell** Plot weight-window generator mesh and cell outlines. **MeshTaly** Plot TMESH mesh tally boundaries. **MT+Cell** Plot TMESH mesh tally boundaries and cell outlines.. **The CellLine and No Lines options are always available. WW MESH and WW+Cell are available only when the WWP card calls for using a superimposed weight-window mesh (5th entry negative) and a WWINP file is provided. WWG MESH and WWG+Cell are available only when a MESH card appears in the input and when the WWG card requests superimposed mesh generation (2nd entry=0). MeshTaly and MT+Cell are available only when a TMESH mesh tally has been requested.** **Note: After a line mode is chosen, select "Redraw" from the bottom menu to force the selected mesh and/or cell lines to be drawn on the plot.**
PostScript	**When activated ("PScript on"), writes the *next* plot to the postscript file (default name, PLOTM.PS), thus placing a publication-quality picture in the file. To create a postscript image of the current plot, activate the PostScript command and then select "Redraw" from the bottom menu. After one plot is written to the postscript file, the PostScript button is reset.** **The function of the PostScript button is equivalent to the text command FILE with no argument; i.e., only the next plot is written to the file.**
ROTATE	**Toggles between two modes: "ROTATE on" and "ROTATE off." "ROTATE on" interchanges the first two basis vectors, resulting in a 90° rotation of the plot.** **Note: After a rotation mode is chosen, select "Redraw" from the bottom menu to force the plot to be redrawn with new orientation.**
COLOR *var*	**Toggles colors on and off.** **Color shading of geometry plots may be used for any cell quantity. By default, the parameter *var* registers the cell parameter "mat," which indicates that plot colors are assigned to materials. By toggling the COLOR button, all color can be turned off, presenting only a line drawing after a Redraw is accomplished. Alternatively, the cell parameter on which the plot color scheme is based can be changed to any parameter in the right margin control menu appropriate to the problem. To change the *var* parameter, select a cell parameter from the right menu, click the COLOR button to turn off color, then choose COLOR again to reactivate it. The new selected cell parameter will now register as *var*. A change in state of the COLOR *var* parameter requires that "Redraw" be selected from the bottom menu to display the revised plot.**
LEVEL	**Toggles through universe levels in repeated structures geometry. If there are no sublevels, then the LEVEL button is not active. The button label identifies the level to be plotted if levels are present in the input. Requires that the Redraw command from the bottom menu be selected to create the revised plot.**

Command	Result
XY or YZ or ZX	**Alter plot perspective to corresponding planar combinations:** **the XY command sets the basis to (1 0 0 0 1 0);** **the YZ command sets the basis to (0 1 0 0 0 1); and** **the ZX command sets the basis to (0 0 1 1 0 0).** **In all cases, the origin is unchanged.**
LABEL *lab*$_1$ *lab*$_2$	**Controls the status of surface and cell labels.** **If *lab*$_1$ is set to sur, then surface labels are displayed.** **If *lab*$_1$ is set to off, then surface labels are not displayed.** **If *lab*$_2$ is set to *var*, then the cell label parameter, *var*, is displayed. To change the *var* parameter, select a cell parameter from the right menu, then click the *lab*$_2$ button to change the label type to the new selection. A change in state of any LABEL parameter requires that "Redraw" be selected from the bottom menu to display the revised plot.**
LEGEND	**When activated, displays a contour plot legend for a mesh tally. The legend will display the association of the color key to the numerical values in the plot.**
MBODY	**Effects the labeling of macrobody surfaces.** **If MBODY is on and if *lab*$_1$ of the LABEL command is set to sur., then general macrobody surface numbers are displayed. No surface numbers are displayed if sur is inactive.** **If MBODY is off and if *lab*$_1$ of the LABEL command is set to sur., then macrobody facet numbers for each macrobody surface are displayed. No surface numbers are displayed if sur is inactive.** **A change in state of MBODY requires that "Redraw" be selected from the bottom menu to display the revised plot.**
FMESH	**Cycle through mesh tallies. Does not change plot layout. Only present if mesh tallies exist in the input. A change in state of FMESH requires that "Redraw" be selected from the bottom menu to display the revised plot.**
"Click here ..."	**Clicking in this area toggles the acceptance of a text plot command in this box. Up to 29 characters representing one or more complete plot commands can be entered. On acceptance, either more input can be entered or a redraw is done, depending on the command given.** **Note: For extended access to the command-line interface, use the PLOT> option in the bottom menu to pass control to the terminal window.**
Right Margin Commands: Parameter choices for cell LABELs, Edit quantities, COLOR variable (See Note 1.)	
cel	**Cell labels/colors will be cell numbers (DEFAULT for cell label, *lab*$_2$).**
imp	**Cell labels will be importance by particle type.**
rho	**Cell labels/colors will be atom densities.**
den	**Cell labels/colors will be mass densities.**
vol	**Cell labels will be volumes (calculated or user-supplied).**
fcl	**Cell labels will be forced collisions by particle type.**
mas	**Cell labels will be masses.**
pwt	**Cell labels will be photon production weights.**
mat	**Cell labels/colors will be material numbers (DEFAULT for COLOR variable, *var*).**
tmp	**Cell labels/colors will be temperature for time index 1, TMP1.**

Command	Result
Wwn	Cell labels will be weight windows for energy or time index 1, WWN1, by particle type.
Ext	Cell labels will be exponential transform by particle type.
Pd	Cell labels will be detector contribution by particle type.
Dxc	Cell labels will be DXTRAN contributions.
U	Cell labels will be universe numbers.
Lat	Cell labels will be lattices.
Fill	Cell labels will be filling universes.
Ijk	Cell labels will be lattice indices.
Nonu	Cell labels will be fission turnoffs.
Pac	Cell labels will be particle activity, column.
Tal	Cell labels will be mesh tallies.
PAR	Selects particle type for cell quantities that have particle-specific values (e.g., IMP:<*pl*>).
N	Selects a numerical index for cell quantities that have indexed values. Example: WWN3:P would provide photon weight windows in the 3rd energy group and be selected by clicking WWN & N.
Bottom Margin Commands	
Enter Data	Activated by selecting "Click here or picture or menu". Allows entry of a text plot command per keyboard entry (e.g., ORIGIN 0. 0. 0. will locate plot origin at x, y, z = 0, 0, 0) Up to 29 characters representing one or more complete plot commands can be entered. Upon acceptance, either more input can be entered or a redraw is done, depending on the command given. Note: For extended access to the command-line interface, use the Plot> option in the bottom menu to pass control to the terminal window.
Redraw	Triggers a redraw of the plot.
Plot>	Passes control to the command-line window enabling traditional plot commands to be entered. Once in the command-line mode, control can be returned to the interactive plotter with the command INTERACT. Note: For brief text commands, use the "Click here..." button to type up to 29-character text commands.
End	Terminates the plot session and exit PLOT.
Plotting Superimposed Weight-Window Mesh	
MESH off	Toggled to MESH *on* position by clicking when a mesh has been generated by WWINP card entry.
wwn..par..N	Yields weight-window particle type and number.
N	N=-1, results in no lines. N=0, sets MESH *off*. N=1, sets WW MESH.
WWMESH	Appears only if WWINP file is read in.

Note 1: The right menu is used to set cell values for cell labels and to edit quantities and related indices. The buttons in the right menu are used to select the type of cell labels and the values to be displayed in the Edit area of the plot. After selecting a new label, you must toggle the `lab`$_2$ button off and back on to set it to the new parameter. Then, manually trigger a redraw.

There are two other buttons in the lower portion of the right menu. The `PAR` button selects the particle type for cell quantities that have particle-specific values (for example, `imp:p`). The `N` button selects a numerical index for cell-quantities that have indexed values (for example, `WWN1:`*`n`* for first-energy-bin weight windows for neutrons).

The plot area is active at all times when the interactive plotter is enabled. However, it is not active when the command-line interface is in use (`Plot>`*option*) except for text commands that need mouse input from the plot window.

Options that use plot-area interaction include the following:

ZOOM	When it occurs in the plot area, the second mouse click of this command selects a new origin.
ORIGIN	Click in the plot window to set the origin.
LOCATE	(Command-Prompt Mode) A mouse click in the plot area provides a display of several values at the selected location.
CURSOR	Two mouse clicks are used to define new plot window boundaries. The larger dimension of the selected rectangle determines one edge of the new plot.

A mouse click in the plot area without any other selected option will cause the cell, location, and variable value for the selected location to be displayed above the left menu. This area is labeled "Value for." The variable displayed is selected using the right menu.

5.2.4 Interactive Geometry Plotting in Command-Prompt Mode

In command-prompt mode, plot requests consist of a sequence of commands terminated by a carriage return. A command consists of a keyword, usually followed by some parameters. Lines can be continued by typing an `&` before the carriage return, but each keyword and its associated parameters must be complete on one line. Keywords and parameters are blank-delimited with no more than128 characters per line. Commas and equals signs are interpreted as blanks. Keywords can be shortened to any degree not resulting in ambiguity, but must be spelled correctly. Parameters following the keywords cannot be abbreviated. Numbers can be entered in free-form format and do not require a decimal point for floating-point data. Keywords and parameters remain in effect until you change them.

A detailed description of each of the PLOT keywords and its associated parameters is provided in Table 5-3. These commands are typically entered after a `plot>` prompt or they are given in a command file for batch processing (Section 5.2.7).

To enter the command-prompt interface of the geometry plotter from point-and-click mode, use the mouse to select the `plot>` button in the bottom menu of the plot window. You may return to point-and-click mode by giving the command "`INTERACT`."

Table 5-3. PLOT Commands

Command	Description
Device-Control Commands **Normally PLOT draws plots on the user's terminal. By using the following commands, the user can specify that plots not be drawn on the terminal and/or that they be sent to a graphics metafile or postscript file for processing later by a graphics utility program.**	
TERM *n*	**Output device type is specified by *n*.** ***n*=0 for a terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphics metafile. TERM 0 is equivalent to putting NOTEK on MCNP6's execute line.** **n=1 restores visible plotting window on next plot request.**
FILE [*aa*]	**Send or do not send plots to the graphics metafile PLOTM.PS according to the value of the parameter *aa*. The graphics metafile is not created until the first FILE command is entered. FILE has no effect in the NOTEK or TERM 0 cases.** **The allowed values of *aa* are the following:** **If *aa* is blank, only the current plot is sent to the graphics metafile.** **If *aa*=ALL, the current plot and all subsequent plots are sent to the metafile until another FILE command is entered.** **If *aa*=NONE, the current plot is not sent to the metafile nor are any subsequent plots until another FILE command is entered.**
VIEWPORT *aa*	**Make the viewport rectangular or square according to the value of *aa*. This option does not affect the appearance of the plot. It only determines whether space is provided beside the plot for a legend and around the plot for scales.** **If *aa*=RECT, allow space beside the plot for a legend and around the plot for scales. (DEFAULT)** **If *aa*=SQUARE, the legend area, the legend, and scales are omitted, making it possible to print a sequence of plots on some sort of strip medium so as to produce one long picture free from interruptions by legends. Note: Use of the SQUARE option disables the interactive-window plotter capability.**
General Commands	
&	**Continue reading commands for the current plot from the next input line. The & must be the last thing on the line.**
INTERACT	**Return to the interactive, mouse-driven geometry plot interface. This command is used to return from the terminal-command interface when the PLOT option is invoked from the interactive plotter.**
RETURN	**If PLOT was called by MCPLOT, control returns to MCPLOT. Otherwise RETURN has no effect.**
MCPLOT	**Call or return to the MCPLOT tally and cross-section plotter.**
PAUSE [*n*]	**Use with COM=*filename* option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the ENTER key is pressed.**
END	**Terminate execution of PLOT.†**

Command	Description
Inquiry Commands When one of these commands is encountered, the requested display is made and then PLOT waits for the user to enter another line, which can be just pressing the ENTER key, before resuming. The same thing will happen if PLOT sends any kind of warning or comment to the user as it prepares the data for a plot.	
`OPTIONS` or `?` or `HELP`	Display a list of the PLOT command keywords and available colors.
`STATUS`	Display the current values of the plotting parameters.
Plot Commands Plot commands define the values of the parameters used in drawing the next plot. Parameters entered for one plot remain in effect for subsequent plots until they are overridden, either by the same command with new values of by a conflicting command.	
`BASIS` x_1 y_1 z_1 x_2 y_2 z_2	Orient the plot so that the direction (x_1 y_1 z_1) points to the right and the direction (x_2 y_2 z_2) points up. The default values are `0 1 0  0 0 1`, causing the *y*-axis to point to the right and the *z*-axis to point up. The two vectors do not have to be normalized, but they should be orthogonal. If the two vectors are not orthogonal, MCNP6 will choose an arbitrary second vector that is orthogonal to the first vector. MCNP6 will ignore the command if parallel or zero-length vectors are entered.
`ORIGIN` v_x v_y v_z	Position the plot so that the origin, which is in the middle of the plot, is at the point (v_x, v_y, v_z). The default values are `0 0 0`. The `BASIS` vectors are relative to this point.
`EXTENT` e_h e_v	Set the scale of the plot so that the horizontal distance from the origin to either side of the plot is e_h and the vertical distance from the origin to the top or bottom is e_v. If e_v is omitted, it will be set equal to e_h. If e_v is not equal to e_h, the plot will be distorted. The default values are `100` and `100`, creating a 200×200 cm viewport..
`PX` v_x	Plot a cross section of the geometry in a plane perpendicular to the *x*-axis at a distance v_x from the origin. This command is a shortcut equivalent of `BASIS 0 1 0  0 0 1  ORIGIN` v_x v_y v_z, where v_y and v_z are the current values of v_y and v_z.
`PY` v_y	Plot a cross section of the geometry in a plane perpendicular to the *y*-axis at a distance v_y from the origin.
`PZ` v_z	Plot a cross section of the geometry in a plane perpendicular to the *z*-axis at a distance v_z from the origin.

Command	Description
LABEL *s c des*	Put labels of size *s* on the surfaces and labels of size *c* in the cells. Use the quantity indicated by *des* for the cell labels. The parameters *c* and *des* are optional. The sizes are relative to 0.01 times the height of the view surface. If *s* or *c* is zero, that kind of label will be omitted. If *s* or *c* is not zero, it must be in the range from 0.2 to 100. The defaults are *s*=1, *c*=0 and *des*=CEL. The possible values of *des* follow, where ":<*pl*>" indicates the particle type. CEL — cell names IMP:<*pl*> — importance RHO — atom density DEN — mass density VOL — volume FCL:<*pl*> — forced collision MAS — mass PWT — photon-production weight MAT — material number TMP*n* — temperature (*n*=index of time) WWN*n*:<*pl*> — weight-window lower bound (*n*=energy or time interval) EXT:<*pl*> — exponential transform PD*n* — detector contribution (*n*=tally number) DXC:<*pl*> — DXTRAN contribution U — universe LAT — lattice type FILL — filling universe IJK — lattice indices of repeated structures/lattice geometries NONU — fission turnoff
LEVEL *n*	Plot only the n^{th} level of a repeated structure geometry. A negative entry (DEFAULT) plots the geometry at all levels. (Note, $n \leq 20$.)
MBODY *on|off*	*on* Display only the macrobody surface number. (DEFAULT) *off* Display the macrobody surface facet numbers.
MESH *n*	Controls plotting of the weight-window and weight-window-generator superimposed mesh. If *n*=0 No Lines — Plot cells not outlined in black. If *n*=1 CellLine — Plot geometric cells, outlined in black. (DEFAULT) If *n*=2 WW MESH — Plot weight-window mesh. If *n*=3 WW+Cell — Plot weight-window mesh + CellLine. If *n*=4 WWG MESH — Plot weight-window generator mesh. If *n*=5 WWG+Cell — Plot weight-window generator mesh + CellLine. If *n*=6 MeshTaly — Plot TMESH mesh tally boundaries (RMESH, CORA, etc., required) If *n*=7 MT+Cell — Plot TMESH mesh tally boundaries + CellLine The CellLine and No Lines options are always available. WW MESH and WW+Cell are available only when the WWP card calls for using a superimposed weight-window mesh (i.e., a negative 5th entry appears on the WWP card) and a WWINP file is provided. The WWG MESH and WWG+Cell options are available only when a MESH card appears in the input and when the WWG card requests superimposed mesh generation (2nd entry=0).Similarly, MeshTaly and MT+Cell are available only when a TMESH mesh tally has been requested..

Command	Description
FMESH *n*	Plot **FMESH** mesh tally *n*. Changes the layout of the plot depending on the type of mesh tally. For rectangular meshes, the horizontal axis is in the direction of the dimension with the most number of bins, and the vertical axis is in the direction of the dimension with the second most number of bins. For cylindrical plots, the horizontal axis is along the axis of the cylinder and the vertical axis is along the θ=0 plane. The center of the plot in both cases is at the center of the mesh. To keep the original layout, use the **FMESH** button of the interactive plotter. **FMESH off** will turn off the mesh tally plotter.
SCALES *n*	Put scales and a grid on the plot. Scales and grids are incompatible with **VIEWPORT SQUARE**. If *n*=0, neither scales nor a grid are displayed. (DEFAULT) If *n*=1, display scales on the edges. If *n*=2, display scales on the edges and a grid on the plot.
CONTOUR *cmin* *cmax* [*cstep*] [%|PCT|LIN|LOG] [OFF]	Valid for **TMESH** mesh tallies. The parameters *cmin*, *cmax*, and *cstep* are the minimum, maximum, and step values for contours, respectively. The *cstep* entry is ignored and can be omitted. If either the % symbol or the **PCT** keyword is included, the first three parameters are interpreted as percentages of the minimum and maximum values of the dependent variable. The default values are 5 95 10 %. If the keyword **LIN** appears, interpret the step values as absolute values of contour levels. If the keyword **LOG** appears, space the contour levels logarithmically between *cmin* and *cmax*. The default values are 1E-4 1E-2 12 LOG. If the **OFF** keyword appears, use the following defaults: 0 100 %
COLOR *n*	Turn color on or off, set the resolution, or select the physical property for color shading. If *n*=ON, turn color on. (DEFAULT) If *n*=OFF, turn color off. If 50≤*n*≤3000, set the color resolution to *n*. A larger value increases resolution and drawing time. If *n*=BY *aa*, select the physical property to use for geometry shading. Allowed *aa* options for **COLOR BY** include: MAT material (DEFAULT) DEN gram density RHO atom density TMP temperature CEL cell number If *n*=GRADIENT, use a continuous gradient of 256 colors to show the cell values. If *n*=SOLID, use a solid color to represent a range of cell values. When (DEN/RHO/TMP) is used, the geometry will be shaded using the color gradient mode. Linear interpolation between the minimum non-zero value and the maximum value is used to select the color. A color bar legend of the shades will be drawn in the right margin. The legend is labeled with the property name and the minimum and maximum values. See Figure 5-1 for an example of coloring by density (DEN). Coloring by material (MAT) does not invoke a color bar legend.

Command	Description
SHADE m_1=*value* m_2=*value* ... m_i=*value*	**This command is only valid when MAT is used to COLOR BY (the default). Make the cells containing problem material number m_i a particular color, as determined by the parameter *value*. The parameter *value* can be a color name or a number from 1–64 representing the color index. Use the LABEL command to display material numbers. The *value* entry designates the desired color (e.g., green, blue, etc.). Note: *Color names are case sensitive*. The command OPTIONS will list available colors if your display is a color monitor. The index of a color name is in top-bottom, left-right order.**
Zoom Commands Zoom commands redefine the origin, bases, and extent relative to the current origin, bases, and extent. The new origin, bases, and extent will be used for all subsequent plots until they are again redefined, either by zoom commands or by plot commands. The zoom commands are usually used to zoom in on some feature of the plot.	
CENTER d_h d_v	**Change the origin of the plot by the amount d_h in the horizontal direction and by the amount d_v in the vertical direction. This command is usually used to define the center of a portion of the current plot that the user wants to enlarge.**
FACTOR *f*	**Enlarge the plot by the factor 1/*f*. The parameter *f* must be greater than 10^{-6}.**
THETA *th*	**Rotate the plot counterclockwise by the angle *th*, in degrees.**
CURSOR	**Present the graphics cursor and prepare to receive cursor input from the user. This command is available only if the terminal has a graphics cursor capability. The user defines a rectangular area to be enlarged by moving the cursor to one corner of the rectangle and entering the cursor trigger, then moving it to the diagonally opposite corner of the rectangle and entering the cursor trigger again. On most terminals the cursor trigger is any key other than the ENTER key followed by ENTER. If the extents were equal before the cursor command was entered, the smaller of the two extents defined by the cursor input is made equal to the larger one. The CURSOR command should be the only command on the input line.**
RESTORE	**Restore the origin and extent to the values they had before the most recent CURSOR command. The RESTORE command should be the only command on the input line. It cannot be used to undo the effects of the CENTER, FACTOR, and THETA commands.**
LOCATE	**Present the graphics cursor and prepare to receive cursor input from the user. This command is available only if the terminal has a graphics cursor capability. The user moves the cursor to a point in the picture and enters the cursor trigger. The *x*-, *y*-, *z*-coordinates of the point are displayed. The LOCATE command should be the only command on the input line.**

5.2.5 Plotting Embedded-Mesh Geometries

The MCNP6 plotter supports color-shaded plotting of the materials, mass density, or number density of an imported embedded mesh. For these cases the values from the external mesh geometry file (typically a LNK3DNT or Abaqus-style file) are used; these values may vary element to element.

For mass density (`den`) and number density (`rho`) plots, each element will be shown in one solid color. What is plotted is the element net value, i.e., the net mass density or net number density of the element. The color distribution is set by the minima and maxima. These net values are also the values reported for plot queries when "den" or "rho" is selected from the right-hand-side interactive menu.

For material plots, multi-material zones may appear striped as the color to plot is chosen randomly based on the material mass fraction. This means that redrawing a color-by-mat plot may give a slightly different striping. For example, in a two-material element with a 50/50 mass – fraction mix, approximately 50/50 color striping will display horizontally. If "mat" is selected from the right-hand-side interactive menu, clicking on a spot containing multiple materials will randomly select which material to report. Repeated clicking on such a spot may show different materials on different clicks. Void elements in the mesh are not shaded (i.e., shown as white) on material plots.

5.2.6 Geometry Debugging

Surfaces appearing on a plot as red dashed lines usually indicate that adjoining space is improperly defined. Dashed lines caused by a geometry error can indicate space that has been defined in more than one cell or space that has never been defined. These geometry errors need to be corrected. Dashed lines also can occur because the plot plane corresponds to a bounding planar surface. The plot plane should be moved so it is not coincident with a problem surface. Dashed lines can indicate a cookie cutter cell or a DXTRAN sphere. These are not errors. The reason for the presence of dashed lines on an MCNP6 plot should be understood before running a problem.

When checking a geometry model, errors may not appear on the two-dimensional slice chosen, but one or more particles will get lost in tracking. To find the modeling error, use the coordinates and trajectory of the particle when it got lost. Entering the particle coordinates as the ORIGIN and the particle trajectory as the first basis vector will result in a plot displaying the problem space.

5.2.7 Geometry Plotting in Batch Mode

Although MCNP6 can be run in a batch environment without much difficulty, user interaction with the plotter is significantly reduced. If you are not using an interactive graphics terminal, use the NOTEK option on the MCNP6 execution line or set TERM=0 along with other PLOT keywords when first prompted by PLOT. Every view you plot will be put in a local graphics metafile or postscript file called PLOT*n* where *n* begins at M and goes to the next letter in the alphabet if PLOTM exists. In the interactive mode, plots can be sent to this graphics metafile with the FILE keyword. (See the keyword description in Table 5-3 for a complete explanation.) For some graphics systems, the PLOT*n*.PS file is a postscript file that can be sent to a postscript printer.

5.3 The Tally and Cross-Section Plotter, MCPLOT

MCPLOT plots tally results produced by MCNP6 as well as cross-section data used by MCNP6. It can draw ordinary two-dimensional *x-y* plots and contour or color-filled tally plots of three-dimensional data. MCPLOT supports a wide variety of plot options. More than one curve can be plotted on a single *x-y* plot. Tally plots can be created from tally data that exists within a MCTAL or RUNTPE file. However, if one is plotting from a MCTAL file, not all options are available because not all the information is available in that format.

In addition to plotting tally results, MCPLOT also plots cross-section data specified in an INP file—either individual nuclides or the complete material composed of constituent nuclei properly weighted by atomic fraction. The data plotted reflect adjustments to the cross sections made by MCNP6 such as energy cutoffs, neutron cross-section temperatures, $S(\alpha,\beta)$ treatment, summation of photon reactions to provide a total photon cross section, simple physics treatment for photon data, generation of electron stopping powers and other electron data, and more. Cross-section plots cannot be made from a RUNTPE file.

MCNP6 can plot proton cross sections. The reaction numbers are similar to the neutron reaction numbers: all positive. The principal proton cross sections are the following: ±1=total, ±2=non-elastic, ±3=elastic, ±4=heating, and >4=various reactions. On the LA150H proton library, the only available reaction is MT=5 with its multiplicities, 1005, 9005, 31,005, etc. The multiplicity reaction numbers for interaction reaction MT=5 are 1005 for neutrons, 9005 for protons, 31,005 for deuterons, etc. To find out which reactions are available for a particular nuclide or material, enter an invalid reaction number, such as MT=99, and MCNP6 will list the available proton reactions and the available yields, such as 1005, 32,001, and 34,002. The proton multiplicity, MT=9001, 9004, 9005, etc., generally is available, along with the total cross section and heating number, MT=1, MT=4. Entering a bad nuclide, e.g., `XS=12345.67H`, will cause MCNP6 to list the available proton nuclides.

Final tally results can be plotted after particle transport has finished. The temporary status of one or more tallies can be displayed during the run as transport is ongoing. (Note: This capability is not always possible in parallel computations.) After transport is finished, MCPLOT is invoked by typing a `Z` on the MCNP6 execution line, either as a separate procedure using existing RUNTPE or MCTAL files:

`MCNP6 Z RMCTAL=`<*mctal_filename*> or

`MCNP6 Z RUNTPE=`<*runtpe_filename*> ,

or as part of a regular uninterrupted MCNP6 run. To superimpose mesh tally contours with problem geometries, initiate MCPLOT using one of the two execute lines above and then enter the geometry plotter using the PLOT command.

There are two ways to request that a plot be produced periodically during the run: use an `MPLOT` card (Section 3.3.7.2.5) in the INP file or use the TTY interrupt feature (Section 1.4.2). (Note: This capability is not always possible during parallel computations.) The TTY interrupt `<ctrl-c>m` causes MCNP6 to pause at the end of the history that is running when the interrupt occurs and allows plots to be made by calling MCPLOT, which takes plot requests from the terminal. During run-time plotting, no output is sent to the COMOUT file. In addition, the following commands can not be used after invoking MCPLOT with an interrupt: `RMCTAL`, `RUNTPE`, and `DUMP`. The `END` or `RETURN` commands are used to exit MCPLOT or return MCNP6 to transport mode. Cross-section data cannot be displayed after a TTY interrupt or by use of the MPLOT card.

Color contour plots may be created of mesh tally, radiography tally, and lattice tally results. Mesh tallies also can be plotted superimposed over problem geometries. All of these plots are done in MCNP6 without the need of auxiliary post-processing codes; the plots can be made either at the end of a calculation or while a calculation proceeds by using the MPLOT card.

MCPLOT can make tally plots on a machine different from the one on which the problem was run by using the MCTAL file. When the INP file has a PRDMP card with a non-zero third entry, a MCTAL file is created at the end of the run. The MCTAL file contains all the tally data in the last RUNTPE dump. MCTAL is a coded ASCII file that can be converted and moved from one kind of machine to another. When the MCTAL file is created, its name can be specified in the execute line using the following format:

`MCNP6 I=`*`inpfile`* `MCTAL=`*`filename`*

The default *filename* is a unique name based on MCTAL.

The MCPLOT "HELP" command provides an alphabetized four-column listing of options [DUR09]. At the bottom of the four-column list are instructions describing how to

1) invoke a listing of all HELP commands with an explanation of their function and use syntax ("HELP ALL"),
2) provide a listing of function and syntax for a single HELP command ("HELP <*command*>"),
3) request an overview of the MCPLOT capability ("HELP OVERVIEW"), and
4) summarize input and execution-line options ("HELP EXECUTE").

For examples of using MCPLOT, see Section 5.4.

5.3.1 Execution Line Options Related to MCPLOT Initiation

To run only MCPLOT and plot tallies upon termination of the job by MCNP6, enter the following command:

`MCNP6 Z KEYWORD[=`*`value`*`(`*`s`*`)]`

where Z invokes MCPLOT. The allowed keywords are explained in Table 5-4. Cross-section data cannot be plotted by this method.

The execute line command

`MCNP6 INP=`*`filename`* `IXRZ KEYWORD[=`*`value`*`(`*`s`*`)]`

causes MCNP6 to run the problem specified in *filename*, following which the prompt mcplot> appears for MCPLOT commands. Both cross-section data and tallies can be plotted using this method after the run is complete. Cross-section data cannot be plotted after a TTY interrupt or by use of the MPLOT card.

The execute line command

```
MCNP6 INP=filename IXZ KEYWORD[=value(s)]
```

provides the most common way to plot cross-section data. The problem cross sections are read in, but no transport occurs. When using this method to plot cross sections, the following commands cannot be used: `BAR`, `CONTOUR`, `DUMP`, `FREQ`, `HIST`, `PLOT`, `RETURN`, `RMCTAL`, `RUNTPE`, `SPLINE`, `WASH`, and `WMCTAL`.

Table 5-4. MCPLOT Execution Line Options

Keyword Options	Description
`NOTEK`	**Suppress plotting at the terminal and send all plots to the graphics metafile, PLOTM. The keyword `NOTEK` is for production and batch situations and is used when the user's terminal has no graphics capability.**
`COM=`*`filename`*	**Use file *`filename`* as the source of plot requests. When an end-of-file (EOF) is read, control is transferred to the terminal. In a production or batch situation, end the file with an `END` command to prevent transfer of control. Never end the COM file with a blank line. If `COM` is absent, the terminal is used as the source of plot requests.**
`RUNTPE=`*`filename`*	**Read file *`filename`* as the source of MCNP6 tally data. The default file name is RUNTPE, if it exists. If the default RUNTPE file does not exist, the user will be prompted for an `RMCTAL` or `RUNTPE` command. The name for the RUNTPE can be specified on the execution line via the RUNTPE=*`filename`* execute-line option.**
`RMCTAL=`*`filename`*	**Read the MCTAL file, *`filename`*, as the source of the MCNP6 tally data. The default is MCTAL, if it exists.**
`PLOTM=`*`filename`*	**Name the graphics metafile *`filename`*. The default name is PLOTM. For some systems this metafile is a standard postscript file and is named PLOTM.PS. When CGS is being used, there can be no more than six characters in *`filename`*. Unique names for the output file, PLOTM, will be chosen by MCNP6 to avoid overwriting existing files.**
`COMOUT=`*`filename`*	**Write all plot requests to file *`filename`*. The default name is COMOUT. MCPLOT writes the COMOUT file in order to give the user the opportunity to do the same plotting at some later time, using all or part of the old COMOUT file as the COM file in the second run. Unique names for the output file, COMOUT, will be chosen by MCNP6 to avoid overwriting existing files.**

Plot requests are normally entered from the keyboard of a terminal; alternatively, they can be entered from a file. A plot is requested by entering a sequence of plot commands following a prompt character. The request is terminated by the ENTER key not immediately preceded by an `&` or by a `COPLOT` command. Commands consist of keywords usually followed by some parameters, either space or comma delimited.

Defaults are available for nearly everything. If MCNP6 is run with `Z` as the execute line message, and if file RUNTPE is present with more than one energy bin in the first tally, and if the ENTER key is pressed in response to the MCPLOT prompt, a lin-log histogram plot of tally/MeV vs. energy, with error bars and suitable labels, will appear on the screen.

5.3.2 Plot Conventions and Command Syntax

5.3.2.1 2D PLOT

The origin of coordinates for the MCPLOT 2D option is at the lower left corner of the picture. The horizontal axis is called the *x*-axis. It is the axis of the independent variable such as user bin or cell number or energy. The vertical axis is called the *y*-axis. It is the axis of the dependent variable such as flux or current or dose. Each axis can be either linear or logarithmic.

5.3.2.2 CONTOUR PLOT

Similarly, the origin of coordinates for MCPLOT's contour plot option is at the lower left corner of the picture. The horizontal axis is called the *x*-axis. It is the axis of the first of the two independent variables. The vertical axis is called the *y*-axis. It is the axis of the second independent variable. The contours represent the values of the dependent variable. Only linear axes are available. Each contour is drawn in a different color depending on its value with respect to the *z*-value extrema. Extensions to the `FREE` and `CONTOUR` commands allow for shaded contour plots of tally and mesh data.

For additional examples involving contour plots see Section 5.4.3 and Section 5.4.4.

5.3.2.3 COLOR-WASH PLOT

This plot option is similar to contour plotting, but instead of drawing contours of $z(x,y)$ data, each tally bin is filled with a color selected by the tally value in the bin. The axis conventions are the same as in contour plotting. This option is selected with the command `WASH`. If two free variables have been selected (with the `FREE` command), a color-filled plot is drawn. This is a useful option for radiography tallies. A palette of 64 colors ranging from red to yellow to green to blue is used. The color index is selected by linear interpolation between the *z*-minimum and the *z*-maximum values.

5.3.2.4 MCPLOT COMMAND SYNTAX

Like the geometry plotter, each MCPLOT command consists of a command keyword that in most cases is followed by some parameters. Keywords and parameters are entered space delimited with no more than128 characters per line. Commas and equals signs are interpreted as spaces. A plot request can be continued onto another line by typing an & before the ENTER key, but each command (the keyword and its parameters) must be complete on one line. Command keywords, but not parameters, can be abbreviated to any degree not resulting in ambiguity, but they must be correctly spelled. The term "current plot" means the plot that is being defined by the commands currently being typed in, which might not be the plot that is showing on the screen. Only those commands marked with a dagger (†) in the list presented in Table 5-5 can be used after the first `COPLOT` command in a plot request because the others all affect the framework of the plot or are for contour or 3D plots only.

5.3.3 Tally Plot Commands Grouped by Function

Table 5-5. MCPLOT Commands

Command	Description
Device-Control Commands Normally MCPLOT draws plots on the user's terminal. By using the following commands, the user can specify that plots not be drawn on the terminal and/or that they be sent to a graphics metafile or postscript file for processing later by a graphics utility program.	
`TERM` *n*	Output device type is specified by *n*. *n*=`0` for a terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphics metafile. `TERM 0` is equivalent to putting `NOTEK` on MCNP6's execute line. `n=1` restores visible plotting window on next plot request.
`FILE [`*aa*`]`	Send or do not send plots to the graphics metafile PLOTM.PS according to the value of the parameter *aa*. The graphics metafile is not created until the first `FILE` command is entered. `FILE` has no effect in the `NOTEK` or `TERM 0` cases. The allowed values of *aa* are the following: If *aa* is blank, only the current plot is sent to the graphics metafile. If *aa*=`ALL`, the current plot and all subsequent plots are sent to the metafile until another `FILE` command is entered. If *aa*=`NONE`, the current plot is not sent to the metafile nor are any subsequent plots until another `FILE` command is entered.
General Commands	
`&`	Continue reading commands for the current plot from the next input line. The `&` must be the last thing on the line.†
`COPLOT`	Plot a curve according to the commands entered so far and keep the plot open for co-plotting one or more additional curves. `COPLOT` is effective for 2D plots only. If `COPLOT` is the last command on a line, it functions as if it were followed by an `&`.
`FREQ` *n*	Specifies the interval between calls to MCPLOT to be every *n* histories. In KCODE calculation, the interval is every *n* cycles. If *n* is negative, the interval is in CPU minutes. If *n*=`0`, MCPLOT is not called while MCNP6 is running histories. Note: An 8-byte integer is allowed for keyword `FREQ`.. (DEFAULT: *n*=`0`)
`RETURN`	If MCPLOT was called by MCNP6 while running histories or by PLOT while doing geometry plotting, control returns to the calling subroutine. Otherwise `RETURN` has no effect.
`PLOT`	Call or return to the PLOT geometry plotter. This cannot be done when plotting from a MCTAL file.
`PAUSE [`*n*`]`	Use with `COM=`*filename* option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the ENTER key is pressed.
`END`	Terminate execution of MCPLOT.†

Command	Description
Inquiry Commands: When one of these commands is encountered, the requested display is made and then MCPLOT waits for the user to enter another line, which can be just pressing the ENTER key, before resuming. The same thing will happen if MCPLOT sends any kind of warning or comment to the user as it prepares the data for a plot.	
`OPTIONS or ? or HELP`	Display a list of the MCPLOT command keywords.†
`STATUS`	Display the current values of the plotting parameters.†
`PRINTAL`	Display the numbers of the tallies in the current RUNTPE or MCTAL file.†
`IPTAL`	Display the IPTAL array for the current tally. This array tells how many elements are in each dimension of the current 8-dimensional tally.†
`PRINTPTS`	Display the *x-y* coordinates of the points in the current plot. `PRINTPTS` is not available for co-plots, contour plots, color-wash plots, or 3D plots.
File Manipulation Commands	
`RUNTPE` *`filename n`*	Read dump *`n`* from RUNTPE file *`filename`*. If the parameter *`n`* is omitted, the last dump in the file is read.†
`DUMP` *`n`*	Read dump *`n`* of the current RUNTPE file.†
`WMCTAL` *`filename`*	Write the tally data in the current RUNTPE dump to MCTAL file *`filename`*.†
`RMCTAL` *`filename`*	Read MCTAL file *`filename`*.†
Parameter-Setting Commands: Parameters entered for one curve or plot remain in effect for subsequent curves and plots until they are either reset to their default values with the `RESET` command or are overridden, either by the same command with new values, by a conflicting command, or by the `FREE` command that resets many parameters. There are two exceptions: `FACTOR` and `LABEL` are effective for the current curve only. An example of a conflicting command is `BAR`, which turns off `HIST`, `PLINEAR`, and `SPLINE`.	
`TALLY` *`n`*	Define tally *`n`* as the current tally.† The parameter *`n`* is the tally designation on the `F` card in the INP file of the problem represented by the current RUNTPE or MCTAL file. The default is the first tally in the problem, which is the lowest numbered neutron tally or, if none, then the lowest numbered photon tally or, if none, then the lowest numbered electron tally.
`PERT` *`n`*	Plot a perturbation associated with a tally, where *`n`* is a number on a `PERT` card.† The command `PERT 0` will reset `PERT` *`n`*.
`LETHARGY`	Divide tally bin by lethargy bin width for log energy abscissa. Produces visually accurate area plots for a 2D logarithmic energy abscissa (`FREE E`). A lethargy-normalized plot is equivalent to plotting *ef*(*e*). (Note: `LOGLIN` or `LOGLOG` must be specified and `NONORM` must not be invoked.) (See Section 5.5.)
`NONORM`	Suppress bin normalization. The default in a 2D plot is to divide the tallies by the bin widths if the independent variable is cosine, energy, or time. However, also see the description of the MCTAL file (Section 5.3.4). Bin normalization is not done in 3D, contour, or color-wash plots.

Command	Description
FACTOR *a f* [*s*]	**Multiply the data for axis *a* by the factor *f* and then add the term *s*.†** **The parameter *a* is X, Y, or Z.** **The parameter *s* is optional. If *s* is omitted, it is set to zero. For the initial curve of a 2D plot, reset the axis limits (XLIMS or YLIMS) to the default values. The value given by FACTOR affects only the current curve or plot.**
RESET *aa*	**Reset the parameters of command *aa* to their default values.†** **The parameter *aa* can be a parameter-setting command, COPLOT, or ALL. If *aa* is ALL, the parameters of all parameter-setting commands are reset to their default values. After a COPLOT command, only COPLOT, ALL, or any of the parameter-setting commands that are marked with an † in this list may be reset. Resetting COPLOT or ALL while COPLOT is in effect causes the next plot to be an initial plot.**
Titling Commands (The double quotes are required.)	
TITLE *n* "*aa*"	**Use *aa* as line *n* of the main title at the top of the plot. The allowed values of *n* are 1 and 2. The maximum length of *aa* is 40 characters. The default is the comment on the FC card for the current tally, if any. Otherwise it is the name of the current RUNTPE or MCTAL file plus the name of the tally. KCODE plots have their own special default title.**
BELOW	**Put the title below the plot instead of above it. The keyword BELOW has no effect on 3D plots.**
SUBTITLE *x y* "*aa*"	**Write subtitle *aa* at location x, y, which can be anywhere on the plot including in the margins between the axes and the limits of the screen. The values of *x* and *y* are *x*- and *y*-axis values. The maximum length of *aa* is 40 characters.**
XTITLE "*aa*"	**Use *aa* as the title for the *x*-axis. The default is the name of the variable represented by the x-axis. The maximum length of *aa* is 40 characters.**
YTITLE "*aa*"	**Use *aa* as the title for the *y*-axis. The default is the name of the variable represented by the y-axis. The maximum length of *aa* is 40 characters.**
ZTITLE "*aa*"	**Use *aa* as the title for the *z*-axis in 3D plots. The default is the name of the variable represented by the z-axis. The maximum length of *aa* is 40 characters.**
LABEL "*aa*"	**Use *aa* as the label for the current curve.† It is printed in the legend beside a sample of the line style used to plot the curve. The value of LABEL reverts to its default value, blank, after the current curve is plotted. If LABEL is blank, the name of the RUNTPE or MCTAL file being plotted is printed as the label for the curve. The maximum length of *aa* is 10 characters.**

Command	Description
Commands that Specify What is to be Plotted: **Tallies in MCNP6 are binned according to the values of eight different independent variables. Because only one or two of those variables can be used as independent variables in any one plot, one or two of the eight independent variables have to be designated as free variables, and the rest become fixed variables. Fixed values (bin numbers) have to be defined, explicitly or by default, for all of the fixed variables. The default value for each fixed variable is the total bin, if present; otherwise the first is used instead.**	
FREE *x* [*y*] [*n*X*m*] [ALL] [NOALL]	**Use variable *x* (*y* blank) or variables *x* and *y* as the independent variable or variables in the plot. Valid values for *x* and *y* are the tally bin indices F, D, U, S, M, C, E, T, I, J, and K, where I, J, and K refer to lattice or mesh indices. If only *x* is specified, 2D plots are made. If both *x* and *y* are specified, contour, color-wash, or 3D plots are made, depending on whether 3D is in effect. The default value of *xy* is E, and gives a 2D plot in which the independent variable is energy.** **The *n*X*m* entry specifies the number of bins associated with the I and J lattice indices. (Only valid when *x*=I or *xy*=IJ.)** **The ALL entry specifies that the minimum and maximum contour range should be taken from all the tally bins. (Only valid when *x*=I or *xy*=IJ.) Omitting this parameter results in the default minimum and maximum contour range, which includes only those tally values contained in the specified 2D plot.** **The NOALL entry specifies that the minimum and maximum contour range should be taken only from those of the FIXED command slice. (DEFAULT)** **The FREE command resets XTITLE, YTITLE, ZTITLE, XLIMS, YLIMS, HIST, BAR, PLINEAR, and SPLINE to their defaults.** **For more information regarding usage of the FREE command, see "Additional Guidance When Using the FREE Command" following this table.**
FIXED *q n*	**Set *n* as the bin number for fixed variable *q*.† The symbols that can be used for *q*, and the kinds of tally bins they represent are the following:** **F cell, surface, or detector** **D total vs. direct or flagged vs. unflagged** **U user-defined** **S segment** **M multiplier** **C cosine** **E energy** **T time** **I 1st lattice/mesh index** **J 2nd lattice/mesh index** **K 3rd lattice/mesh index** **Restriction: Only the J and K indices are allowed for the 1D IJK plot and only the K index is allowed for a 2D IJK contour plot.**
SET *f d u s m c e t*	**Define which variables are free and define the bin numbers of the fixed variables. SET does the job of the FREE and several FIXED commands in one compact command. The value of each parameter can be a bin number (the corresponding variable is then a fixed variable) or an asterisk (*) (the corresponding variable is then a free variable). If there is only one *, 2D plots are made. If there are two, contour or 3D plots are made. SET performs the same resetting of parameters that FREE does.**

Command	Description
TFC *x*	**Plot the tally fluctuation chart of the current tally. The independent variable is *nps*, the number of source histories.** **Allowed values of *x* include the following:** **M** mean* **E** relative error* **F** figure of merit* **L** 201 largest tallies vs *x* (NONORM for frequency vs *x*) **N** cumulative number fraction of $f(x)$ vs *x* **P** probability $f(x)$ vs *x* (NONORM for number frequency vs *x*) **S** SLOPE of the high tallies as a function of *nps* **T** cumulative tally fraction of $f(x)$ vs *x* **V** VOV as a function of *nps* **1–8** 1 to 8 moments of $f(x)*x^{1\text{ to }8}$ vs *x* (NONORM for $f(x)*\Delta x*x^{1\text{ to }8}$ vs *x*) **1c–8c** 1 to 8 cumulative moments of $f(x)*x^{1\text{ to }8}$ vs *x* ***This data is available when plotting from a MCTAL file.**
KCODE *i*	**The independent variable is the KCODE cycle. The individual estimator plots start with cycle one. The average col/abs/trk-len plots start with the fourth active cycle.** **Plot k_{eff} or removal lifetime according to the value of *i*.† If *i*=** **1** k (collision) **2** k (absorption) **3** k (track) **4** prompt removal lifetime (collision) **5** prompt removal lifetime (absorption) **6** Shannon entropy of fission source distribution (Can be plotted only from RUNTPE file, not from MCTAL file) **11–15** the quantity corresponding to *i*-10, averaged over the cycles so far in the problem. **16** average col/abs/trk-len k_{eff} and one estimated standard deviation **17** average col/abs/trk-len k_{eff} and one estimated standard deviation by cycle skipped. Cannot plot fewer than 10 active cycles. **18** average col/abs/trk-len k_{eff} figure of merit **19** average col/abs/trk-len k_{eff} relative error
Commands for Cross-Section Plotting	
XS *m*	**Plot a cross section according to the value of *m*.†** **Option 1: *m*=M*n*, a material card in the INP file for material *n*. Example: XS M15. The available materials will be listed if a material is requested that does not exist in the INP file.** **Option 2: *m*=*z*, a nuclide ZAID. Example: XS 92235.50C. The full ZAID must be provided. The available nuclides will be listed if a nuclide is requested that does not exist in the INP file.** **Option 3: *m*=?. Print out a cross-section plotting primer.**
MT *n*	**Plot reaction *n* of material or nuclide specified by XS *m*.† The default is the total cross section. The available reaction numbers in the data file will be listed if one enters a reaction number that is invalid or doesn't exist (e.g., 999)**

Command	Description
PAR <*pl*>	Plot the data for particle type <*pl*>, where <*pl*> can be N, P, E or H of material M*n*.† The default is the source particle type for XS=M*n*. For XS=*z*, the particle type is determined from the data library type. For example, 92000.01g defines PAR=P. Must be first entry on the line.
Commands that Specify the Form of 2D Plots	
LINLIN	Use linear *x*-axis and linear *y*-axis. (DEFAULT for tally contour plots)
LINLOG	Use linear *x*-axis and logarithmic *y*-axis. (DEFAULT for all except tally contour plots)
LOGLIN	Use logarithmic *x*-axis and linear *y*-axis.
LOGLOG	Use logarithmic *x*-axis and logarithmic *y*-axis.
XLIMS *min max nsteps* YLIMS *min max nsteps*	Define the lower limit, *min*, upper limit, *max*, and number of subdivisions, *nsteps*, on the *x*- or *y*-axis. The parameter *nsteps* is optional for a linear axis and is ineffective for a logarithmic axis. In the absence of any specification by the user, the values of *min*, *max*, and *nsteps* are defined by an algorithm in MCPLOT.
SCALES *n*	Put scales on the plots according to the value of *n*: If *n*=0, no scales on the edges and no grid. If *n*=1, scales on the edges (DEFAULT) If *n*=2, scales on the edges and a grid on the plot.
HIST	Make histogram plots.† This is the default if the independent variable is cosine, energy, or time.
PLINEAR	Make piecewise-linear plots.† This is the default if the independent variable is not cosine, energy, or time.
SPLINE [*x*]	Use spline curves in the plots.† If the parameter *x* is included, rational splines of tension *x* are plotted. Otherwise Stinem and cubic splines are plotted. Rational splines are available only with the DISSPLA graphics system.
BAR	Make bar plots.†
NOERRBAR	Suppress error bars.† The default is to include error bars.
THICK *x*	Set the thickness of the plot curves to the value *x*.† The legal values lie in the range from 0.01 to 0.02. The default value of THICK is 0.02.
THIN	Set the thickness of the plot curves to the legal minimum of 0.01.†
LEGEND [*x y*]	Include or omit the legend according to the values of optional parameters *x* and *y*. If no *x* and no *y*, put the legend in its normal place. (DEFAULT) If *x*=0 and no *y*, omit the legend. If both *x* and *y* defined, for 2D plots only, put most of the legend in its usual place, but put the part that labels the plot lines at location *x*, *y*, where the values of x and y are based on the units and values of the *x*- and *y*- axes.

Command	Description
Commands that Specify the Form of Contour Plots	
CONTOUR **[*cmin cmax cstep*]** **[%|PCT|LIN|LOG]** **[ALL|NOALL]** **[LINE|NOLINE]** **[COLOR|NOCOLOR]**	**The parameters *cmin*, *cmax*, and *cstep* are the minimum, maximum, and step values for contours, respectively.** **If either the % symbol or the PCT keyword is included, the first three parameters are interpreted as percentages of the minimum and maximum values of the dependent variable. The default values are 5 95 10 %.** **If the keyword LIN appears, interpret the step values as absolute values of contour levels.** **If the keyword LOG appears, space the contour levels logarithmically between *cmin* and *cmax*, with *cstep* values between. (DEFAULT option with the following values: 1E-4 1E-2 12 LOG)** **The ALL keyword specifies that the minimum and maximum contour range should be taken from all of the tally bins. (Default is to use the bins only in the current plot, or NOALL.)** **The LINE|NOLINE option controls plotting of contour lines.** **The COLOR|NOCOLOR option controls shading of the contours.**
WASH *aa*	**Set or unset $z(x,y)$ plotting to use color-wash instead of contours. The parameter *aa* can be one of two values:** **If *aa*=ON Turn on color-wash plotting for two free variables.** **If *aa*=OFF Turn off color-wash plotting and return to contour plotting for two free variables. (DEFAULT)** **Any value for *aa* other than on is equivalent to OFF.**
Commands for FMESH Mesh Tally Plots **MCNP6 uses the geometry plotter to display the results of the FMESH mesh tally. The default layout depends on the type of mesh tally. For rectangular meshes, the horizontal axis is in the direction of the dimension with the most number of bins, and the vertical axis is in the direction of the dimension with the second most number of bins. For cylindrical plots, the horizontal axis is along the axis of the cylinder and the vertical axis is along the theta=0 plane. The center of the plot in both cases is at the center of the mesh. Different views are obtained by using the MCNP6 geometry plotter commands. Exiting the mesh tally plotter will return the code to the tally plotter. Note: There are two ways to change the FMESH mesh that is plotted. One way is to use the FMESH button of the interactive plotter command panel. This will change the mesh tally but not the plot attributes (basis, extent, and origin). The second method is to enter the FMESH *n* command in the command box. This will reset the plot layout to the default for that particular mesh tally.**	
FMESH *n*	**Plot FMESH mesh tally *n*.**
FMRELERR *n*	**Plot the relative errors of FMESH mesh tally *n*. If tally number *n* is not provided, plots the relative error for the current mesh.**
ZLEV n_1 n_2 n_3 ...	**Controls the scale of the FMESH mesh tally results. The parameters n_i, can have the following values:** **If n_i=LOG, the tally data scaling is set to logarithmic. (DEFAULT)** **If n_i=LIN, the tally data scaling is set to linear numeric value.** **If no values of n_i are provided, the scale is set to the default for the particular color mode.** **If only one value of n_i is provided, sets the lower limit of the plot.** **If two values of n_i are provided, sets the lower and upper limits of the plot.** **If three or more values of n_i are provided, sets the value of the color gradients.**
EBIN *n*	**Plot energy bin *n* of the current FMESH mesh tally. The total energy bin is the last bin of the tally.**

Command	Description
TBIN *n*	**Plot time bin *n* of the current FMESH mesh tally. The total time bin is the last bin of the tally.**
† available with COPLOT	

Additional Guidance When Using the FREE Command:

- For TMESH mesh tallies, the *i*, *j*, and *k* parameters of the FREE command refer to the CORA, CORB, and CORC mesh-tally dimensions.
- For lattice tallies, the *i*, *j*, and *k* parameters of the FREE command refer to *i*, *j*, and *k* lattice indices.
- For radiography tallies, the command FREE S C is used to make a contour plot of the *s*- and *t*- radiography axes.
- For lattice tallies that are not specified fully, the [*n*X*m*] dimensions must be provided. Mesh and radiography tallies are always specified fully, so [*n*X*m*] is never required for them.
- One-dimensional mesh, radiography, and lattice tallies may be specified by giving the free dimension of the FREE command and fixing the other two dimensions:

```
FREE I   FIXED  J=10   FIXED  K=12
```

5.3.4 MCTAL Files

A MCTAL file contains the tally data of one dump of a RUNTPE file. It can be written by the MCRUN module of MCNP6 or by the MCPLOT module, by other codes, or even by hand in order to send data to MCPLOT for co-plotting with MCNP6 tally data. Data from TMESH mesh tallies are written to the MCTAL file; however, data from FMESH mesh tallies are not.

As written by MCNP6, a MCTAL file has the format shown below, but only as much of it as is essential to contain the information of real substance is necessary. Furthermore the numerical items do not need to be in the columns implied by the formats as long as they are in the right order, are blank delimited, and have no embedded blanks. For example, to give MCPLOT a table of something versus energy, the user might write a file as simple as the following:

```
E    7    1
    .2   .4   .7   1   3   8   12
VALS
    4.00E-5   .022   5.78E-4   .054   3.70E-5   .079   1.22E-5   .122
    7.60E-6   .187   2.20E-6   .245   9.10E-7   .307
```

If more than one independent variable is wanted, other lines such as a T line followed by a list of time values would be needed and the table of tally/error values would need to be expanded. If more than one table of tally/error values is wanted, the file would have to include an NTAL line followed by a list of arbitrarily chosen tally numbers, a `TALLY` line, and lines to describe all of the pertinent independent variables would have to be added for each table.

When the limits on permitted cell and surface numbers were expanded to 99,999,999, the format of MCTAL files was modified to accommodate these values. The cell and surface numbers for the problem are first checked to see if any are greater than 99,999. If not, then the traditional formatting is used when writing the MCTAL file. If there are numbers greater than 99,999, then `I10` format is used instead for these integers written to the MCTAL file. Although the MCTAL file is defined to be free-format, some simple user-written utility programs that read the MCTAL file may expect fixed format. If such user-written programs cannot be modified to handle the larger integers, then users should be careful to use only numbers less than 99,999 for cell and surface numbers in their input files.

The form of the MCTAL file as written by MCNP6 follows:

`kod, ver, probid, knod, nps, rnr` (2A8,A19,15,I15,1x,I15)

`kod`	is the name of the code, MCNP6.
`ver`	is the version, 6.2.
`probid`	is the date and time when the problem was run and, if it is available, the designator of the machine that was used.
`knod`	is the dump number.
`nps`	is the number of histories that were run.
`rnr`	is the number of pseudorandom numbers that were used.

One blank followed by columns 1–79 of the problem identification line, which is the first line in the problem's INP file. (1x,A79)

`NTAL n    NPERT m` (A4,I6,1X,A5,I6)

`n`	is the number of tallies in the problem.
`m`	is the number of perturbations in the problem.

List of the tally numbers, on as many lines as necessary. (16I5*)

The following information is written for each tally in the problem.

`TALLY m i j k` (A5,I5*,I21,2I5)

`m`	is the problem name of the tally, one of the numbers in the list after the `NTAL` line.
`i`	If `i>0`, then `i` is the particle type: 1=N, 2=P, 3=N+P, 4=E, 5=N+E, 6=P+E, 7=N+P+E, where N=neutron, P=photon, E=electron. If `i<0`, then `i` is the *number* of particle types and the next MCTAL line will list which particles are used by the tally.
`j`	is the type of detector tally where 0=none, 1=point, 2=ring, 3=pinhole radiograph (FIP), 4=transmitted image radiograph (rectangular grid, FIR), 5=transmitted image radiograph (cylindrical grid, FIC)
k	is tally modifier information for *f or +f (or zero for no f modifier)

List of `0/1` entries indicating which particle types are used by the tally. `(40I2)`
(Only present if particle type value (`i`) above is negative.)

Each entry, in order, represents the ordinal assigned to particles in Table 2-2. Thus, the first entry is `1` if neutrons are a tally particle and `0` if they are not; the fourth entry is `1` if there are muons and `0` if there are not, etc.

The `FC` card lines, if any, each starting with 5 blanks} `(5x,A75)`

`F n` `(A2,I8)`

`n` is the number of cell, surface, or detector bins.

List of the cell or surface numbers, on as many lines as necessary. `(11I7*)`

If a cell or surface bin is made up of several cells or surfaces, a zero is written. This list is omitted if the tally is a detector tally.

`D n` `(A2,I8)`

`n` is the number of total vs. direct or flagged vs. unflagged bins.

For detectors, `n=2` unless there is an `ND` on the `F5` card; for cell and surface tallies, `n=1` unless there is an `SF` or `CF` card.

`U n or UT n or UC n` `(A2,I8)`

`n` is the number of user bins, including the total bin if there is one.

If there is only one unbounded bin, `n=0` instead of `1`. If there is a total bin, the character `U` at the beginning of the line is followed by the character `T`. If there is cumulative binning, the character `U` at the beginning of the line is followed by the character `C`. These conventions concerning a single unbounded bin and the total bin also apply to the `S`, `M`, `C`, `E`, and `T` lines below.

`S n or ST n or SC n` `(A2,I8)`

`n` is the number of segment bins.

If the tally is a radiograph tally, then a list of the bin boundaries will be printed.

`M n or MT n or MC n` `(A2,I8)`

`n` is the number of multiplier bins.

`C n f or CT n f or CC n f` `(A2,I8,I4)`

`n` is the number of cosine bins.

`f` is an integer flag.

If `f=0` or is absent, the cosine values in the next list below are bin boundaries. Otherwise they are the points where the tally values ought to be plotted, and the tally values are not under any circumstances to be divided by the widths of cosine bins. The `E` and `T` lines below have similar flags.

List of cosine values, on as many lines as necessary. `(6ES13.5)`

`E n f or ET n f or EC n f` `A2,I8,I4`

`n` is the number of energy bins.

List of energy values, on as many lines as necessary. `(6ES13.5)`

`T n f or TT n f or TC n f` (A2,I8,I4)

`n` is the number of time bins.

List of time values, on as many lines as necessary. (ES13.5)

`VALS` (A4)

or

`VALS PERT` (A10)

List of tally/error data pairs, on as many lines as necessary. (4(ES13.5,F7.4))

The order is what a 9-dimensional Fortran array would have if it were dimensioned (`2,NT,NE,...,NF`), where `NT` is the # of time bins, `NE` is the # of energy bins, ..., and `NF` is the # of cell, surface, or detector bins. The values here are exactly the same as are printed for each tally in the OUTP file.

`TFC n jtf` (A3,I5,8I8)

`n` is the number of sets of tally fluctuation data.

`jtf` is a list of 8 numbers, the bin indexes of the tally fluctuation chart bin.

List of four numbers for each set of tally fluctuation chart data, `NPS`, tally, error, figure of merit. (I15,3ES13.5)

This is the end of the information written for each tally.

`KCODE nc ikz mk` (A5,3I5) or (A5, 3I10) if > 9999

`nc` is the number of recorded KCODE cycles.

`ikz` is the number of settle cycles.

`mk` is the number of variables provided for each cycle.

List of 3 k_{eff} and 2 removal lifetime values for each recorded KCODE cycle if `mk=0` or `5`; if `mk=19`, the whole `RKPL(19,MRKP)` array is given. (5ES12.6)

* This field is increased for big problems (cells or surfaces > 99,999)

5.4 TALLY PLOTTING EXAMPLES

5.4.1 Example of Use of COPLOT

Assume all parameter-setting commands have been previously defined. The following input line will put two curves on one plot:

```
RUNTPE A COPLOT RUNTPE B
```

The first curve will display tally data from `RUNTPE A` and the second curve will display tally data from `RUNTPE B` for the same tally number. Unless reset somehow, MCPLOT will continue to read from `RUNTPE B`.

Next we might type the following command:

```
XLIMS min max     TALLY 11   COPLOT RMCTAL AUX   TALLY 41 &
COPLOT RUNTPE A   TALLY 1
```

These commands change the upper and lower limits of the x-axis to *max* and *min*, respectively; define TALLY 11 as the current tally; and plot the first curve from RUNTPE B, the second curve from TALLY 41 data on MCTAL file AUX, and the third curve from TALLY 1 data on RUNTPE A. Future plots will display data from RUNTPE A unless reset.

The command

```
TALLY 24    NONORM    FILE    COPLOT    TALLY 44
```

will send a frame with two curves to the graphics metafile.

5.4.2 Tally Fluctuation Chart History Score Plotting

Two-dimensional plots of a tally $F(x)=xf(x)$ are made by dividing the tally bin value by the width of the tally bin $x_{i+1}-x_i$. Visually Accurate Area (VAA) $F(x)$ plots are plots whose visual area under the curve is an accurate representation of the tally in each of the tally bins; i.e., the visual area represents $F(x)(x_{i+1}-x_i)$ for all abscissa values. A VAA plot will be produced for a linlin0 (linear abscissa scale, linear ordinate scale starting at 0) $F(x)$ plot; i.e., the area of $F(x)$ from x_i to x_{i+1} correctly represents the bin tally value visually for all x when both the abscissa and ordinate scales are linear and the smallest ordinate value is zero.

In a similar manner to the linlin0 VAA plot above, a VAA plot of $F(x)$ on a loglin0 (log abscissa scale, linear ordinate scale starting at 0) plot is produced if the tally bin value is divided by the difference in the logarithms of the abscissa values. If $y=\ln(x)$, then $G(y)$ is defined to be

$$G(y)=(\text{tally bin value})/(\ln(x_{i+1})-\ln(x_i))=(\text{tally bin value})/(y_{i+1}-y_i).$$

A loglin0 plot of $G(y)$ is a VAA plot of $F(x)$ because y is linear on a log abscissa and $G(y)(y_{i+1}-y_i)$ is the area of the tally bin.

The relation between $G(y)$ and $F(x)$ is

$$G(y)|dy|=F(x)|dx|,$$

where

$$dy=d\ln(x)=dx/x.$$

Therefore

$$G(y)=xF(x).$$

This y normalizing of the tally bin value to make a loglin $G(y)$ plot is equivalent to making a loglin $xF(x)$ plot. Lethargy plotting of an energy-dependent tally F(energy) (see Section 5.5) is the equivalent of plotting $G(\ln(\text{energy}))=\text{energy}\times F(\text{energy})$ on a loglin0 scale to produce a VAA plot for the tally F(energy).

These normalizing statements can be generalized to any function $h(x)$. The VAA interpretation of a 2D plot therefore depends on the abscissa axis scale. A linlin0 plot of $h(x)$ is a VAA $h(x)$ plot and a loglin0 $h(x)$ plot is a VAA plot for $h(x)/x$. If $h(x)/x$ is a useful quantity, then the VAA plot of $h(x)/x$ is also useful.

Two-dimensional plots from a RUNTPE (not a MCTAL) file of the empirical history score probability density function $f(x)$ moments can be made using the Tally Fluctuation Chart (`TFC`) tally plot commands (see Table 5-5, under the section entitled, "Commands that Specify What is to be Plotted"). The tally $F(x)=xf(x)$. From the discussion above, a loglin0 $F(x)$ plot can be interpreted as a VAA plot for $f(x)$; i.e., the area under the curve on a loglin0 scale represents where the $f(x)$ sampling has occurred. A linlin0 $F(x)$ plot can be interpreted as a VAA plot for the tally $F(x)$.

Based on these observations, the following statements can be made about `TFC` commands to create $f(x)$ moment plots for the TFC bin of a tally (without the `NONORM` option):

- $f(x)$ TFC bin plots are VAA plots when
  1) `TFC P` [$f(x)$] is on a linlin0 scale; and
  2) `TFC 1` [$xf(x)$] is on a loglin0 scale.
- $xf(x)=F(x)$ TFC bin tally plots are VAA plots when
  1) `TFC 1` [$xf(x)=F(x)$] is on a linlin0 scale; and
  2) `TFC 2` [$x^2f(x)=xF(x)$] is on a loglin0 scale.
- $xnf(x)$ TFC bin tally moment plots are VAA plots when
  1) `TFC` *n* [$x^nf(x)$] is on a linlin0 scale; and
  2) `TFC` *n*`+1` [$x^{n+1}f(x)$] is on a loglin0 scale.

The VAA contributions to the n^{th} $f(x)$ moment can be viewed with an $x^nf(x)$ linlin0 plot or an $x^{n+1}f(x)$ loglin0 plot. The empirical $f(x)$ slope result can be checked by viewing a `TFC` *n* plot. If the high-score $f(x)$ tail for a long-tailed distribution (not a finite distribution) is proportional to $1/x^n$, then the `TFC` *n* plot will be a statistical constant at the high x scores. A large score $f(x)$ slope of at least n exists if the high-score `TFC` *n* [$x^nf(x)$] values are decreasing. VAA $f(x)$ moment plots can be a useful tool in studying the detailed impact of variance reduction techniques on $f(x)$ (not the history sampling time as function of x) and the efficiency of a calculation.

5.4.3 Radiography Tally Contour Plot Example

Tally output may be plotted as 2D color contours from either MCTAL or RUNTPE files. For example, a radiography tally with *s*- and *t*-axes specified on `FS` and `C` cards can be plotted with the `MCNP6 Z` execute option, as illustrated below.

The following example is a radiograph of a 4-cm-radius, 1-cm-thick ^{238}U disc with an embedded 4-mm-void sphere and skew-oriented 1-cm × 1-cm × 8-mm box. The input file is

```
Radiography Tally
1 5 -25.0 -1  4 5 imp:p=1
2 0        1 -2   imp:p=1
3 0           2   imp:p=0
4 0          -4   imp:p=1
5 0          -5   imp:p=1

1 RCC     0 0 0 0 0 1 4
2 RPP   -100 100  -100 100  -100 100
4 SPH    3 0  0.5  0.4
5 BOX   -1 1 0.1  0.6 0.8 0  -0.8 0.6 0  0 0 0.8
mode p
nps     100 5
sdef    pos=0 0 -20 axs=0 0 1 rad=d1 ext=0 vec=0 0 1 dir=d2 erg=6
si1      0 0.1
sp1    -21   1
si2     -1   1
sp2    -31   1
m5     92238 1
print
prdmp    2j  1
tir5:p   0 0 10 0 0 0 -100 0 100 0
fs5    -10. 99i 10.
c5     -10. 99i 10.
```

The *x*-*y* geometry plot of this geometry is given in Figure 5-2.

To get the contour plot, type the following MCNP6 execution line command:

```
MCNP6 Z RUNTPE=filename
```

The contour plots also may be read from a MCTAL file instead of the RUNTPE file. When the code gives you the MCPLOT prompt, enter two dimensions with the `FREE` command (Table 5-5); for example, `S` and `C`:

```
MCPLOT>FREE SC   .
```

Recall that the possible tally dimensions are

`F`	surface / cell / detector `F` card bin
`D`	total / direct or flagged bin
`U`	user bin
`S`	segment or radiography *s*-axis bin
`M`	multiplier bin

C	cosine or radiography *t*-axis bin
E	energy bin
T	time bin
I	1st lattice/mesh index
J	2nd lattice/mesh index
K	3rd lattice/mesh index

The results are plotted in Figure 5-3. The embedded sphere and box are seen plainly in the disc.

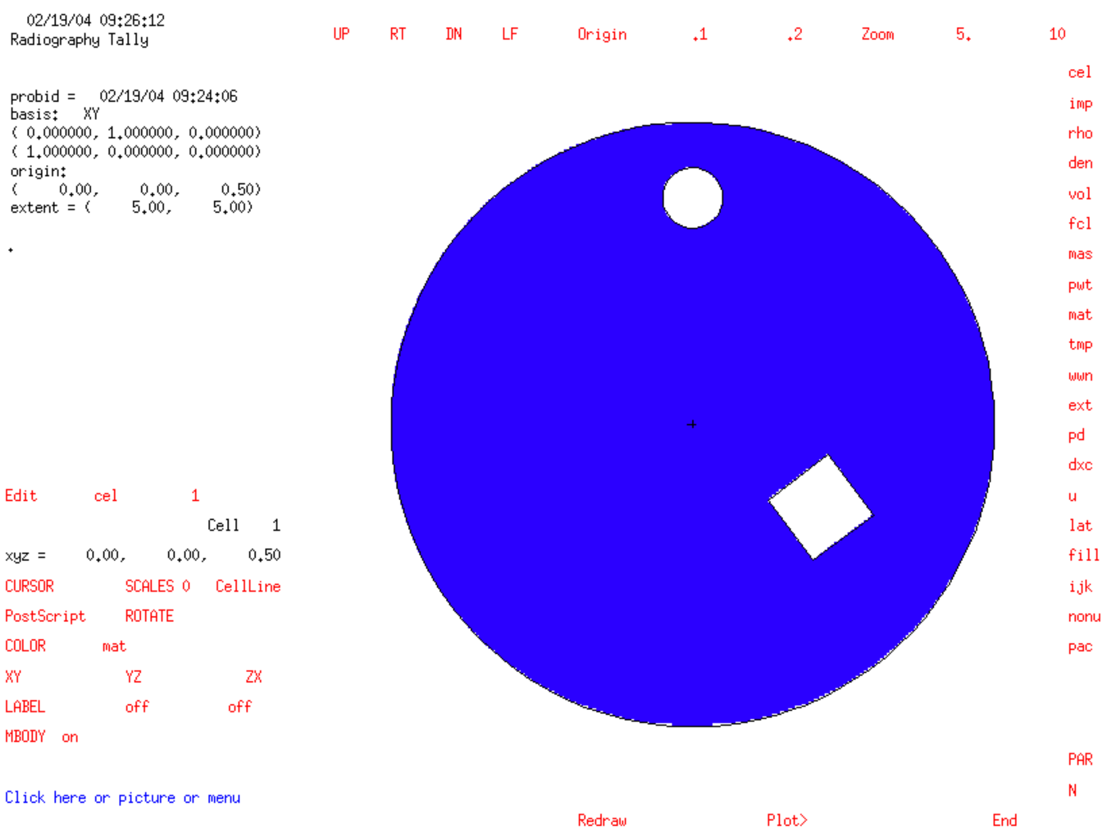


Figure 5-2. Geometry plot of radiograph example.

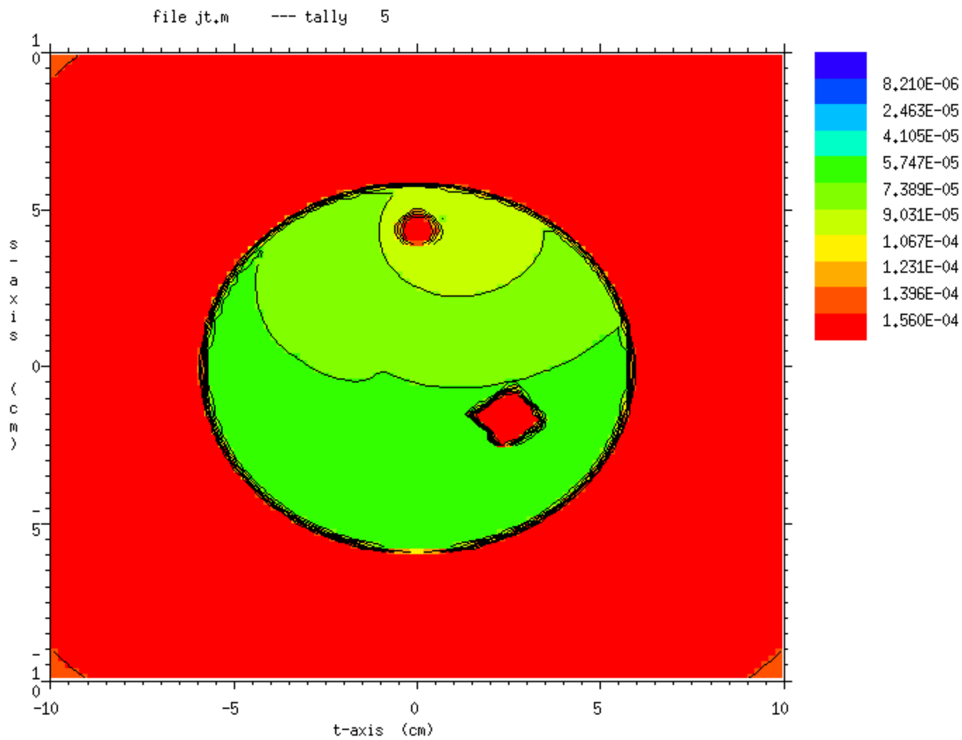


Figure 5-3. Scattered photon radiographic image of ^{238}U disc.

5.4.4 TMESH Mesh Tally Plot Examples

TMESH mesh tallies may be plotted either in the MCNP6 tally plotter (MCPLOT) from MCTAL files or superimposed over geometry plots in the geometry plotter (PLOT) from RUNTPE files.

5.4.4.1 MCPLOT TMESH MESH TALLY

Figure 5-4 shows a TMESH mesh tally of a critical configuration of seven identical barrels of fissionable material. The mesh tally is generated from an MCTAL file in the MCPLOT tally plotter.

The input file for this problem is

```
cylinders containing critical fluid in macrobody hex lattice
1 1 -8.4      -1      u=1    imp:n=1
2 0           -2      u=1    imp:n=1
3 2 -2.7      -3 1 2  u=1    imp:n=1
4  3 -.001     3      u=1    imp:n=1
```

```
10 3 -.001    -6 lat=2 u=2   imp:n=1 fill=-2:2 -2:2 0:0
                                     2 2 2 2 2
                                     2 2 1 1 2
                                     2 1 1 1 2
                                     2 1 1 2 2
                                     2 2 2 2 2
11 0          -8             imp:n=1 fill=2
50 0           8             imp:n=0

1 rcc 0  0 0  0 12 0  5
2 rcc 0 12 0  0 8  0  5
3 rcc 0 -1 0  0 22 0  6
6 rhp 0 -1 0  0 22 0  9 0 0
8 rcc 0 -1 0  0 22 0  30

m1    1001 5.7058e-2   8016 3.2929e-2
     92238 2.0909e-3  92235 1.0889e-4
m2   13027 1
m3   7014 .8 8016 .2
c
fc14 total keff in each element
f4:n (1<10[-2:2 -2:2 0:0]<11)
fq4 f m
sd4 1 24r
f14:n   (1<10[-1 1 0])  (1<10[0 1 0])
        (1<10[-1 0 0])  (1<10[0 0 0])  (1<10[1 0 0])
        (1<10[0 -1 0])  (1<10[1 -1 0]) t
fq14 f m
sd14 1 7r
tf14 4
fm14 (-1 1 -6 -7)
print -160
prdmp 2j 1
kcode 1000 1 10 50
ksrc 0 6 0  18 6 0  -18 6 0  9 6 15  -9 6 15  9 6 -15  -9 6 -15
tmesh
 rmesh12
 cora12  -30. 99i 30.
 corb12  0. 12.
 corc12  -30. 99i 30.
endmd
```

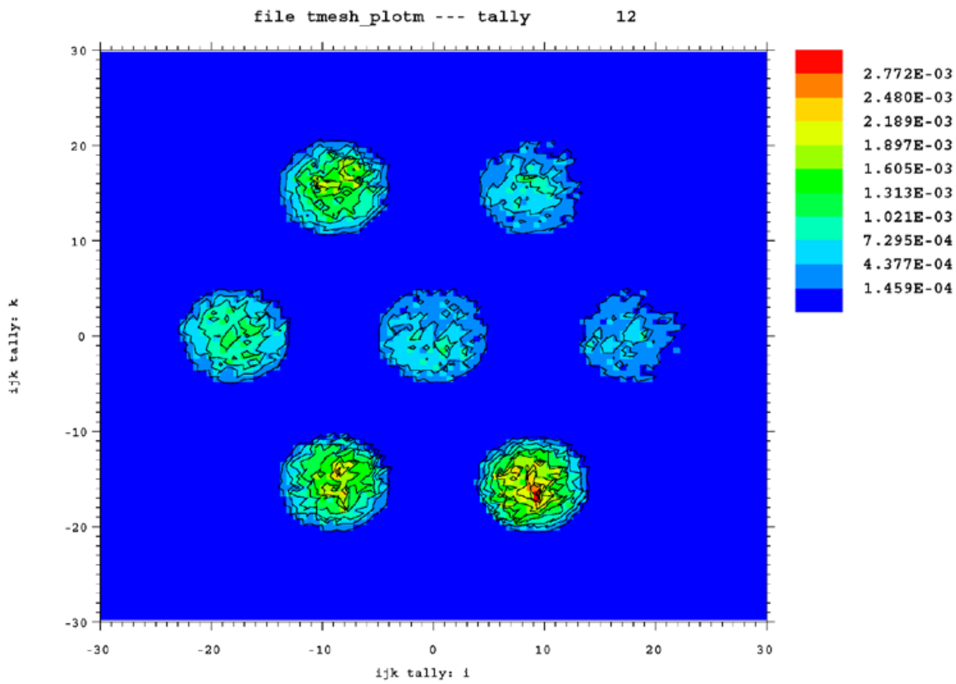


Figure 5-4. Mesh tally of barrel geometry.

The plot commands are

```
mcplot> rmctal <mctal filename>
mcplot> tal 12 free ik
```

The geometry is shown in Figure 5-5.

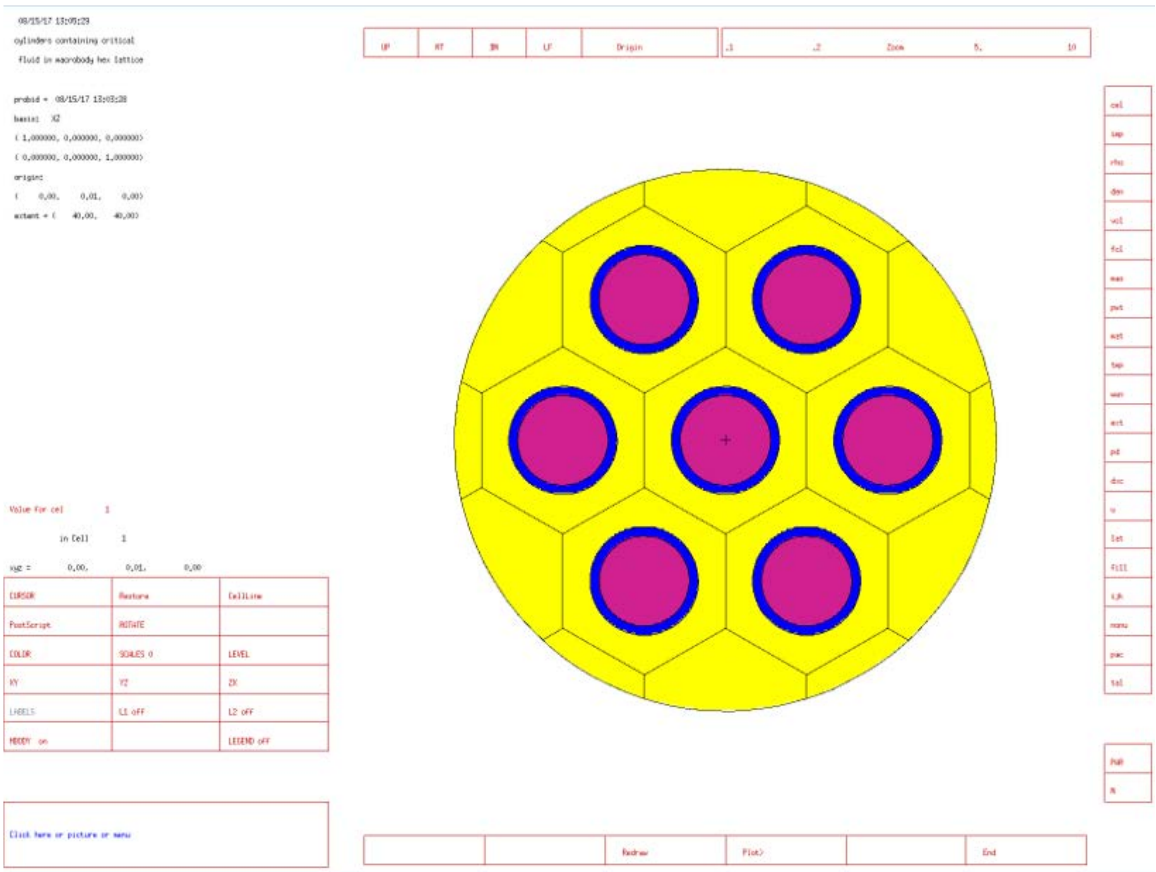


Figure 5-5. Geometry of the seven-barrel problem.

5.4.4.2 SUPERIMPOSED GEOMETRY PLOT TMESH MESH TALLY

Figure 5-6 shows the `TMESH` mesh tally results superimposed over the geometry plot. First, the RUNTPE file must be loaded using the `MCNP6 Z` option and the MCNP geometry plotter invoked:

```
mcnp6 z r=<runtpe_filename>
mcplot> plot
```

Next, the MCNP geometry needs to be oriented such that the mesh tally is in view. For the geometry of Figure 5-5, click on the lowest box on the left side and enter

```
or 0 4 0 py 4 ex 40 la 0 0
```

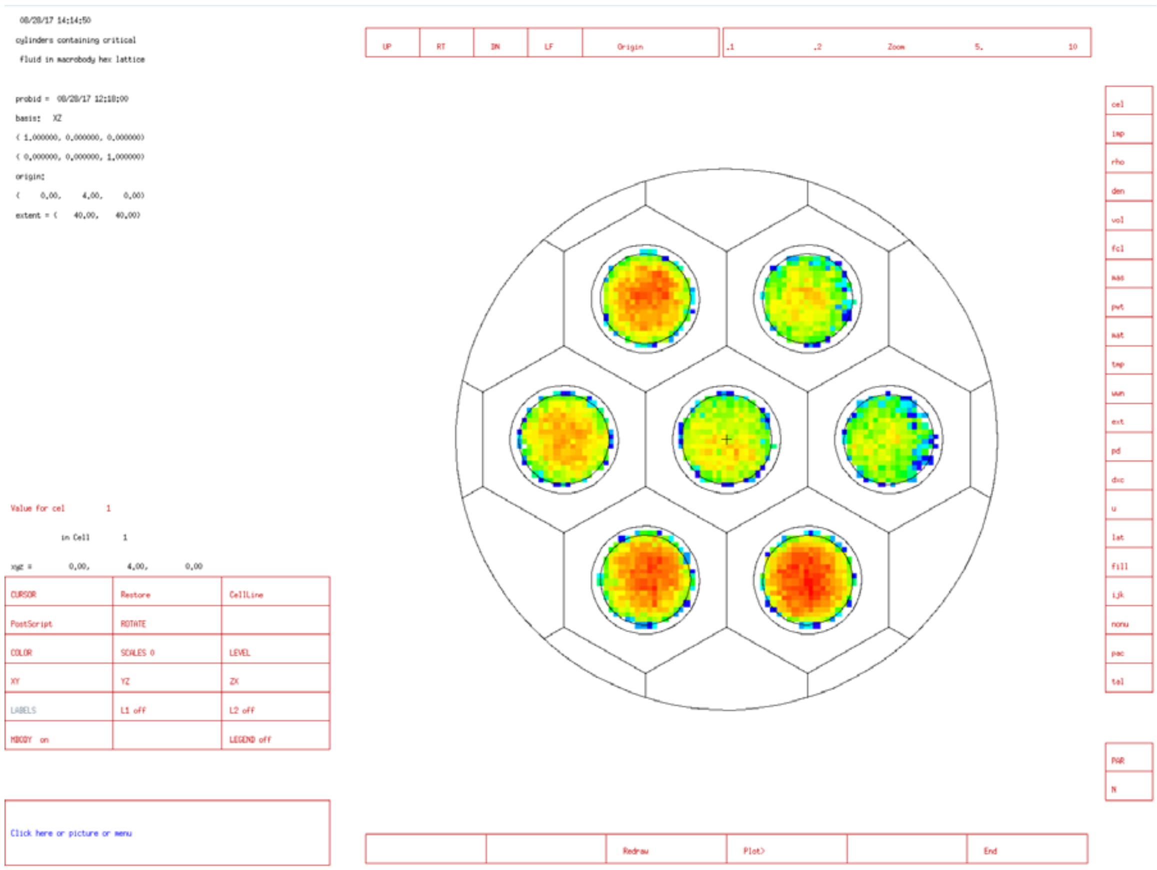


Figure 5-6. TMESH Mesh plot superimposed on geometry plot.

To plot the tally results, make the mesh tallies the "Edit" quantity by clicking the "tal" button in the far-right column of the screen.

Click `tal` (make mesh tallies the "Edit" quantity),

Click `N` (cycle through available mesh tally numbers), and

The "`Edit`" quantity, e.g., `tal12.1`, now has been specified. Next, change the color parameter (default = "`cel`"), by clicking `COLOR` twice.

Click `COLOR` (will change "`cel`" to "`off`"),

Click `COLOR` (will change "`off`" to the "Edit" quantity, "`tal12.1`"), and

Click `Redraw` (bottom center button—to make new picture).

In addition, the actual mesh tally grid can be displayed by clicking "`CellLine`" and cycling through the options to get either "`MeshTaly`" (which draws mesh tally grid lines over the plot) or "`MT+Cell`" (which draws mesh tally grid lines and cell surface lines over the plot).

5.4.5 MCPLOT FREE Command Examples

Example 1:

The following command

```
FREE  I 64x64 FIXED J=38 FIXED K=30   .
```

specifies a 1D lattice tally plot of the cell bins, which should correspond to a lattice tally with 64 "`I`" index bins, 64 "`J`" index bins, and at least 30 "`K`" index bins. With the "`K`" index set to 30 and the "`J`" index to 38, the offset into the `F`-bins will be $29 \times 64 \times 64 + 37 \times 64 = 121{,}152$. The minimum and maximum values will be determined from the 64 "`I`" bin values included in the plot. If the "`J`" and "`K`" indices are not specified, their default value of `1` is assumed, which results in an offset of 0.

Example 2:

The following command

```
FREE  IJ 10x30 ALL FIXED K=60
```

specifies a 10×30 2D contour plot, which should correspond to a lattice tally with 10 "`I`" bins, 30 "`J`" bins, and at least 60 "`K`" bins. Note that the "`K`" index is specified using the `FIXED` command, which sets the offset into the `F`-bins as $60 \times 10 \times 30 = 18{,}000$. In this case, the contour range is taken from all of the `F`-bin tally values.

For additional information involving lattice tally plots see Section 5.4.7.

5.4.6 Photonuclear Cross-Section Plots

MCNP6 can plot photonuclear data in addition to the photoatomic data of MCNP6.

Photoatomic reaction numbers are all negative: -1=incoherent, -2=coherent, -3=photoelectric, -4=pair production, -5=total, and -6=heating. For the MCNP6 photonuclear cross-section plotting, the reaction numbers all are positive. The principal photonuclear cross sections are as follows: 1=total, 2=non-elastic, 3=elastic, 4=heating, and >4=various reactions such as 18, which is (γ,*f*). The photonuclear yields (multiplicities) for various secondary particles are specified by adding 1000 times the secondary particle number to the reaction number. For example, 31,001 is the total yield of deuterons (particle type `D`=31), 34,001 is the total yield of alphas (particle type `A`=34), and 1018 is the total number of neutrons (particle type `N`=1) from fission. To find out which reactions are available for a particular nuclide or material, enter an invalid reaction number, such as M*T*=99 and MCNP6 will list the available photonuclear reactions and the available yields, such as 1018, 31,018, and 34,018. Entering a bad nuclide, `XS=12345.67U`, will cause MCNP6 to list the available nuclides.

Figure 5-7 illustrates a photonuclear cross-section plot of the total photonuclear cross section, MT=1, for material 11 and its constituents, carbon and lead.

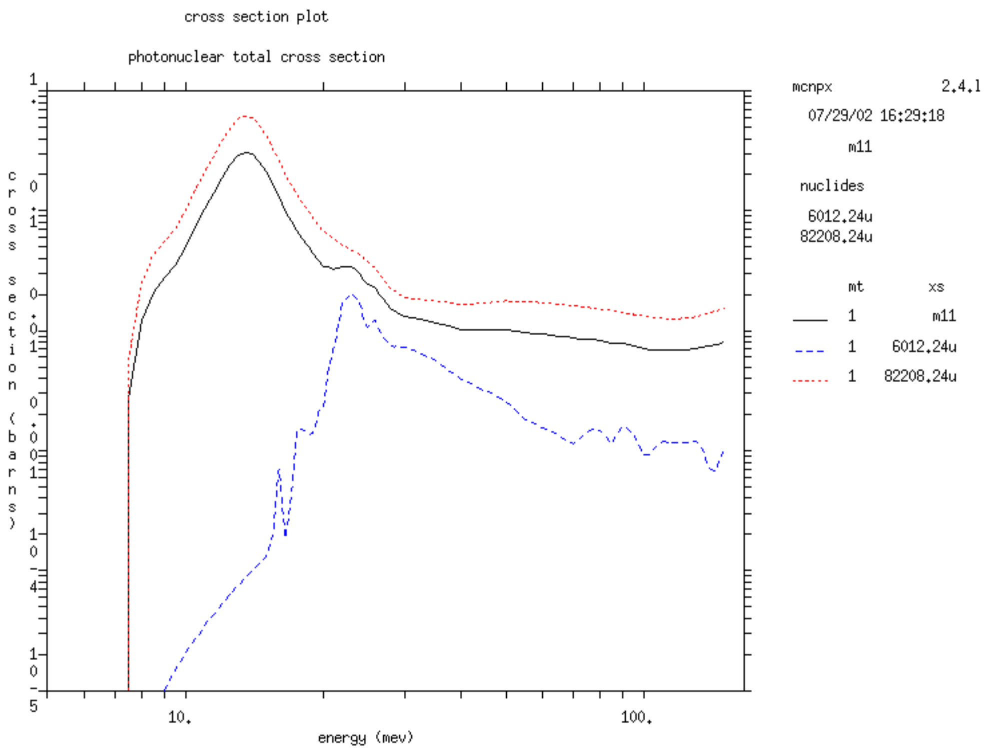


Figure 5-7. Photonuclear cross-section plot.

5.4.7 Lattice Tally Plot Example

Lattice tallies also may be plotted as either 1D or 2D contour plots. An example of a lattice tally 1D plot is

```
free i 64x64 fix j = 38 fix k = 30   .
```

This command specifies a 1D lattice tally plot of the cell bins, which should correspond to a lattice tally with 64 "i" index bins, 64 "j" index bins, and at least 30 "k" index bins. With the "k" index set to 30 and the "j" index to 38, the offset into the f bins will be $29 \times 64 \times 64 + 37 \times 64 = 121{,}152$. The minimum and maximum values will be determined from the 64 "i" bin values included in the plot. If the "j" and "k" indices are not specified, their default value of 1 is assumed, which results in an offset of 0.

An example of a lattice tally 2D contour plot is

```
free ij 10x30 all fix k=60
```

This example specifies a 10 × 30 2D contour plot, which should correspond to a lattice tally with 10 "`i`" bins, 30 "`j`" bins, and at least 60 "`k`" bins. Note that the "`k`" index is specified using the "`fix`" command, which sets the offset into the f bins as 60 × 10 × 30 = 18,000. In this case, the contour range is taken from all of the f-bin tally values.

5.4.8 Weight-Window-Generator Superimposed Mesh Plots

MCNP6 can plot the `WWG` superimposed mesh specified on the `MESH` card in an input file. MCNP4C3 and older MCNPX versions could plot only the weight-window superimposed mesh used in a problem, and a WWINP file had to be provided. In the MCNP6 geometry plotter, toggle `CellLine` for the following options:

`No Lines`	Plot cells not outlined in black
`CellLine`	Plot geometric cells, outlined in black
`WW MESH`	Plot the weight-window superimposed mesh (WWINP required)
`WW+Cell`	Plot superimposed mesh and cells, outlined in black
`WWG MESH`	Plot MESH card WWG mesh
`WWG+Cell`	Plot WWG mesh and cells, outlined in black
`MeshTaly`	Plot mesh tally boundaries
`MT+Cell`	Plot mesh tally boundaries + CellLine

The `CellLine` and `No Lines` options are always available. `WW Mesh` and `WW+Cell` are available only when the `WWP` card calls for using a superimposed weight-window mesh (fifth entry negative) and a WWINP file is provided. `WWG MESH` and `WWG+Cell` are available only when a `MESH` card is in the input file and when the `WWG` requests superimposed mesh generation (`WWG` card second entry equals `0`). In all cases, the cells may be outlined in black (`CellLine`, `WW+Cell`, `WWG+Cell`) or the cells simply may be colored without outlining (`WW MESH`, `WWG MESH`, `No Lines`).

5.4.8.1 CYLINDRICAL MESH EXAMPLE

Example:

Input file: *inp10*

```
Demonstration of WWG Plot
1 1 1.0   -1  imp:p 1
2 0        1  imp:p 0

1 rcc 0 0 0  0 10 0  5

mode p
sdef sur 1.3 vec 0 1 0 dir 1 erg 100
m1 1001 2 8016 1
nps 1000
```

```
f1:p 1.2
wwg 1 0
mesh geom=cyl origin=0 -1 0  ref=0 .1 0  axs=0 1 0  vec=1 0 0
     imesh 6   iints 7  jmesh 12  jints 7   kmesh 1   kints 3
```

Com file: *com10*

```
ex 10 lab 0 0 px 0 mesh 4
pause
py 5
pause
```

Execution line:

```
mcnp6 i=inp10  com=com10  ip
```
.

Or, instead of using the command file (with plot commands in command mode), the interactive plotter can be used:

```
mcnp6 i=inp10 ip
```
,

click	`CellLine`	to get `WWG+Cell`
	`label sur`	to turn off surface labels
	`XY`	to get `px=0` view (axial view, Fig. 12)
	`Zoom 10`	to get 10 × magnification (click twice)
	`Origin`	click in the center of material to center picture
	`ZX`	to get `py=5` view (radial view, Fig. 13)

The above COM file or plot commands in the command mode generate the two plots shown in Figure 5-8 and Figure 5-9.

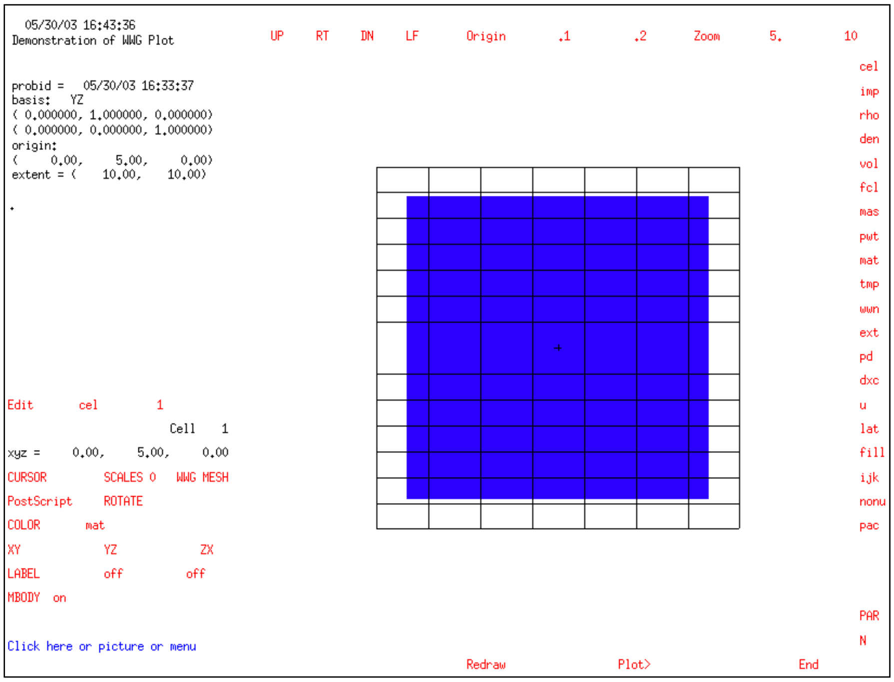


Figure 5-8. WWG mesh plot, axial view.

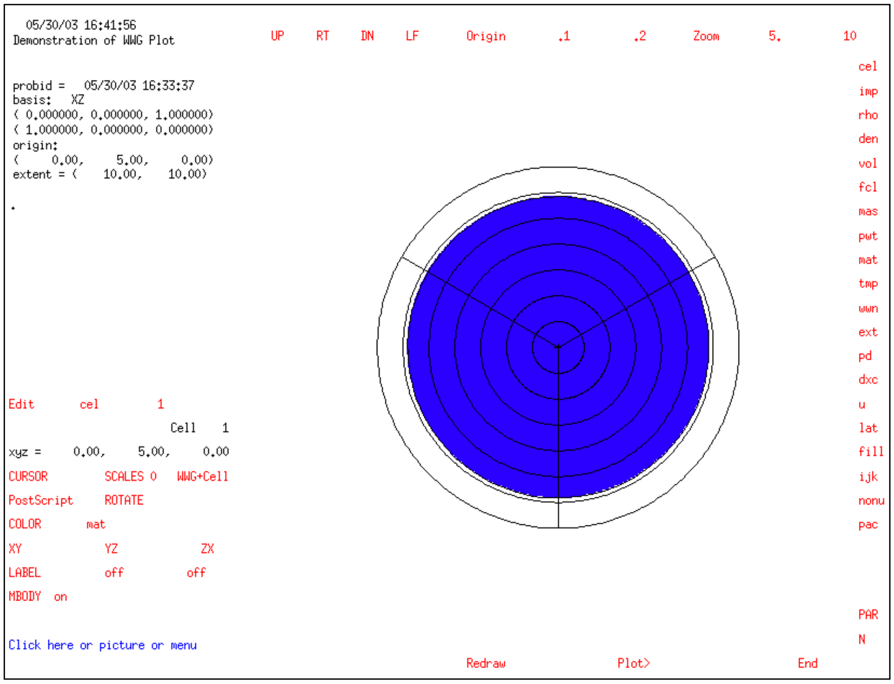


Figure 5-9. WWG plot, radial view.

5.4.8.2 SPHERICAL MESH EXAMPLE

The spherical mesh geometry may be thought of as an orange where the theta (θ) azimuthal angles are the bounds between slices or, alternatively, as a globe where the phi (φ) polar angles are latitude and the theta (θ) azimuthal angles are longitude. The north pole is at φ=0 degrees; the south pole is at φ=180 degrees; London is at θ=0 degrees and all the way around the globe at θ=360 degrees.

The interface for geometry plots of the spherical mesh window boundaries is the same as for cylindrical mesh boundaries. Geometry plots are colored by the input weight windows from the WWINP file by selecting `WWN` as the `COLOR` option. The weight window and weight-window generator mesh boundaries are plotted by clicking "`CellLine`" to get to the `WWG` or `WW` options. The command-prompt plot commands would be "`LA 0 1 wwn COLOR on LA 0 0`" to color by input windows. The commands "`MESH 2`" and "`MESH 4`" plot the generator mesh from the `MESH` card and weight-window mesh from the WWINP file.

Figure 5-10 through Figure 5-12 illustrate three views of a geometry divided into cells coincident with the spherical mesh, so that each color represents a specific geometry and mesh cell in each view. Figure 5-11 and Figure 5-12, drawn through the mesh sphere origin and normal and orthogonal to the polar axis, give the intuitive polar (Figure 5-11) and azimuthal (Figure 5-12) views. However, skewed, off-center plots of spherical meshes with skew axes give very non-intuitive plots as illustrated in Figure 5-10.

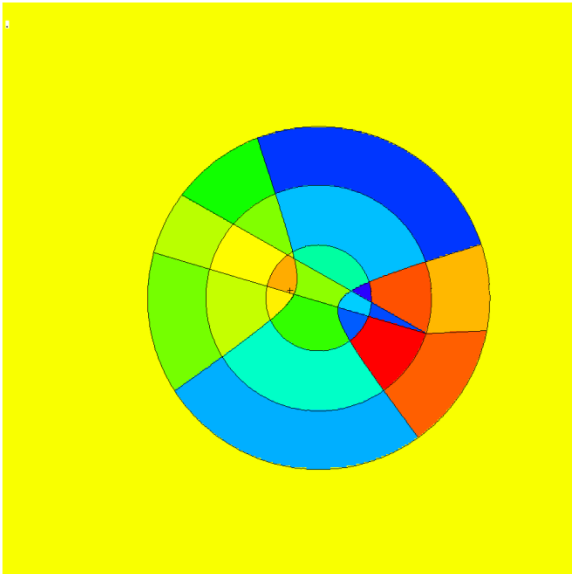


Figure 5-10. The data to generate this plot view follow:

Plot view:
`basis .84514 -.0507093 .169031 .408248 .408248 -.816497, or -3 -9 -20, ex 100.`
Spherical mesh orientation:
`origin 7 -9 -12, axs .4 -.5 .2, vec .1 -.2 -.7`

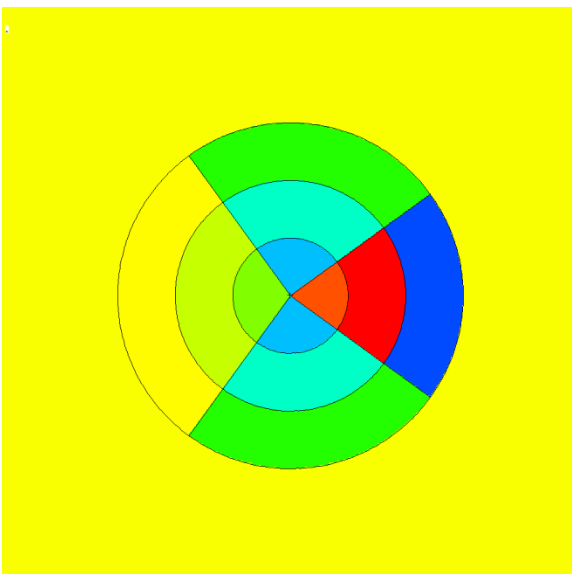


Figure 5-11. Plot view orthogonal to polar axis showing polar bins `JMESH` = 36 and 126 degrees. The polar axis (0 degrees) is to the right and is not plotted.

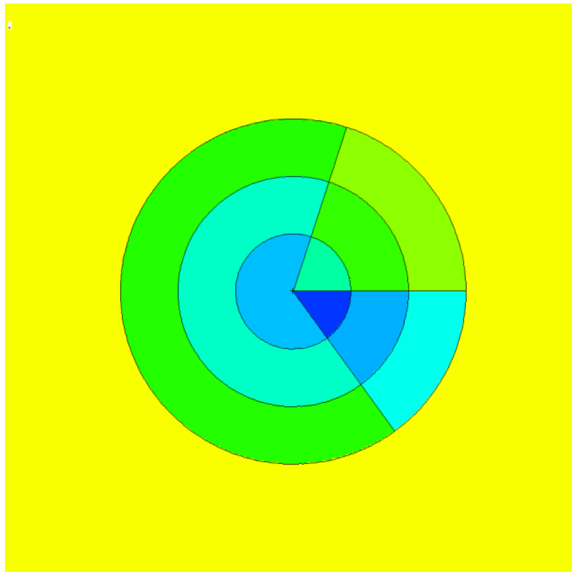


Figure 5-12. View normal to polar axis at origin showing azimuthal planes at `KMESH` = 72, 306, and 360 degrees. The azimuthal vector, `VEC`, is to the right (360 degree plane)

5.5 NORMALIZATION OF ENERGY-DEPENDENT TALLY PLOTS

This section discusses two methods of normalizing an energy-dependent tally for plotting:

- dividing by the width of each energy bin, and
- dividing by the logarithmic width of each energy bin (i.e., dividing by the lethargy width).

This section also discusses how to obtain plots that provide an easy visualization for the tally results by the area under the curve. Examples of both normalizations are provided for a logarithmic energy abscissa.

5.5.1 MCNP6 Tally Values and Energy-Normalized Tallies

Assume that an MCNP6 energy-dependent tally density such as flux or reaction rate has a form of *f(E)* per unit energy. An MCNP6 tally result T_i in energy bin *i* from *f(E)* is

$$T_i = \int_{E_{l_i}}^{E_{u_i}} f\left(E\right) dE \quad \text{tally units,} \tag{5.1}$$

where the energy bin limits are E_{l_i} to E_{u_i}. The T_i's tend to be small for small energy bins and large for larger energy bins. Thus, there is no explicit information about the density *f(E)* in the T_i's unless all energy bins have the same constant width, in which case the correct histogram shape of *f(E)* is obtained from the T_i's. The average value of *f(E)* over the energy range ΔE_i between E_{l_i} and E_{u_i} is

$$f_i(E) = \frac{\int_{E_{l_i}}^{E_{u_i}} f(E)dE}{\int_{E_{l_i}}^{E_{u_i}} dE} = \frac{T_i}{E_{u_i} - E_{l_i}} \quad \text{(tally units)/(unit energy).} \tag{5.2}$$

The $f_i(E)$'s are the bin-wise histogram representations of the tally of $f(E)$ because they are the average values of $f(E)$ in each energy bin. Note that $f_i(E)$ is a constant between E_l and E_u.

This $E_u - E_l$ normalizing of T_i, the default for a 2D MCNP6 energy-dependent tally spectral plot, is generally agreed to be the proper way to display the $f_i(E)$'s when the abscissa E of a 2D plot is linear. When a `LINLIN` (linear abscissa and linear ordinate) plot of $f_i(E)$'s is made with the ordinate starting at zero, the visual area under each histogram represents T_i. This type of visually correct area plot will be termed a Visually Accurate Area (VAA) plot. A VAA plot provides correct visual information about the tally by the area under the histogram.

The average energy $\overline{E}_i$ for each $f_i(E)$ bin is

$$\overline{E}_i = \frac{\int_{E_{l_i}}^{E_{u_i}} Ef(E)dE}{\int_{E_{l_i}}^{E_{u_i}} f(E)dE} \approx \frac{\int_{E_{l_i}}^{E_{u_i}} Ef_i(E)dE}{\int_{E_{l_i}}^{E_{u_i}} f_i(E)dE} = \frac{E_{u_i} + E_{l_i}}{2} \quad , \tag{5.3}$$

where the $f_i(E)$ histogram approximation to $f(E)$ cancels out. $\overline{E}_i$ is used as the average energy for plotting the statistical error bars for tally bin i.

5.5.2 Definition of Neutron Lethargy

The lethargy U of a neutron with energy E is defined to be

$$U = \ln\left(\frac{E_0}{E}\right) = \ln(E_0) - \ln(E) \quad , \tag{5.4}$$

where E_0 is the upper neutron energy for the problem. On the average, neutrons lose a fixed fraction of their energy in each elastic collision with a specific isotope above thermal energies. The lethargy U is used in nuclear reactor analysis to assess the average logarithmic energy loss of these elastically scattered neutrons.

A neutron with energy E_0 has zero lethargy. As the neutron loses energy, its lethargy increases (hence the name "lethargy" because the neutron becomes more lethargic) and is always positive because no energy is greater than E_0. A neutron with zero energy has infinite lethargy.

For eigenvalue problems, MCNP6 calculates the Energy of the Average neutron Lethargy causing Fission (EALF):

$$\text{EALF} = \exp\left\{\int \ln(E)\Phi(E)\Sigma_f(E)dE \Big/ \int \Phi(E)\Sigma_f(E)dE\right\} \quad , \tag{5.5}$$

where $\Phi(E)$ is the neutron flux and $\Sigma_f(E)$ is the fission cross section (the E_0's cancel). MCNP6 can plot energy-dependent tallies versus a logarithmic energy scale using lethargy for tally bin normalization.

5.5.3 Lethargy-Normalized Tallies for a Logarithmic Energy Abscissa

When the abscissa E is logarithmic, the T_i normalizing procedure often preferred involves the differences in the natural logs (*ln*) of the energy instead of the differences in the energies. It is useful to relate the differences in the logs of the bin energies to the often used neutron lethargy U:

$$\ln(E_{u_i}) - \ln(E_{l_i}) = U_{l_i} - U_{u_i} \quad , \tag{5.6}$$

where U_{l_i} is the lethargy at E_{l_i} and U_{u_i} is the lethargy at E_{u_i} (the $\ln(E_0)$ terms cancel: see Eqn. (5.4)).

The tally T_i can be converted to an average bin *i* lethargy-normalized value $F_i(U)$ by

$$F_i(U) = \frac{T_i}{\ln(E_{u_i}/E_{l_i})} = \frac{T_i}{U_{l_i} - U_{u_i}} \text{ (tally units)/(unit lethargy).} \tag{5.7}$$

The $F_i(U)$'s are the histogram approximation to $F(U)$ per unit lethargy. MCNP6 plots the $F_i(U)$'s instead of the $f_i(E)$'s for a $\ln(E)$ abscissa when the `LETHARGY` plot command is used. The $F_i(U)$'s are not plotted when the energy abscissa is linear. Only the $f_i(E)$'s and T_i's can be plotted for a linear E abscissa. A `LOGLIN` (log abscissa and linear ordinate) plot of the $F_i(U)$'s is a VAA plot because the $\ln(E)$ abscissa is linear in U and the area under the histogram is visually correct.

5.5.4 Relation of Tally Lethargy Normalizing to Tally Energy Normalizing

To determine the functional form of $F(U)$ in terms of $f(E)$, equate the U and E density function areas to produce

$$F(U)dU = -f(E)dE \quad . \tag{5.8}$$

The negative sign is required because E decreases as U increases. Integrating the left hand side of Eqn. (5.8) from U_{u_i} to U_{l_i} is equal to T_i, as is the integral of the right hand side from E_{u_i} to E_{l_i}.

The differential dU can be written in terms of energy E from Eqn. (5.4) as

$$dU = -d\{\ln(E)\} = \frac{-dE}{E} \quad . \tag{5.9}$$

Substituting Eqn. (5.9) for dU into Eqn. (5.8) gives

$$F(U) = Ef(E) \quad . \tag{5.10}$$

Eqn. (5.10) shows that $F(U)$ can be thought of as the energy E times $f(E)$. Thus, besides producing VAA LOGLIN plots, lethargy-normalized plots have the additional virtue of flattening the $1/E$ neutron flux shape that often occurs in neutron spectra. For an $f(E)$ that has a $1/E$ shape everywhere, $F_i(U)$ is a constant for all i (as opposed to the widely varying $f_i(E)$'s), which produces a VAA plot for the $1/E$ shape. Lethargy-normalized plots remove many of the decades of $f_i(E)$ change, represent the $1/E$ portions of the spectrum as a constant, and make understanding and comparing the $F_i(U)$ results easier.

5.5.5 Average Energy for a Lethargy-Normalized Tally

The lethargy-averaged energy $<E_i>$ for energy bin i is defined as

$$< E_i >= \frac{\int_{U_{u_i}}^{U_{l_i}} EF(U)dU}{\int_{U_{u_i}}^{U_{l_i}} F(U)dU} \quad . \tag{5.11}$$

For the histogram approximation of $F(U)$ by $F_i(U)$, the $F_i(U)$'s cancel, and changing variables using Eqn. (5.9) gives

$$< E_i >\approx \frac{\int_{U_{u_i}}^{U_{l_i}} EdU}{\int_{U_{u_i}}^{U_{l_i}} dU} = \frac{\int_{E_{l_i}}^{E_{u_i}} dE}{\int_{E_{l_i}}^{E_{u_i}} \frac{dE}{E}} = \frac{E_{u_i} - E_{l_i}}{\ln\left(\frac{E_{u_i}}{E_{l_i}}\right)} \quad . \tag{5.12}$$

In the limit as $E_{u_i} - E_{l_i}$ becomes small, $< E_i >\approx \overline{E}_i$ in Eqn. (6.3) as expected. This average $<E_i>$ is considered to be the centroid energy for a lethargy-normalized bin and is used in MCNP6 to plot statistical error bars, BAR plots, and PLINEAR plots, as well as printing the plotted points using the PRINTPTS command.

5.5.6 MCNP6 LETHARGY Command for Lethargy Normalization

Lethargy-normalized plots of energy-dependent tallies with a log energy abscissa are made with the LETHARGY plotting command. This command cannot be used for cross-section plots. For this command to apply, "FREE E" must be active, "LOGLIN" or "LOGLOG" axes must be used, and the "NONORM" command must not be invoked. The LETHARGY command cannot be used after a COPLOT command and can be disabled to return to energy-bin-width tally normalization for a log energy abscissa by using RESET LETHARGY. Switching from a logarithmic energy to a linear energy abscissa with LETHARGY in use will automatically change a plot of the $F_i(U)$'s to the $f_i(E)$'s. Switching back to the log energy abscissa will again plot the $F_i(U)$'s.

If an E_0 were specified for a log abscissa plot, a linear lethargy abscissa could be specified starting at the right with a value of zero at E_0 and linearly increasing to the left in steps of about 2.3 per energy decade decrease. MCNP6 does not label the abscissa as lethargy because of the difficult energy interpretation. The logarithmic energy decades are plotted instead to allow easier interpretation of the areas under the lethargy-normalized histogram. For this reason, there is neither a need nor a provision to specify E_0.

5.5.7 Requirements for Producing a Visually Accurate Area (VAA) Tally Plot

Consider the characteristics of a function of one variable, such as an MCNP6 2D tally histogram plot. One important quantity for this histogram is the integral over the tally range, which is the total MCNP6 tally. Another important characteristic is the shape of this histogram that provides information about where the largest regions of the tally have occurred. The area of a tally range under the plotted curve is a measure of the contribution of each range to the total.

The area under this curve is best visualized with both the abscissa and the ordinate having a linear scale. The ordinate usually has a lower value of zero to represent correctly the curve area. A `LINLIN` plot of the $f_i(E)$'s fits these criteria and therefore is a VAA plot. Often linear scales do not allow complete display of a tally, so logarithmic scales must be used. A logarithmic axis scale typically changes by decades. Each decade change on the abscissa changes a ΔE for a specified length along the abscissa by a decade. The area under the `LOGLIN` $f_i(E)$ curve is proportional to ΔE, which is not reflected in the visual area representation on the log abscissa plot. A logarithmic ordinate does not visually display the correct tally contribution under the curve because this area in the plot is proportional to the number of ordinate decades. When both axes are logarithmic, the visual interpretation in the plot of the area under the curve is further obscured.

The lethargy variable U is linear in the logarithm of the energy as defined in Eqn. (5.4). U values for decreasing energy E values of E_0, $E_0/10$, and $E_0/100$ are 0, 2.3, and 4.6. Therefore, a `LOGLIN` plot of the $F_i(U)$'s instead of the $f_i(E)$'s satisfies the VAA plot linear scale criterion for visually examining the area under a curve. The area under each histogram $F_i(U)$ is $F_i(U)*(U_{l_i}-U_{u_i})$, which is exactly the bin i tally T_i as defined in Eqn. (5.7). Similarly, the area under all the $F_i(U)$'s is the sum of the T_i's, which is the total MCNP6 tally. A `LOGLIN` plot of the $F_i(U)$'s *is* a VAA plot; a `LOGLIN` plot of the $f_i(E)$'s is *not* a VAA plot.

5.5.8 Comparisons of Energy and Lethargy Tally Normalizations for a Log Energy Abscissa

Energy-normalized and lethargy-normalized log energy abscissa tally plots for two analytic and two critical uranium assembly problems are discussed to show which are VAA plots. The two analytic $f(E)$ examples will be accurate to three significant figures in the text.

Example 1: A Constant $f(E)$=0.100 from 0.0001 to 10 MeV

The first example is the tally of a uniform energy source between 0.0001 and 10 MeV. The expected value of all $f_i(E)$'s is 0.100. Figure 5-13 shows a plot of the five energy-normalized $f_i(E)$'s, each with an energy bin width of a decade. The tally T_i in the energy bin from 1 to 10 MeV is $(10-1)*0.1=0.9$. The next lowest energy bin tally is $(1-0.1)*0.1=0.09$. The tally bin T_i's are decreasing by a decade per decade decrease in energy, but the $f_i(E)$'s are a statistically constant 0.1. Visually interpreting this `LOGLIN` plot of the $f_i(E)$'s by the area under the curve is not useful because the energies are changing by decades along the logarithmic energy abscissa.

Figure 5-14 shows a `LOGLIN` lethargy-normalized plot of the corresponding five $F_i(U)$'s. (The "f(u) = ef(e) bin normed" text on the right hand side of the plot is a reminder that this is a lethargy-normalized plot.) The shapes of the $f_i(E)$'s in Figure 5-13 and the $F_i(U)$'s in Figure 5-14 are completely different. $F_i(U)$ for the 1 to 10 MeV tally bin is $0.9/\ln(10/1) = 0.391$. The area in the plot of this bin is $\ln(10/1) * 0.391 = 0.900$, which is the correct T_i for this bin. The tally bin area from 0.1 to 1 MeV is $\ln(1/0.1) * 0.391 = 0.0900$. The visual areas of each of the tally bins represent the tally for that bin because of the linear lethargy abscissa obtained by the lethargy normalization. *The* `LOGLIN` *lethargy-normalized plot in Figure 5-14 clearly displays the relative contribution of each of the five tally bins by the area under the histogram. Figure B-3 is a VAA plot.*

Figure 5-15 shows the same plot as in Figure 5-14, except the ordinate is now logarithmic. The five $F_i(U)$'s are the same in both plots, but the visual area interpretation in Figure 5-15 is misleading because the ordinate scale is logarithmic. Nevertheless, Figure 5-15 is useful for assessing the behavior of the $F_i(U)$'s that are small and cannot be seen in Figure 5-14 with the linear ordinate.

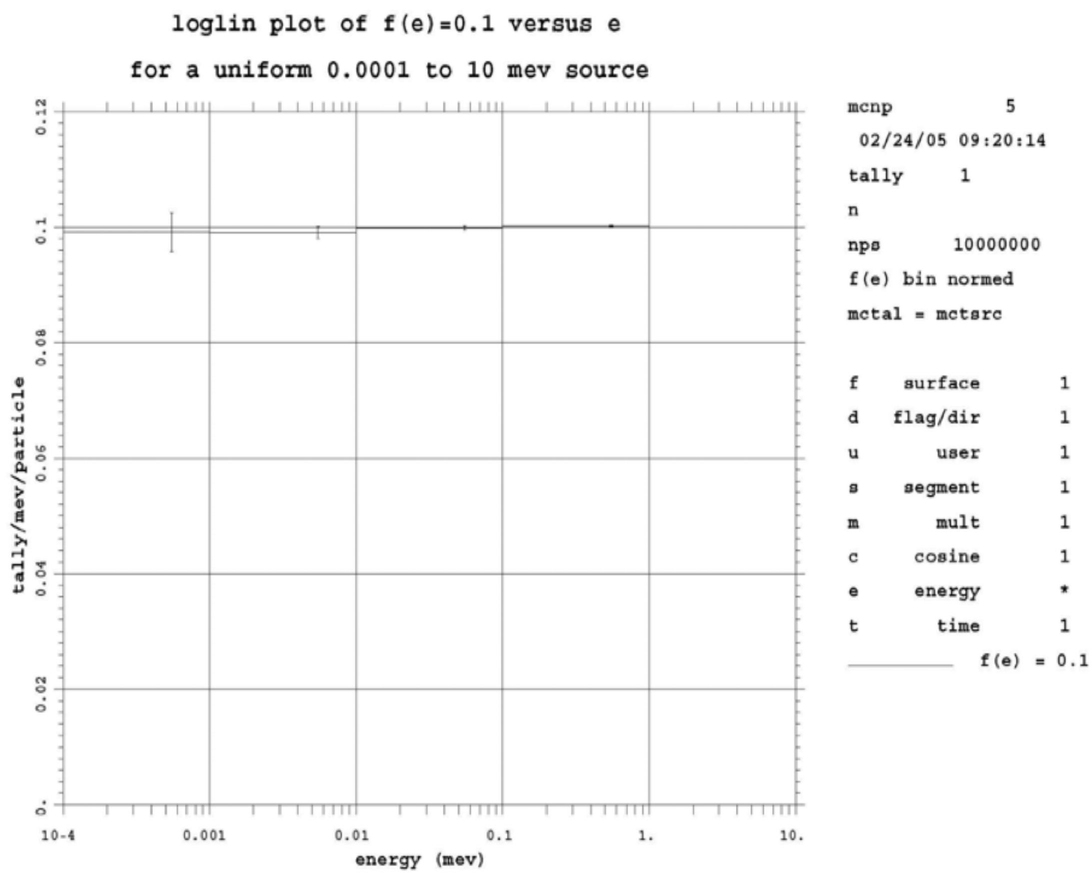


Figure 5-13. A LOGLIN plot of energy-normed f_i(E) versus E for a uniformly sampled energy source between 0.0001 and 10 MeV. The expected value of all f_i(E)'s is 0.1.

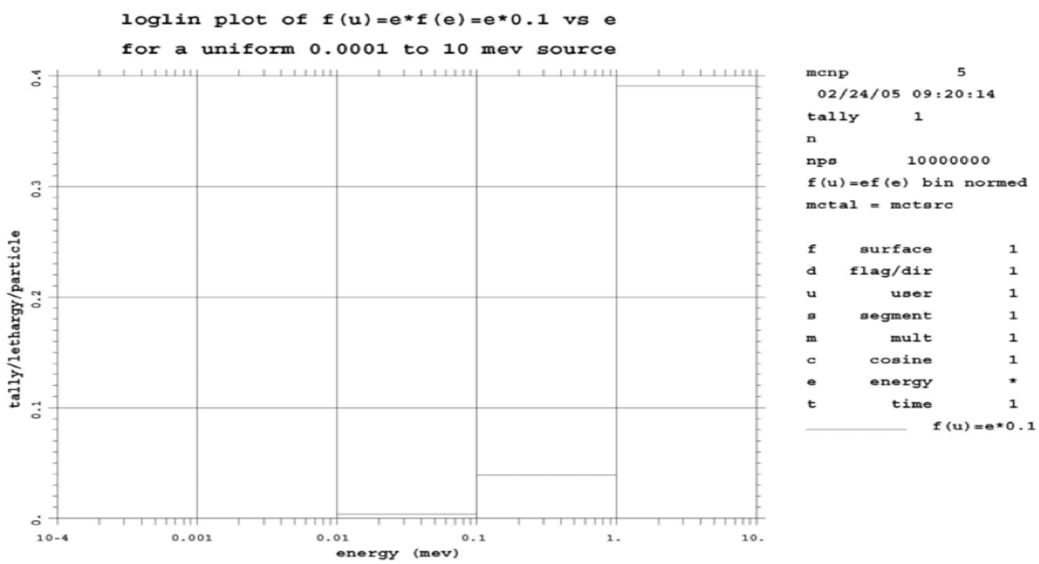


Figure 5-14. A LOGLIN plot of lethargy-normed energy-normed F_i(E) versus E for a uniformly sampled energy source between 0.0001 and 10 MeV. The area F_i(E) *ΔU_i of each tally bin is the tally value.

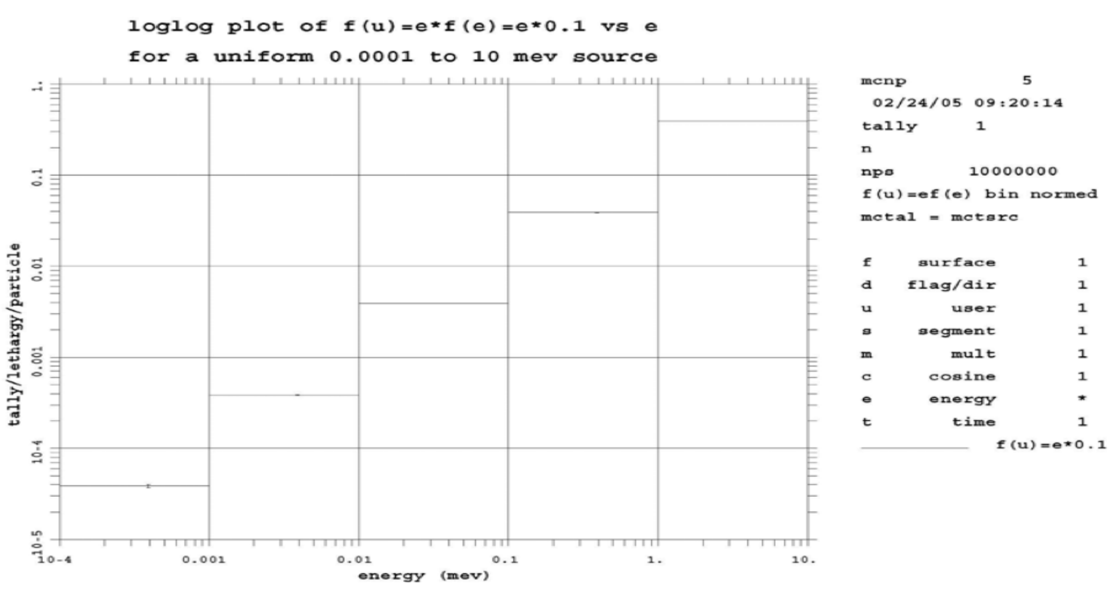


Figure 5-15. A LOGLOG plot of F_i(U) versus E for a uniformly sampled energy source between 10^{-4} and 10 MeV. The smaller tallies not visible at lower energies in Figure 5-14 can be seen here.

Example 2: $f(E)$=0.087/E from 10^{-6} to 0.1 MeV

For a second example, an equal-lethargy 50-bin tally was made of a 1/E energy source from 10^{-6} to 0.1 MeV. The lethargy width of each tally bin is $\ln(0.1/10^{-6})/50 = 0.23$. All T_i's have an expected value of $0.23/\ln(0.1/10^{-6}) = 0.02$ for the equal lethargy energy bins. Figures 5-16 and 5-17 show `LOGLIN` and `LOGLOG` plots of the $f_i(E)$'s. Each tally bin has a relative error of 0.2%. The $f_i(E)$'s have the expected 1/E shape of the source. The histograms in both figures decrease with increasing energy because the Ti's are constant and ΔE_i's are continuously increasing. Neither Figure 5-16 nor 5-17 is a VAA plot because neither shows a meaningful visual under-the-curve area representation of the Ti's for this tally.

The lethargy-normalized plot of the $F_i(U)$'s in Figure 5-18 is a VAA plot. The $F_i(U)$'s are a statistical constant (0.02/0.23=0.087) for $f(E)$=1/E, as predicted by Eqn. (6.10). Figure 5-18 shows visually that all equal lethargy widths contribute equally to the total tally, which is correct for the 1/E source. The integral under the curve of Figure 5-18 is $0.087 * \ln(0.1/10^{-6}) = 1$, which is the source strength. Once again, the shapes of the $f_i(E)$'s in Figures 5-16 and 5-17 and the $F_i(U)$'s in Figure 5-18 are completely different.

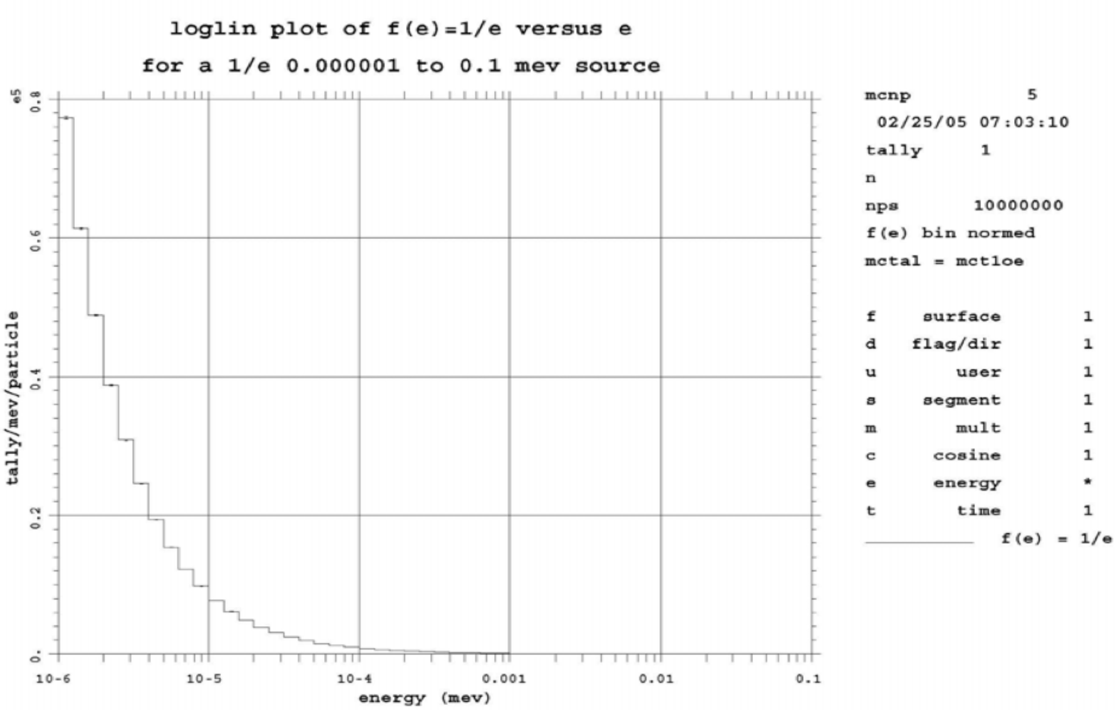


Figure 5-16. A LOGLIN plot of f_i(E) versus 1/E energy source between 10^{-6} and 0.1 MeV. Equal lethargy bin spacing (0.23) in energy is used, so all bins contribute the same amount to the tally for the 1/E source.

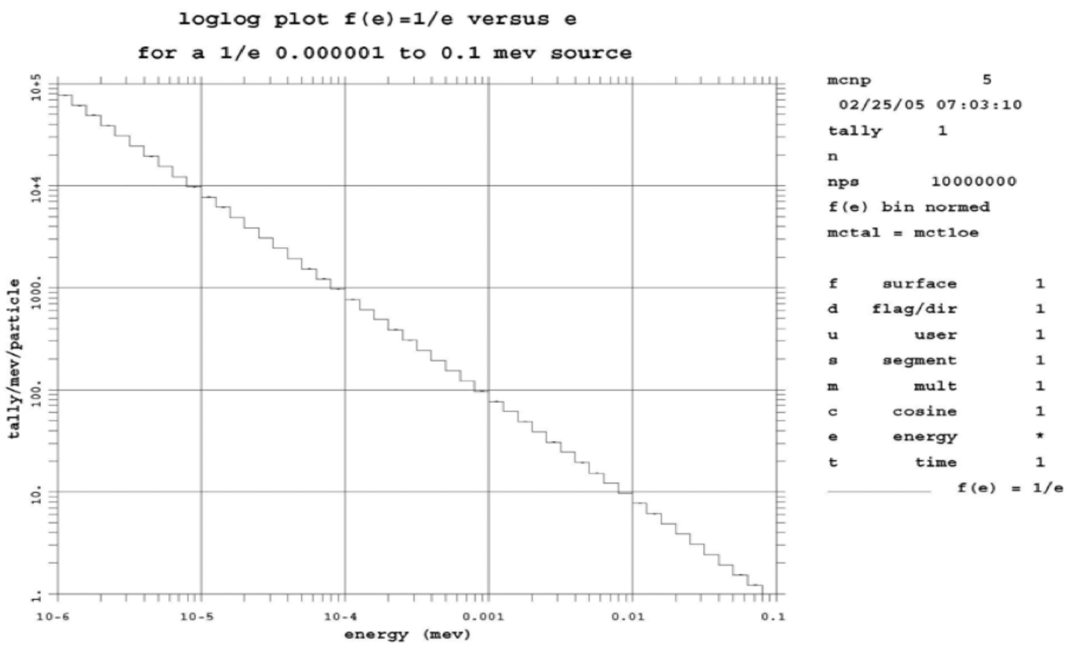


Figure 5-17. A LOGLOG plot of f_i(E) versus 1/E energy source between 10^{-6} and 0.1 MeV. The 1/E behavior of f_i(E) is evident.

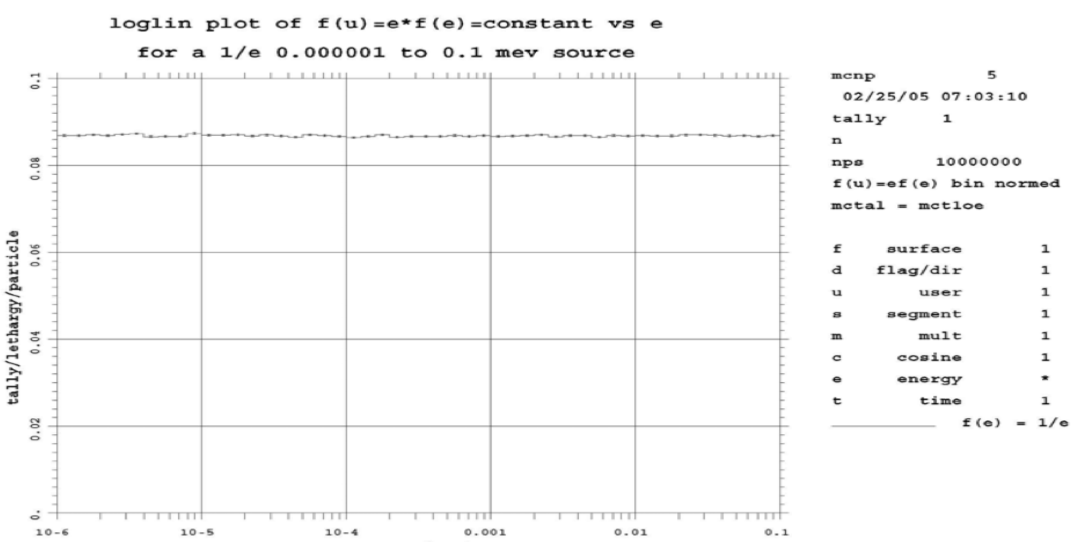


Figure 5-18. A LOGLIN plot of F_i(U) = E*f(E) = E*(0.087/E) = 0.087 versus 1/E energy source between 10^{-6} and 0.1 MeV. The integral of this plot is unity, which is the source strength.

Example 3: Neutron Fluxes and Fission Rate Spectra for Two Critical Uranium Systems

A third and more realistic example is a comparison of $f_i(E)$ and $F_i(U)$ plots for the neutron fluxes and fission rate spectra calculated by MCNP6 for two critical uranium systems:

1. a water-reflected, water-moderated array of 18×20 2.35% low-enriched uranium (LEU) UO_2 aluminum clad fuel elements [DEA04]; and
2. the Godiva bare metal 93.7% highly-enriched uranium (HEU) sphere [LAB04].

The calculations were performed with pre-ENDF/B-VII uranium isotope cross sections (from Los Alamos National Laboratory Group T-16) that are identified by a ".69c." All other isotopes in the LEU system used ENDF/B-VI ".66c" cross sections with ".60t" S(α,β) data for light water and polyethylene. The calculated k_{eff} for the LEU system is 0.9968 with an estimated standard deviation of 0.0003. The HEU system k_{eff} is 0.9987 with a standard deviation of 0.0003. The calculated EALF for the LEU and HEU systems is 1.0×10^{-7} MeV and 0.82 MeV. The calculated percentages of the incident neutrons causing fission by energy range are listed in Table 5-6.

Figures 5-19 and 5-20 compare the energy-normalized and lethargy-normalized plots of the neutron flux $f_i(E)$'s and $F_i(U)$'s for the thermal LEU and fast HEU systems. The areas under all curves are one. Only the HEU flux values with relative errors less than 0.1 were plotted, which is the reason this flux curve terminates abruptly. The plots of the $f_i(E)$'s in Figure 5-19 do not convey the contributions of the $f_i(E)$ flux by the area under the curve because both scales are logarithmic. The 1/E flux behavior for the LEU system is evident in the figure over much of the ten decades of the $f_i(E)$'s. Figure 5-19 is not a VAA plot.

Figure 5-20 is a VAA plot because the visual area under each curve accurately represents the contributions to the total flux by energy range because both axes are linear. The 1/E $f_i(E)$ flux behavior is characterized as the flat $F_i(U)$ range, as predicted by Eqn. (5.10).

Table 5-6. Percentage of Fission Rates by Incident Neutron Energy

System	Spectrum	Less than 0.625 eV	0.625 eV to 100 keV	Greater than 100 keV
LEU	Thermal	91.4	4.5	4.1
HEU	Fast	0.	5.4	94.6

Figure 5-21 shows a `LOGLOG` plot of the fission rate $f_i(E)$'s versus E for the thermal neutron spectrum LEU and fast high-energy spectrum HEU systems. Each curve is divided by the total tally over all energies so the area under each curve is unity. Figure 5-21 shows the thermal and fast fission rate shapes, but does little to convey the fission rate percentages shown in Table 5-6. Figure 5-21 is *not* a VAA plot.

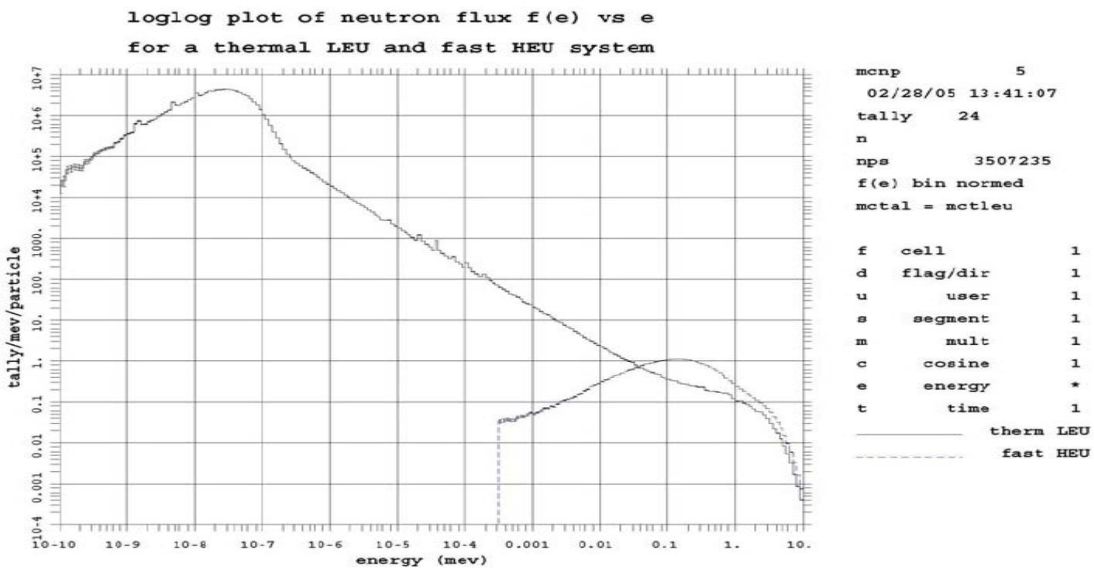


Figure 5-19. A LOGLOG plot of energy-normed neutron flux $f_i(E)$ versus E for the thermal LEU (larger curve) and fast HEU (smaller curve) systems. The area under curves is one.

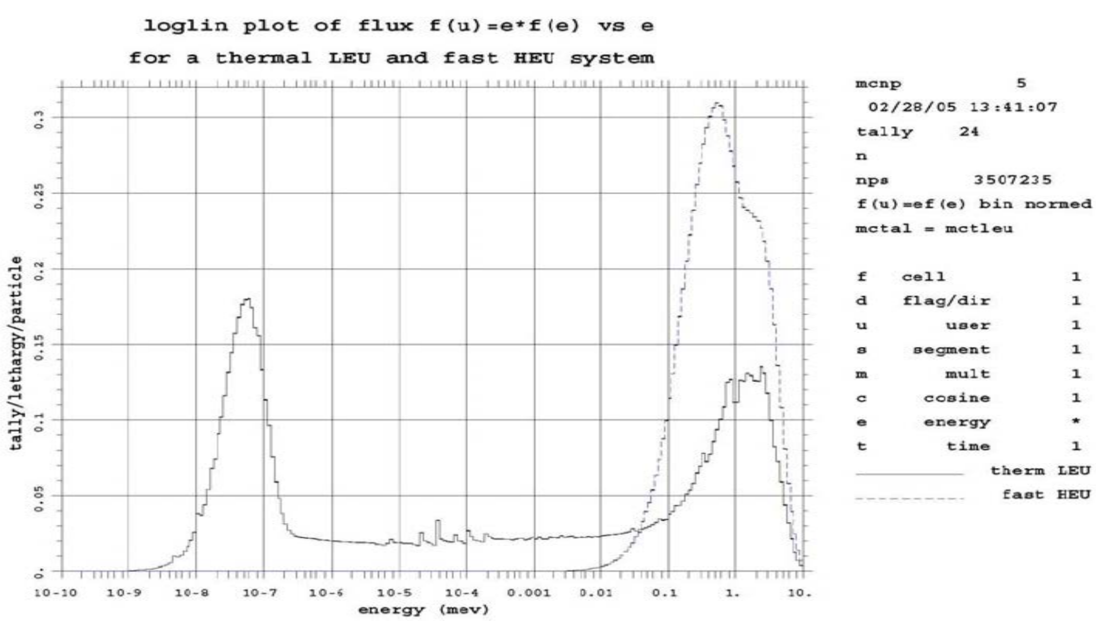


Figure 5-20. A LOGLIN plot of the lethargy-normed flux $F_i(U)$ versus E for the thermal LEU (smaller curve) and fast HEU (larger curve) systems. The area under curves is one.

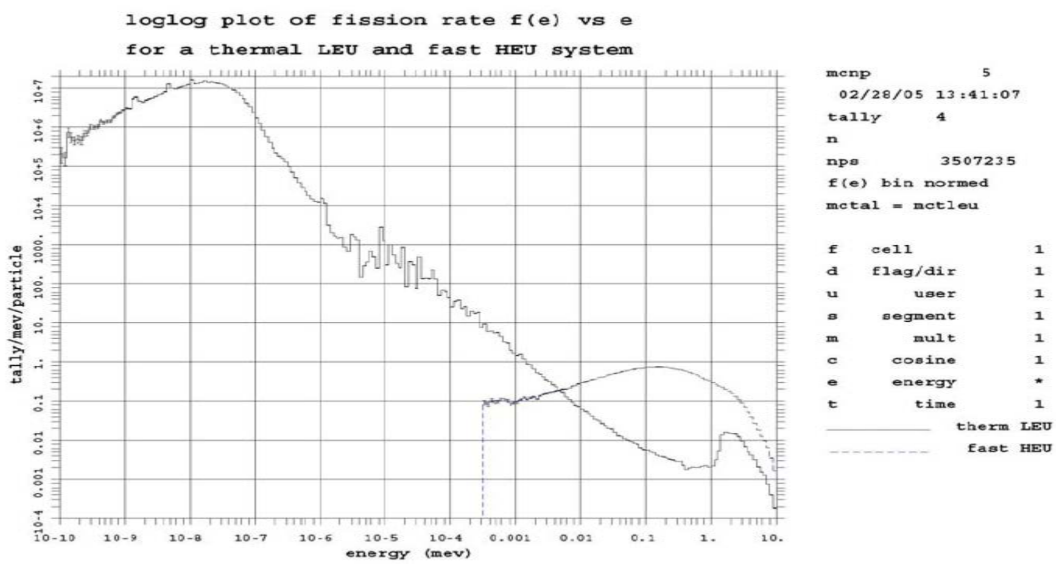


Figure 5-21. A LOGLOG plot of the fission rate $f_i(E)$ versus E for the thermal LEU (larger curve) and fast HEU (smaller curve) systems. The area under curves is one.

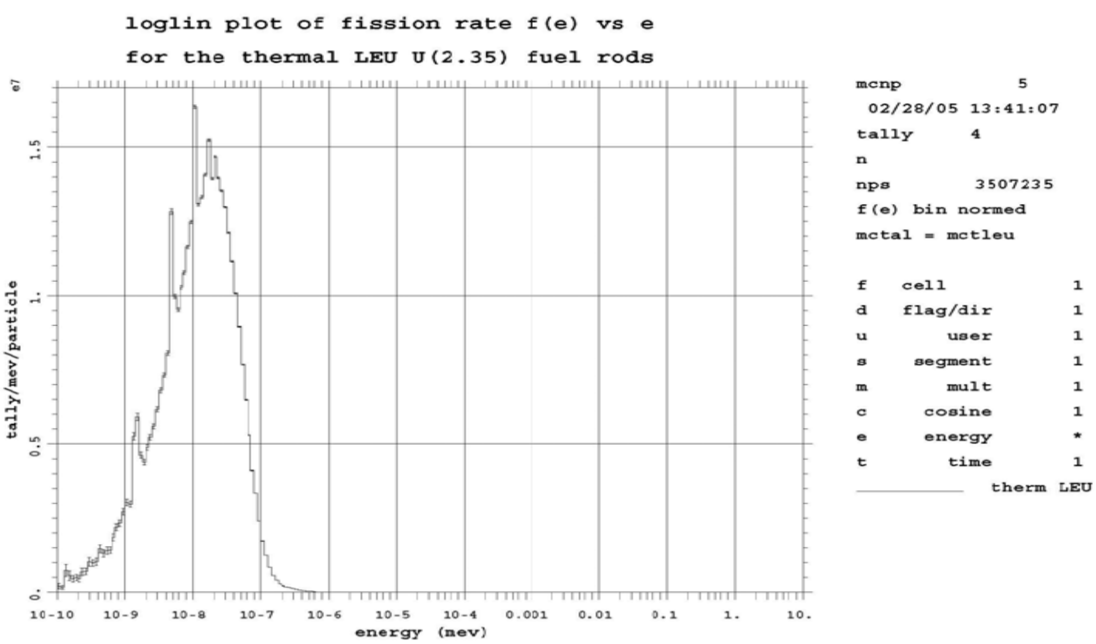


Figure 5-22. A LOGLIN plot of the fission rate $f_i(E)$ versus E for the thermal LEU. The area under curve is one.

Figure 5-22 shows a `LOGLIN` plot of the $f_i(E)$'s versus E for just the LEU system. The area under this curve representation of the LEU system also *does not* visually agree with the results in Table 5-6: there is no curve area above 6×10^{-7} MeV (0.6 eV). This conclusion about incorrect visual areas is not surprising since the $F(U)$ and $f(E)$ shapes differ so markedly for the first two simple examples. Figure 5-22 is *not* a VAA plot.

Figure 5-23 shows a `LOGLIN` VAA plot of the fission rate $F_i(U)$'s versus E for both systems. The area beneath both curves is one. Now the fission rate percentages occurring in each energy range become clear and visually match the results in Table 5-6. The `LOGLIN` lethargy-normalized plot in Figure 5-23 visually conveys much more information about the fission rate characteristics as a function of energy than the plot of the $f_i(E)$'s in Figures 5-21 and 5-22.

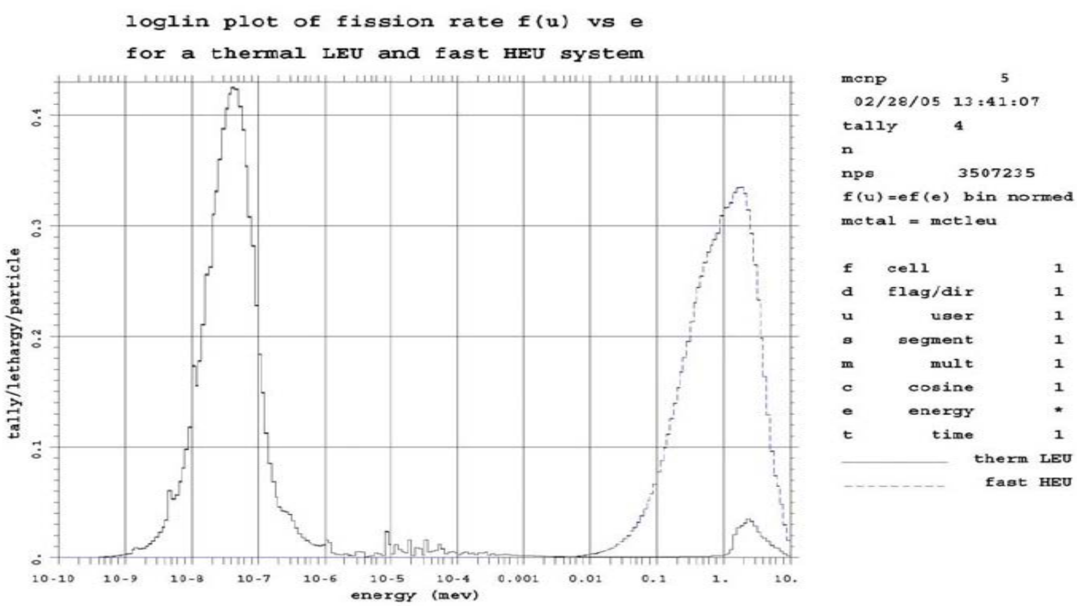


Figure 5-23. A LOGLIN plot of the fission rate f_i*(E)* versus E for the thermal LEU (left curve) and fast HEU (right curve) systems. The area under curves is one.

Comparing the LEU $f_i(E)$'s in Figure 5-22 with the LEU $F_i(U)$'s in Figure 5-23 shows that the $f_i(E)$ thermal fission rate peak in Figure 5-22 is skewed toward the lower energies. This shift is caused by the ever-increasing $1/\Delta E_i$ for decreasing energies. The visual area representation of the LEU tally is correct for $F_i(U)$ in Figure 5-23 and incorrect for $f_i(E)$ in Figure 5-22.

Figure 5-24 shows a `LOGLOG` plot of the fission rate $F_i(U)$'s versus E. Even though the visual area under this curve is misrepresented by the log ordinate, the behavior of the smaller $F_i(U)$ values versus E becomes clearer.

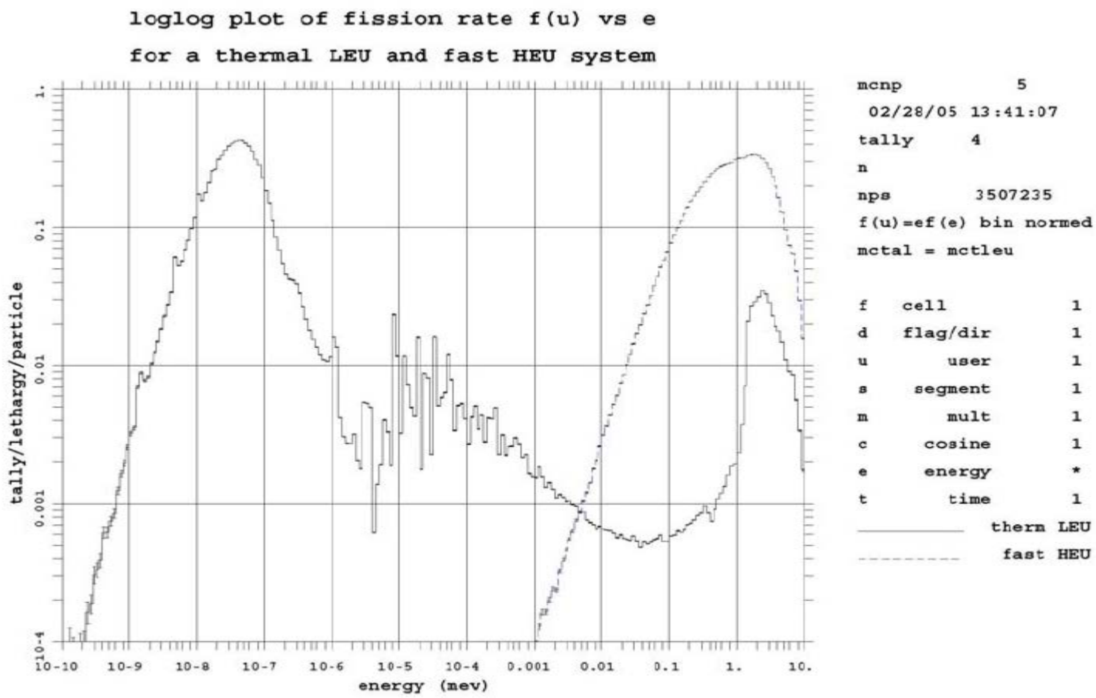


Figure 5-24. A LOGLOG plot of the fission rate $F_i(E)$ versus E for the thermal LEU (left curve) and fast HEU (right curve) systems. The area under curves is one.

5.5.9 Summary of Energy-Normalized and Lethargy-Normalized MCNP6 Tally Plots

Visually Accurate Area (VAA) plots allow an accurate visual assessment of the contributions made to a tally by various ranges. For a `LINLIN` plot, the energy-normalized $f_i(E)$'s are VAA plots. For a `LOGLIN` plot, the `LETHARGY` command produces lethargy-normalized $F_i(U)$'s that are VAA plots. All other plots, which may provide useful information about the tally, are *not* VAA plots. The energy location in a tally bin of the statistical error bars for energy-normalized and lethargy-normalized plots is different, as shown by Eqns. (5.3) and (5.12).

VAA plots are useful tools that allow visual assessment of the characteristics of the tally by examining the area under the curve. Equal abscissa bin spacing is not required for VAA plots. The more uniform the abscissa intervals are, however, the easier the area visualization becomes; e.g., it may be hard to estimate the area for a narrow bin that is much higher than other bins. If the abscissa intervals are all the same length, then the shape of a plot is identical to a `NONORM` plot where the bin *Ti*'s themselves are plotted. The magnitude of the two curves will differ by the bin-width normalization. MCNP6 can create lethargy-normalized plots for ln(*E*) abscissas for all particle types when the `LETHARGY` plotting command is used.

The Bottom-line: Both the `LINLIN` energy-normalized and `LOGLIN` lethargy-normalized plots of energy-dependent tallies allow a direct tally contribution visualization by the area under the histogram.

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7 APPENDIX A—A SUMMARY OF MCNP6 COMMANDS

Appendix A is a summary of general information, input cards, and plot commands. It is intended to be used by intermediate to advanced users as a quick reference. A less experienced user should not expect to find Appendix A sufficient. Right justified page numbers are cross-references to pages in the MCNP6 manual where detailed information can be found (for example, 3-32 refers to Section 3 page 32). The terms "card" and "command" are used interchangeably to mean one or more lines of input. File and card names are shown in this appendix in UPPER case; however, upper, lower, or mixed case is also allowed.

Section 7.1 provides general information regarding format, file names, how to execute, etc. Sections 7.2, 7.3, and 7.4 provide information on input file commands, geometry plotting commands, and tally and cross-section plotting commands, respectively. Each of these three sections contains the following subsections:

1. alphabetical command list with a one-line description,
2. alphabetical one-line list by command function category, and
3. alphabetical command list with a very concise description of each command.

7.1 GENERAL INFORMATION, FILE NAMES, EXECUTION LINE, UNITS

7.1.1 Form of Input (INP) File: Required to Initiate & Run a Problem

See also Section 2.1.

INP Element	Type	Description / Format	Section
Message Block	Optional	`MESSAGE:` begins in column 1 followed by execution line options and files. Omit INP=. A blank line must follow a provided message block.	2.4
Title Card	Required	One line up to 128 characters long. Is the first INP file line if no message block is provided.	2.5
Cell Cards	Required		2.8
Blank Line	Required	Delimiter between cell cards and surface cards.	--
Surface Cards	Required		2.8
Blank Line	Required	Delimiter between surface cards and data cards	--
Data Cards	Required	All other cards. Most INP file commands in Section 8.2 are of this type.	2.8
Blank Line	Recommended	Terminates INP file. Anything written after last blank line will not be read as a part of the problem	--

7.1.2 Form of CONTINUE Input File: Requires a RUNPTE File

(Recap of Section 2.2.) CONTINUE and RUNTPE files are needed for continuation if the prior run finished all NPS histories or KCODE cycles. An unfinished problem requires only RUNTPE for continuation.

In a CONTINUE input file the number of histories or cycles can be increased as follows:

1. Change `NPS` to new total (not increment) number of histories.
2. Change the fourth `KCODE` card entry to new total number of cycles.
3. Change `CTME` to the number of additional minutes for the continue-run.
4. Use `NPS=–1` to reprint the results portion of the OUTP file.

The word `CONTINUE` begins in column 1 of line one followed by data cards on subsequent lines. The following data cards are allowed in a continue-run after the `CONTINUE` line:

`CTME`, `DBCN`, `DD`, `EMBED`, `FQ`, `IDUM`, `KCODE`, `LOST`, `FMESH`, `MESH`, `MPLOT`, `NPS`, `PRDMP`, `PRINT`, `RAND`, `RDUM`, `STOP`, `TALNP`, `ZA`, `ZB`, `ZC`, and `ZD`.

A blank line terminator is recommended. Anything else can be put after the blank line terminator.

7.1.3 MCNP6 File Names and Contents

(Recap of Table 1-2 of Section 1.4.1.) File path names must be ≤256 characters or ≤255 characters with the `NAME` option. All files can be renamed on the execute line or in the MESSAGE block except WXXA. Only enough of the default file name needs to be typed so that it is unique:

```
MCNP6 i=infile o=outfile mc=mcfile wwi=wwifile
```

MCNP6 Default File Name	File Description
COM	Plotter command input file name.
COMOUT	Plotter command output file name.
DUMN1, DUMN2	Dummy file names 1 and 2. Used with `FILE`, the file creation card (See Section 3.3.7.3.6)
HISTP	History tape file.
INP	Original problem input file (cannot be renamed in the message block).
KSENTAL	ASCII KCODE sensitivity output file.
LINKIN	LNK3DNT file name to be input into MCNP6. Used with embedded structures.

MCNP6 Default File Name	File Description
LINKOUT	LNK3DNT file name to be output from MCNP6. Used with embedded structures.
MCTAL	ASCII tally results file (Section 5.3.4).
MDATA	Binary `TMESH` mesh tally results file for `TMESH` mesh tallies.
MESHTAL	ASCII `FMESH` mesh tally results file for `FMESH` mesh tallies.
NAME	User-supplied input file name that generates other files named with an appended letter.
OUTP	Output file name of problem results.
PARTINP	PARTISN input file name for MCNP6 to output.
PLOTM	Graphics postscript file name.
PTRAC	Particle tracks file name.
RSSA	Binary surface source read file name.
RUNTPE	Binary problem start/restart data.
SRCTP	Binary KCODE source distribution.
WSSA	Binary surface source write file name.
WWINP	Weight-window input file name.
WWONE	Single energy- or time-independent weight-window output.
WWOUT	Output file name from the weight-window generator.
WXXA	Binary surface source scratch file name (cannot be renamed).
XSDIR	Cross-section tables directory. Note: Although name reassignment of the directory file is accomplished using the `XSDIR=` option on the execution line, the default name for the XSDIR file in MCNP 6.2) is `xsdir_mcnp6.2`.

- The `NAME` option provides a short-hand method to name the MCNP6-generated files by assigning file names in a predictable way.

For example, the execution line designation

```
NAME=input
```

appends a predictable letter to the end of the file name "`input`" to create file names for the following generated files.

```
OUTP=inputo RUNTPE=inputr SRCTP=inputs MCTAL=inputm PTRAC=inputp
```

The file name "`input`" must be ≤255 characters long,

If one of the suffixes is not available (e.g., `inputo` already exists), the code will exit with an error. Unlike default naming where the suffix letter can change (e.g., `outp` -> `outr` -> `outs`…), using the `NAME` option requires the specific suffixes be available.

- Unique abbreviations (e.g., `o` for `outp`) also may be used on the execution line to reassign default file names:

```
i=input o=outtest r=runtest
i=test n=test.
```

The first example reads from the file "`test`" and creates `OUTP=outtest` and `RUNTPE=runtest`, defaulting any remaining filenames. The second example reads from file "`test`" and uses the `NAME` prefix to create `OUTP=test.o`, `RUNTPE=test.r`, etc.

7.1.4 MCNP6 Execution Line Options and Useful Combinations

(See Table 1-2 of Section 1.4.1.) To run an executable named MCNP6, type the command line: `MCNP6` *`options files`* . The execution line options follow. Single-character options can be run together (e.g., IP). Default file names are listed in Section 7.1.3 above.

Execution Line Options	Description of Option
`I`	Read the problem specified in the INP input file and check for input errors.
`X`	Get the cross-section tables required by the problem.
`R`	Execute the problem, i.e., transport particles.
`P`	Initiate the geometry plotter and plot the problem geometry provided in an INP or RUNTPE file.
`Z`	Initiate the tally/cross-section plotter and plot tally results from existing RUNTPE or MCTAL files or, alternatively, plot cross sections from designated INP file (IXZ).
`M`	Execute module to create LNK3DNT format geometry file.
`IXR`	Read and check the input file, get cross sections, and transport particles. {DEFAULT}
`IP`	Read and check the input file and plot the geometry.
`IX`	Read the input file and material cross sections and check for errors.
`IXZ`	Read and check the input file, read the cross sections, and plot the cross sections.
`IPXRZ`	Execute all options. (usually not practical)
`C` *m*	Perform a continue-run starting with dump *m*. (If the dump number *m* is omitted, use the last dump on the `RUNTPE`)
`CN`	Perform a continue-run, but write each dump immediately after fixed data on RUNTPE.
`DBUG` *n*	Write one-line debug information to the output file every *n* histories. (See the second entry on the `DBCN` card, `DBCN(2)`). Note that 8-byte integer values are allowed for *n*.
`DEV-TEST`	Delete execution-dependent quantities from files for comparison to test templates. (See also the 3rd entry on the `PRDMP` card.
`FATAL`	Run the problem even if fatal input errors are found. (This option is *not* recommended.)
`NOTEK`	Suppress terminal plotting and send plots to graphics metafile PLOTM.
`PRINT`	Create the full output file. (Same as if as a blank `PRINT` card appears in the input file.)

Execution Line Options	Description of Option
TASKS *m*	Use shared-memory (OpenMP) parallelism (threads) This keyword may be used in conjunction with MPI on a hybrid-parallel system. *m* = number of threads (per MPI process) Many options, including DBCN(2,3,4), SSW, and PTRAC, are incompatible with tasks >1 and will result in a fatal error. The incompatibility is often due to loss of order in output files. The examples mentioned above are all of this sort (output sequencing). For such cases, using the FATAL command-line option will allow the code to run threaded, but will provide outputs that do not match sequential execution.
BALANCE	Provides load balancing when used with MPI. (Not available with KCODE runs.)
EOL	Add to execute line after all other MCNP6 keywords to mark the end of the MCNP6 command line, separating it from directives added by MPICH. Required if the MPICH implementation of MPI is used.

7.1.5 Execution Lines for Various Type of Problems

(Recap of Section 1.4.1.) To run an executable named MCNP6, type:

MCNP6 *options files*

Examples of three different MCNP6 execution lines for an initial run of a problem follow:

MCNP6

All options and filenames defaulted. Appropriate when the input file exists and is named INP. Output files (e.g., OUTP, RUNTPE) will be created with default file names. On subsequent executions, names will be modified by changing the last letter of the default name (e.g., outp → outq → outr…) until an available name is created or all options have been tried.

MCNP6 INP=test1 OUTP=testout1 RUNTPE=testrun1

The equal sign assigns user-defined file names to replace the default file names. The files for which names are provided must be available for read or write with the exact names provided

MCNP6 n=test1

The n notation invokes the NAME option. This execute line will cause the default output files to be assigned the following file names. All necessary filenames (depending on execution options) must be available for reading and/or writing.

```
INP=test1                   OUTP=test1o        RUNTPE=test1r
MCTAL=test1m                SRCTP=test1s       TRAC=test1p
WWOUT=test1e                WWONE=test11       MESHTAL=test1msht
MDATA=test1d                HISTP=test1h       PARTINP=test1partinp
LINKIN=test1partlinkin      LINKOUT=test1linkout
```

Many command line entries can be placed, instead, in the input file within the MESSAGE BLOCK. This approach can be used to simplify the command line for problem setups with complicated options.

Continuation Runs: To continue (restart) an MCNP6 run, type:

```
mcnp6 c run=file inp=continue_file
mcnp6 cn run=file inp=continue_file
```

`mcnp6 c run=file inp=continue_file` to append to the RUNTPE file
`mcnp6 cn run=file inp=continue_file` to begin writing after the RUNTPE fixed data

If the initial problem did not complete, a continue input file is not needed. A problem can be continued as many times as desired (see PRDMP card to control the number of dumps stored on the RUNTPE).

Geometry Plotting: To plot problem geometry, type:

`mcnp6 ip inp=`*`filename`*` ...` or
`mcnp6 p runtpe=`*`filename`*` ...`

Cross Section Plotting: To plot problem cross-sections, type:

`mcnp6 ixz inp=`*`filename`*` ...`

Type "XS?" for cross-section plotting printer at the command prompt.

Tally Plotting: To plot problem tally results, type:

`mcnp6 z runtpe=`*`filename`*` ...` or
`mcnp6 z mctal=`*`mctal_filename`*` ...`

At the plotter command prompt, type "?" for a list of available plot commands. Typing "HELP <*command*>" will provide a description of a specific command.

7.1.6 MCNP6 Physical Units and Tally Units

(See Section 2.)

Length = centimeters (cm)
Area = cm^2
Volume = cm^3
Mass = grams (g)
Energy = MeV
Time = shakes (10^{-8} s)

Temperature = MeV (kT: see TMP card)
Atom Density = atoms/barn-cm
Heating Numbers = MeV/collision
Mass Density = g/cm^3
Cross Sections = barn (10^{-24} cm^2)

Source weight (see SDEF card, WGT entry) are in particles (pulse) or particles/unit time(steady state).

Tally units: All tallies below have additional units of “per unit source time” for steady state simulations. Units can be modified by tally multipliers. (See Section 3.3.5.7)

Type	Description	Units
F1	current tally = particle weight (WGT)	particles
F2	surface flux tally = WGT / (cosine of surface crossing angle) / area	particles/cm^2
F4	volume flux (path length) tally = WGT ∗ (track length) / (cell volume)	particles/cm^2

Type	Description	Units
F5, FIP, FIC, FIP	point detector(s) = WGT ∗ exp(-mean free paths) ∗ p(u) / (2∗π∗radius^2)	particles/cm^2
F6	heating tally = (F4 tally)∗(total macro xsec) ∗ (heating #) / (gram density)	MeV/gram
F7	fission heating = (F4 tally)∗(total macro fission xsec)∗Q/(gram density)	MeV/gram
F8	pulse-height tally = collective history weight deposited in the detector	pulses
Note: *F converts weight to energy*weight or other energy-deposition tally units		

7.1.7 MCNP6 Interrupts

You can send a query, request to stop or request to abort to MCNP6 during execution with the following keyboard interrupts. (See Section 1.4.2.) Press <ENTER> after each entry:

`<ctrl c>`	problem status (run mode gives time, current history, and collisions)
`<ctrl c>s`	problem status (run mode gives time, current history, and collisions)
`<ctrl c>m`	make interactive tally plots (enter END or RETURN to return to calculation)
`<ctrl c>q`	quit and terminate gracefully after current history
`<ctrl c>k`	kill immediately (all files created for the problem are incomplete)

Note that these interrupts do not work with MPI-enabled compilations. This is because MPI catches the interrupts and (usually) aborts ungracefully upon any `<ctrl c>`. Interrupts may also not work as specified on non-Linux operating systems.

7.1.8 Example of an MCNP6 Fixed-Source INP File

Steps to Run a Fixed-Source MCNP6 Problem	Section
Fixed source requires: SDEF, SSR (with RSSA file), or user-defined source subroutine.	3.3.4
Always plot the geometry and inspect OUTP file cell volumes and masses.	1.5.1
Use tips in manual for correct and efficient problems.	1.5
Inspect ten statistical check results for tally fluctuation chart bin (see TF*n* card).	3.3.5.19
Form valid statistical confidence intervals for result precision using statistical checks.	3.3.5

Example: The following is an INP file for a Cf-252 SDEF fixed point source in a water cylinder. This example has no MESSAGE block:

```
point Cf-252 fission source in a cylinder of water (required title card)
c begin cell cards for fixed source sample problem
1 1 -1. -1 -2 3             $ cylinder of water
2 0     1:2:-3              $ all space outside the cylinder
c end cell cards; next line is required blank line delimiter

c begin surface specifications after blank line delimiter
1 cy  20.                   $ cylinder about the y axis
2 py  10.                   $ top plane of water cylinder
3 py -10.                   $ bottom plane of water cylinder
```

```
c rcc 0 –10 0 0 20 0 20      $ equivalent macrobody definition commented out
c end surface cards; next line is required blank line delimiter

c begin data section after blank line delimiter
mode n p                     $ coupled neutron-photon problem
sdef erg=d1 pos=0 0 0        $ cf-252 point source at origin; pos=0 0 0 is default
sp1 -3 1.025 2.926           $ use a watt fission spectrum for cf-252
imp:n,p 1 0                  $ set both neutron and photon importances at same time
m1 1001 .66667 8016 .33333   $ define h2o using h and o atom fractions
mt1 lwtr   $ use light water S(a,b) thermal neutron treatment
f1:n  1 2 3 (1 2 3)  $ neutron current tally over each surface and total
f11:p 1 2 3 T                $ photon current tally over each surface and total
f4:n  1                      $ tally the average neutron flux in water cylinder cell
f14:p 1                      $ tally the average photon flux in water cylinder cell
nps 40000                    $ terminate after 40000 neutron histories
print                        $ print everything about the calculation
c end data section; optional blank line terminator follows
```

Let say this input file is named "cf252". To run the problem, you could use one of the following forms:

```
mcnp6 inp=cf252
mcnp6 i=cf252
mcnp6 n=cf252.
```

The first two forms will create default-named output files (OUTP, RUNTPE). The third form will generate output files with names such as cf252.o, cf252.r, etc.

7.1.9 Example of a k_{eff} Eigenvalue INP File

Steps to Run a Eigenvalue (KCODE) MCNP6 Problem	**Section**
Requires a KCODE card to define problem parameters.	3.3.4.9
Requires KSRC card or SDEF card or SRCTP file for the initial spatial fission source.	3.3.4.9 3.3.4.1
KOPTS card can be used for point-kinetics parameters.	3.3.4.11
Use enough settle cycles to reach fundamental spatial mode. (See statistical checks, plots.)	--
Always plot the geometry and inspect OUTP file cell volumes and masses.	--
Use tips in manual for correct and efficient problems.	1.5
Inspect cell sampling of fission, k_{eff} data normality, batched data, and printed k_{eff} plots.	--
Form valid statistical confidence intervals for precision of the k_{eff} result.	--
A continue-run requires only the RUNTPE file. (No SRCTP file is required.)	2.2

For help with KCODE, see Los Alamos National Laboratory report, LA-UR-09-00380, "Criticality Calculations with MCNP5: A Primer" by Roger Brewer (2009).

Example: The following INP file determines the criticality, k_{eff}, for a highly enriched uranium sphere (GODIVA). This example has no MESSAGE block:

```
godiva: skip 30, run a total of 130 keff cycles with 1000 neutrons per cycle
1 1 -18.74 -1 imp:n=1       $ enriched uranium sphere (godiva)
2 0         1 imp:n=0       $ zero importance
c end cell cards; next line is required blank line delimiter

1 so 8.741                  $ radius of sphere
c end surface cards; next line is required blank line delimiter

kcode 1000 1.0 30 130       $ kcode defines a criticality calculation
ksrc  0 0 0                 $ initial keff spatial distribution is one point at origin
m1 92235 -93.71 92238 -5.27 92234 -1.02   $ use weight fractions and default xsecs
c tally the track length keff
f4:n  1                     $ track length tally in cell 1
fc4 cell 1 flux tally is converted into track length keff tally
fm4  -1. 1 -6 -7            $ multiply by atom density of material 1 times xs times nu
sd4   1.                    $ set tally divisor to 1 so tally is volume integrated
e4 .001 .01 .1 .5 1 18i 20  $ create energy bins (MeV) for track length keff tally
print                       $ print all possible tables
```

This input is assumed to be saved in a file named godiva. To run the problem, type:

```
mcnp6 i=godiva name=godiva.
```

To continue the above problem for another 100 cycles (for a total of 230 cycles) and add automatic plotting, a continuation input file, named here "contgodiva", is needed and would contain the following three lines (four counting the final blank line):

```
continue                          $ must starting in column 1
kcode  1000 1.0 30 230            $ changes the final cycle count
mplot freq 10 kcode 16 scales 2 $ adds auto plotting of the three combined keff tally
```

To continue the calculation, type:

```
mcnp6 c i=contgodiva runtpe=godiva.r.
```

7.2 INPUT (INP) FILE COMMANDS

7.2.1 Input Command Formats

(See Section 2.3 above for more information on card format.) Gennerally no distinction is made between upper and lower case: MCNP6 input is case insensitive, except for the source comments and tally comments(SC and FC cards).

Completely blank lines are reserved as delimiters between major input sections. However, whole-line comments are permitted. Such lines must start with "`c `".

7.2.1.1 HORIZONTAL 128-CHARACTER INPUT FORMAT

(See Section 2.8.1.) Card names and cell and surface numbers begin in columns 1–5 followed by at least one space. Remaining columns through 128 are for free-field data separated by at least one space. Cards can be continued in two ways:

- Columns 1 through 5 of the next card are blank.
- An ampersand (&) at the end of the present card; With this format, the continuation card can start anywhere.

The first form is not allowed for the general comment "`c`" card. Neither form is allowed on `C`, `FC`*n*, `SC`*n*, all of which are comment cards: general comment, tally comment, source comment, respectively.

Tabs are converted to the appropriate number of spaces. Unprintable characters (including ^M characters at the ends of lines in files created in DOS format) are converted to blanks.

Five shorthand features aid with input card preparation (See Section 2.8.1.):

n`R`	repeat the immediately preceding entry on card *n* times (`2 5R` is equivalent to `2 2 2 2 2 2`)
n`I`	insert *n* linear interpolates between preceding and following numbers (`1 2I 4` is equivalent to `1 2 3 4`)
n`ILOG`	insert *n* logarithmically spaced interpolates between preceding and following numbers (`.01 2ilog 10.` is equivalent to `.01 .1 1. 10.`). Numbers must be non-zero and have the same sign.
n`M`	multiply the previous entry by *n* (`1 3m 3m 3m` is equivalent to `1 3 9 27`)
n`J`	jump over *n* items on the card and use the default values for the these *n* entries

Examples of some allowed combinations: `1 3M 2r` (`1 3 3 3`), `1 3M I 5` (`1 3 4 5`), and `1 R 6M` (`1 1 6`)

Examples of some illegal combinations: `3J 4R`, `1 4I 3M`, and `1 4I J`

7.2.1.2 VERTICAL (COLUMN) INPUT FORMAT FOR CELL PARAMETERS AND SOURCE DISTRIBUTIONS

(See Section 2.8.2.) Column input can be useful for entering related values in a form that is easy to comprehend. Cell, Surface and Source data are three common examples where columnar input can be useful.

A column input block starts with a "#" sign (somewhere in columns 1 to 5) followed by a list of MCNP6 card names. Cell names (numbers), if any, begin in columns 1 to 5 followed by values to column 128. The # card syntax can be used more than once in an input deck.

Example**:** Here are a set of DE4, DF4 cards defined in horizontal and columnar forms:

Horizontal:
```
de4   1E-6   1
df4   1E-4   20
```

Column:
```
#   de4   df4
    1E-6  1
    1E-4  20
```

When a distribution such as this has many values requiring multiple lines of entry, the column input helps keep things aligned.

7.2.1.3 PARTICLE DESIGNATORS

(See Section 2.9.) Some commands require a particle designator *<pl>*, where *<pl>* can be any particle symbol listed in the table below. The designator is a colon (`:`) followed by a particle symbol after the command name. Each particle type has such a single-character symbol.

White space (at least one blank) must follow the particle symbol(s) before subsequent data entries. Multiple particle types are entered as follows: `NPE` or `N,P,E` (but not separated by spaces). The only tallies that can have multiple particle types are `F6:N,P` and `F8:P,E`.

MCNP6 Particles								
IPT	**Particle**	**Symbol**	**IPT**	**Particle**	**Symbol**	**IPT**	**Particle**	**Symbol**
1	neutron (n)	`n`	14	negative cascade; negative xi baryon⁻ (Ξ^-)	`y`	27	anti negative sigma baryon ($\bar{\Sigma}^-$)	`~`
2	photon (γ)	`p`	15	omega baryon (Ω^-)	`o`	28	anti cascade; anti neutral xi baryon ($\bar{\Xi}^0$)	`c`
3	electron (e^-)	`e`	16	positive (μ^+)	`!`	29	positive cascade; positive xi baryon (Ξ^+)	`W`
4	negative muon (μ^-)	`|`	17	anti electron neutrino ($\bar{\nu}_e$)	`<`	30	anti omega ($\bar{\Omega}^-$)	`@`
5	anti neutron ($\bar{n}$)	`q`	18	anti muon neutrino ($\bar{\nu}_m$)	`>`	31	deuteron (d)	`D`
6	electron neutrino (ν_e)	`u`	19	anti proton ($\bar{p}$)	`g`	32	triton (t)	`T`
7	muon neutrino (ν_m)	`v`	20	positive pion (π^+)	`/`	33	hellion (^3He)	`S`
8	positron (e^+)	`f`	21	neutral pion (π^0)	`z`	34	alpha particle (α)	`A`

MCNP6 Particles								
IPT	**Particle**	**Symbol**	**IPT**	**Particle**	**Symbol**	**IPT**	**Particle**	**Symbol**
9	proton (p^+)	`H`	22	positive kaon (K^+)	`k`	35	negative pion (π^-)	`*`
10	lambda baryon (Λ^0)	`L`	23	kaon, short (K^0_S)	`%`	36	negative kaon (K^-)	`?`
11	positive sigma baryon (Σ^+)	`+`	24	kaon, long (K^0_L)	`^`	37	heavy ions‡	`#`
12	negative sigma baryon (Σ^-)	`-`	25	anti lambda baryon ($\overline{\Lambda}^0$)	`b`			
13	cascade; xi baryon (Ξ^0)	`X`	26	anti positive sigma baryon ($\overline{\Sigma}^+$)	`_`			

‡ The "#" symbol represents all possible heavy ion types, in other words, any ion that is not one of the four light ions available in MCNP6. A list of heavy ions available for transport is provided in Appendix I.

Commands requiring a particle designator (one or more) include the following:

CUT	DXC*m*	DXT	ELPT	EMBEE	ESPLT	EXT
F*n*	F*n*A	FCL	FIC*n*	FIP*n*	FIR*n*	FMESH*n*
IMP	MX	PERT*m*	PHYS	SPABI	TSPLT	UNC
WWE	WWGE	WWGT	WWN*i*	WWP	WWT	

7.2.2 Input Commands (Alphabetical)

The table of input commands that follows uses the following symbolism:

- *n* indicates a number is required
- *m* indicates a number for cards relating to materials is required
- `:`<*pl*> means a particle type indicator is required
- I8 means that some entries on this card can be 8-byte integers. The characters “I8” should not be present in the input deck.

Card Name	Description	[max # of entries]	Section
ACT	Activation control card to specify delayed-particle options		3.3.3.3
& (*ampersand*)	Preceded by at least one space, an ampersand appearing at the end of a line signals that the following line contains a continuation of data.		2.3
AREA	Whole surface area specifications	# of surfaces	3.3.1.2
AWTAB	User-specified atomic weight in pairs: “ZAID atomic-weight-ratio”		3.3.2.8
BFLCL	Assigns magnetic field numbers to cells		3.3.3.11.2

Card Name	Description	[max # of entries]	Section
BFLD*n*	Defines the properties of magnetic field *n*		3.3.3.11.2
BBREM	Bias for high-energy bremsstrahlung photons		3.3.6.14
blank	Blank lines separate MESSAGE, cell, surface, and data blocks		2.1
BURN	Define parameters for material depletion/burnup in eigenvalue calculations.		3.3.4.13
C	INP file comment card (no continuation is allowed)		2.6
C*n*	Cosine bins for a type 1 ally		3.3.5.5
cell cards	Define geometry cells with materials (M*m* card) or void (0)		2.8
CF*n*	Tally contributions from flagged cells separately for tally	# of cells	3.3.5.12
CM*n*	Multipliers for cosine bins of tally n for type 1 tallies		3.3.5.11
CMESH*i*:<*pl*>	TMESH control card indicating a cylindrical mesh tally and the mesh tally type		3.3.5.24.1
CONTINUE	First card in file for continue-run (C or CN on execute line)		2.2
CORA*i*	TMESH boundaries for the first coordinate direction		3.3.5.24
CORB*i*	TMESH boundaries for the second coordinate direction		3.3.5.24
CORC*i*	TMESH boundaries for the third coordinate direction		3.3.5.24
COSY	Assigns COSY map numbers to individual cells		3.3.3.11.1
COSYP	Defines the magnetic field parameters for the COSY maps		3.3.3.11.1
CTME	Computer time limit in minutes for the problem	1	3.3.7.1.2
CUT:<*pl*>	Time, energy, and implicit capture/weight cutoffs	5	3.3.3.4.1
data cards	Define particles, physics, source, materials, variance reduction, tallies, ...		2.8
DAWWG	Deterministic automated weight-window generator for structured embedded meshes		3.3.1.6.1
DBCN[I8]	Debug information card	100	3.3.7.3.2
DD*n*	Detector and DXTRAN diagnostics and contribution card		3.3.6.11
DE*n*	Dose energy card (use with the DF*n* card)		3.3.5.8
DF*n*	Dose function card (use with the DE*n* card)		3.3.5.8
DM	ZAID aliases for deterministic materials		3.3.1.6.1
$ *(dollar sign)*	Comment at end of input line; appears only in echo of input file in OUTP		2.3
DRXS	Discrete reaction neutron cross-section card		3.3.2.12
DS*n*	Dependent source distribution card		3.3.4.5
DXC*n*:<*pl*>	DXTRAN contribution for DXTRAN sphere *n*	# of cells	3.3.6.13
DXT:<*pl*>	Defines DXTRAN spheres	53	3.3.6.10
E*n*	Upper bounds of energy bins (MeV) for tally *n*		3.3.5.3

Card Name	Description	[max # of entries]	Section
ELPT:<*pl*>	Cell energy cutoff (greater of ELPT:<*pl*> or CUT:<*pl*> applies)	# of cells	3.3.3.4.2
EM*n*	Multipliers for energy bins of tally *n* on the E*n* card		3.3.5.9
FIELD	Allows modeling of planetary gravitational effects on neutrons		3.3.3.12
EMBEB	Embedded elemental edit energy-bin boundaries card		3.3.1.6.2
EMBED	Embedded geometry specification card		3.3.1.6.2
EMBEE	Embedded elemental edits control card		3.3.1.6.2
EMBEM	Embedded elemental edit energy-bin multipliers card		3.3.1.6.2
EMBTB	Embedded elemental edit time-bin boundaries card		3.3.1.6.2
EMBTM	Embedded elemental edit time-bin multipliers card		3.3.1.6.2
ERGSH*i*	Provides energy or time limits for information to be stored to TMESH mesh tally	2	3.3.5.24.1
ESPLT:<*pl*>	Energy splitting and Russian roulette card	40	3.3.6.5
EXT:<*pl*>	Exponential transform (use weight window; FCL not allowed)	# of cells	3.3.6.7
F*n*:<*pl*>	Create cell, surface, or point tally *n* (*F for energy)		3.3.5.1
F*n*A:<*pl*>	Symmetric ring detector flux tally, where A=X, Y, or Z axis		3.3.5.1.2
FC*n*	Comment printed in OUTP for tally *n* (& continuation not allowed)		3.3.5.2
FCL:<*pl*>	Force collisions by cell	# of cells	3.3.6.9
FIC*n*:<*pl*>	Flux image on a cylindrical image grid	10	3.3.5.1.2
FILES	User file creation card	30	3.3.7.3.7
FILL	Fill cell or lattice elements with universes (*FILL= rotation matrix in degrees)	# of cells	3.3.1.5.3
FIP*n*:<*pl*>	Flux image through a pinhole to a planar rectangular image grid	10	3.3.5.1.2
FIR*n*:<*pl*>	Flux image radiograph on a planar rectangular image grid	10	3.3.5.1.2
FMn	Tally multiplier card for tally *n*		3.3.5.7
FMESH*n*:<*pl*>	Create an FMESH mesh track length tally		3.3.5.25
FMULT	Enables users to override or add additional fission multiplicity data.		3.3.3.8
FQ*n*	Print hierarchy card for ordering of OUTP tallies	8	3.3.5.6
FS*n*	Subdivide cell of surface into segments for tallying	# surfaces	3.3.5.14
FT*n*	Special treatments for tally *n*		3.3.5.18
FU*n*	User-defined TALLYX tally input; required by some FT*n* options		3.3.5.16
HISTP	Create LAHET-compatible files		3.3.7.2.6
HSRC	Mesh for Shannon entropy of fission source distribution	9	3.3.4.12
IDUM	Integer array available for user-modified code (see RDUM)	2000	3.3.7.3.4

Card Name	Description	[max # of entries]	Section
`IMP:<pl>`	Cell importances; required unless weight windows used	# of cells	3.3.6.1
`KCODE`	Define a criticality eigenvalue (k_{eff}) problem	8	3.3.4.9
`KOPTS`	Criticality calculation options card for point kinetics parameters		3.3.4.11
`KPERT`	Calculates the change in reactivity from a perturbation to a KCODE problem		3.3.5.22
`KSEN`	Specify cross-section sensitivity profile for KCODE problem		3.3.5.23
`KSRC`	Starting source point locations for KCODE problem		3.3.4.10
`LAT`	Defines a cell as a hexahedral (`LAT=1`) or hexagonal prism (`LAT=2`) lattice	# of cells	3.3.1.5.2
`LCA`	Choose intranuclear cascade/pre-equilibrium model	11	3.3.3.7.2
`LCB`	Choose particle interaction model	8	3.3.3.7.3
`LCC`	Control parameters for INCL4 and ABLA	10	3.3.3.7.4
`LEA`	Control parameters for Bertini, ISABEL, and INCL	8	3.3.3.7.5
`LEB`	Control parameters for HETC implementation	4	3.3.3.7.6
`LOST`	Lost particle abort/debug print control card	2	3.3.7.3.3
`M`*m*	Material definition card for cells containing material *m*		3.3.2.1
macrobody	Solid geometry primitives for enclosed regions of space (see surfaces)		3.2.2.4
`MESH`	Superimposed importance mesh for mesh-based weight-window generator		3.3.6.4.4
`MESSAGE`	Optional first line of INP file containing execution line		2.4
`MGOPT`	Multigroup forward/adjoint transport option	7	3.3.2.11
`MODE`	Definition of particles to be transported in the problem	37	3.3.3.1
`MPHYS`	Model physics card to allow the use of physics models in the calculation		3.3.3.7.1
`MPLOT`^{I8}	Produce plots of tallies while the problem is running		3.3.7.2.5
`MSHMF`*j*	Provides energy-response function pairs for `TMESH` mesh tallies		3.3.5.24.1
`MT`*m*	$S(\alpha,\beta)$ thermal neutron treatment for material *m*		3.3.2.2
`MX`	Enables mixing and matching of physics models and data tables		3.3.2.3
`NONU`	Treat fission as a capture as a function of cell	# of cells	3.3.2.7
`NOTRN`	Do only direct (unscattered) type 5 detector tallies from `N` or `P` source	0	3.3.5.20
`NPS`^{I8}	Number of particles to run from the fixed source	2	3.3.7.1.1
`#`	Vertical column input format; also complement geometry operator; also heavy ions particle symbol		
`OTFDB`	On-the-fly Doppler broadening		3.3.2.5
`PD`*n*	Detector contribution control by cell for tally *n*	# of cells	3.3.6.12

Card Name	Description	[max # of entries]	Section
PERT*n*:<*pl*>	Perturbation of material density, composition, or reaction cross-section data		3.3.5.21
PHYS:<*pl*>	Control physics used for particle transport	15	3.3.3.2
PIKMT	Photon-production bias card for coupled neutron-photon problems		3.3.6.15
PRDMP[I8]	Print, dump, TFC, and rendezvous control	5	3.3.7.2.3
PRINT	Control the printing of optional tables to the OUTP file		3.3.7.2.1
PTRAC[I8]	Generate a file named PTRAC of user-filtered particle events		3.3.7.2.4
PWT	Control neutron-induced photons produced by cell; MODE N,P or NPE	# of cells	3.3.6.17
RAND[I8]	Selection and setting of pseudorandom number generator	12	3.3.7.3.1
RDUM	Real array available to the user (see IDUM)	2000	3.3.7.3.5
READ	Read input from external file		3.1
RMESH*i*:<*pl*>	TMESH control card indicating a rectangular mesh tally and the mesh tally type		3.3.5.24.1
repeated structures	See FILL, LAT, LIKE *n* BUT, TRCL, U		3.3.1.5
SB*n*	Bias for source distribution *n*		3.3.4.4
SC*n*	Comment for source distribution *n* for OUTP (& continuation not allowed)		3.3.4.6
SD*n*	Tally divisors for volume or area, with or without FS card segments		3.3.5.15
SDEF	General fixed source specification		3.3.4.1
SF*n*	Surface flagging card for tally *n*	# of surfaces	3.3.5.13
SI*n*	Source information for distribution *n*		3.3.4.2
SMESH*i*:<*pl*>	TMESH control card indicating a spherical mesh tally and the mesh tally type		3.3.5.24.1
SPABI:<*pl*>	Secondary particle biasing		3.3.6.16
SPDTL	Prevent or force lattice speed tally enhancements	1	3.3.5.26
SP*n*	Source probability for distribution n		3.3.4.3
SSR	Surface source read card for file RSSA		3.3.4.8
SSW	Write surface source to WSSA file		3.3.4.7
STOP	Enables termination of calculations when a desired tally precision is reached	3	3.3.7.1.3
surface cards	Surface equation coefficients, surface by points, and macrobodies		2.8
T*n*	Create time bins in shakes (10^{-8} s) for tally *n*		3.3.5.4
TALNP	Tally no-print card to delete tally bin values from the OUTP file	100	3.3.7.2.2

Card Name	Description	[max # of entries]	Section
TF*n*	Select one bin for tally *n* to be used in tally fluctuation chart	8	3.3.5.19
THTME	Times for thermal neutron temperatures of cells on TMP*n* card(s)	99	3.3.3.6
title card	One line of required input as problem title		2.1
TM*n*	Time bin multiplier card		3.3.5.10
TMESH	Block initiation card indicating that TMESH information cards follow.		3.3.5.24
TMP*n*	Free-gas thermal temperature card for time *t* on THTME card	# of cells	3.3.3.5
TOTNU	Total fission card to include delayed neutrons for steady state	1	3.3.2.6
TR*n*	Surface transformation (*TR*n*= basis matrix in degrees)	13	3.3.1.3
TRCL	Cell transformation (*TRCL= rotation matrix in degrees)	13	3.3.1.4
TROPT	Transport options cards for selecting physics options for particle transport		3.3.3.9
TSPLT:<*pl*>	Time splitting and Russian roulette card	40	3.3.6.6
U	Describes what universe a cell belongs to (best put on cell card)	# of cells	3.3.1.5.1
UNC	Un-collided secondaries card to define if secondaries are un-collided		3.3.3.10
URAN	Stochastic geometry card for HTGRs	8	3.3.1.5.4
VAR	Controls variance reduction methods		3.3.6.2
VECT	Define any number of vectors for exponential transform or user patches		3.3.6.8
VOID	Delete all cell materials to check geometry/sources, calculate volumes	# of cells	3.3.2.10
VOL	Whole cell volume specifications	# of cells	3.3.1.1
WWE:<*pl*>	Weight-window energy or time intervals; use with WWN	99	3.3.6.3.1
WWG	Weight-window generation card	9	3.3.6.4.1
WWGE:<*pl*>	Weight-window generation energy or time bounds; use with WWG	15	3.3.6.4.2
WWGT:<*pl*>	Weight-window generation time bounds; use with WWG	15	3.3.6.4.3
WWN*i*:<*pl*>	Cell based lower weight-window bounds for i^{th} WWE or WWT; use with WWP	# of cells	3.3.6.3.3
WWP:<*pl*>	Weight-window parameter card; use with WWE or WWT	11	3.3.6.3.4
WWT:<*pl*>	Weight-window time intervals; use with WWN	99	3.3.6.3.2
XS*n*	Load cross-section evaluation *n* not listed in XSDIR file directory	11	3.3.2.9
ZA, ZB, ZC, ZD	Separate cards for inputting user data to user-modified code		3.3.7.3.6

7.2.3 Input Commands (by Function)

The table that appears below groups input commands by functionality. Within each function group, the cards are listed alphabetically. The table uses the following symbolism:

- *n* indicates a number is required
- *m* indicates a number for cards relating to materials is required
- :<*pl*> means a particle type indicator is required
- I8 means that some entries on this card can be 8-byte integers. The characters "I8" should not be present in the input deck.

Card Name	Description	[max # of entries]	Section
GEOMETRY SPECIFICATION			
AREA	Whole surface area specifications	# of surfaces	3.3.1.2
FILL	Fill cell or lattice elements with universes (*FILL= rotation matrix in degrees)	# of cells	3.3.1.5.3
LAT	Defines a cell as a hexahedral (LAT=1) or hexagonal prism (LAT=2) lattice	# of cells	3.3.1.5.2
macrobody	Solid geometry primitives for enclosed regions of space (see surfaces)		3.2.2.4
repeated structures	See FILL, LAT, LIKE *n* BUT, TRCL, U		3.3.1.5
TR*n*	Surface transformation (*TR*n*= basis matrix in degrees)	13	3.3.1.3
TRCL	Cell transformation (*TRCL= rotation matrix in degrees)	13	3.3.1.4
U	Describes what universe a cell belongs to (best put on cell card)	# of cells	3.3.1.5.1
URAN	Stochastic geometry card for HTGRs	8	3.3.1.5.4
VOL	Whole cell volume specifications	# of cells	3.3.1.1
EMBEDDED GEOMETRY SPECIFICATION			
DAWWG	Deterministic automated weight-window generator for structured embedded meshes		3.3.1.6.1
DM	ZAID aliases for deterministic materials		3.3.1.6.1
EMBEB	Embedded elemental edit energy-bin boundaries card		3.3.1.6.2
EMBED	Embedded geometry specification card		3.3.1.6.2
EMBEE	Embedded elemental edits control card		3.3.1.6.2
EMBEM	Embedded elemental edit energy-bin multipliers card		3.3.1.6.2
EMBTB	Embedded elemental edit time-bin boundaries card		3.3.1.6.2
EMBTM	Embedded elemental edit time-bin multipliers card		3.3.1.6.2
EMBDE	Embedded elemental edit dose energy-bin boundaries card		3.3.1.6.2
EMBDF	Embedded elemental edit dose energy-bin multipliers card		3.3.1.6.2

Card Name	Description	[max # of entries]	Section
MATERIALS SPECIFICATION			
AWTAB	User-specified atomic weight in pairs: "ZAID atomic-weight-ratio"		3.3.2.8
DRXS	Discrete reaction neutron cross-section card		3.3.2.12
M*m*	Material definition card for cells containing material *m*		3.3.2.1
MT*m*	*S*(α,β) thermal neutron treatment for material *m*		3.3.2.2
MGOPT	Multigroup forward/adjoint transport option	7	3.3.2.11
MX	Enables mixing and matching of physics models and data tables		3.3.2.3
NONU	Treat fission as a capture as a function of cell	# of cells	3.3.2.7
OTFDB	On-the-fly Doppler broadening		3.3.2.5
TOTNU	Total fission card to include delayed neutrons for steady state	1	3.3.2.6
VOID	Delete all cell materials to check geometry/sources, calculate volumes	# of cells	3.3.2.10
XS*n*	Load cross-section evaluation *n* not listed in XSDIR file directory	11	3.3.2.9
PHYSICS SPECIFICATION			
ACT	Activation control card to specify delayed-particle options		3.3.3.3
BFLCL	Assigns magnetic field numbers to cells		3.3.3.11.2
BFLD*n*	Defines the properties of magnetic field *n*		3.3.3.11.2
COSY	Assigns COSY map numbers to individual cells		3.3.3.11.1
COSYP	Defines the magnetic field parameters for the COSY maps		3.3.3.11.1
CUT:<*pl*>	Time, energy, and implicit capture/weight cutoffs	5	3.3.3.4.1
ELPT:<*pl*>	Cell energy cutoff (greater of ELPT:<*pl*> or CUT:<*pl*> applies)	# of cells	3.3.3.4.2
FIELD	Allows modeling of planetary gravitational effects on neutrons		3.3.3.12
FMULT	Enables users to override or add additional fission multiplicity data.		3.3.3.8
LCA	Choose intranuclear cascade/pre-equilibrium model	11	3.3.3.7.2
LCB	Choose particle interaction model	8	3.3.3.7.3
LCC	Control parameters for INCL4 and ABLA	10	3.3.3.7.4
LEA	Control parameters for Bertini, ISABEL, and INCL	8	3.3.3.7.5
LEB	Control parameters for HETC implementation	4	3.3.3.7.6
MODE	Definition of particles to be transported in the problem	37	3.3.3.1
MPHYS	Model physics card to allow the use of physics models in the calculation		3.3.3.7.1
PHYS:<*pl*>	Control physics used for particle transport	15	3.3.3.2
THTME	Times for thermal neutron temperatures of cells on TMP*n* card(s)	99	3.3.3.6

Card Name	Description	[max # of entries]	Section
TMP*n*	Free-gas thermal temperature card for time *t* on THTME card	# of cells	3.3.3.5
TROPT	Transport options cards for selecting physics options for particle transport		3.3.3.9
UNC	Un-collided secondaries card to define if secondaries are un-collided		3.3.3.10
SOURCE SPECIFICATION			
BURN	Define parameters for material depletion/burnup in eigenvalue calculations.		3.3.4.13
DS*n*	Dependent source distribution card		3.3.4.5
HSRC	Mesh for Shannon entropy of fission source distribution	9	3.3.4.12
KCODE	Define a criticality eigenvalue (k_{eff}) problem	10	3.3.4.9
KOPTS	Criticality calculation options card for point kinetics parameters		3.3.4.11
KSRC	Starting source point locations for KCODE problem		3.3.4.10
SB*n*	Bias for source distribution *n*		3.3.4.4
SC*n*	Comment for source distribution *n* for OUTP (& continuation not allowed)		3.3.4.6
SDEF	General fixed source specification		3.3.4.1
SI*n*	Source information for distribution *n*		3.3.4.2
SP*n*	Source probability for distribution n		3.3.4.3
SSR	Surface source read card for file RSSA		3.3.4.8
SSW	Write surface source to l file		3.3.4.7
TALLIES SPECIFICATION			
C*n*	Cosine bins for a type 1 ally		3.3.5.5
CF*n*	Tally contributions from flagged cells separately for tally	# of cells	3.3.5.12
CM*n*	Multipliers for cosine bins of tally *n* for type 1 tallies		3.3.5.11
CMESH*i*:<*pl*>	TMESH control card indicating a cylindrical mesh tally and the mesh tally type		3.3.5.24.1
CORA*i*	TMESH boundaries for the first coordinate direction		3.3.5.24
CORB*i*	TMESH boundaries for the second coordinate direction		3.3.5.24
CORC*i*	TMESH boundaries for the third coordinate direction		3.3.5.24
DE*n*	Dose energy card (use with the DF*n* card)		3.3.5.8
DF*n*	Dose function card (use with the DE*n* card)		3.3.5.8
E*n*	Upper bounds of energy bins (MeV) for tally *n*		3.3.5.3
EM*n*	Multipliers for energy bins of tally *n* on the E*n* card		3.3.5.9
ENDMD	Terminates TMESH mesh tally information block	0	3.3.5.24.1
ERGSH*i*	Provides energy or time limits for information to be stored to TMESH mesh tally	2	3.3.5.24.1

Card Name	Description	[max # of entries]	Section
Fn:<pl>	Create cell, surface, or point tally n (*F for energy)		3.3.5.1
FnA:<pl>	Symmetric ring detector flux tally, where A=X, Y, or Z axis		3.3.5.1.2
FCn	Comment printed in OUTP for tally n (& continuation not allowed)		3.3.5.2
FICn:<pl>	Flux image on a cylindrical image grid	10	3.3.5.1.2
FIPn:<pl>	Flux image through a pinhole to a planar rectangular image grid	10	3.3.5.1.2
FIRn:<pl>	Flux image radiograph on a planar rectangular image grid	10	3.3.5.1.2
FMn	Tally multiplier card for tally n		3.3.5.7
FMESHn:<pl>	Create an FMESH mesh track length tally		3.3.5.25
FQn	Print hierarchy card for ordering of OUTP tallies	8	3.3.5.6
FSn	Subdivide cell of surface into segments for tallying	# surfaces	3.3.5.14
FTn	Special treatments for tally n		3.3.5.18
FUn	User-defined TALLYX tally input; required by some FTn options		3.3.5.16
KPERT	Calculates the change in reactivity from a perturbation to a KCODE problem		3.3.5.22
KSEN	Specify cross-section sensitivity profile for KCODE problem		3.3.5.23
MSHMFj	Provides energy-response function pairs for TMESH mesh tallies		3.3.5.24.1
NOTRN	Do only direct (unscattered) type 5 detector tallies from N or P source	0	3.3.5.20
PERTn:<pl>	Perturbation of material density, composition, or reaction cross-section data		3.3.5.21
RMESHi:<pl>	TMESH control card indicating a rectangular mesh tally and the mesh tally type		3.3.5.24.1
SDn	Tally divisors for volume or area, with or without FS card segments		3.3.5.15
SFn	Surface flagging card for tally n	# of surfaces	3.3.5.13
SMESHi:<pl>	TMESH control card indicating a spherical mesh tally and the mesh tally type		3.3.5.24.1
SPDTL	Prevent or force lattice speed tally enhancements	1	3.3.5.26
Tn	Create time bins in shakes (10^{-8} s) for tally n		3.3.5.4
TFn	Select one bin for tally n to be used in tally fluctuation chart	8	3.3.5.19
TMn	Time bin multiplier card		3.3.5.24
TMESH	Block initiation card indication the TMESH information cards follow.		3.3.5.24
VARIANCE REDUCTION			
BBREM	Bias for high-energy bremsstrahlung photons		3.3.6.14
DDn	Detector and DXTRAN diagnostics and contribution card		3.3.6.11

Card Name	Description	[max # of entries]	Section
`DXCn:<pl>`	DXTRAN contribution for DXTRAN sphere *n*	# of cells	3.3.6.13
`DXT:<pl>`	Defines DXTRAN spheres	53	3.3.6.10
`ESPLT:<pl>`	Energy splitting and Russian roulette card	40	3.3.6.5
`EXT:<pl>`	Exponential transform (use weight window; `FCL` not allowed)	# of cells	3.3.6.7
`FCL:<pl>`	Force collisions by cell	# of cells	3.3.6.9
`IMP:<pl>`	Cell importances; required unless weight windows used	# of cells	3.3.6.1
`MESH`	Superimposed importance mesh for mesh-based weight-window generator		3.3.6.4.4
`PDn`	Detector contribution control by cell for tally *n*	# of cells	3.3.6.12
`PIKMT`	Photon-production bias card for coupled neutron-photon problems		3.3.6.15
`PWT`	Control neutron-induced photons produced by cell; `MODE N,P` or `NPE`	# of cells	3.3.6.17
`SPABI:<pl>`	Secondary particle biasing		3.3.6.16
`TSPLT:<pl>`	Time splitting and Russian roulette card	40	3.3.6.6
`VAR`	Controls variance reduction methods		3.3.6.2
`VECT`	Define any number of vectors for exponential transform or user patches		3.3.6.8
`WWE:<pl>`	Weight-window energy or time intervals; use with `WWN`	99	3.3.6.3.1
`WWG`	Weight-window generation card	9	3.3.6.4.1
`WWGE:<pl>`	Weight-window generation energy or time bounds; use with `WWG`	15	3.3.6.4.2
`WWGT:<pl>`	Weight-window generation time bounds; use with `WWG`	15	3.3.6.4.3
`WWNi:<pl>`	Cell based lower weight-window bounds for i^{th} `WWE` or `WWT`; use with `WWP`	# of cells	3.3.6.3.3
`WWP:<pl>`	Weight-window parameter card; use with `WWE` or `WWT`	11	3.3.6.3.4
`WWT:<pl>`	Weight-window time intervals; use with `WWN`	99	3.3.6.3.2
PROBLEM TERMINATION			
`CTME`	Computer time limit in minutes for the problem	1	3.3.7.1.2
`NPS`^{I8}	Number of particles to run from the fixed source	2	3.3.7.1.1
`STOP`	Enables termination of calculations when a desired tally precision is reached	3	3.3.7.1.3
OUTPUT CONTROL			
`DBCN`^{I8}	Debug information card	100	3.3.7.3.2
`HISTP`	Create LAHET-compatible files		3.3.7.2.6
`LOST`	Lost particle abort/debug print control card	2	3.3.7.3.3
`MPLOT`^{I8}	Produce plots of tallies while the problem is running		3.3.7.2.5

Card Name	Description	[max # of entries]	Section
PRDMP[I8]	Print, dump, TFC, and rendezvous control	5	3.3.7.2.3
PRINT	Control the printing of optional tables to the OUTP file		3.3.7.2.1
PTRAC[I8]	Generate a file named PTRAC of user-filtered particle events		3.3.7.2.4
RAND[I8]	Selection and setting of pseudorandom number generator		3.3.7.3.1
TALNP	Tally no-print card to delete tally bin values from the OUTP file	100	3.3.7.2.2
USER TOOLS			
FILES	User file creation card	30	3.3.7.3.7
IDUM	Integer array available for user-modified code (see RDUM)	2000	3.3.7.3.4
RDUM	Real array available to the user (see IDUM)	2000	3.3.7.3.5
ZA, ZB, ZC, ZD	Separate cards for inputting user data to user-modified code		3.3.7.3.6
GENERIC INP FILE			
& (*ampersand*)	Preceded by at least one space, an ampersand appearing at the end of a line signals that the following line contains a continuation of data.		2.3
blank	Blank lines separate MESSAGE, cell, surface, and data blocks		2.1
C	INP file comment card (no continuation is allowed)		2.6
cell cards	Define geometry cells with materials (M*m* card) or void (0)		2.8
CONTINUE	First card in file for continue-run (C or CN on execute line)	0	2.2
data cards	Define particles, physics, source, materials, variance reduction, tallies, ...		2.8
$ *(dollar sign)*	Comment at end of input line; appears only in echo of input file in OUTP		2.3
MESSAGE	Optional first line of INP file containing execution line		2.4
#	Vertical column input format; also complement geometry operator; also heavy ions particle symbol		
READ	Read input from external file		3.1
surface cards	Surface equation coefficients, surface by points, and macrobodies		2.8
title card	One line of required input as problem title		2.1

7.2.4 Concise Input Command Descriptions

Each MCNP6 input command (i.e., card) described in the table below uses the following notation conventions to enhance clarity:

- *n* indicates a number is required
- *m* indicates a number for cards relating to materials is required
- *i*, *j*, and *k* represent index values

- :<*pl*> indicates a particle type indicator is required
- Default values, if any, are provided in braces {}
- Parameters, which appear in italic *lower-case italic text*, must be input in order
- Keywords, which appear in CAPITALIZED text, are not order-dependent

Additionally, MCNP6 card names and mnemonics indicating surface type are capitalized. In the table, a general section on MCNP6 card type descriptions is followed by a discussion of the required format for cell cards, surface cards, and each data card (in alphabetical order). Note that duplicate card names are not allowed and will results in a fatal error.

Card Name	Description	Section
MCNP6 Input File Card Types		
MESSAGE:	Optional first line(s) of INP file containing execution information. A blank line delimiter must appear between the message block and title card. The message block must start with the string MESSAGE: followed by a space and then by MCNP6 execution line parameters: KEYWORD=*value* … KEYWORD=*value exec_options other_options* Each KEYWORD is an MCNP6 default file name; *value* is the user-supplied file name; *exec_options* may include a combination of I, P, X, R, and/or Z; and *other_options* may include C, CN, or DEBUG: Lines of data in the message block must reside in columns 1–128 and all but the first line must be a continuation line. The default input file name, INP, may not be reassigned in a message block. Information entered on an execution line takes precedence over conflicting information in the message block.	1.3.1
Blank	A blank line must be used to separate message, cell, surface, and data blocks and optionally terminate the input file.	
Title card	Consists of one line of required input not to exceed column 128. Is the first line in the input file or the first line appearing after the message block blank line delimiter.	1.3.1
Cell cards	Define cells that describe the geometry. (See description of format below.)	1.3.2
Surface cards	Describe surfaces that define the cells of the geometry using surface equation coefficients, surface by points, and macrobodies. (See description of format below.)	1.3.3
Data cards	Define particles, physics, source, materials, variance reduction, tallies, output parameters, etc. , desired for the problem.	1.3.4
CONTINUE	Either the first card in continue-run input file or the first line after the optional message block and its associated blank line delimiter. Data cards allowed in continue-run include: CTME, DBCN, DD, EMBED, FQ, IDUM, KCODE, LOST, FMESH, MESH, MPLOT, NPS, PRDMP, PRINT, RAND, RDUM, STOP, TALNP, ZA, ZB, ZC, ZD	2.2
MCNP6 Special Input Symbols		
& (ampersand)	If an ampersand (&) preceded by at least one blank space appears at the end of a line of input, the next line (columns 1–128) will be interpreted as a continuation of the data.	2.3

<table>
<tr><th>Card Name</th><th>Description</th><th>Section</th></tr>
<tr><td># (pound sign)</td><td>The pound symbol (#) is interrupted by MCNP6 three different ways:
1) Indicates data is input by vertical (column) format. The symbol # must appear in columns 1–5 and be followed on the same line by at least one blank and the MCNP6 card names (either all cell parameter cards, all surface parameter cards, all source parameter cards, etc.) for which data is provided. The data is then provided in columnar fashion under the appropriate card names (128-column limit applies). For each horizontal set of data points, an optional cell or surface numbers may appear in columns 1–5.
2) Complement geometry operator used to define cell geometry. In the geometry description of a cell card, the format #n, where n is a cell number, defines the space not in cell n.
3) Symbol for heavy ion particles.</td><td>2.3
1.3.2
2.9</td></tr>
<tr><td>$ (dollar sign)</td><td>Allows comment to be added at end of input line. Comment appears only in echo of input file in OUTP file. See C comment card or FC or SC cards.</td><td>2.3</td></tr>
<tr><th colspan="3">MCNP6 Input File Cell Card Format</th></tr>
<tr><td>cell cards</td><td>Form 1: j m d geom params
Form 2: j LIKE n BUT list
j = cell number assigned by user; begins in columns 1–5; j=1–99999999, except j=1–99999 with transformation
m = material number on associated Mm card
=0 ⇒ void cell
d = cell material density or absent if m=0
>0 ⇒ atom density in units of atoms/barn-cm (10^{-24} atoms/cm^3)
<0 ⇒ mass density in units of grams/cm^3
geom = signed surface numbers and Boolean operators which are:
space intersection operator
: union operator
# complement operator; must be followed by a cell number
params = cell parameters with form: KEYWORD=value. Allowed keywords are: U, TRCL, FILL, LAT, DXC, EXT, FCL, IMP, NONU, PD, PWT, TMP, VOL, WWN, ELPT, COSY, BFLCL, and UNC.
LIKE n BUT = gives cell j all attributes of problem cell n except what appears in list.
list = keywords list above under params plus MAT (material number) and RHO (density)</td><td>3.2.1</td></tr>
<tr><th colspan="3">MCNP6 Input File Surface Card Format</th></tr>
<tr><td>surface cards</td><td>Form : j n A list
j = surface number assigned by user; begins in columns 1–5; j=1–99999999, except j=1–999 when is a surface of a repeated structure or affected by TRCL transformation
*j is specular reflecting surface and +j is white boundary condition reflector. Point detectors and DXTRAN spheres should generally not be used with reflectors.</td><td>3.2.2</td></tr>
</table>

Card Name	Description	Section
	n = absent if no coordinate transformation >0 specifies number of TR*n* card <0 surface *j* periodic with surface *n* where *j* and *n* are both planes	3.3.1.3
	A = mnemonic from following list:	
	P general plane; PX, PY, PZ plane normal to *x*-, *y*-, or *z*-axis; SO sphere at origin; S general sphere; SX, SY, SZ sphere centered on *x*-, *y*-, or *z*-axis; CX, CY, CZ cylinder on *x*-, *y*-, or *z*-axis; C/X, C/Y, C/Z cylinder parallel to *x*-, *y*-,or *z*-axis; KX, KY, KZ cone on *x*-, *y*-, or -axis; K/X, K/Y, K/Z cone parallel to *x*-, *y*-,or *z*-axis; SQ special quadratic; GQ general quadratic; TX, TY, TZ torus with axis parallel to *x*-, *y*-,or *z*-axis;	3.2.2.1
	X, Y, or Z axisymmetric surfaces defined by points; P general plane defined by three points; ARB arbitrary polyhedron	3.2.2.2 3.2.2.3
	macrobodies BOX arbitrarily oriented orthogonal box ELL ellipsoid HEX or RHP right hexagonal prism RCC right circular cylinder REC right elliptical cylinder RPP rectangular parallelepiped SPH sphere TRC truncated right-angle cone WED wedge	3.2.2.4
	list The list of values that define the selected surface type. See or specific entries required for each surface.	Table 3-3

MCNP6 Input File Data Card Formats

Card Name	Description	Section
ACT	KEYWORD=*value(s)* ... FISSION= NONE — Create no delayed particles from fission events. N,P,E,A — Create delayed neutrons (N), delayed gammas (P), delayed beta particles (E), and/or delayed alpha particles (A) from fission events. Only those listed will be created. {N} ALL — Create all delayed particles from fission events. NONFISS= NONE — Create no delayed particles from non-fission events. {NONE} N,P,E,A — Create delayed neutrons (N), delayed gammas (P), delayed beta particles (E), and/or delayed alpha particles (A) from non-fission events. Only those listed will be created. ALL — Create all delayed particles from non-fission events. DN= MODEL — Production of delayed neutrons uses models only. LIBRARY — Production of delayed neutrons uses libraries only. {LIBRARY} BOTH — Production of delayed neutrons uses models when libraries are missing. PROMPT — treat prompt and delayed neutrons as prompt. DG= LINES — Sample delayed gammas using models based on line-emission data augmented by MG. MG — Sample delayed gammas using models based on 25-group emission data. NONE — Do not create delayed gammas. {NONE} THRESH= *f* — The fraction of highest-amplitude discrete delayed-gamma lines, *f*, that will be retained. {0.95} DNBIAS= *n* — Produce up to *n* delayed neutrons per interaction. {analog} NAP= m — Number of activation products for which cumulative distribution functions will be calculated once and stored for reuse. {10}	3.3.3.3
AREA	x_1 x_2 ... x_i ... x_n {MCNP6-calculated areas if available} where x_i are surface area specifications in cm^2. Number of entries equals the total number of surfaces in the problem.	3.3.1.2
AWTAB	$zaid_1$ aw_1 $zaid_2$ aw_2 ... {cross-section file XSDIR} where $zaid_i$ is the nuclide or element identifier used on the M*m* material card excluding the *x* for data class specification aw_i is the atomic weight ratio. Atomic weight ratios that differ from those provided in the XSDIR file may lead to negative neutron energies.	3.3.2.8

<table>
<tr><th>Card Name</th><th>Description</th><th>Section</th></tr>
<tr><td>BBREM</td><td>b_1 b_2 b_3 ... b_{49} m_1 m_2 ... m_n
where b_1 is any positive value (currently unused).
b_2...b_{49} are bias factors for the bremsstrahlung energy spectrum from low to high.
m_1...m_n is a list of n materials for which biasing in invoked.</td><td>3.3.6.14</td></tr>
<tr><td>BFLCL</td><td>type
where   type is the type of magnetic field: CONST, QUAD, or QUADFF.
KEYWORD=value(s) ...
FIELD=   For type=CONST, FIELD=the magnetic field strength (Tesla). For type=QUAD or QUADFF, FIELD=the magnetic field gradient (Tesla/cm).
VEC=   For type=CONST, VEC=the direction of the magnetic field. {0 0 1} For type=QUAD or QUADFF, VEC=the plane that corresponds to the x-axis of a focusing quadrupole.
MXDEFLC=   Maximum deflection angle per step size (mrad) {10}
MAXSTEP=   Maximum step size (cm) {100}
AXS=   For quadrupole field, the direction cosines of the quadrupole beam axis. {0 0 1}
FFEDGES=   For quadrupole field, a list of surface numbers to which fringe field edge kicks are to be applied.
REFPNT=   For quadrupole field, a point anywhere on the quadrupole beam axis. {0 0 0}</td><td>3.3.3.11.2</td></tr>
<tr><td>BFLDn</td><td>m or m_1 m_2 ... m_K
where m_i is the magnetic field number for cell i.</td><td>3.3.3.11.2</td></tr>
<tr><td>BURN</td><td>KEYWORD=value(s) ...
TIME=t_1 t_2 ...   Incremental time duration t_1 (in days) for each successive burn step. {1}
PFRAC=f_1 f_2 ...   Fraction f_i of total system power applied to burn step t_i. If a single f_1 value is provided, but multiple time steps are specified, the first time step will be assigned a power fraction of f_1; subsequent time steps will have a power fraction of 0. {1.0 for all t_i}
POWER=pwr   Total recoverable fission system power (MW) {1}
MAT=m_1 m_2 ...   Material numbers of materials to be burned. If m_i<0, then recoverable energy per fission and neutrons per fission are computed and contribute to the power normalization, but the material is not burned.
OMIT=m_i n_i j_{i1} j_{i2} ... j_{in} For each specified material number m_i, omit the following n_i isotopes from the transport calculation: j_{i1}, j_{i2}, … j_{in}. Each j_{ik} is provided in ZZZAAA format.</td><td>3.3.4.13</td></tr>
</table>

Card Name	Description	Section
	AFMIN=af_1 af_2 — af_1 is the atom fraction below which an isotope will no longer be tracked in the transport calculation. {1.0E-10} af_2 is the transmutation chain convergence criteria used in CINDER90. {1.0E-10} BOPT=b_1 b_2 b_3 — b_1 is Q-value multiplier {1.0} b_2 controls the ordering and content of the output. If the value of b_2 is 1, 2, 3, or 4, then only Tier 1 fission products are output by decreasing mass, total activity, specific activity, or increasing ZZZAAA, respectively. If b_2 is 11, 12, 13, or 14, then Tier 2 fission products are output by decreasing mass, total activity, specific activity, or increasing ZZZAAA, respectively. If b_2 is 21, 22, 23, or 24, then Tier 3 fission products are output by decreasing mass, total activity, specific activity, or increasing ZZZAAA, respectively. {1} b_3 allows the user to disallow the use of high-energy physics models. If b_3=-1, a fatal error occurs if models are used; if b_3=0, the atom fraction of any data using a model is set to 0; if b_3=1, the problem runs with models. {-1} MATVOL=v_1 v_2 ... v_n — Used to provide the volume of all cells containing a burn material in a repeated structure or lattice geometry. Each v_i entry is the volume of all cells containing burn material m_i. If MATVOL is used then each m_i entry on the MAT keyword must have a corresponding v_i entry on MATVOL. MATMOD=(See Section 3.3.4.13) — Allows concentration changes as a function of time step. SWAPB=(See Section 3.3.4.13) — Allows the definition of the filling universe to be changed.	
C	Single line comment card in input file; the "C" must appear in column 1 followed by a space; the comment line may be up to128 characters long.	2.6

<table>
<tr><th>Card Name</th><th>Description</th><th>Section</th></tr>
<tr><td>Cn</td><td>Cn c_1 c_2 ... c_k [T] [C] or *Cn ϕ_1 ϕ_2 ... ϕ_k [T] [C] {1 bin}
where n is the associated tally number
c_i is the upper cosine limit of the i^{th} angular bin for tally n. Values are monotonically increasing. (c_1>-1 and c_k=1)
For type 5 image tallies, the c_i values are the monotonically increasing t-axis values.
ϕ_i is the upper angular limit of the i^{th} angular bin for tally n expressed in degrees. Values are monotonically decreasing. (ϕ_1<180 and ϕ_k=0)
T, optional entry, provides the total tally over all specified angular bins. Not available for image tallies.
C, optional entry, causes the bin values to be cumulative and the last angular bin to be the total over all angles. Not available for image tallies.
Can be used with tally type 1 (surface current), tally type 2 (surface flux), and type 5 image tally. Required if CMn card is present.</td><td>2.2</td></tr>
<tr><td>CFn</td><td>c_1 c_2 ... c_k
where n is a tally number not ending in 5 or 8 (see FTn card with keyword ICD).
c_i are problem cells numbers where tracks leaving are flagged for a second (subset) tally.
Tally contributions from flagged cells are listed separately in addition to the normal total tally n.</td><td>3.3.5.12</td></tr>
<tr><td>CMn</td><td>m_1 m_2 ... m_k
where n is a tally number.
m_i is a multiplier to be applied to the i^{th} cosine bin of tally n.
Valid for type 1 and type 2 tallies. Requires Cn card. Number of entries same as the number of entries on the Cn card.</td><td>3.3.5.11</td></tr>
<tr><td>CMESH<i>i</i>:<<i>pl</i>>_{<i>j</i>}
RMESH<i>i</i>:<<i>pl</i>>_{<i>j</i>}
SMESH<i>i</i>:<<i>pl</i>>_{<i>j</i>}</td><td>CMESH specifies a cylindrical TMESH mesh tally, RMESH specifies a rectangular TMESH mesh tally, SMESH specifies a spherical TMESH mesh tally.
KEYWORD=<i>value(s)</i> ...
where <<i>pl</i>>_{<i>j</i>} is the particle type(s) to be tallied, if required by the mesh tally type
<i>i</i> is a user-defined mesh tally number for which the last digit, <i>i</i>, defines the type of TMESH mesh tally (1⇒track-averaged, 2⇒ source, 3⇒energy deposition, or 4⇒DXTRAN)
KEYWORD Options depend on mesh tally type:
Type 1 Track-Averaged Mesh Tally {FLUX}
TRAKS Tally the number of tracks through each mesh volume.
FLUX Average fluence is particle weight times track length divided by volume in units of number/cm³. If the source is considered to be steady state in particles per second, then the value becomes flux in number/cm²/s.
DOSE <i>ic int iu fac</i> {10 1 1 1.0}
where <i>ic</i> indicates the conversion coefficient choice
<i>int</i> indicates the interpolation method
<i>iu</i> selects the units of the results
<i>fac</i> provides a normalization factor for the dose
POPUL Tally the population in each volume</td><td>3.3.5.24</td></tr>
</table>

Card Name	Description	Section
	`PEDEP` Score the average energy deposition per unit volume for the particle type *<pl>*. `MFACT` *j int ir con* {none `1 0 1.0`} where *j* is a number referring to an energy-dependent response function given on an `MSHMF`*j* card. If *j*=-`1`, it is followed by a single-value used as a constant multiplier *int* =`1` for linear interpolation, *int* =2 for logarithmic *ir*=`0` for a response that is a function of the energy deposited; else the response is a function of current particle energy *con* is a constant multiplier `TRANS` *n* where *n* is a `TR`*n* card number used to translate and/or rotate the entire mesh. Type 2 Source Mesh Tally `TRANS=` *n* where *n* is a `TR`*n* card number used to translate and/or rotate the entire mesh. Type 3 Energy Deposition Mesh Tally {`TOTAL`} `TOTAL` Score energy deposited from any source `DE/DX` Score ionization from charged particles `RECOL` Score energy transferred to recoil nuclei above tabular limits `TLEST` Score track length folded with tabular hearing numbers `EDLCT` Score non-tracked particles assumed to deposit energy locally `MFACT` *j int ir con* {none `1 0 1.0`} where *j* is a number referring to an energy-dependent response function given on an `MSHMF`*j* card. If *j*=-`1`, it is followed by a single-value used as a constant multiplier *int* =`1` for linear interpolation, *int* =2 for logarithmic *ir*=`0` for a response that is a function of the energy deposited; else the response is a function of current particle energy *con* is a constant multiplier `TRANS` Type 4 DXTRAN Mesh Tally `TRANS=` *n* where *n* is a `TR`*n* card number used to translate and/or rotate the entire mesh.	
`CONTINUE`	Option to continue running from an existing RUNTPE file.	2.2
`CORA`*i* `CORB`*i* `CORC`*i*	$corra_{n,1}$ $corra_{n,2}$ ... $corrb_{n,1}$ $corrb_{n,2}$ ... $corrc_{n,1}$ $corrc_{n,2}$ .. where *n* is the `TMESH` mesh tally number on the associated `(R/C/S)MESH` card. $corr(a/b/c)_{i,j}$ describe the `TMESH` boundaries for the first, second, and third coordinate directions, respectively, as defined by the mesh type (rectangular, cylindrical, spherical) prior to any transformation.	3.3.5.24

Card Name	Description	Section
COSY	*m* or m_1 m_2 ... m_K where m_i is the COSY map number for cell *i*.	3.3.3.11.1
COSYP	*prefix axsh axsv* $emap_i$ where *prefix* is the prefix number for the COSY map files. *axsh* is the horizontal axis orientation. *axsv* is the vertical axis orientation. $emap_i$ is the operating beam energy of the i^{th} map assigned.	3.3.3.11.1
CTME	*tme* where *tme* is the maximum time limit for the problem in CPU minutes. For a continue-run job, *tme* represents *additional* minutes for the problem to be run; the value is not cumulative.	3.3.7.1.2
CUT:<*pl*>	*t e* wc_1 wc_2 *swtm* {Defaults: *t* *e* wc_1 wc_2 *swtm* neutrons: very large 0.0 -0.50 -0.25 * photons: neutron cutoff 0.001 -0.50 -0.25 * photons w/ PHT: neutron cutoff 0.001 0.0 0.0 * electrons: neutron cutoff 0.001 0.0 0.0 * * All other particles same as electron values; minimum source weight if the general source is used; ignored for KCODE calculation} where *t* is the time cutoff in shakes. *e* is the lower energy cutoff in MeV. wc_1 and wc_2 are the upper and lower weight cutoffs. respectively. If wc_n<0, the cutoff is relative to the source weight; if wc_n>0, the cutoff is relative to cell importances; if wc_1=0, analog capture occurs at all energies. *swtm* is the minimum source weight; value is ignored for KCODE calculations.	3.3.3.4.1
DAWWG	KEYWORD=*value*(*s*) ...] Keywords: POINTS = *n*, number of sample points in each coordinate direction for each mesh element. {1} XSEC = <*name*>, identifies the cross-section library that will be passed to the discrete ordinates code for weight-window generation. BLOCK = *k*, identifies to which PARTISN block the values of the listed keywords are to be passed. Allowed keywords are provided in Table 3-25.	3.3.1.6.1
DBCN	x_1 x_2 ... x_{30} where most of the x_i values are discussed in Los Alamos National Laboratory report LA-UR-13-23395, "Summary of DBCN Options in MCNP6," by H. Grady Hughes III. The newest values are described in Section 3.3.7.3.2	3.3.7.3.2

Card Name	Description	Section
DD*n*	k_1 m_1 k_2 m_2 ... {0.1 1000} where n=0 or blank indicates a global DD card, applied to all detector tallies. n=1 provides detector diagnostics for neutron DXTRAN spheres. n=2 provides detector diagnostics for photon DXTRAN spheres. n ending in 5 indicates a tally number for a specific non-image detector tally. k_i provide criterion for small score tally contribution Russian roulette for detector *i* in tally *n*. For k_i<0, DXTRAN or detector scores $>\|k_i\|$ will always be made and contributions $<\|k_i\|$ are subject to Russian Roulette. $0<k_i\leq 1$, all DXTRAN or detector contributions are made for the first *dmmp* histories. Then, any contribution to the detector or sphere $>k_iA_i$, where A_i is the average score per history to a DXTRAN sphere or a detector *i* of tally *n*, will always be made, but any contribution $<k_iA_i$ is subject to Russian roulette. k_i=0, no Russian roulette is played on small DXTRAN or detector scores. m_i are criterion for printing large detector tally or DXTRAN contributions. For m_i=0, no diagnostic print. m_i>0 and $k_i\geq 0$, no diagnostic print for first *dmmp* histories. Thereafter, the first 600 contributions larger than $m_ik_iA_i$ will be printed. m_i>0 and k_i<0, then the first 600 contributions larger than $m_i\|k_i\|$ will be printed.	3.3.6.11
De*n*	*a* e_1 e_2 ... e_k where *n* is the tally number. *a*=LOG causes logarithmic interpolation method for energy table. {LOG} *a*=LIN causes linear interpolation method for energy table. e_i are monotonically increasing energy values. Number of values must equal number of f_i values on DF*n* card.	3.3.5.8
DF*n*	*b* f_1 f_2 ... f_k or UI=*j* FAC=*f* *int* IC=*i* where *n* is the tally number. *b*=LOG causes logarithmic interpolation method for dose function table. {LOG} *b*=LIN causes linear interpolation method for dose function table. f_i are corresponding values of the dose function for the e_i on the DE*n* card. *j*=1 specifies U.S. units (rem/h/source_particle). *j*=2 specifies international units (sieverts/h/source_particle). *f*=-1 specifies ICRP60 (1990) normalization. *f*=-2 specifies LANSCE albatross response function. *f*>0 provides a user-specified normalization factor. {1} INT=LOG specifies LOGLIN interpolation for energy. INT=LIN specifies LINLIN interpolation for energy. *i* is the standard dose function as given in Table 3-91 of the Manual. {10}	3.3.5.8

Card Name	Description	Section
DM	$zaid_1$ $zaid_2$ $zaid_3$ ... where $zaid_i$ are the aliases for deterministic materials. .	3.3.1.6.1
DRXS	*blank* or $zaid_1$ $zaid_2$ ... where *blank* causes use of 262-energy-group discrete reaction cross sections for all nuclides. $zaid_i$ is the nuclide number of the form ZZZAAA.*ab* for discrete reaction. Continuous scattering kinematics are used in the discrete reaction treatment.	3.3.2.12
DS*n*	*option* j_1 ... j_k {H} or T i_1 j_i ... i_k j_k or Q v_1 s_i ... v_k s_k where *n* is the source distribution number between 1 and 999 If *option* is absent or *option*=H, source variable values (j_i) are given as continuous distribution (for scalar variables only). If *option*=L, discrete source variable values follow. If *option*=S, distribution numbers follow. T indicates values of the dependent variable (j_i) follow values of the independent variable (i_i), which must be a discrete scalar variable. Q indicates distribution numbers (s_i) follow values of the independent variable (v_i), which must be a monotonically increasing set of scalar values.	3.3.4.5
DXC*m*:<*pl*>	p_1 p_2 ... p_j ... {*m*=0; p_i=1.} where *m* indicates to which DXTRAN sphere the DXC card applies. If *m*=0 or *m* is absent, the DXC card applies to all the DXTRAN spheres in the problem. <*pl*> is the particle designator. p_i is the probability of contribution to DXTRAN sphere *m* from cell *j*.	3.3.6.13
DXT:<*pl*>	x_1 y_1 z_1 ri_1 ro_1 x_2 y_2 z_2 ri_2 ro_2 ... dwc_1 dwc_2 *dpwt* where <*pl*> is the particle designator x_1 y_1 z_1 are the coordinates of the point at the center of the i^{th} pair of spheres. ri_i is the radius of the i^{th} inner sphere. ro_i is the radius of the i^{th} outer sphere. dwc_1 is the upper weight cutoff in the spheres. {0} dwc_2 is the lower weight cutoff in the spheres. {0} *dpwt* is the minimum photon weight; entered on DXT:N card only. {0}	3.3.6.10
E*n*	e_1 e_2 ... e_k [NT] [C] where *n* is the tally number. e_i is the monotonically increasing upper energy bound of the i^{th} energy bin of tally *n*.. NT deletes the total energy bin (optional). C causes bin values to be cumulative (optional).	3.3.5.3
ELPT:<*pl*>	x_1 x_2 ... x_j ... {CUT<*pl*> card energy cutoff} where <*pl*> is the particle designator. x_j is the lower energy cutoff for cell *j*.	3.3.3.4.2

Card Name	Description	Section
EM*n*	m_1 m_2 ... m_k where n is the tally number. m_i is the multiplier to be applied to the i^{th} energy bin.	3.3.5.9
EMBEB EMBED EMBEE EMBEM EMBTB EMBTM	Refer to Section 3.3.1.6.2.	3.3.1.6.2
ENDMD	TMESH mesh tally block terminator	3.3.5.24
ERGSH*i*	e_1 e_2 where e_1 is the lower energy limit and $-e_1$ is the lower time limit for information to be stored to mesh tally i e_2 is the upper energy limit and $-e_2$ is the upper time limit for information to be stored to mesh tally i	3.3.5.24.1
ESPLT:<*pl*>	r_i e_i r_2 e_2 ... r_k e_k where <*pl*> is the particles designator $r_i>1$ indicates that the particles will be split into r_i tracks $0<r_i<1$ is the Russian roulette survival probability $r_i=1$ indicates there is no action e_i is the energy at which splitting or Russian roulette occur	3.3.6.5
EXT:<*pl*>	a_1 a_2 ... a_j ... where <*pl*> is the particle designator. a_j.is of the form QV*m* where Q is a constant stretching parameter for cell j between 0 and 1 or Q=S where $S=\Sigma_c/\Sigma_t$, the capture cross section and V*m* specifies the stretching direction for cell j and m is a unique integer associated with the vector entry provided on the VECT card.	3.3.6.7

Card Name	Description	Section
F*n*:<*pl*>	c_1 c_2 ... c_k T or c_1 (c_2 c_3 ... c_i) ... c_k T where <*pl*> is the particle designator *n* defines the tally type: 1 current integrated over a surface 2 flux averaged over a surface 4 flux averaged over a cell 6 energy deposition averaged over a cell (*F = jerks/g) 7 fission energy deposition averaged over a cell (*F = jerks/g) 8 pulse-height tally (+F8 = charge deposition tally) 5 flux at a point x y z r_0 ... ND where x y z are the coordinates of the detector location r_0 is the radius of sphere of exclusion (in cm if r_0>0, in mfp if r_0<0) ND disallows printing of detector contributions in tally *n*. 5X, 5Y, or 5Z a_0 r r_0 ... ND where a_0 is the distance along the axis where ring plane intersects axis r is the radius of the detector ring r_0 is the radius of sphere of exclusion (in cm if r_0>0, in mfp if r_0<0) ND disallows printing of detector contributions in tally *n*. where c_i is the problem number of the cell or surface for tallying (c_i c_{i+1} c_{i+2}) is the union of tally cells or surfaces and provides an unnormalized value if tally represents a sum and normalized if tally represents an average. T provides a total over all listed cells or surfaces For tally types 1,2,4,6,7,and 8, the format for repeated structure/lattice entries is s_1 (s_2 ... s_3) ((s_4 s_5)<(c_1 c_2 [I_1 ... I_2])<(c_3 c_4 c_5)) ... where s_i is the problem number of the cell or surface, a U=universe number from the FILL card, or T c_i is the problem number of a cell filled with a universe or U=universe number I_i is the index data for a lattice cell element with three possible formats: I_1 is the 1st lattice element of cell c_2 as defined in the FILL array I_1:I_2 I_3:I_4 I_5:I_6 is a range of lattice elements I_1 I_2 I_3, I_4 I_5 I_6 are specific individual lattice elements	3.3.5.1
FC*n*	*info* where *n* is the tally number *info* is a one-line user title for tally *n* that appears in output and MCTAL files	3.3.5.2
FCL:<*pl*>	x_1 x_2 ... x_j ... {all 0} where <*pl*> is the particle designator x_i is the number of forced collisions in cell *i*, $-1 \le x_i \le 1$. If x_i>0, forced collisions apply to entering and collided particles in cell *i*; if x_i<0, then forced collisions apply only to particles entering cell *i*; if x_i=0, then no forced collisions occur.	3.3.6.9

Card Name	Description	Section
FIC*n*:<*pl*>	x_1 y_1 z_1 r_0 x_2 y_2 x_2 f_1 f_2 f_3 where *n* is the tally number ending in 5 for point detector tally <*pl*> is the particle designator: N=neutrons, P=photons x_1 y_1 z_1 are the coordinates of the center of the cylinder on which the grid is established. r_0=0. (Do not put image grid in a scattering medium.) x_2 y_2 x_2 are the reference coordinates of the axis of the cylinder from (x_2 y_2 x_2 to x_1 y_1 z_1) f_1=0 indicates both direct (source) and scattered contributions are scored at the image grid. If f_1=-1, only the scattered contributions are scored. f_2 is the radius of the cylinder on which the grid is to be established. f_3=0 indicates that contributions are directed to the center of each image grid bin (pixel); $f_3 \neq 0$ indicates contributions are made with a random offset from the center of the grid bin.	3.3.5.1.2
FIELD		3.3.3.12
FILES	*unit_no. filename access form record_length ...* where *unit_no.* is an integer between 1 and 99. *filename* is the name of the file to be created. *access* is either SEQUENTIAL or DIRECT. {S} *form* is either FORMATTED or UNFORMATTED. {F if S, U if D} *record_length* is the record length in the direct access file.	
FILL	*n*(*t*) or i_1:i_2 j_1:j_2 k_1:k_2 $m_1(t)$ $m_2(t)$ ... $m_j(t)$ ... (cell card) or n_1 n_2 ... n_T (data card) where *n* is a universe number. *t* is an optional transformation number or the transformation itself. i_1:i_2 j_1:j_2 k_1:k_2 is a range of *i*,*j*,*k* lattice indices. m_j is the universe number for the i^{th} element of the lattice array with T elements. n_j is the universe number with which each cell is to filled in the same order as the cells appear in the cell card section.	
FIP*n*:<*pl*>	x_1 y_1 z_1 r_0 x_2 y_2 x_2 f_1 f_2 f_3 where *n* is the tally number ending in 5 for point detector tally <*pl*> is the particle designator: N=neutrons, P=photons x_1 y_1 z_1 are the coordinates of the center of the pinhole. r_0=0. (Do not put image grid in a scattering medium.) x_2 y_2 x_2 are the reference coordinates that establish the reference direction cosines for the normal to the detector grid (x_2 y_2 x_2 to x_1 y_1 z_1) f_1>0 provides the radius of a cylindrical collimator, centered on and parallel to the reference direction, that establishes a radial field of view through the object. f_2=0 represents a perfect point pinhole. If f_2>0, the provided value is the radius of the pinhole perpendicular to the reference direction. f_3 is the distance from the pinhole at x_1 y_1 z_1 to the image grid center in the reference direction.	3.3.5.1.2

Card Name	Description	Section
FIR*n*:<*pl*>	x_1 y_1 z_1 r_0 x_2 y_2 x_2 f_1 f_2 f_3 where *n* is the tally number ending in 5 for point detector tally <*pl*> is the particle designator: N=neutrons, P=photons x_1 y_1 z_1 are the coordinates of the center of the image grid. r_0=0. (Do not put image grid in a scattering medium.) x_2 y_2 x_2 are the reference coordinates defining the outward normal to the image grid (x_2 y_2 x_2 to x_1 y_1 z_1). f_1=0 indicates both direct (source) and scattered contributions are scored at the image grid. If f_1=-1, only the scattered contributions are scored. f_2 is the radial field of view on the image grid. f_3=0 indicates that contributions are directed to the center of each image grid bin (pixel); $f_3 \neq 0$ indicates contributions are made with a random offset from the center of the grid bin.	3.3.5.1.2
FM*n*	*(bin_set$_1$) (bin_set$_2$) ...* [T] or [C] where *n* is the tally number not ending in 8 and cannot be zero or blank. *bin_set$_i$*= ((multiplier_set$_1$)(multiplier_set$_2$) ... (attenuator_set)) where attenuator_set= *c* –1 m_1 px_1 m_2 px_2 ... multiplier_set$_i$=*c m* (*reaction_list$_1$*) (*reaction_list$_2$*) ... special_multiplier_set$_i$=C –*k* and c>0 is a multiplicative constant and c<0 can be used with type 4 tally only and indicates multiply by |c| times tally cell atom density –1 is a flag indicating an attenuator rather than multiplier set. m_i = material number identified on an M*m* card px is the density times thickness of attenuating material; interpreted as atom density if positive and mass density if negative. k=–1 tallies number of particle tracks (collisions for detectors) k=–2 tallies neutron population integrated over time T prompts code to provide a total over all bin sets (optional). C prompts the code to provide cumulative tally bins (optional). *reaction_list$_i$* = sum and/or product of ENDF or special reaction numbers. Some special non-standard reaction numbers follow. Units are barns unless otherwise noted. Neutrons: -1 total cross section without thermal -2 absorption cross section -3 elastic cross section without thermal -4 average hearing number (MeV/collision) -5 photon production cross section -6 fission cross section -7 fission $\overline{\nu}$ (neutrons per fission) -8 fission Q value (MeV/fission) Photons: -1 incoherent scattering cross section -2 coherent scattering cross section -3 photoelectric cross section -4 pair production cross section -5 total cross section -6 photon heating number (MeV/collision)	3.3.5.7

Card Name	Description	Section
FMESH*n*:<*pl*>	where *n* is the tally number <*pl*> is the particle designator Keywords: GEOM {XYZ} = XYZ or REC for Cartesian mesh geometry; RZT or CYL for cylindrical geometry ORIGIN {0,0,0} = x,y,z coordinates in MCNP6 cell geometry superimposed mesh origin (bottom center for cylindrical or bottom; left, behind for rectangular AXS {0,0,1} = direction vector of the cylindrical mesh axis VEC {1,0,0} = direction vector, along with AXS that defines the plane for angle θ=0 IMESH = coarse mesh locations in x (rectangular) or r (cylindrical) direction IINTS {1} = number of fine meshes within corresponding coarse meshes JMESH = coarse mesh locations in y (rectangular) or z (cylindrical) direction JINTS {1} = number of fine meshes within corresponding coarse meshes KMESH = coarse mesh locations in z (rectangular) or θ (cylindrical) direction KINTS {1} = number of fine meshes within corresponding coarse meshes EMESH {-∞,E_{max}} = values of coarse meshes in energy EINTS {1} = number of fine meshes within corresponding energy meshes ENORM {NO} = tally results are normalized per unit energy TMESH {-∞,T_{max}} = values of coarse meshes in time TINTS {1} = number of fine meshes within corresponding time meshes TNORM {NO} = tally results are normalized per unit time FACTOR {1.} = multiplicative factor for each mesh OUT {COL} = IJ, IK, or JK for 2D matrices written to MESHTAL, where IJ indicates xy or rz 2D matrices; IK indicates xz or rθ 2D matrices; JK indicates yz or zθ 2D matrices = COL to specify column format for mesh tallies written to MESHTAL = CF to specify column output plus mesh volumes and tallies multiplied by mesh volumes TR = transformation number to be applied to the tall mesh INC {0 INFINITE} = lower and upper range of collisions that will contribute to tally TYPE {FLUX} = FLUX to tally neutron volume fluxes = SOURCE to tally neutron source points KCLEAR {0} = clears out mesh tally every *n* cycles	3.3.5.25

Card Name	Description	Section
FMULT	*zaid* [KEYWORD=*value*(*s*) ...] where *zaid* is the nuclide identifier for which data are entered. Keywords: SFNU = *nu*, the value of $\bar{\nu}$ for sampling spontaneous fission multiplicity from a Gaussian distribution with width *w*, OR = x_1 x_2 ..., values that provide the cumulative probability distribution of spontaneous fission multiplicity WIDTH = *w*, the Gaussian width for sampling $\bar{\nu}$ for both spontaneous and induced fission. SFYIELD = *y*, spontaneous fission yield (n/s-g). WATT = *a* *b*, watt energy spectrum parameters *a* and *b* for spontaneous fission neutron energy sampling. METHOD = *m*, the selected Gaussian sampling algorithm method. DATA = *d*, the selected fission sampling technique. . SHIFT = *d*, the selected method to preserve $\bar{\nu}$.	3.3.3.8
FQ*n*	a_1 ... a_7 a_8 where *n* is the tally number a_i designators will define the tally print hierarchy for ordering of printed output; a_7 data will appear in columns (vertical) and a_8 data will be in rows (horizontal). a_i = F cell, surface, or detector tally D direct or flagged tally U user bins S segment tallies M multiplier bins C cosine bins E energy bins T time bins	3.3.5.6
FS*n*	s_1 s_2 ... [T] or [C] where *n* is the tally number (not type 5 detector or type 8). s_i is a signed problem number of a segmenting surface OR. s_i are monotonically increasing s-axis values for type 5 image tallies FIC, FIP, FIR T specifies total of all tallies (optional, not active for image tallies) C specifies cumulative tally in segments (optional, not active for image tallies)	3.3.5.14
FT*n*	ID_1 $p_{1,1}$ $p_{1,2}$ $p_{1,3}$ ... ID_2 $p_{2,1}$ $p_{2,2}$ $p_{2,3}$ ... where n is the tally number ID_i is an alphabetic keyword identifier $p_{i,j}$ are parameters associated with a particular ID_i, if any Available entries include the following: FRV v_1 v_2 v_3 Fixed reference direction vector for tally 1 cosine binning GEB *a b c* Gaussian detector energy broadening of a tally result. The parameters specify the FWHM (= $a + b\sqrt{E + cE^2}$), where E is the energy of the particle.	3.3.5.18

Card Name	Description	Section
FT*n cont.*	`TMC` *a b* — Time convolution for a square wave pulse from time *a* to *b* `INC` — Tally by the number of particle collisions `ICD` — Tally detector contributions by cell `SCX` *k* — Tally by `SI`*k* source distribution(s) plus total `SCD` — Tally specific source distributions `PTT` — Tally by multigroup particle type `ELC` *c* — Charged particle current tally depending on *c*: *c*=1 negatively charged particles make negative scores *c*=2 charged particles and antiparticles put into separate user bins plus total *c*=3 for the effect of *c*=1 and *c*=2 plus total `PHL` [n t_{a1} b_{a1} t_{a2} b_{a2} ... t_{bn} b_{bn}] [det_1] [m t_{b1} b_{b1} t_{b2} b_{b2} ... t_{bm} b_{bm}] [det_2] [j t_{b1} b_{b1} t_{b2} b_{b2} ... t_{bj} b_{bj}] [det_3] [k t_{b1} b_{b1} t_{b2} b_{b2} ... t_{bk} b_{bk}] [det_4] [`TDEP` *tg tt*] Pulse-height light tally with anticoincidence. Allows the `F8` tally to be based on energy/light deposition in up to four regions as specified via one or two `F6` tallies. The parameters *n*, *m*, *j*, and *k* are the number of `F6` tallies for the 1st, 2nd, 3rd, and 4th detector regions, respectively. The paired t_{xi} b_{xi} entries are the pairings of tally number and `F`-bin number for the *n* tallies of the first detector region and for the *m* tallies of the second detector region. The det_i parameter allows an optional detector descriptor for each region. The `TDEP` keyword specifies a trigger tally number (*tg*) and associated energy threshold (*tt*). `CAP` [-m_c] [-m_o] i_1 i_2 [`GATE` *td tw*] ... Converts the `FT8` pulse-height tally to a neutron capture tally. The m_c parameter is the maximum number of captures (optional {21}), m_o is the maximum number of moments (optional {12}), i_n are the capture nuclides, `GATE` indicates a time gate (optional) with predelay time *td* and gate width *tw*. `RES` [z_1 z_2] or `RES` [z_{a1} z_{a2} ...] Converts the `FT8` pulse-height tally to a residual nuclei tally for all possible residual nucleus ion types {default}, an optional range of z-numbers ([z_1 z_2]), or explicitly specified heavy-ion ZZZAAA identifiers ([z_{a1} z_{a2} ...]). When using the heavy-ion particle type (#), the `FT RES` options will work with type 1, 2, 4, and 6 tallies. `TAG` *a* Allows the user to separate a tally into components based on how and where the scoring particle was produced. Only implemented for `N`, `P`, and `E` tallies. The parameter, *a*, specifies how scatter is to be treated. Requires `FU` special tally card. `LET` Allows track length tallies to record flux as a function of stopping power instead of energy. When the `LET` treatment is specified, the values provided in the energy bins are	

Card Name	Description	Section
FT*n cont.*	interpreted as stopping power values with units of MeV/cm. This option can be applied to charged particle tallies only. ROC *nhb* [*m*] Separates tallies into two components, signal and noise so that a Receiver-Operatore Characteristic (ROC) curve can be generated. The parameter *nhb* sets the number of histories per batch. The optional parameter *m* specifies the maximum number of batches that will be kept and analyzed. PDS *c* This pre-collision estimator includes the contribution of all possible reactions before the collision isotope and resulting reaction are sampled. The parameter *c* specifies how the sampling of the collision is performed for the next-event estimator. FFT Segregates the tally into contributions according to which fission occurred first. No parameters follow the keyword, but an FU card is required. COM t [a] The FT8 COM tally option produces a Compton image stored in an associated FIR radiography tally t using algorithm a.	
FU*n*	[x_1 x_2 ... x_k] [NT] [C] where *n* is the tally number x_i is an input parameter establishing user bin *i* (optional) NT inhibits creation of the total bin (optional) C causes cumulative tally in user bins (optional)	3.3.5.16
HISTP	[-*lhist*] [icl_1 icl_2 ...] where -*lhist* controls the number or words written to a HISTP file {-500000000} icl_i are cell numbers for which events occurring within these cells are recorded to the HISTP file {all cells}	3.3.7.2.6
HSRC	n_x x_{min} x_{max} n_y y_{min} y_{max} n_z z_{min} z_{max} where n_x is the number of mesh intervals in the *x* direction x_{min} is the minimum *x*-value for the mesh x_{max} is the maximum *x*-value for the mesh (similar descriptions of *y*- and *z* directions)	3.3.4.12
IDUM	i_1 i_2 ... i_{50} {all 0} where i_i is an integer number for the i^{th} entry in an integer array available for user-modified code.	3.3.7.3.4
IMP:<*pl*>	*x* or x_1 x_2 ... x_N where <*pl*> is the particle designator *x* is the cell importance as presented on the cell card x_i is the importance for cell *i* presented on a data card, where the number of entries must equal the number of cells in the problem, N.	3.3.6.1

Card Name	Description	Section
KCODE	*nsrck rkk ikz kct msrk knrm mr kc8* where *nsrck* is the nominal neutron source size per cycle {1000} *rkk* is the initial guess for k_{eff} {1} *ikz* is the number of cycles to be skipped before beginning tally accumulation {30} *kct* is the total number of cycles to be calculated {*ikz*+100} *msrk* is the number of neutron source points for which to allocate storage {>4499 or 2×*nsrck* } *knrm* is the method of tally normalization, 0=weight, 1=number {0} *mrkp* is the number of k_{eff} cycles to be stored in the RKPL array {651} *kc8*=1 causes the summary and tally information to be averaged over active cycles only; *kc8*=0 causes the summary and tally information to be averaged over active and inactive cycles {1}	3.3.4.9
KOPTS	KEYWORDS=<*values*> ... Keywords: BLOCKSIZE = *ncy*, the number of cycles in blocks for adjoint weighting {10} KINETICS = YES, calculate point-kinetics information = NO, do not calculate point-kinetics information {NO} PRECURSOR = YES, calculate detailed precursor information = NO, do not calculate detailed precursor information {NO} KSENTAL = MCTAL, write the sensitivity profiles in a MCTAL-like file.	3.3.4.11
KPERT*n*	KEYWORDS=<*values*> ... Keywords: CELL = list of cells to which to apply the perturbation MAT = list of materials that are to be substituted in each of the perturbed cells listed in the CELL keyword. RHO = list of densities corresponding to each of the perturbed cells listed in the CELL keyword. ISO = list of ZAIDs that the perturbation impacts. RXN = list of MT or special reaction numbers that the perturbation impacts. ERG = list of energies over which to apply the perturbation. LINEAR = YES, do not use the perturbed fission source in the denominator. = NO, use the perturbed fission source in the denominator.	3.3.5.22

Card Name	Description	Section
KSEN*n*	*sens* KEYWORDS=<*values*> ... *where* *sens*=XS indicates a cross-section or nuclear data sensitivity. Keywords: CELL = list of cell numbers for spatial zoning. MAT = Like the CELL keyword except material numbers are used as opposed to cell numbers. Zones are defined to encompass all cells containing that material. ISO = list of ZAIDs for which sensitivities are desired. RXN = list of reaction MT numbers of special reaction numbers. ERG = list of energy bin boundaries over which to provide the sensitivities. For cross sections and fission **ν**, energies are those entering the collision; for fission-chi and scattering laws, energies are those exiting the collision. (Minimum of two entries.) EIN = range of incident energy bins. (fission-chi or scattering law sensitivities only). COS = range of direction-change cosines for the scattering events (scattering law only). CONSTRAIN = NO, do not renormalize the energy (or cosine) sensitivity distribution. = YES, renormalize the energy(or cosine) sensitivity distribution.	3.3.5.23
KSRC	x_1 y_1 z_1 x_2 y_2 z_2 ... where x_i y_i z_i are the locations of initial neutron source points in fissile material	3.3.4.10
LAT	*n* or n_1 n_2 ... n_N where *n* defines the cell as an infinite square lattice comprised of hexahedra (*n*=1) or triangular lattice comprised of hexagonal prisms (*n*=2) as presented on a cell card n_i defines the *i*th cell as an infinite square lattice comprised of hexahedra (*n*=1) or triangular lattice comprised of hexagonal prisms (*n*=2) as presented on a data card, where the number of entries must equal the number of cells in the problem, N.	3.3.1.5.2
LCA	*ielas ipreq iexisa ichoic jcoul nexite npidk noact icem* where *ielas*=0 indicates no nucleon elastic scattering *ielas*=1 indicates elastic scattering for neutrons only *ielas*=2 indicates elastic scattering for neutrons and protons {default} *ipreq*=0 indicates no pre-equilibrium model will be used *ipreq*=1 indicates use of pre-equilibrium model after intranuclear cascade {default} *ipreq*=2 and *iexisa*=0 causes *ipreq*=1 and *ipreq*=3 to be selected randomly, with an energy-dependent probability that goes to *ipreq*=3 at low energies and to *ipreq*=1 at high incident energies. (If *iexisa*≠0, defaults to *ipreq*=1.) *ipreq*=3 and *iexisa*=0 causes the use of pre-equilibrium model instead of the intranuclear cascade. (If *iexisa*≠0, defaults to	3.3.3.7.2

Card Name	Description	Section
	ipreq=1.) *iexisa*=0 prohibits use of ISABEL intranuclear cascade (INC) model for any particle {default if *icem*=2} *iexisa*=1 causes use of Bertini model for nucleons and pions and ISABEL model for other particle types {default} *iexisa*=2 causes use of ISABEL model for all incident particle types The parameter *ichoic* is a combination of four integers (*ijkl*) that control the ISABEL intranuclear cascade model: {0023} *i*=0 causes use of partial Pauli blocking *i*=1 causes use of total Pauli blocking *i*=2 prohibits use of Pauli blocking *j*=0 causes no interaction between particles already excited above the Fermi sea *j*>0 is the number of time steps to elapse between such "CAS-CAS" interactions *k*=0 causes use of Meyer's density prescription with 8 steps *k*=1 causes use of original (isobar) density prescription with 8 steps *k*=2 causes use of Krappe's folded-Yukawa prescription for radial density in 16 steps, with a local density approximation to the Thomas-Fermi distribution for the (sharp cutoff) momentum distribution. *k*=3 is the same as *k*=0 but using the larger nuclear radius of the Bertini model *k*=4 is the same as *k*=1 but using the larger nuclear radius of the Bertini model *k*=5 is the same as *k*=2 but using the larger nuclear radius of the Bertini model *l*=1 causes reflection and refraction to be performed at the nuclear surface, but no escape cutoff for isobars *l*=2 causes reflection and refraction to be performed at the nuclear surface, with escape cutoff for isobars *l*=3 prohibits reflection and refraction from being performed, with escape cutoff for isobars *l*=4 is the same as *l*=1 but using a 25-MeV potential well for pions *l*=5 is the same as *l*=2 but using a 25-MeV potential well for pions *l*=6 is the same as *l*=3 but using a 25-MeV potential well for pions *jcoul*=1 indicates the Coulomb barrier is on {default} *jcoul*=0 indicates the Coulomb barrier is off *nexite*=1 indicates the nuclear recoil energy is subtracted to get excitation energy *nexite*=0 indicates the nuclear recoil energy is NOT subtracted to be excitation energy *npidk*=0 forces π^- to interact by nuclear capture (INC) when cutoff is reached {default} *npidk*=1 forces π^- to terminate by decay at the pion cutoff energy *noact*=-2 causes source particles immediately to collide; all progeny escape *noact*=-1 allows nuclear interactions of source particles only;	

Card Name	Description	Section
	transport and slowing down are turned off *noact*=0 turns off all non-elastic reactions *noact*=1 performs normal transport {default) *noact*=2 indicates attenuation mode—transport primary source particles without non-elastic reactions *icem*=0 causes use of the Bertini or ISABEL model determined by the *iexisa* parameter *icem*=1 causes use of the CEM03.03 model {default} *icem*=2 causes use of the INCL4 model (default evaporation model is ABLA) *ilaq*=0 causes use of LAQGSM03.03 to handle all heavy-ion interactions as well as all light-ion interactions above 940 MeV/nucleon. ISABEL will handle light-ion interactions below this energy. Use LAQGSM03.03 for protons and neutrons above the energy cutoff specified by parameters *flenb1* and *flenb2* on the LCB card *ilaq*=1 causes use of LAQGSM03.03 to handle all heavy-ion interactions as well as all light-ion interactions.	

Card Name	Description	Section
LCB	*flenb1 flenb2 flenb3 flenb4 flenb5 flenb6 ctofe flim0* where *flenb1* is the kinetic energy for nucleons below which the CEM/Bertini/INCL INC model will be used {3500 MeV} *flenb2* is the kinetic energy for nucleons above which the LAQGSM03.03 high-energy generator will be used {3500 MeV} *flenb3* is the kinetic energy for pions below which the CEM/Bertini/INCL INC model will be used {2500 MeV} *flenb4* is the kinetic energy for pions above which the LAQGSM03.03 high-energy generator will be used {2500 MeV} *flenb5* is the kinetic energy for nucleons below which the ISABEL INC model will be used {800 MeV} *flenb6* is the kinetic energy for nucleons above which an appropriate model will be used; if *iexisa*=2, *flenb6* applies to all particle types; if *iexisa*=1, *flenb6* applies to all particles except nucleons and pions {800 MeV} *ctofe*≥0 is the cutoff kinetic energy for particle escape during the INC when using the Bertini model *ctofe*<0 creates a random cutoff kinetic energy for particle escape during the INC when using the Bertini model that is uniformly distributed from zero to twice the mean binding energy of a nucleon and is sampled for each projectile-target interaction and separately for neutrons and protons. {-1.0} *flim0*>0 indicates the correction for mass-energy balancing in the cascade stage will permit the kinetic energies of secondary particles to be reduced by no more than a fraction of *flim0* in attempting to obtain a non-negative excitation of the residual nucleus and a consistent mass-energy balance; a cascade will be resampled if the correction exceeds *flim0* *flim0*=0 indicates no correction for mass-energy balancing will be attempted and a cascade will be resampled if a negative excitation is produced *flim0*<0 causes the maximum correction for mass-energy balancing in the cascade stage to be 0.02 for incident energy above 250 MeV, 0.05 for incident energy below 100 MeV, and equal to 5/(incident energy) between those limits {-1}	3.3.3.7.3
LCC	*stincl v0incl* {1.0 45} where *stincl* is a rescaling factor of the cascade duration {1.0} *v0incl* is the potential depth {45}	3.3.3.7.4

Card Name	Description	Section
LEA	*ipht icc nobalc nobale ifbrk ilvden ievap nofis* where *ipht*=0 causes generation of de-excitation photons to be off *ipht*=1 causes generation of de=excitation photons to be on {default} *icc*=0 causes use of the continuum model for the PHT physics *icc*=1 causes use of the Troubetzkoy (E1) model for the PHT physics *icc*=2 causes use of the intermediate model (hybrid between *icc*=1 and *icc*=2) for the PHT physics *icc*=3 causes use of the spin-dependent model for the PHT physics *icc*=4 causes use of the full model with experimental branching ratios for the PHT physics {default} *nobalc*=0 causes use of mass-energy balancing in the cascade phase *nobalc*=1 turns off use of mass-energy balancing in the cascade phase {default} *nobale*=0 causes use of mass-energy balancing in the evaporation stage {default} *nobale*=0 turns off use of mass-energy balancing in the evaporation stage *ifbrk*=1 causes use of Fermi-breakup model for atomic mass number A≤13 and for 14≤A≤20 with excitation below 44 MeV {default} *ifbrk*=0 causes use of Fermi-breakup model for atomic mass number A≤5 *ilvden*=-1 causes use of original HETC level-density formulation *ilvden*=0 causes use of Gilbert-Cameron-Cook-Ignatyuk level-density model {default} *ilvden*=1 causes use of the Julich level-density parameterization as a function of mass number *ievap*=0 causes use of RAL fission evaporation model {default) *ievap*=1 causes use of ORNL fission evaporation model *ievap*=2 causes use of ABLA fission evaporation model *nofis*=1 allows fission {default} *nofis*=0 suppresses fission	3.3.3.7.5
LEB	*yzere bzere yzero bzero* where *yzere* is the Y0 parameter in the level-density formula for atomic number Z≤70 {1.5} *bzere* is the B0 parameter in the level-density formula for atomic number Z≤70 {8.0} *yzero* is the Y0 parameter in the level-density formula for atomic number Z≥71 and all fission fragments {1.5} *bzero* is the B0 parameter in the level-density formula for atomic number Z≥71 and all fission fragments {10 for *ievap*=0 and for *ievap*=1}	3.3.3.7.6
LOST	*lost1 lost2* {10 10} where *lost1* is the number of particles which can be lost before the job aborts *lost2* is the maximum number of debug prints made for lost particles	3.3.7.3.3

<table>
<tr><th>Card Name</th><th>Description</th><th>Section</th></tr>
<tr><td>Mm</td><td>zaid₁ fraction₁ zaid₂ fraction₂ ... [KEYWORD=value(s) ...]
where m corresponds to the material number on a cell card
zaid_i is a full ZZZAAA.abx or partial ZZZAAA identifier for constituent i and where ZZZ represents the atomic number, AAA the atomic mass, ab the specified library, and x the data class
Keyword:
GAS = j, a flag or density correction to electron stopping power, where j=0 indicates the material is in the solid or liquid state {default} and j=1 indicates the material is in the gaseous state
ESTEP = n1, the number of electron sub-steps per energy step
HSTEP = n2, the number of proton or other charged-particle sub-steps (exclusive of electrons, but including heavy ions) per energy step
NLIB = abx, changes the default neutron table identifier to abx
PLIB = abx, changes the default photon table identifier to abx
PNLIB = abx, changes the default photonuclear table identifier to abx
ELIB = abx, changes the default electron table identifier to abx
HLIB = abx, changes the default proton table identifier to abx
COND = j, a flag that sets the conduction state of a material for EL03 evaluation, where j>0 indicates material is a conductor if at least one conducting component, j=0 indicates material is a non-conductor if at least one non-conducting component, and j<0 indicates material is a non-conductor</td><td>3.3.2.1</td></tr>
<tr><td>MESH</td><td>KEYWORD=value(s) ...
Keyword:
GEOM {XYZ} = XYZ or REC for Cartesian mesh geometry; RZT or CYL for cylindrical geometry
REF = x,y,z coordinates of reference point
ORIGIN {0 0 0} = x,y,z coordinates in MCNP6 cell geometry superimposed mesh origin (bottom center for cylindrical or bottom; left, behind for rectangular
AXS {0 0 1} = direction vector of the cylindrical mesh axis
VEC {1 0 0} = direction vector, along with AXS that defines the plane for angle θ=0
IMESH = coarse mesh locations in x (rectangular) or r (cylindrical) direction
IINTS {1} = number of fine meshes within corresponding coarse meshes
JMESH = coarse mesh locations in y (rectangular) or z (cylindrical) direction
JINTS {1} = number of fine meshes within corresponding coarse meshes
KMESH = coarse mesh locations in z (rectangular) or θ (cylindrical) direction
KINTS {1} = number of fine meshes within corresponding coarse meshes</td><td>3.3.6.4.4</td></tr>
</table>

Card Name	Description	Section
MGOPT	*mcal igm iplt isb icw fnw rim* where *mcal*=F indicates a forward multigroup problem *mcal*=A indicates an adjoint problem (adjoint KCODE is not allowed) *igm* is the total number of energy groups for all kinds of particles in the problem; a negative total indicates a special electron-photon problem *iplt*=0 indicates IMP values set the cell importances; weight windows are ignored for cell importance splitting and Russian roulette {default} *iplt*=1 indicates weight windows are provided and are transformed into energy-dependent cell importances *iplt*=2 indicates weight windows do what they normally do *isb*=0 specifies that adjoint collisions are biased by infinite-medium fluxes {default} *isb*=1 specifies that adjoint collisions are biased by weight-window functions *isb*=2 specifies that adjoint collisions are not biased *icw*=0 specifies that weight windows are not generated {default} *icw*≠0 is the reference cell name for generated weight windows; requires volumes be supplied or calculated for all cells of non-zero importance *fnw* is the normalization value for generated weight windows {1} *rim* is the generated weight-windows compression limit {1000}	3.3.2.11
MODE	<*pl*>$_1$ ... <*pl*>$_M$ where <*pl*>$_i$ are particle designators of particles to be transported in the problem {N}	3.3.3.1
MPHYS	MPHYS [ON/OFF] MPHYS OFF Disable the use of physics models. {Default for MODE N, P, E} MPHYS ON Enable use of physics models. {Default for MODE other than N, P, E.}	3.3.3.7.1
MPLOT	KEYWORD=*value(s)* ... Allows plots to be produced while the problem is running. See manual, Section 5.3.3 for lists of keywords.	3.3.7.2.5
MSHMF*j*	e_1 f_1 e_2 f_2 ... e_i f_i where *j* is an arbitrary integer between 1 and 9 e_i f_i are pairs of energies and the corresponding response functions	3.3.5.24.1
MT*m*	x_1 ... where *m* is the material identifier on a corresponding M*m* card x_i is an $S(\alpha,\beta)$ thermal neutron treatment identifier corresponding to an isotope for material *m* on the M*m* card	3.3.2.2

Card Name	Description	Section
MX*m*:<*pl*>	$zaid_1$ $zaid_2$ ... where *m* is the material number of an M*m* card that must precede the MX*m* card <*pl*> is the particle identifier [N (neutron), P (photonuclear), H (proton), A (alpha), D (deuteron), T (triton), and S (hellion)] $zaid_i$ is the ZZZAAA identifier of replacement nuclide for the i^{th} nuclide on the M*m* card.	3.3.2.3
NONU	*a* or [a_1 a_2 ... a_N] where *a*=0 indicates fission in the cell is to be treated as capture, gammas are produced (cell card format) {default} *a*=1 indicates fission in the cell is to be treated as real, gammas are produced (cell card format) *a*=2 indicates fission in the cell is to be treated as capture, gammas are not produced (cell card format) a_i=0 indicates fission in cell *i* is to be treated as capture, gammas are produced (data card format) {default} a_i=1 indicates fission in cell *i* is to be treated as real, gammas are produced (data card format) a_i=2 indicates fission in cell *i* is to be treated as capture, gammas are not produced (data card format) a_i values have no entry indicates fission in all cells is to be treated like capture (data card format)	3.3.2.7
NOTRN	If the NOTRN card appears in the INP file, only direct (unscattered) contributions are made to point detectors and the detector grid	3.3.5.20
NPS	*npp npsmg* where *npp* is the total number of histories to be run in the problem *npsmg* is the number of histories for which direct source contributions are to be made to a radiography grid.	3.3.7.1.1
OTFDB	OTFDB $zaid_1$ $zaid_2$ ... where $zaid_i$ are the ZZZAAA.*abx* identifiers for OTF Doppler broadening data tables.	3.3.2.5
PD*n*	*p* or p_1 p_2 ... p_N where *n* is a tally number ending in 5 *p* is the probability of contribution to detector *n* from cell (cell card format) {1} p_i is the probability of contribution to detector *n* from cell *i* (data card format {1 for all *i*'s}	3.3.6.12

Card Name	Description	Section
PERT*n*:<*pl*>	KEYWORD=*value(s)* ... where *n* is a unique arbitrary perturbation number ≤99999999 <*pl*> is the particle designator [N (neutron), P (photon), or N,P (combined neutron-photon)] Keywords: CELL c_1 ... c_k = comma or space delimited list of cells to which to apply perturbation MAT *m* = single material number of an existing M*m* card with which to fill all cells listed in CELL keyword RHO *rho* = single value of perturbed density of cells listed after CELL keyword METHOD {1} = 1 performs 1st and 2nd order perturbation calculation and prints the differential change in the tally = 2 performs 1st order perturbation calculation only and prints the differential change in the tally = 3 performs 2nd order perturbation calculation only and prints the differential change in the tally = -1, -2, or -3 same as above except the perturbed tally is printed rather than the differential ERG e_{LB} e_{UB} = lower and upper energy entries to specify energy range for perturbation RXN rx_1 ... = ENDF/B reaction numbers to which to apply perturbation	3.3.5.21

Card Name	Description	Section
PHYS:E	*emax ides iphot ibad istrg bnum xnum rnok enum numb i_mcs_model* J J *efac electron_method_boundary* where *emax* is the upper limit for electron energy {*emax* on PHYS:N card or 100 MeV if no PHYS:N card} *ides*=0/1 indicates photons will/will not produce electrons {0} *iphot*=0/1 indicates electrons will/will not produce photons {0} *ibad*=0 provides full bremsstrahlung tabular angular distribution {default} *ibad*=1 provides simple bremsstrahlung angular distribution approximation *istrg*=0/1 indicates sampled/expected-value straggling for electron energy loss {0} *bnum*=0 indicates bremsstrahlung photons will not be produced *bnum*>0 specifies the production of *bnum* times the analog number of bremsstrahlung photons {1} *bnum*<0 is a special bremsstrahlung treatment for EL03 electrons *xnum*=0 indicates x-ray photons will not be produced by electrons *xnum*>0 specifies the production of *xnum* times the analog number of electron-induced x-rays {1} *rnok*=0 indicates knock-on electrons will not be produced *rnok*>0 specifies the production of *rnok* times the analog number of knock-on electrons {1} *enum*=0 indicates photon-induced secondary electrons will not be produced *enum*>0 specifies the production of *enum* times the analog number of photon-induced secondary electrons {1} *numb*=0 specifies analog bremsstrahlung production {default} *numb*>0 specifies production of bremsstrahlung on each sub step *i_mcs_model*=1 specifies turn off angular deflection *i_mcs_model*=0 specifies select the standard Goudsmit-Sunderson angular deflection method. *efac* specifies the stopping power energy spacing {0.917} *electron_method_boundary* specifies the energy above which MCNP6 transports electrons by the condensed-history algorithms and below which the single-event method is used. {1.0e-3}	3.3.3.2.3

Card Name	Description	Section
PHYS:H	*emax ean tabl* J *istrg* J *recl* J J J *i_mcs_model i_int_model i_els_model efac* where *emax* is the proton upper energy limit {*emax* on PHYS:N card or 100 MeV if no PHYS:N card} *ean* is the analog energy limit above which implicit energy is performed and below which analog capture is performed {0} *tabl*≥0 specifies the use of physics models for energies above table and data tables for those below tabl, if available (otherwise use models) *tabl*=-1 specifies the use of data tables up to their upper limit for each nuclide and then use physics models above this energy J is an unused placeholder (for both the 4th , 6th , and 7th through 9th entries) *istrg*=0 specifies use of Vavilov model for charged-particle straggling {default} *istrg*=1 specifies use of continuous slowing-down approximation for charged-particle straggling *recl*=0 specifies no light-ion recoil {default} 0<*recl*≤1 specifies the number of light ions to be created at each proton elastic scatter event with light nuclei H, D, T, ^{3}He, and ^{4}He *i_int_model*=-1 specifies to turn off angular deflection *i_int_model*=0 specifies to process all interactions *i_int_model*=1 specifies no secondaries, inelastic collisions treated as weight reduction *i_int_model*=2 specifies no secondaries, inelastic collisions treated as removal *i_els_model*=-1 specifies no elastic scattering *i_els_model*=0 specifies elastic scattering by Prael/Liu/Striganov model *efac* controls stopping power energy spacing {0.917}	3.3.3.2.4

Card Name	Description	Section
PHYS:N	*emax emcnf iunr* J J J *coilf cutn ngam* J J *i_int_model i_els_model* where *emax* is the upper limit for neutron energy {100} *emcnf* is the analog energy limit above which implicit energy is performed and below which analog capture is performed {0} *iunr*=0/1 indicates that unresolved resonance range probability tables are on/off *coilf*=0 indicates light-ion recoil is off, NCIA is off .001<*coilf*<1.001 light-ion recoil makes *coilf* ions from elastic scatter 1.001<*coilf*<2.001 light-ion recoil makes *coilf*-1 ions from elastic scatter, NCIA ions from neutron capture *coilf=3* indicates light-ion recoil is off, NCIA ions from neutron capture 3.001<*coilf*<4.001 light-ion recoil makes *coilf*-3 ions from elastic scatter, NCIA ions from neutron capture *coilf=5* indicates light-ion recoil is off, NCIA ions from neutron capture *cutn*≥*0* specifies to use physics models for energies above *cutn* and data tables for energies below *cutn* if available, else use models *cutn*=-1 specifies to mix and match, using tables where available to the tables' upper energy limits, then use physics models *cutn*>*emax* specifies to eliminate all model physics arrays *ngam*=0 no photons are produced *ngam*=1 photons are produced using ACE. (Default) *ngam*=2 photons are produced using CGM. *i_int_model*=-1 specifies no interactions *i_int_model*=0 specifies to process all interactions *i_int_model*=1 specifies no secondaries, inelastic collisions treated as weight reduction *i_int_model*=2 specifies no secondaries, inelastic collisions treated as removal *i_els_model*=-1 specifies no elastic scattering *i_els_model*=0 specifies elastic scattering by Prael/Liu/Striganov model	3.3.3.2.1

Card Name	Description	Section
PHYS:P	*emcpf ides nocoh ispn nodop* J *fism* where *emcpf* is the upper energy limit for detailed photon physics treatment {*emax* on PHYS:N card or 100 MeV if no PHYS:N card} *ides*=0 indicates that generation of electrons in MODE E problems or bremsstrahlung photons with the thick-target bremsstrahlung model is turned on {default} *ides*=1 indicates that generation of electrons in MODE E problems or bremsstrahlung photons with the thick-target bremsstrahlung model is turned off *nocoh*=0/1 specifies coherent scattering will/will not occur {0} *ispn*=1/0/-1 specifies biased/none/analog photonuclear production is turned on {0} *nodop*=0/1 indicates photon Doppler energy broadening will/will not occur {0} *fism*=0/1 indicates to sample fission from ACE libraries/LLNL fission model	3.3.3.2.2

Card Name	Description	Section
PHYS:<*pl*>	*emax* J J J *istrg* J *xmunum xmugam* J J *i_mcs_model i_int_model i_els_model efac* where <*pl*> is a particle designator other than N, P, E, or H *emax* is the particle upper energy limit {*emax* on PHYS:N card or 100 MeV if no PHYS:N card} J is an unused placeholder *istrg*=0 specifies use of Vavilov model with an energy correction addressing stopping powers {default} *istrg*=1 specifies use of continuous slowing-down ionization model *xmunum*=-1 specifies use only x-ray literature data *xmunum*=1 specifies emit all x-rays including data from literature and from the MUON/RURP code package *xmugam* specifies the probability for emitting k-shell photon {0.65} *i_mcs_model*=-1 specifies turn off angular deflection *i_mcs_model*=0 specifies to use FermiLab angular deflection model with Vavilov straggling *i_mcs_model*=1 specifies to use Gaussian angular deflection model with Vavilov straggling *i_mcs_model*=2 specifies to use FermiLab couple energy/angle MCS model *i_int_model*=-1 specifies no interactions *i_int_model*=0 specifies to process all integrations *i_int_model*=1 specifies no secondaries, inelastic collisions treated as weight reduction *i_int_model*=2 specifies no secondaries, inelastic collisions treated as removal *i_els_model*=-1 specifies no elastic scattering *i_els_model*=0 specifies elastic scattering by Prael/Liu/Striganov model *efac* controls stopping power energy spacing {0.917}	3.3.3.2.5
PIKMT	$zaid_1$ $ipik_1$ $mt_{1,1}$ $pmt_{1,1}$ .... $mt_{1,ipik_1}$ $pmt_{1,ipik_1}$ $zaid_2$ ... where $zaid_i$ is the full or partial element identifier of the i^{th} data-set entry $ipik_i$=0 indicates no biasing of photon production for $zaid_i$ $ipik_i$=-1 indicates no photons are produced from $zaid_i$ $ipik_i$>0 indicates biased photon-production for $zaid_i$ with $ipik_i$ partial photon-production reactions to be sampled $mt_{i,j}$ is an identifier for photon-production reactions to be sampled (valid only if $ipik_i$>0) $pmt_{i,j}$ controls the frequency with which the specified *mt* reactions are sampled (valid only if $ipik_i$>0)	3.3.6.15

Card Name	Description	Section
PRDMP	*ndp ndm mct ndmp dmmp* {end of problem -60 0 large 0} where *ndp*>0 specifies to print tallies every *ndp* histories or kcode cycles {end of problem} *ndp*<0 specifies to print tallies every *ndp* minutes of running time *ndm*>0 specifies to dump to the RUNTPE file every *ndm* histories or criticality cycles *ndm*<0 specifies to dump to the RUNTPE file every *ndm* minutes of running time {-60} *mct*>0 specifies to write a MCTAL file at problem completion *mct*=0 suppresses the printing of a MCTAL file {DEFAULT} *mct*=-1 specifies to write a MCTAL file at problem completion, but references to code name, version number, problem ID, figure of merit, and anything else having to do with running time are omitted from MCTAL and OUTP *mct*=-2 specifies that additional prints in OUTP are turned off to assist in comparing multitasking output *ndmp* specifies the maximum number of dumps to be kept on the RUNTPE file {large} *dmmp*>0 specifies to write the tally fluctuation charts every *dmmp* histories or number of KCODE cycles *dmmp*=0 specifies to write the tally fluctuation charts every 1000 particles or, if multiprocessing, 10 times total during the run *dmmp*<0 specifies to write the tally fluctuation charts every 1000 particles	3.3.7.2.3
PRINT	[x_1 x_2 ... x_i ...] or blank or ALL where no entries causes the basic output to be printed {DEFAULT} x_i>0 prints the basic output plus tables x_1, x_2 ... x_i<0 prints the full output except tables x_1, x_2 ... ALL produces the full output print of all tables	3.3.7.2.1

Card Name	Description	Section
PTRAC	KEYWORD=*value(s)* ... <u>Output Control Keywords:</u> BUFFER amount of storage available for filtered events {100} FILE ASC/BIN/AOV/BOV to indicate ASCII output/binary output/ASCII output, overwriting existing ASCII PTRAC file/binary output, overwriting existing binary PTRAC file {BIN} MAX Maximum number of events per history to write to PTRAC file {10000} MEPH Maximum number of events per history to write to PTRAC file{all events} WRITE POS/ALL to specify only x,y,z location with related cell and material numbers / x,y,z location with related cell and material numbers as well as the direction cosines and particle energy, weight, and time {POS} <u>Event Filter Keywords (one or more events can be specified):</u> EVENT = SRC, initial source events = BNK, bank events = SUR, surface events = COL, collision events = TER, termination events = CAP, coincident capture events FILTER specifies additional MCNP6 variables for filtering; the parameter values consist of one numerical entry (representing an exact value) or two numerical entries (representing a range of values) and a variable mnemonic TYPE list of particle identifiers for which to filter events {all} <u>History Filter Keywords:</u> NPS =*a,b* where $a<b$, sets the range of particle histories for which events will be output {all histories} CELL = list of cell numbers that will contribute to PTRAC file SURFACE = list of surface numbers that will contribute to PTRAC file TALLY = list of tally numbers that will contribute to PTRAC file; a negative TALLY entry indicates that the corresponding VALUE entry is a multiplier rather than an absolute value VALUE = the tally fluctuation chart cutoff above which history events will be written; number of entries must equal the number of entries of the TALLY keyword {10}	3.3.7.2.4
PWT	w or w_1 w_2 ... w_j where $w>0$ specifies that photons are produced with weights $>w$ times the ratio of the source cell importance to collision cell importance $w=0$ specifies that exactly one proton per neutron collision is created in the cell $w<0$ specifies that photon production is relative to the starting source weight $w=-1.0e6$ turns off neutron-induced photon production in the cell w_j is the relative threshold weight of photons produced at neutron collisions in the j^{th} cell (data card entries) and the interpretation of the entries is the same as for the cell-card entries above; number of entries must equal the number of cells in the problem	3.3.6.17

Card Name	Description	Section
RAND	KEYWORD=*value(s)* ... Keywords: GEN *n* = type of pseudorandom number generator to be used by MCNP6 {1} *n*=1 selects MCNP6 Lehmer 48-bit congruential generator *n*=2 selects L'Ecuyer 63-bit generator number 1 (period=9.2×10^{18} numbers) *n*=3 selects L'Ecuyer 63-bit generator number 2 (period=9.2×10^{18} numbers) *n*=4 selects L'Ecuyer 63-bit generator number 3 (period=9.2×10^{18} numbers) SEED *m* = initial random number generator seed (must end in odd digit) {19073486328125} STRIDE *j* = number of random numbers between source particles {152917} HIST *k* = advance generator to start first history with history *k* random number {1}	3.3.7.3.1
RDUM	r_1 r_2 ... r_{50} {all 0} where r_i is a real number for the i^{th} entry	3.3.7.3.5
READ	KEYWORD=*value(s)* ... Keywords: FILE *fn* causes input from the file *fn* to be inserted after the READ card in the MCNP6 input deck NOECHO suppresses printing of the input cards following the READ card ECHO resumes echoing of the input after a NOECHO keyword was given in a previous READ card; echoing also will resume with the next READ card is encountered without the NOECHO keyword DECODE *pwd* allows reading of an encrypted file; the encrypted input file is not echoed and many default print tables are turned off to protect data in the encrypted file ENCODE *pwd* allows writing of an encrypted file	3.1
RMESH*i*:<*pl*>	See CMESH*i*:<*pl*>.	

<table>
<tr><th>Card Name</th><th>Description</th><th>Section</th></tr>
<tr><td>SBn</td><td>option b_1 ... b_k or f a b
where n is the distribution number corresponding to the distribution number on the SDEF and SIn cards
option determines how the b values will be interpreted:
D indicates b values are bin probabilities for an H or L distribution on SIn card
C indicates b values are cumulative bin probabilities for H or L distribution on the SIn card
V indicates b values are for cell distributions and probabilities are proportional to cell volumes
if no option value is given, it is the same as D for an H or L on the SIn card or probability density for an A distribution on the SIn card
b_i are source-variable biased probability values
f is a designator for a built-in function. Only allowed values are
-21 power law $p(x)=c|x|^a$ (valid for DIR, RAD, or EXT)
-31 exponential $p(\mu)=e^{a|\mu|}$ (valid for DIR or EXT)
a and b are parameters for the built-in function</td><td>3.3.4.4</td></tr>
<tr><td>SCn</td><td>comment
where n is the distribution number
comment is user-supplied text describing the source</td><td>3.3.4.6</td></tr>
<tr><td>SDn</td><td>(d_{11} ... d_{1m}) (d_{21} ... d_{2m}) ... (d_{k1} ... d_{km})
where n is the tally number (cannot end in 5 or 8 and cannot be 0)
k is the number of cells or surfaces of Fn card, including T if present
m is the number of segmenting bins on the FSn card, including the remainder segment and the total segment if FSn has a T
d_{ij} are the area, volume, or mass of the j^{th} segment of the i^{th} surface or cell bin for tally n</td><td>3.3.5.15</td></tr>
</table>

Card Name	Description	Section
SDEF	KEYWORD=*value(s)* ... Keywords: CEL starting source cell number or cell rejection SUR starting source surface number {0 for cell source} ERG source energy {14 MeV} TME source time {0 shakes} DIR cosine of the angle between VEC and *uuu*,*vvv*,*www* {Azimuthal angle is always sampled uniformly in 0º to 360º; isotropic if volume source; cosine distribution if surface source} VEC Reference vector for DIR in vector notation {Volume source: required unless volume source is isotropic; Surface source: normal to surface with sign determined by NRM} NRM Sign of the surface normal {+1} POS Reference point for position sampling in vector notation {0,0,0} RAD Radial distance of the position from POS or AXS {0} EXT Distance from POS along AXS for a volume source; cosine of angle from AXS for surface source {0} AXS Reference vector for EXT and RAD {no direction} X X-coordinate of position {0} Y Y-coordinate of position {0} Z Z-coordinate of position {0} CCC Cookie-cutter cell for rejection ARA Surface area (required only for direct contributions to point detectors from plane surface) WGT Particle weight (input as explicit value only) {1} TR Source particle transformation (A corresponding TR*n* card is required) EFF Rejection efficiency criterion for position sampling (input as explicit value only) {0.01} PAR Source particle type by symbol or number; add negative sign for antiparticle and use a distribution for sampling multiple particle types; to specify a particular heavy ion, set PAR to ZZZAAA, the isotope identifier of the ion; PAR may be set to SF for spontaneous fissions {If no MODE card, N; If MODE card, lowest IPT number or symbol represented on MODE card} To specify individual repeated-structure/lattice sources: s_1 (s_2 ... s_3) ((s_4 s_5)<(c_1 c_2[i_1 ... i_2])<(c_3 c_4 c_5)) ... where s_i is the problem number of a cell or surface, a universe (U) number as defined in a FILL array, or T c_i is a problem number of a cell filled with a universe or a universe (U) number (U) i_i is index data for a lattice cell element with three possible formats: *i* — the *i*th lattice element of cell c_2 as defined in the FILL array i_1:i_2 i_3:i_4 i_5:i_6 — a range of lattice elements (defined in FILL array) i_1 i_2 i_3, i_4 i_5 i_6 — specific lattice elements (i_1,i_2,i_3) and (i_4,i_5,i_6)	3.3.4.1

Card Name	Description	Section
SF*n*	s_1 ... s_k where *n* is a tally number not ending in 5, 8 or 0 s_i are problem surface numbers whose tally contributions are to be flagged when a particle crosses any of the s_i surfaces including macrobody facets	3.3.5.13
SI*n*	*option* i_1 ... i_k where *n* is the distribution number corresponding to the distribution number on the SDEF card *option* determines how the *i* values will be interpreted: H or absent indicates *i* values are monotonically increasing bin boundaries of a histogram probability distribution L indicates *i* values are discrete source-variable values A indicates *i* values are points where a probability density is defined (Entries must be monotonically increasing, with the lowest and highest values defining the range of the variable.) S indicates *i* values are distribution numbers (these can also have the S option) i_i are source-variable values or distribution numbers	3.3.4.2
SMESH*i*:<*pl*>	See CMESH*i*:<*pl*>.	
SPABI:<*pl*>	*xxx*... e_1 s_1 e_2 s_2 ... where <*pl*> is the secondary particle designator *xxx* is an undelimited list of primary particles to be considered (e.g., NPHE); if all particles are to be considered, the entry should be ALL e_i is the upper energy bin limit of secondary particles; the lower bin limit is assumed to be zero s_i>1 indicates to use splitting 0≤s_i≤1 indicates to use roulette	3.3.6.16
SPDTL	KEYWORD where FORCE forces the use of the lattice speed tally enhancement OFF prevents the user of the lattice speed tally enhancement	3.3.5.26

Card Name	Description	Section
SP*n*	*option* p_1 ... p_k or *f a b* where *n* is the distribution number corresponding to the distribution number on the SDEF and SI*n* cards *option* determines how the *p* values will be interpreted: D indicates *p* values are bin probabilities for an H or L distribution on SI*n* card {DEFAULT} C indicates *p* values are cumulative bin probabilities for H or L distribution on the SI*n* card V indicates *p* values are for cell distributions and probabilities are proportional to cell volumes if no *option* value is given, it is the same as D for an H or L on the SI*n* card or probability density for an A distribution on the SI*n* card p_i are source-variable probability values *f* is a designator for a built-in function. Allowed values are -2 Maxwell fission spectrum (valid for ERG); uses *a* with default value of 1.2895 MeV -3 Watt fission spectrum (valid for ERG); uses *a* and *b* with default values of 0.965 MeV and 2.29 MeV^{-1}, respectively -4 Gaussian fusion spectrum (valid for ERG); uses *a* and *b* with default values of -0.01 MeV and -1, respectively -5 evaporation spectrum (valid for ERG); uses *a* with default value of 1.2895 MeV -6 Muir velocity Gaussian fusion spectrum (valid for ERG); uses *a* and *b* with default values of -0.01 MeV and -1, respectively -7 spare functions for the user to add one (valid for ERG); uses *a* and *b* -21 power law $p(x)=c\|x\|^a$ (valid for DIR, RAD, or EXT), uses *a* where the default value is 1 for DIR; 1 or 2 for RAD; and 0 for EXT -31 exponential $p(\mu)=ce^{a\|\mu\|}$ (valid for DIR or EXT); uses *a* with a default value of 0 -41 Gaussian distribution in time or position (valid for TME or X,Y,Z); uses *a* and *b* with default for *b* =0, none for *a* *a* and *b* are parameters for the built-in function	3.3.4.3

Card Name	Description	Section
SSR	KEYWORD=*value*(*s*) ... Keywords: OLD s_1 s_2 ... — list of problem surface numbers, including facets, that are a subset of the surfaces on the SSW card {all surfaces in original run} CEL c_1 c_2 ... — list of cells in which KOCDE fission particles were written {all cells in original run} NEW s_{a1} s_{a2} ... s_{an} s_{b1} s_{b2} ... s_{bn} — surface numbers from which to start particles in this run {OLD} PTY <*pl*>$_1$ <*pl*>$_2$ ... — source particle types {all particles types in original run} COL — =-1 indicates to start only those particles that came directly from the source without a collision =0 indicates to start particles without regard to collisions {0} =1 indicates to start only particles with collisions before crossing the surface WGT — constant particle weight multiplier for accepted particles {1} TR *n* — a transformation number (TR*n*) or distribution number D*n* (SI*n*, SP*n*, SB*n*) PSC *c* — a non-negative constant representing the power of polar angle cosine (sphere) for source to detector and DXTRAN $p(\mu)$ AXS *u v w* — direction cosines for reference vector for EXT (sphere only) EXT D*n* — distribution *n* to bias sampling of cosine from AXS (sphere only) POA *c* — minimum polar angle cosine (sphere) for particle acceptance {0} BCW *r zb ze* — cylindrical window of rad *r*, from *zb* to *ze* from sphere center, where 0<*zb* <*ze*.	3.3.4.8
SSW	s_1 s_2 (c_1 ... c_k) s_3 ... s_n KEYWORD=*value*(*s*) ... where s_i is a surface number, with appropriate sign to indicate sense, for which crossing information is written, including facets c_i is a problem cell number; positive value denotes a cell the particle is entering, negative value denotes a cell the particle is leaving Keywords: SYM — =0 indicates no symmetry is assumed {default} =1 indicates spherical symmetry is assumed =2 directs code to write particles bidirectionally crossing the surface(s) PTY <*pl*>$_1$ <*pl*>$_2$ ... — source particle types {all particles types in original run} CEL c_1 c_2 ... — list of cells in which KOCDE fission particles are to be written, active cycles only {all cells in original run}	3.3.4.7

Card Name	Description	Section
STOP	KEYWORDS=*value(s)* Keywords: NPS *n* stop calculation after *n* particle histories CTME *m* stop calculations after *m* minutes of computer time F*k* *e* Stop calculation when the tally fluctuation chart of tally *k* has a relative error less than *e*	3.3.7.1.3
T*n*	t_1 ... t_2 [NT] [C] where *n* is the tally number; 0 applies bins to all tallies without a Tn card t_i upper time of the i^{th} bin of tally *n*; list must be monotonically increasing NT is an optional entry to inhibit automatic total over all time bins C is an optional entry that causes time bin entries to be cumulative	3.3.5.4
TALNP	n_1 n_2 ... where if no entries are provided, turns off bin prints for all tallies in the problem n_i>0 means remove bin prints of this tally number from OUTP file n_i=0 means restore all bin prints; used in a continue-run input file, 0 must be the only entry on the TALNP card n_i<0 means restore bin prints for the tally numbers listed on the TALNP card in a continue-run input file	3.3.7.2.2
TF*n*	i_f i_d i_u i_s i_m i_c i_e i_t where *n* is the tally number; cannot be 0 i_f is the ordinal number of cell, surface, or detector bin on F*n* card {1} i_d is the total, flagged, or un-collided flux {1, total} i_u is the ordinal number of the user bin {last bin} i_s is the ordinal number of the segment bin {last bin} i_m is the ordinal number of the multiplier bin on the FM*n* card {1} i_c is the ordinal number of the cosine bin {last bin} i_e is the ordinal number of the energy bin {last bin} i_t is the ordinal number of the time bin {last bin}	3.3.5.19
THTME	t_1 t_2 ... t_N where t_i are monotonically increasing times for TMP*n* temperatures; number of entries, N, is equal to the total number of thermal times specified	3.3.3.6
TM*n*	m_1 m_2 … m_N where *n* is the tally number; 0 applies to all tallies with a TM*n* card m_i is the multiplier to be applied to the i^{th} time bin of tally *n*; number of entries, N, is equal to the total number of entries on the T*n* card	3.3.5.10
TMESH	Block initiation card indicating that TMESH information cards follow	3.3.5.24
TMP*n*	*t* (cell card entry) $t_{i,n}$ $t_{2,n}$ … $t_{N,n}$ (data card entries) where *n* is the index of time on the THTME card *t* is the temperature of cell at time *n*, in kT (MeV) $t_{i,n}$ is the temperature in kT (MeV) of cell *i* at time *n* on THTME card kT = 8.617×10^{-11} (T+273.15), where T is in degrees Celsius = 4.787×10^{-11} (T+459.67), where T is in degrees Fahrenheit	3.3.3.5

Card Name	Description	Section
TOTNU	[NO] where if card is absent or present with no entry, then the code will use total ν, i.e., prompt and delayed fission neutrons if the "NO" entry appears, only prompt fission neutrons are used	3.3.2.6
TR*n*	o_1 o_2 o_3 *xx' yx' zx' xy' yy' zy' xz' yz' zz' m* {0 0 0 1 0 0 0 1 0 0 0 1 1} where *n* is the number assigned to the transformation o_1 o_2 o_3 is the displacement vector of the transformation {0 0 0} *xx' ... zz'* is the rotation matrix of the transformation {1 0 0 0 1 0 0 0 1} *m*=1 indicates the displacement vector is the location of the origin of the auxiliary coordinate system, defined in the main system {1} *m*=-1 indicates the displacement vector is the location of the origin of the main coordinate system, defined in the auxiliary system	3.3.1.3
TRCL	*n* (cell card entry) (o_1 o_2 o_3 *xx' yx' zx' xy' yy' zy' xz' yz' zz' m*) (data card entry) where *n* is the number of the corresponding TR*n* card data card entries are described in TR*n* card description	3.3.1.4
TROPT	KEYWORDS=*value(s)* Keywords: MCSCAT =OFF, multiple coulomb scattering is disabled, no angular deflection occurs =FNAL1 =GAUSSIAN =FNAL2, treats ELOSS=STRAG1 as ELOSS=CSDA ELOSS =OFF, no energy loss occurs during slowing down =STRAG1, CSDA is used with straggling =CSDA NREACT =OFF, no nuclear reactions occur =ATTEN, attenuation is burned on and absorption weighting occurs at collision =REMOVE, incident particle is killed NESCAT =OFF, acts as a delta-scatter for the elastic process in a transport calculation =ON GENXS = no file name, read the edit input from a file named INXC =<*filename*>, read the edit input from a file named *filename*	3.3.3.9
TSPLT:<*pl*>	r_i t_i r_2 t_2 ... r_k t_k where <*pl*> is the particles designator r_i>1 indicates that the particles will be split into r_i tracks 0<r_i<1 is the Russian roulette survival probability t_i is the time at which splitting or Russian roulette occur	3.3.6.6

Card Name	Description	Section
U	n or n_1 n_2 ... n_N where n is the universe number to which a cell belongs n_i are universe numbers assigned to each cell of the problem in the same order as the cells appear in the cell card section; number of entries must equal number of cells in the problem, N	3.3.1.5.1
UNC	j or j_1 j_2 ... j_N where j_i=0, secondaries are considered to be collided for the cell i j_i=1, secondaries are considered un-collided for the cell i	3.3.3.10
URAN	n_1 dx_1 dy_1 dz_1 n_2 dx_2 dy_2 dz_2 where n_1 is the universe number for applying stochastic transformation; only when used to fill a lattice element dx_1 is the maximum translation in ±x direction dy_1 is the maximum translation in ±y direction dz_1 is the maximum translation in ±z direction n_2, dx_2, dy_2, dz_2 are optional second stochastic transformation universe and parameters	3.3.1.5.4
VAR	KEYWORD=*value* Keyword: RR=OFF or NO indicates that Russian roulette game of weight windows and cell/time/energy importances are turned off.	3.3.6.2
VECT	V$_m$ x_m y_m z_m ... V$_n$ x_n y_n z_n ... where V$_j$ is the vector number j that is referenced on the EXT:<*pl*> card x_j y_j z_j is the coordinate triplet to define vector V$_j$	3.3.6.8
VOID	[c_1 c_2 ...] where if no entries are provided, void all cells in the problem c_i indicates that all material is to be removed from cell c_i	3.3.2.10
VOL	x or x_1 x_2 …x_N [NO] where x is the volume of the cell x_i is the volume of the i^{th} cell; number of entries must be equal to the number of cells in the problem, N NO indicates that no cell-volume or surface-area calculations are to be performed	3.3.1.1
WWE:<*pl*>	e$_1$ e$_2$ ... e$_k$ where <*pl*> is the particle designator e_i is the upper energy (or time) bound of the i^{th} window (k<100), monotonically increasing e_{i-1} is the lower energy (or time) bound of the i^{th} window, e_0=0	3.3.6.3.1

Card Name	Description	Section
WWG	i_t i_c w_g J J J J i_E where i_t is the problem tally number (n on the Fn card); the particular tally bin for which the weight-window generator is optimized is defined by the TFn card i_c>0 invokes the cell-based weight-window generator with i_c as the reference cell i_c=0 invokes the mesh-based weight-window generator w_g is the value of the generated lower weight-window bound for cell i_c or for the reference mesh w_g=0 indicates the lower weight-window bound will be half the average source weight J is an unused placeholder i_E=0 means to interpret the WWGE entries as energy bins i_E=1 means to interpret the WWGE entries as time bins	3.3.6.4.1
WWGE:<pl>	e_1 e_2 ... e_j where <pl> is the particle designator no entries will automatically generate ten decades of energies (or times) e_i is the upper energy (or time) bound for the i^{th} weight window to be generated , monotonically increasing; e_0=0	3.3.6.4.2
WWGT:<pl>	t_1 t_2 ... t_j where <pl> is the particle designator t_i is the upper energy (or time) bound for the i^{th} weight-window group to be generated, monotonically increasing; t_0=-∞	3.3.6.4.3
WWNi:<pl>	w_i or w_{i1} w_{i2} ... w_{ij} ... where <pl> is the particle designator i is the energy (or time) index w_i>0 indicates the particles entering/colliding in the cell are split or rouletted by WWP:<pl> w_i=0 indicates no weight-window game is played in the cell and energy (time) bin i weight cutoff is on w_i=-1 indicates any particle entering the cell in energy bin i is killed w_{ij} are similar to the w_i values, but are related to the values of the lower weight bound in cell j and energy (time) bin i; appear on a data card	3.3.6.3.3

Card Name	Description	Section
`WWP:`*<pl>*	*wupn wsurvn mxspln mwhere switchn mtime mult etsplt wu* where <pl> is the particle designator *wupn* is a number ≥2 such that if the particle weight goes above *wupn* times the lower weight bound, the particle will be split {5} *wsurvn* is a value between 1 and *wupn* such that if the particle survives the Russian roulette game, its weight becomes the minimum of *wsurvn* × the lower weight bound and WGT × *mxspln* {0.6 × *wupn*} *mxspln* is a number >1 such that no particle will ever be split more than *mxspln*-for-one or be rouletted more harshly than one-in-*mxspln*; for zero window cells or meshes, *mxspln* =2 {5} *mwhere* controls where to check a particle's weight: *mwhere*=-1, check the weight at collisions only; *mwhere*=0, check the weight at surfaces and collisions {default}; *mwhere*=1, check the weight at surfaces only *switchn* controls where to get the lower weight-window bounds: *switchn*=<0, get the lower weight-window bounds from an external WWINP file containing either cell- or mesh-based lower weight-window bounds; *switchn*=0, get the lower weight-window bounds from WWN*i* cards {default}; *switchn*>0, set the lower weight-window bounds equal to *switchn* divided by the cell importances from the IMP card *mtime*=0/1 indicates energy/time-dependent weight windows {0} *mult*>0 is a multiplicative constant for weight-window lower bounds found on WWN*i* cards or WWINP file mesh-based windows of particle type *<pl>* {1} *etsplt*=0 indicates that entries on the ESPLT an TSPLT cards are used solely to scale the weight window {default} *etsplt*=1 indicates that entries on the ESPLT an TSPLT cards are used to split/roulette particles as well as scale the weight windows *wu* limits the maximum lower weight-window bound for any particle, energy, or time to *wu*; if *wu*=0, there is no limit {0}	3.3.6.3.4
`WWT:`*<pl>*	$t_1\ t_2\ ...\ t_i\ ...\ t_j$ where t_i is the upper time bound of the i^{th} window t_{i-1} is the lower time bound of the i^{th} window $t_0 = -\infty$, by definition	3.3.6.3.2
XS*n*	$zaid_i\ aw_i$ ... where *n* is an arbitrary cross-section identification number $zaid_i$ is a nuclide identifier (ZZZAAA.*abx*)used on the M*m* material card aw_i is the atomic weight ratio associated with nuclide *i* ... are the remaining XSDIR entries for the user-provided cross-section table	3.3.2.9
ZA, ZB, ZC, ZD	Separate cards for inputting data to user-modified code; data must be stored by user	3.3.7.3.6

7.3 GEOMETRY PLOTTING COMMANDS

7.3.1 Geometry Plotting Command Formats

Command lines used to initiate the geometry plotter include

```
MCNP6 IP [i=<input>]
```

which means to read the `INP` file, perform consistency checks, and plot, or

```
MCNP6 P [r=<runtpe>]
```

which means to plot from an existing `RUNTPE` file. In the first form without specifying the input filename, the file `inp` is read. In the second form without specifying the `RUNTPE` name, a file named `runtpe` must exist.

Within the geometry plotter, the entries `?` or `HELP` or `OPTIONS` displays the plot commands. The user need type only enough of a command to distinguish it as unique.

7.3.2 Geometry Plotting Commands (Alphabetical)

See Table 5-3 for full descriptions of each geometry plotting command.

Command Name	Description
`&` (*ampersand*)	Continue reading commands from next line. Must be last character on the line.
`?`	Display list of graphics commands and available plot colors.
`BASIS`	Define plot orientation. See also `PX`, `PY`, and `PZ`.
`CENTER`	Change the origin by a shift in the horizontal and vertical directions.
`COLOR`	Turn color on/off, set resolution, and select physical property for shading.
`CURSOR`	Present cursor to enlarge an area. Only command on line. See `RESTORE`.
`END`	Terminate plotting.
`EXTENT`	Define the horizontal and vertical extent of the plot.
`FACTOR`	Enlarge the plot view by the factor 1/F ($F>10^{-6}$).
`FILE`	Send/do not send plot to file PLOTM.PS.
`FMESH` *n*	Plot mesh tally *n*.
`HELP`	Display list of graphics commands and available plot colors.
`INTERACT`	Return to interactive mode from terminal window input mode.
`LABEL`	Define label size and cell quantity to display.
`LEVEL`	Plot only level *n* of a repeated structure geometry.
`LOCATE`	Display x, y, z-coordinates of cursor.
`MBODY`	When set to `OFF`, display macrobody surface facet numbers.
`MCPLOT`	Call or return to the tally/cross-section plotter MCPLOT.
`MESH`	Superimposed weight-window mesh plotting (`-1/0/1` = no lines/off/on)

Command Name	Description
OPTIONS	Display list of graphics commands and available plot colors.
ORIGIN	Define the origin of the center of the plot.
PAUSE	Hold each displayed plot *n* seconds. Use with COM option.
PX VX	Plot plane perpendicular to *x*-axis at VX. (BASIS = 0 1 0 0 0 1)
PY VY	Plot plane perpendicular to *y*-axis at VY. (BASIS = 1 0 0 0 0 1)
PZ VZ	Plot plane perpendicular to *z*-axis at VZ. (BASIS = 1 0 0 0 1 0)
RESTORE	Restore ORIGIN and EXTENT to their values before CURSOR command.
RETURN	Returns program control to MCPLOT.
RUNTPE	Open the specified RUNTPE file with p options and plot the geometry.
SCALES	Put scales and grid on the plot. (Not for use with VIEWPORT SQUARE)
SHADE	Select cell color my material number.
STATUS	Display the current values of the plotting parameters.
TERM	Prevent plots from being drawn at the terminal.
THETA	Rotate the plot counterclockwise TH degrees.
VIEWPORT	Select the viewport region as rectangular or square.

7.3.3 Geometry Plotting Commands (by Function)

See Table 5-3 for full descriptions of each geometry plotting command.

Command Name	Description
DEVICE SPECIFICATION	
FILE	Send/do not send plot to file PLOTM.PS.
TERM	Prevent plots from being drawn at the terminal.
VIEWPORT	Select the viewport region as rectangular or square.
GENERAL COMMANDS	
&	Continue reading commands from next line. Must be last character on the line.
END	Terminate plotting.
MCPLOT	Call or return to the tally/cross-section plotter MCPLOT.
PAUSE	Hold each displayed plot *n* seconds. Use with COM option.
RETURN	Returns program control to MCPLOT.
INQUIRY COMMANDS	
?, HELP, OPTIONS	Display list of graphics commands and available plot colors.
STATUS	Display the current values of the plotting parameters.

Command Name	Description
PLOT COMMANDS	
BASIS	Define plot orientation. See also PX, PY, and PZ.
COLOR	Turn color on/off, set resolution, and select physical property for shading.
EXTENT	Define the horizontal and vertical extent of the plot.
FMESH *n*	Plot mesh tally *n*.
INTERACT	Return to interactive mode from terminal window input mode.
LABEL	Define label size and cell quantity to display.
LEVEL	Plot only level *n* of a repeated structure geometry.
MBODY	When set to OFF, display macrobody surface facet numbers.
MESH	Superimposed weight-window mesh plotting (-1/0/1 = no lines/off/on)
ORIGIN	Define the origin of the center of the plot.
PX VX	Plot plane perpendicular to *x*-axis at VX. (BASIS = 0 1 0 0 0 1)
PY VY	Plot plane perpendicular to *y*-axis at VY. (BASIS = 1 0 0 0 0 1)
PZ VZ	Plot plane perpendicular to *z*-axis at VZ. (BASIS = 1 0 0 0 1 0)
RUNTPE	Open the specified RUNTPE file with p options and plot the geometry.
SCALES	Put scales and grid on the plot. (Not for use with VIEWPORT SQUARE)
SHADE	Select cell color my material number.
ZOOM COMMANDS	
CENTER	Change the origin by a shift in the horizontal and vertical directions.
CURSOR	Present cursor to enlarge an area. Only command on line. See RESTORE.
FACTOR	Enlarge the plot view by the factor 1/F ($F>10^6$).
LOCATE	Display x, y, z-coordinates of cursor.
RESTORE	Restore ORIGIN and EXTENT to their values before CURSOR command.
THETA	Rotate the plot counterclockwise TH degrees.

7.3.4 Concise Geometry Plotting Command Descriptions

See Table 5-3 for full descriptions of each geometry plotting command.

To initiate the geometry plotter, use the command line

MCNP6 IP *options*

to process the input and plot, or

MCNP6 P *options*

to initiate plotting using an existing RUNTPE file.

The *options* that are available on the execution line include

NOTEK	to suppress terminal plotting and send plots to file PLOTM.PS
COM=*fn1*	to input commands contained in file *fn1*
PLOTM=*fn2*	to assign the file name *fn2* to a graphics postscript file {PLOTM.PS}
COMOUT=*fn3*	to create the file *fn3* of terminal plot commands {COMOUT}
RUNTPE=*fn4*	to open a specified RUNTPE file, *fn4*, and plot with the P (not IP) execution option {RUNTPE}

The following table of commands is a copy of Table 5-3

Geometry Plotting Commands	
Command	**Description**
Device-Control Commands	
TERM *n*	Output device type is specified by *n*. *n*=0 for a terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphics metafile. TERM 0 is equivalent to putting NOTEK on MCNP6's execute line. n=1 restores visible plotting window on next plot request.
FILE [*aa*]	Send or do not send plots to the graphics metafile PLOTM.PS according to the value of the parameter *aa*. The graphics metafile is not created until the first FILE command is entered. FILE has no effect in the NOTEK or TERM 0 cases. The allowed values of *aa* are the following: If *aa* is blank, only the current plot is sent to the graphics metafile. If *aa*=ALL, the current plot and all subsequent plots are sent to the metafile until another FILE command is entered. If *aa*=NONE, the current plot is not sent to the metafile nor are any subsequent plots until another FILE command is entered.
VIEWPORT *aa*	Make the viewport rectangular or square according to the value of *aa*. This option does not affect the appearance of the plot. It only determines whether space is provided beside the plot for a legend and around the plot for scales. If *aa*=RECT, allow space beside the plot for a legend and around the plot for scales. (DEFAULT) If *aa*=SQUARE, the legend area, the legend, and scales are omitted, making it possible to print a sequence of plots on some sort of strip medium so as to produce one long picture free from interruptions by legends. Note: Use of the SQUARE option disables the interactive-window plotter capability.
General Commands	
&	Continue reading commands for the current plot from the next input line. The & must be the last thing on the line.

Geometry Plotting Commands	
Command	**Description**
`INTERACT`	Return to the interactive, mouse-driven geometry plot interface. This command is used to return from the terminal-command interface when the PLOT option is invoked from the interactive plotter.
`RETURN`	If PLOT was called by MCPLOT, control returns to MCPLOT. Otherwise `RETURN` has no effect.
`MCPLOT`	Call or return to the MCPLOT tally and cross-section plotter.
`PAUSE [`*n*`]`	Use with `COM=`*filename* option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the ENTER key is pressed.
`END`	Terminate execution of PLOT.
Inquiry Commands	
`OPTIONS` or `?` or `HELP`	Display a list of the PLOT command keywords and available colors.
`STATUS`	Display the current values of the plotting parameters.
Plot Commands	
`BASIS` x_1 y_1 z_1 x_2 y_2 z_2	Orient the plot so that the direction (x_1 y_1 z_1) points to the right and the direction (x_2 y_2 z_2) points up. The default values are `0 1 0  0 0 1`, causing the *y*-axis to point to the right and the *z*-axis to point up. The two vectors do not have to be normalized, but they should be orthogonal. If the two vectors are not orthogonal, MCNP6 will choose an arbitrary second vector that is orthogonal to the first vector. MCNP6 will ignore the command if parallel or zero-length vectors are entered.
`ORIGIN` v_x v_y v_z	Position the plot so that the origin, which is in the middle of the plot, is at the point (v_x, v_y, v_z). The default values are `0 0 0`. The `BASIS` vectors are relative to this point.
`EXTENT` e_h e_v	Set the scale of the plot so that the horizontal distance from the origin to either side of the plot is e_h and the vertical distance from the origin to the top or bottom is e_v. If e_v is omitted, it will be set equal to e_h. If e_v is not equal to e_h, the plot will be distorted. The default values are `100` and `100`, creating a 200×200 cm viewport..
`PX` v_x	Plot a cross section of the geometry in a plane perpendicular to the *x*-axis at a distance v_x from the origin. This command is a shortcut equivalent of `BASIS  0 1 0  0 0 1  ORIGIN` v_x v_y v_z, where v_y and v_z are the current values of v_y and v_z.
`PY` v_y	Plot a cross section of the geometry in a plane perpendicular to the *y*-axis at a distance v_y from the origin.
`PZ` v_z	Plot a cross section of the geometry in a plane perpendicular to the *z*-axis at a distance v_z from the origin.

Geometry Plotting Commands	
Command	**Description**
LABEL *s c des*	Put labels of size *s* on the surfaces and labels of size *c* in the cells. Use the quantity indicated by *des* for the cell labels. The parameters *c* and *des* are optional. The sizes are relative to 0.01 times the height of the view surface. If *s* or *c* is zero, that kind of label will be omitted. If *s* or *c* is not zero, it must be in the range from 0.2 to 100. The defaults are *s*=1, *c*=0 and *des*=CEL. The possible values of *des* follow, where ":<*pl*>" indicates the particle type. CEL — cell names IMP:<*pl*> — importances RHO — atom density DEN — mass density VOL — volume FCL:<*pl*> — forced collision MAS — mass PWT — photon-production weight MAT — material number TMP*n* — temperature (*n*=index of time) WWN*n*:<*pl*> — weight-window lower bound (*n*=energy or time interval) EXT:<*pl*> — exponential transform PD*n* — detector contribution (*n*=tally number) DXC:<*pl*> — DXTRAN contribution U — universe LAT — lattice type FILL — filling universe IJK — lattice indices of repeated structures/lattice geometries NONU — fission turnoff
LEVEL *n*	Plot only the *n*th level of a repeated structure geometry. A negative entry (DEFAULT) plots the geometry at all levels. (Note, $n \leq 20$.)
MBODY *on|off*	*on* Display only the macrobody surface number. (DEFAULT) *off* Display the macrobody surface facet numbers.

Geometry Plotting Commands	
Command	**Description**
MESH *n*	Controls plotting of the weight-window and weight-window-generator superimposed mesh. If *n*=0 `No Lines` Plot cells not outlined in black. If *n*=1 `CellLine` Plot geometric cells, outlined in black. (DEFAULT) If *n*=2 `WW MESH` Plot weight-window mesh. If *n*=3 `WW+Cell` Plot weight-window mesh + `CellLine`. If *n*=4 `WWG MESH` Plot weight-window generator mesh. If *n*=5 `WWG+Cell` Plot weight-window generator mesh + `CellLine`. If *n*=6 `MeshTaly` Plot TMESH mesh tally boundaries (RMESH, CORA, etc., required) If *n*=7 `MT+Cell` Plot TMESH mesh tally boundaries + `CellLine` The `CellLine` and `No Lines` options are always available. `WW MESH` and `WW+Cell` are available only when the WWP card calls for using a superimposed weight-window mesh (i.e., a negative 5th entry appears on the WWP card) and a WWINP file is provided. The `WWG MESH` and `WWG+Cell` options are available only when a MESH card appears in the input and when the WWG card requests superimposed mesh generation (2nd entry=0).Similarly, `MeshTaly` and `MT+Cell` are available only when a TMESH mesh tally has been requested..
FMESH *n*	Plot FMESH mesh tally *n*. Changes the layout of the plot depending on the type of mesh tally. For rectangular meshes, the horizontal axis is in the direction of the dimension with the most number of bins, and the vertical axis is in the direction of the dimension with the second most number of bins. For cylindrical plots, the horizontal axis is along the axis of the cylinder and the vertical axis is along the θ=0 plane. The center of the plot in both cases is at the center of the mesh. To keep the original layout, use the FMESH button of the interactive plotter. `FMESH off` will turn off the mesh tally plotter.
SCALES *n*	Put scales and a grid on the plot. Scales and grids are incompatible with VIEWPORT SQUARE. If *n*=0, neither scales nor a grid are displayed. (DEFAULT) If *n*=1, display scales on the edges. If *n*=2, display scales on the edges and a grid on the plot.
CONTOUR *cmin* *cmax* [*cstep*] [%|PCT|LIN|LOG] [OFF]	Valid for TMESH mesh tallies. The parameters *cmin*, *cmax*, and *cstep* are the minimum, maximum, and step values for contours, respectively. The *cstep* entry is ignored and can be omitted. If either the % symbol or the PCT keyword is included, the first three parameters are interpreted as percentages of the minimum and maximum values of the dependent variable. The default values are `5 95 10 %`. If the keyword LIN appears, interpret the step values as absolute values of contour levels. If the keyword LOG appears, space the contour levels logarithmically between *cmin* and *cmax*. The default values are `1E-4 1E-2 12 LOG`. If the OFF keyword appears, use the following defaults: `0 100 %`

Geometry Plotting Commands	
Command	**Description**
COLOR *n*	Turn color on or off, set the resolution, or select the physical property for color shading. If *n*=ON, turn color on. (DEFAULT) If *n*=OFF, turn color off. If 50≤*n*≤3000, set the color resolution to *n*. A larger value increases resolution and drawing time. If *n*=BY *aa*, select the physical property to use for geometry shading. Allowed *aa* options for COLOR BY include: MAT material (DEFAULT) DEN gram density RHO atom density TMP temperature CEL cell number If *n*=GRADIENT, use a continuous gradient of 256 colors to show the cell values. If *n*=SOLID, use a solid color to represent a range of cell values. When (DEN/RHO/TMP) is used, the geometry will be shaded using the color gradient mode. Linear interpolation between the minimum non-zero value and the maximum value is used to select the color. A color bar legend of the shades will be drawn in the right margin. The legend is labeled with the property name and the minimum and maximum values. See Figure 5-1 for an example of coloring by density (DEN). Coloring by material (MAT) does not invoke a color bar legend.
SHADE m_1=*value* m_2=*value* ... m_i=*value*	This command is only valid when MAT is used to COLOR BY (the default). Make the cells containing problem material number m_i a particular color, as determined by the parameter *value*. The parameter *value* can be a color name or a number from 1–64 representing the color index. Use the LABEL command to display material numbers. The *value* entry designates the desired color (e.g., green, blue, etc.). Note: *Color names are case sensitive*. The command OPTIONS will list available colors if your display is a color monitor. The index of a color name is in top-bottom, left-right order.
Zoom Commands	
CENTER d_h d_v	Change the origin of the plot by the amount d_h in the horizontal direction and by the amount d_v in the vertical direction. This command is usually used to define the center of a portion of the current plot that the user wants to enlarge.
FACTOR *f*	Enlarge the plot by the factor 1/*f*. The parameter *f* must be greater than 10^{-6}.
THETA *th*	Rotate the plot counterclockwise by the angle *th*, in degrees.
CURSOR	Present the graphics cursor and prepare to receive cursor input from the user. This command is available only if the terminal has a graphics cursor capability. The user defines a rectangular area to be enlarged by moving the cursor to one corner of the rectangle and entering the cursor trigger, then moving it to the diagonally opposite corner of the rectangle and entering the cursor trigger again. On most terminals the cursor trigger is any key other than the ENTER key followed by ENTER. If the extents were equal before the cursor command was entered, the smaller of the two extents defined by the cursor input is made equal to the larger one. The CURSOR command should be the only command on the input line.

Geometry Plotting Commands	
Command	**Description**
RESTORE	Restore the origin and extent to the values they had before the most recent CURSOR command. The RESTORE command should be the only command on the input line. It cannot be used to undo the effects of the CENTER, FACTOR, and THETA commands.
LOCATE	Present the graphics cursor and prepare to receive cursor input from the user. This command is available only if the terminal has a graphics cursor capability. The user moves the cursor to a point in the picture and enters the cursor trigger. The *x*-, *y*-, *z*-coordinates of the point are displayed. The LOCATE command should be the only command on the input line.

7.4 TALLY AND CROSS-SECTION PLOTTING COMMANDS

7.4.1 Tally and Cross-Section Plotting Command Formats

Tally plotting and cross-section plotting are each initiated using a specific form of the MCNP6 execute line. The form

MCNP6 Z [*options*]

provides tally plots from RUNTPE and MCTAL files, while

MCNP6 IXZ [*options*]

provides cross-section plots from an INP file only, not from a RUNTPE file.

While plotting tallies or cross-section, remember the following hints:

- You only need enough letters of a command to identify it uniquely (e.g., cop=coplot)
- Enter "?" at a prompt to display a list of tally and cross-section plotting commands
- Enter "xs ?" at a prompt to see a primer in cross-section plotting
- The <ctrl_c>m interrupt allows interactive tally plots during a run; use RETURN or END to exit

7.4.2 Tally and Cross-Sections Plotting Commands (Alphabetical)

See Table 5-5 for full descriptions of these commands.

Command Name	Description
&	Continue reading commands from next line. Must be last character on the line.
?	Display list of tally and cross-section plotting commands.
BAR	Make bar plots of tally data.
BELOW	Put the main title below the plot instead of above it.
CONTOUR	Specify the form of contour plots.

Command Name	Description
COPLOT	Make plot of data so far and keep plot open for more plots (2D only)
DUMP *n*	Read the specified dump *n* from the current RUNTPE
EBIN *n*	Plot energy bin *n* of the current mesh tally.
END	Terminate plotting.
FACTOR	Before plotting, scale the data for the current plot only.
FILE	Send/do not send plot to file PLOTM.PS.
FIXED	Define a fixed bin for the specified variable.
FMESH *n*	Plot mesh tally *n*.
FMRELERR *n*	Plot the relative errors of mesh tally *n*.
FREE	Specify one or two independent variables for the plot.
FREQ	Specifies the interval between automatic runtime plots. (May be an 8-byte integer.)
HELP	Display list of tally and cross-section plotting commands.
HIST	Plot data as a histogram {default for cosine, energy, or time}
IPTAL	Display the tally bin array IPTAL for the current TALLY *n*.
KCODE	Plot individual or average k_{eff} or prompt removal lifetimes by cycle number.
LABEL "*a*"	Use "*a* " as the legend label for the current curve (not contour).
LEGEND	Specify the location of the plot curve legend.
LETHARGY	Divide tally bin by lethargy bin width for log energy abscissa.
LINLIN	Use linear *x*-axis and linear *y*-axis for plots.
LINLOG	Use linear *x*-axis and logarithmic *y*-axis for plots {default}
LOGLIN	Use logarithmic *x*-axis and linear *y*-axis for plots.
LOGLOG	Use logarithmic *x*-axis and logarithmic *y*-axis for plots.
MT	Plot reaction R of material XS *m*
NOERRBAR	Suppress statistical error bars.
NONORM	Do not divide the tally bin by the bin width or area
OPTIONS	Display list of the tally graphics commands keywords.
PAR <*pl*>	Define particle type <*pl*> for cross-section data plot of XS, MT.
PAUSE	Hold each displayed plot *n* seconds. Use with COM option.
PERT *n*	Plot the PERT*n* perturbation for a tally.
PLINEAR	Piecewise linear plots {default for all but cosine, energy, or time}
PLOT	Call or return to the PLOT geometry plotter.
PRINTAL	Display the tally numbers in the current RUNTPE or MCTAL file.
PRINTPTS	Display the *x-y* coordinates of points in the current plot (2D only).
RESET *a*	Reset command "*a* " parameters to default; "ALL" resets all commands.
RETURN	End interactive plotting when running histories.
RMCTAL *fn*	Read MCTAL file *fn*.

Command Name	Description
RUNTPE	Open the specified RUNTPE file and read the specified dump.
SCALES	Select the type of scales and/or grid to put on the plot.
SET	Define free and fixed bin for the eight variables.
STATUS	Display the current values of the plotting parameters.
SUBTITLE	Write a subtitle anywhere on the plot within screen limits.
TALLY *n*	Define tally *n* (*n* of F*n*) as the current tally {first tally}
TERM	Plot to the terminal or send plots to a graphics file.
TFC	Select a tally fluctuation chart value of current tally to plot.
THICK	Set the thickness of the plot curves to *x* from 0.01 to 0.02 {0.02}
THIN	Set the thickness of the plot curves to the minimum 0.01.
TITLE	Create a one or two line title for the plot.
WASH *a*	Set/unset z(x,y) plotting to use color-wash instead of contour.
WMCTAL *fn*	Write the tally data in the current RUNTPE dump to MCTAL file *fn*.
XLIMS	Defines lower and upper limits and number of subdivisions of *x* variable.
XS *m*	Plot a cross section according to *m*: material or nuclide.
XTITLE "*a*"	Use "*a*" as the title for the *x*-axis {name of the *x*-axis variable}.
YLIMS	Defines lower and upper limits and number of subdivisions of *y* variable.
YTITLE "*a*"	Use "*a*" as the title for the *y*-axis {name of the *y*-axis variable}.
ZLEV n_1 n_2 n_3	Controls the scale of the mesh tally results.

7.4.3 Tally and Cross-Section Plotting Commands (by Function)

The following is a copy of Table 5-5.[†]

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
Device-Control Commands	
TERM *n*	Output device type is specified by *n*. *n*=0 for a terminal with no graphics capability. No plots will be drawn on the terminal, and all plots will be sent to the graphics metafile. TERM 0 is equivalent to putting NOTEK on MCNP6's execute line. n=1 restores visible plotting window on next plot request.

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
FILE [*aa*]	Send or do not send plots to the graphics metafile PLOTM.PS according to the value of the parameter *aa*. The graphics metafile is not created until the first FILE command is entered. FILE has no effect in the NOTEK or TERM 0 cases. The allowed values of *aa* are the following: If *aa* is blank, only the current plot is sent to the graphics metafile. If *aa*=ALL, the current plot and all subsequent plots are sent to the metafile until another FILE command is entered. If *aa*=NONE, the current plot is not sent to the metafile nor are any subsequent plots until another FILE command is entered.
General Commands	
&	Continue reading commands for the current plot from the next input line. The & must be the last thing on the line.†
COPLOT	Plot a curve according to the commands entered so far and keep the plot open for co-plotting one or more additional curves. COPLOT is effective for 2D plots only. If COPLOT is the last command on a line, it functions as if it were followed by an &.
FREQ *n*	Specifies the interval between calls to MCPLOT to be every *n* histories. In KCODE calculation, the interval is every *n* cycles. If *n* is negative, the interval is in CPU minutes. If *n*=0, MCPLOT is not called while MCNP6 is running histories. Note: An 8-byte integer is allowed for keyword FREQ.. (DEFAULT: *n*=0)
RETURN	If MCPLOT was called by MCNP6 while running histories or by PLOT while doing geometry plotting, control returns to the calling subroutine. Otherwise RETURN has no effect.
PLOT	Call or return to the PLOT geometry plotter. This cannot be done when plotting from a MCTAL file.
PAUSE [*n*]	Use with COM=*filename* option. Hold each picture for *n* seconds. If no *n* value is provided, each picture remains until the ENTER key is pressed.
END	Terminate execution of MCPLOT.†
Inquiry Commands:	
OPTIONS or ? or HELP	Display a list of the MCPLOT command keywords.†
STATUS	Display the current values of the plotting parameters.†
PRINTAL	Display the numbers of the tallies in the current RUNTPE or MCTAL file.†
IPTAL	Display the IPTAL array for the current tally. This array tells how many elements are in each dimension of the current 8-dimensional tally.†
PRINTPTS	Display the *x-y* coordinates of the points in the current plot. PRINTPTS is not available for co-plots, contour plots, color-wash plots, or 3D plots.

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
File Manipulation Commands	
RUNTPE *filename n*	Read dump *n* from RUNTPE file *filename*. If the parameter *n* is omitted, the last dump in the file is read.†
DUMP *n*	Read dump *n* of the current RUNTPE file.†
WMCTAL *filename*	Write the tally data in the current RUNTPE dump to MCTAL file *filename*.†
RMCTAL *filename*	Read MCTAL file *filename*.†
Parameter-Setting Commands	
TALLY *n*	Define tally *n* as the current tally.† The parameter *n* is the tally designation on the F card in the INP file of the problem represented by the current RUNTPE or MCTAL file. The default is the first tally in the problem, which is the lowest numbered neutron tally or, if none, then the lowest numbered photon tally or, if none, then the lowest numbered electron tally.
PERT *n*	Plot a perturbation associated with a tally, where *n* is a number on a PERT card.† The command PERT 0 will reset PERT *n*.
LETHARGY	Divide tally bin by lethargy bin width for log energy abscissa. Produces visually accurate area plots for a 2D logarithmic energy abscissa (FREE E). A lethargy-normalized plot is equivalent to plotting *ef*(*e*). (Note: LOGLIN or LOGLOG must be specified and NONORM must not be invoked.) (See Section 5.5.)
NONORM	Suppress bin normalization. The default in a 2D plot is to divide the tallies by the bin widths if the independent variable is cosine, energy, or time. However, also see the description of the MCTAL file (Section 5.3.4). Bin normalization is not done in 3D, contour, or color-wash plots.
FACTOR *a f* [*s*]	Multiply the data for axis *a* by the factor *f* and then add the term *s*.† The parameter *a* is X, Y, or Z. The parameter *s* is optional. If *s* is omitted, it is set to zero. For the initial curve of a 2D plot, reset the axis limits (XLIMS or YLIMS) to the default values. The value given by FACTOR affects only the current curve or plot.
RESET *aa*	Reset the parameters of command *aa* to their default values.† The parameter *aa* can be a parameter-setting command, COPLOT, or ALL. If *aa* is ALL, the parameters of all parameter-setting commands are reset to their default values. After a COPLOT command, only COPLOT, ALL, or any of the parameter-setting commands that are marked with an † in this list may be reset. Resetting COPLOT or ALL while COPLOT is in effect causes the next plot to be an initial plot.

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
Titling Commands (The double quotes are required.)	
TITLE *n* "*aa*"	Use *aa* as line *n* of the main title at the top of the plot. The allowed values of *n* are 1 and 2. The maximum length of *aa* is 40 characters. The default is the comment on the FC card for the current tally, if any. Otherwise it is the name of the current RUNTPE or MCTAL file plus the name of the tally. KCODE plots have their own special default title.
BELOW	Put the title below the plot instead of above it. The keyword BELOW has no effect on 3D plots.
SUBTITLE *x y* "*aa*"	Write subtitle *aa* at location x, y, which can be anywhere on the plot including in the margins between the axes and the limits of the screen. The values of *x* and *y* are *x*- and *y*-axis values. The maximum length of *aa* is 40 characters.
XTITLE "*aa*"	Use *aa* as the title for the *x*-axis. The default is the name of the variable represented by the x-axis. The maximum length of *aa* is 40 characters.
YTITLE "*aa*"	Use *aa* as the title for the *y*-axis. The default is the name of the variable represented by the y-axis. The maximum length of *aa* is 40 characters.
ZTITLE "*aa*"	Use *aa* as the title for the *z*-axis in 3D plots. The default is the name of the variable represented by the z-axis. The maximum length of *aa* is 40 characters.
LABEL "*aa*"	Use *aa* as the label for the current curve.† It is printed in the legend beside a sample of the line style used to plot the curve. The value of LABEL reverts to its default value, blank, after the current curve is plotted. If LABEL is blank, the name of the RUNTPE or MCTAL file being plotted is printed as the label for the curve. The maximum length of *aa* is 10 characters.
Commands that Specify What is to be Plotted	
FREE *x* [*y*] [*n*X*m*] [ALL] [NOALL]	Use variable *x* (*y* blank) or variables *x* and *y* as the independent variable or variables in the plot. Valid values for *x* and *y* are the tally bin indices F, D, U, S, M, C, E, T, I, J, and K, where I, J, and K refer to lattice or mesh indices. If only *x* is specified, 2D plots are made. If both *x* and *y* are specified, contour, color-wash, or 3D plots are made, depending on whether 3D is in effect. The default value of *xy* is E, and gives a 2D plot in which the independent variable is energy. The *n*X*m* entry specifies the number of bins associated with the I and J lattice indices. (Only valid when *x*=I or *xy*=IJ.) The ALL entry specifies that the minimum and maximum contour range should be taken from all the tally bins. (Only valid when *x*=I or *xy*=IJ.) Omitting this parameter results in the default minimum and maximum contour range, which includes only those tally values contained in the specified 2D plot. The NOALL entry specifies that the minimum and maximum contour range should be taken only from those of the FIXED command slice. (DEFAULT) The FREE command resets XTITLE, YTITLE, ZTITLE, XLIMS, YLIMS, HIST, BAR, PLINEAR, and SPLINE to their defaults. For more information regarding usage of the FREE command, see "Additional Guidance When Using the FREE Command" following this table.

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
FIXED *q n*	Set *n* as the bin number for fixed variable *q*.† The symbols that can be used for *q*, and the kinds of tally bins they represent are the following: F cell, surface, or detector D total vs. direct or flagged vs. unflagged U user-defined S segment M multiplier C cosine E energy T time I 1^{st} lattice/mesh index J 2^{nd} lattice/mesh index K 3^{rd} lattice/mesh index Restriction: Only the J and K indices are allowed for the 1D IJK plot and only the K index is allowed for a 2D IJK contour plot.
SET *f d u s m c e t*	Define which variables are free and define the bin numbers of the fixed variables. SET does the job of the FREE and several FIXED commands in one compact command. The value of each parameter can be a bin number (the corresponding variable is then a fixed variable) or an asterisk (*) (the corresponding variable is then a free variable). If there is only one *, 2D plots are made. If there are two, contour or 3D plots are made. SET performs the same resetting of parameters that FREE does.
TFC *x*	Plot the tally fluctuation chart of the current tally. The independent variable is *nps*, the number of source histories. Allowed values of *x* include the following: M mean* E relative error* F figure of merit* L 201 largest tallies vs *x* (NONORM for frequency vs *x*) N cumulative number fraction of *f*(*x*) vs *x* P probability *f*(*x*) vs *x* (NONORM for number frequency vs *x*) S SLOPE of the high tallies as a function of *nps* T cumulative tally fraction of *f*(*x*) vs *x* V VOV as a function of *nps* 1–8 1 to 8 moments of $f(x)*x^{1\text{ to }8}$ vs *x* (NONORM for $f(x)*\Delta x*x^{1\text{ to }8}$ vs *x*) 1c–8c 1 to 8 cumulative moments of $f(x)*x^{1\text{ to }8}$ vs *x* *This data is available when plotting from a MCTAL file.

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
KCODE *i*	The independent variable is the KCODE cycle. The individual estimator plots start with cycle one. The average col/abs/trk-len plots start with the fourth active cycle. Plot k_{eff} or removal lifetime according to the value of *i*.† If *i*= 1 k (collision) 2 k (absorption) 3 k (track) 4 prompt removal lifetime (collision) 5 prompt removal lifetime (absorption) 6 Shannon entropy of fission source distribution (Can be plotted only from RUNTPE file, not from MCTAL file) 11–15 the quantity corresponding to *i*-10, averaged over the cycles so far in the problem. 16 average col/abs/trk-len k_{eff} and one estimated standard deviation 17 average col/abs/trk-len k_{eff} and one estimated standard deviation by cycle skipped. Cannot plot fewer than 10 active cycles. 18 average col/abs/trk-len k_{eff} figure of merit 19 average col/abs/trk-len k_{eff} relative error
Commands for Cross-Section Plotting	
XS *m*	Plot a cross section according to the value of *m*.† Option 1: *m*=M*n*, a material card in the INP file for material *n*. Example: XS M15. The available materials will be listed if a material is requested that does not exist in the INP file. Option 2: *m*=*z*, a nuclide ZAID. Example: XS 92235.50C. The full ZAID must be provided. The available nuclides will be listed if a nuclide is requested that does not exist in the INP file. Option 3: *m*=?. Print out a cross-section plotting primer.
MT *n*	Plot reaction *n* of material or nuclide specified by XS *m*.† The default is the total cross section. The available reaction numbers in the data file will be listed if one enters a reaction number that is invalid or doesn't exist (e.g., 999)
PAR <*pl*>	Plot the data for particle type <*pl*>, where <*pl*> can be N, P, E or H of material M*n*.† The default is the source particle type for XS=M*n*. For XS=*z*, the particle type is determined from the data library type. For example, 92000.01g defines PAR=P. Must be first entry on the line.
Commands that Specify the Form of 2D Plots	
LINLIN	Use linear *x*-axis and linear *y*-axis. (DEFAULT for tally contour plots)
LINLOG	Use linear *x*-axis and logarithmic *y*-axis. (DEFAULT for all except tally contour plots)
LOGLIN	Use logarithmic *x*-axis and linear *y*-axis.
LOGLOG	Use logarithmic *x*-axis and logarithmic *y*-axis.

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
XLIMS ***min max nsteps*** **YLIMS** ***min max nsteps***	Define the lower limit, *min*, upper limit, *max*, and number of subdivisions, *nsteps*, on the *x*- or *y*-axis. The parameter *nsteps* is optional for a linear axis and is ineffective for a logarithmic axis. In the absence of any specification by the user, the values of *min*, *max*, and *nsteps* are defined by an algorithm in MCPLOT.
SCALES ***n***	Put scales on the plots according to the value of *n*: If *n*=0, no scales on the edges and no grid. If *n*=1, scales on the edges (DEFAULT) If *n*=2, scales on the edges and a grid on the plot.
HIST	Make histogram plots.† This is the default if the independent variable is cosine, energy, or time.
PLINEAR	Make piecewise-linear plots.† This is the default if the independent variable is not cosine, energy, or time.
SPLINE [*x*]	Use spline curves in the plots.† If the parameter *x* is included, rational splines of tension *x* are plotted. Otherwise Stinem and cubic splines are plotted. Rational splines are available only with the DISSPLA graphics system.
BAR	Make bar plots.†
NOERRBAR	Suppress error bars.† The default is to include error bars.
THICK ***x***	Set the thickness of the plot curves to the value *x*.† The legal values lie in the range from 0.01 to 0.02. The default value of THICK is 0.02.
THIN	Set the thickness of the plot curves to the legal minimum of 0.01.†
LEGEND [*x y*]	Include or omit the legend according to the values of optional parameters *x* and *y*. If no *x* and no *y*, put the legend in its normal place. (DEFAULT) If *x*=0 and no *y*, omit the legend. If both *x* and *y* defined, for 2D plots only, put most of the legend in its usual place, but put the part that labels the plot lines at location *x*, *y*, where the values of x and y are based on the units and values of the *x*- and *y*- axes.

Tally and Cross-Section Plotting Commands By Function	
Command	**Description**
Commands that Specify the Form of Contour Plots	
CONTOUR [*cmin cmax cstep*] [%|PCT|LIN|LOG] [ALL|NOALL] [LINE|NOLINE] [COLOR|NOCOLOR]	The parameters *cmin*, *cmax*, and *cstep* are the minimum, maximum, and step values for contours, respectively. If either the % symbol or the PCT keyword is included, the first three parameters are interpreted as percentages of the minimum and maximum values of the dependent variable. The default values are 5 95 10 %. If the keyword LIN appears, interpret the step values as absolute values of contour levels. If the keyword LOG appears, space the contour levels logarithmically between *cmin* and *cmax*, with *cstep* values between. (DEFAULT option with the following values: 1E-4 1E-2 12 LOG) The ALL keyword specifies that the minimum and maximum contour range should be taken from all of the tally bins. (Default is to use the bins only in the current plot, or NOALL.) The LINE|NOLINE option controls plotting of contour lines. The COLOR|NOCOLOR option controls shading of the contours.
WASH *aa*	Set or unset *z*(*x*,*y*) plotting to use color-wash instead of contours. The parameter *aa* can be one of two values: If *aa*=ON Turn on color-wash plotting for two free variables. If *aa*=OFF Turn off color-wash plotting and return to contour plotting for two free variables. (DEFAULT) Any value for *aa* other than on is equivalent to OFF.
Commands for FMESH Mesh Tally Plots	
FMESH *n*	Plot FMESH mesh tally *n*.
FMRELERR *n*	Plot the relative errors of FMESH mesh tally *n*. If tally number *n* is not provided, plots the relative error for the current mesh.
ZLEV n_1 n_2 n_3 ...	Controls the scale of the FMESH mesh tally results. The parameters n_i, can have the following values: If n_i=LOG, the tally data scaling is set to logarithmic. (DEFAULT) If n_i=LIN, the tally data scaling is set to linear numeric value. If no values of n_i are provided, the scale is set to the default for the particular color mode. If only one value of n_i is provided, sets the lower limit of the plot. If two values of n_i are provided, sets the lower and upper limits of the plot. If three or more values of n_i are provided, sets the value of the color gradients.
EBIN *n*	Plot energy bin *n* of the current FMESH mesh tally. The total energy bin is the last bin of the tally.
TBIN *n*	Plot time bin *n* of the current FMESH mesh tally. The total time bin is the last bin of the tally.
† available with COPLOT	

7.4.4 Concise Tally and Cross-Section Plotting Command Description

To initiate the cross-section plotter, use the command line

`MCNP6 IXZ` *`options`* ,

which forces processing of the input and material cross section so that the cross-section data may be plotted.

Use the command line

`MCNP6 Z` *`options`*

to initiate tally plotting. A RUNTPE or MCTAL file containing tally data must exist. Note that by default, the plotter will display a LINLOG histogram plot of tally/MeV vs energy for the first tally if more than one energy bin exists.

The *options* that are available on the execution line include

NOTEK	to suppress terminal plotting and send plots to file PLOTM.PS
COM=*fn1*	to input commands contained in file *fn1*; must contain and END command
PLOTM=*fn2*	to assign the file name *fn2* to a graphics postscript file {PLOTM.PS}
COMOUT=*fn3*	to create the file *fn3* of terminal plot commands {COMOUT}
RUNTPE=*fn4*	to open a specified RUNTPE file, *fn4*, from which to plot tally data {RUNTPE}
RMCTAL=*fn5*	to open a specified MCTAL file, *fn5*, from which to plot tally data {MCTAL}

See Table 5-5 for full descriotions of these commands.

Command Name	Description
&	Continue reading commands from next line. Must be last character on the line
?	Display list of tally and cross-section plotting commands
BAR	Make bar plots of tally data
BELOW	Put the main title below the plot instead of above it

Command Name	Description
CONTOUR	[*cmin cmax cstep*] [%|PCT|LIN|LOG] [ALL|NOALL] [LINE|NOLINE] [COLOR|NOCOLOR] where *cmin* is the minimum value for contours {5} *cmax* is the maximum value for contours {95} *cstep* is the step value for contours {10} % or PCT indicate *cmin*, *cmax*, and *cstep* are to be interpreted as percentages of the minimum and maximum values of the dependent variables {%} LIN means the step values are absolute values of contour levels LOG means to space the contour levels logarithmically between *cmin* and *cmax*, with *cstep* values between ALL|NOALL specifies that the minimum and maximum contour raged will be taken from all tally bins | tally bins in the current plot only {NOALL } LINE|NOLINE controls plotting | no plotting of contour lines COLOR|NOCOLOR controls shading | no shading of the contours {COLOR }
COPLOT	Make plot of data so far and keep plot open for more plots (2D only)
DUMP *n*	Read the specified dump *n* from the current RUNTPE file
EBIN *n*	Plot energy bin *n* of the current mesh tally; the total energy bin is the last bin of the tally
END	Terminate plotting
FACTOR	*a f* [*s*] where *a*=X or Y or Z, indicating the axis of the plot to be scaled *f* is the value by which to multiply the data on the *a* axis *s* is an optional number to add to the scales (*f*) data
FILE	[ALL] [NONE] where no entries (i.e., blank) sends only the current plot to the graphics metafile ALL sends the current and all subsequent plots to the graphics metafile NONE suppresses sending of the current plot and all subsequent plots to the graphics metafile
FIXED	*q n* where n is the bin number for fixed variable q *q*=F indicates cell, surface, or detector bin *q*=D indicates total bin versus direct or flagged bin versus unflagged *q*=U indicates user-defined bin *q*=S indicates segmented bin *q*=M indicates multiplier bin *q*=C indicates cosine bin *q*=E indicates energy bin *q*=T indicates time bin *q*=I indicates 1st lattice/mesh index *q*=J indicates 2nd lattice/mesh index *q*=K indicates 3rd lattice/mesh index
FMESH *n*	Plot mesh tally *n*.
FMRELERR *n*	Plot the relative errors of mesh tally *n*.; if *n* not provided, plot the relative error for the current mesh

Command Name	Description
FREE	*x*[*y*] [*n*X*m*] [ALL] [NOALL] where *x* is a letter designator (F, D, U, S, M, C, E, T, I, J, K) for the first independent variable {E} *y* is an optional letter designator (F, D, U, S, M, C, E, T, I, J, K) for the second independent variable *n*X*m* specifies the number of bins associated with the I and J lattice indices; valid only when *x*=I or *xy*=IJ ALL indicates that the minimum and maximum contour range should be taken from all the tally bins NOALL indicates that the minimum and maximum contour range should be taken only from those of the FIXED command slice {default}
FREQ	*n* where *n*>0 specifies to plot every *n* histories or KCODE cycles *n*<0 specifies to plot every *n* CPU minutes *n*=0 specifies to not call MCPLOT while MCNP6 is running histories {default} The keyword FREQ may be an i-byte integer.
HELP	Display list of tally and cross-section plotting commands.
HIST	Plot data as a histogram {default for cosine, energy, or time}
IPTAL	Display the tally bin array IPTAL for the current TALLY *n*.
KCODE	*i* where the k_{eff} or removal lifetime is plotted according to the value of *i*: *i*=1 collision estimator *i*=2 absorption estimator *i*=3 track-length estimator *i*=4 collision estimator for prompt removal lifetime *i*=5 absorption estimator for prompt removal lifetime *i*=6 Shannon entropy of fission source distribution; requires RUNTPE *i*=11-15 quantities *i*=1 to *i*=5 averaged over the active cycles *i*=16 average combined col/abs/trk-len k_{eff} *i*=17 average combined col/abs/trk-len k_{eff} by k_{eff} cycles skipped *i*=18 average combined col/abs/trk-len k_{eff} by k_{eff} figure of merit *i*=19 average combined col/abs/trk-len k_{eff} by k_{eff} relative error
LABEL "*a*"	Use "*a* " as the legend label for the current curve (not contour).
LEGEND	[*x y*] where no entry puts the legend in the normal place {default} *x*=0 and no y entry specifies to omit the legend *x*>0 and *y*>0 specifies to put plot lines at location x,y where *x* and *y* are given as values with units of the x and y plot axes; 2D plots only
LETHARGY	Divide tally bin by lethargy bin width for log energy abscissa
LINLIN	Use linear *x*-axis and linear *y*-axis for plots
LINLOG	Use linear *x*-axis and logarithmic *y*-axis for plots {default
LOGLIN	Use logarithmic *x*-axis and linear *y*-axis for plots
LOGLOG	Use logarithmic *x*-axis and logarithmic *y*-axis for plots

Command Name	Description
MT	*r* where *r* is the reaction number of material XS *m* to be plotted
NOERRBAR	Suppress statistical error bars
NONORM	Do not divide the tally bin by the bin width or area
OPTIONS	Display list of the tally graphics commands keywords
PAR <*pl*>	Define particle type <*pl*> for cross-section data plot of XS, MT
PAUSE	*t* where *t* is the number of seconds to hold each displayed plot; use with COM option.
PERT *n*	Plot the PERT*n* perturbation for a tally
PLINEAR	Piecewise linear plots {default for all but cosine, energy, or time}
PLOT	Call or return to the PLOT geometry plotter
PRINTAL	Display the tally numbers in the current RUNTPE or MCTAL file
PRINTPTS	[*fn*] where no entries causes display of the *x*-*y* coordinates of points in the current plot to the terminal *fn* causes x-y coordinates of points in the current plot to be written to file *fn*; one file per set of points
RESET *a*	Reset command "*a* " parameters to default; "ALL" resets all commands
RETURN	End interactive plotting when running histories
RMCTAL *fn*	Read MCTAL file *fn*
RUNTPE *fn n*	Open the specified RUNTPE file *fn* and read the specified dump *n*
SCALES	*n* where *n*=0 puts no scales on the edges and no grid on the plot *n*=1 puts scales on the edges, but no grid on the plot {default} *n*=2 puts scales on the edges and grid on the plot
SET	*f d u s m c e t* where each of the 8 parameters can be a bin number to indicate a fixed variable or a * to indicate a free variable; a 2D plot will have one *, a contour, two * entries
STATUS	Display the current values of the plotting parameters
SUBTITLE	*x y "aa"* where *x y* is the location on the plot to place the subtitle *"aa"* is the text of the subtitle in quotation marks (40-character limit)
TALLY *n*	Define tally *n* (*n* of F*n*) as the current tally {first tally}
TERM	*n* where *n*=1 sends plot to the terminal {default} *n*=0 sends plots to a graphics file; equivalent to NOTEK

Command Name	Description
TFC	*x* where tally fluctuation chart values will be plotted for the current tally according to the value of *x*: *x*=M mean vs. history number *x*=E relative error vs. history number *x*=F figure of merit vs. history number *x*=L up to 201 largest tallies *f(x)* vs. *x* (NONORM for *frequency* vs. *x* *x*=N cumulative number fraction of *f(x)* vs. *x* *x*=P history score probability density function *f(x)* vs. *x* (NONORM for *frequency* vs. *x*) *x*=S slope of history score probability density function *f(x)* vs. *x* *x*=T cumulative tally fraction of *f(x)* [first moment of *f(x)*] *x*=V relative variance of variance vs. history number *x*=1 to 8 1st to 8th moment of *f(x)* vs. history score *x* *x*=1C to 8C 1st to 8th cumulative moment of *f(x)* vs. *x*
THICK *x*	Set the thickness of the plot curves to *x* from 0.01 to 0.02 {0.02}
THIN	Set the thickness of the plot curves to the minimum 0.01.
TITLE	*n "aa"* where *n*=1, then *"aa"* is the text for the first line of the plot title *n*=2, then *"aa"* is the text for the second line of the plot title
WASH *a*	*a* where *a*=ON sets z(x,y) plotting to use color-wash instead of contour *a*=OFF unsets the use of color-wash
WMCTAL *fn*	Write the tally data in the current RUNTPE dump to MCTAL file *fn*.
XLIMS	*min max nsteps* where *min* is the lower limit for the *x* variable *max* is the upper limit for the *x* variable *nsteps* is the number of subdivisions on the linear *x*-axis (no affect on logarithmic)
XS	*m* or *?* where *m* is a material number or complete ZAID for which to plot the cross section *?* prints a short cross-section plotting primer to the terminal
XTITLE "*a*"	Use "*a*" as the title for the *x*-axis {name of the *x*-axis variable}
YLIMS	*min max nsteps* where *min* is the lower limit for the *y* variable *max* is the upper limit for the *y* variable *nsteps* is the number of subdivisions on the linear *y*-axis (no affect on logarithmic)

Command Name	Description
YTITLE "*a*"	Use "*a*" as the title for the *y*-axis {name of the *y*-axis variable}
ZLEV	n_1 n_2 n_3 ... *where* n_i=LOG sets the tally data scaling to logarithmic {default} n_i=LIN sets the tally data scaling to linear number value If no values are given, sets scale to the default for the particular color mode. If only one value is given, sets the lower limit of the plot. If two values are given, sets the lower and upper limits of the plot. If three or more values are given, sets the values of the color gradients.

8 APPENDIX B MESH-BASED WWINP, WWOUT, AND WWONE FILE FORMAT

The mesh-based weight-window input file WWINP and the mesh-based weight-window output files WWOUT and WWONE are ASCII files with a common format. The files consist of three blocks. Block 1 contains the header information, energy and time group numbers, and basic mesh information. Block 2 contains the mesh geometry. Block 3 contains the energy and time group boundaries and lower weight-window bounds. Table 8-1 presents the file format using generic variables. Table 8-2 describes the variables and gives the equivalent variables from the WWINP, WWOUT, and WWONE files.

The three-dimensional array of fine mesh cells is stored by assigning an index number to each cell. The three dimensions are x, y, and z for rectangular meshes, r, z, and θ for cylindrical meshes, and r, φ, and θ for spherical meshes. These may be indexed as `i`, `j`, `k`, with a total of `I`, `J`, `K` meshes in each coordinate direction. The assignment of mesh cells is illustrated in Figure 8-1 for an x,y,z mesh. The cell index number is related to the fine mesh number in each coordinate direction through the following formula:

cell index number = `i + (j – 1)*I + (k – 1)*I*J` .

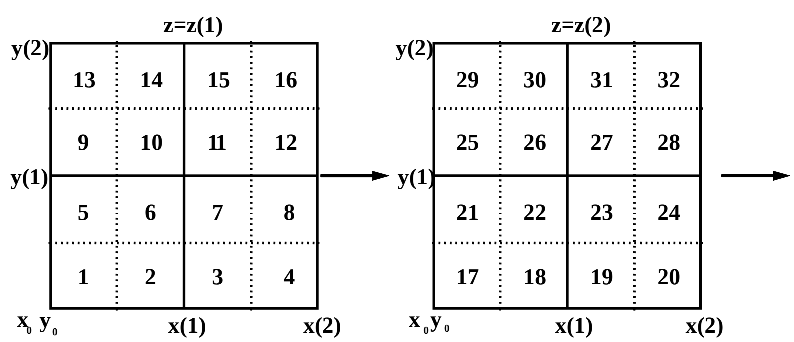

Figure 8-1. Superimposed mesh cell indexing.

Table 8-1. Format of the Mesh-Based WWINP, WWOUT and WWONE Files

FORMAT	VARIABLE LIST
BLOCK 1	
4i10, 20x, a19	*if iv ni nr probid*
7i10	*nt*(1) ... *nt*(*ni*) [if *iv*=2]
7i10	*ne*(1) ... *ne*(*ni*)
6g13.5	*nfx nfy nfz* x_0 y_0 z_0
6g13.5	*ncx ncy ncz nwg* [if *nr*=10]
6g13.5	*ncx ncy ncz* x_1 y_1 z_1 [if *nr*=16]
6g13.5	x_2 y_2 z_2 *nwg* [if *nr*=16]
BLOCK 2	
6g13.5	x_0 (*qx*(*i*), *px*(*i*), *sx*(*i*), *i*=1,*ncx*)
6g13.5	y_0 (*qy*(*i*), *py*(*i*), *sy*(*i*), *i*=1,*ncy*)
6g13.5	z_0 (*qz*(*i*), *pz*(*i*), *sz*(*i*), *i*=1,*ncz*)
BLOCK 3 (for each particle)	
6g13.5	*t*(*i*,1) ... *t*(*i*,*nt*(*i*)) [if *nt*(*i*)>1]
6g13.5	*e*(*i*,1) ... *e*(*i*,*ne*(*i*))
6g13.5	(((*w*(*i*,*j*,*k*,*l*,1) *j*=1,*nft*), *k*=1,*ne*(*i*)), *l*=1,*nt*(*i*))

Table 8-2. Explanations of Variables from Table 8-1

VARIABLE	NAME	DESCRIPTION
If	IF	File type. Only 1 is supported. Unused.
Iv	IV	Time-dependent windows flag (1 / 2 = no / yes)
Ni	NI	Number of particle types
Nr	NR	= 10 / 16 / 16 for rectangular / cylindrical / spherical = number of words to describe mesh
Probed	PROBID	Problem identification description
I	KP	Particle type
nt(*i*)	NWW(KP)	Number of time bins for particle type *i*
ne(*i*)	NGWW(KP)	Number of energy bins for particle type *i*
*nf*x, *nfy*, *nfz*	WWM(1:3)	Total number of fine (x,y,z), (r,z,θ), or (r,φ,θ) mesh bins
x_0, y_0, z_0	WWM(4:6)	Corner of (x,y,z) Cartesian geometry, bottom center of (r,z,θ) cylindrical geometry, or center of (r,φ,θ) spherical geometry

VARIABLE	NAME	DESCRIPTION
ncx, *ncy*, *ncz*	WWM(7:9)	Number of coarse (x,y,z), (r,z,θ), or (r,φ,θ) mesh bins
x_1, y_1, z_1	WWN (10:12)	Vector from x_0 y_0 z_0 to x_1 y_1 z_1 defines (r,z,θ) cylinder or (r,φ,θ) polar axis
x_2, y_2, z_2	WWN(13:15)	Vector from x_0 y_0 z_0 to x_2 y_2 z_2 defines (r,z,θ) cylinder or (r,φ,θ) azimuthal axis
nwg	WWM(NR)	Geometry type 1 / 2 / 3 = (x,y,z) / (r,z,θ) / (r,φ,θ)
px(*i*), *py*(*i*), *pz*(*i*)	WGM(*k*)	Coarse mesh coordinates for (x,y,z), (r,z,θ), or (r,φ,θ)
qx(*i*), *qy*(*i*), *qz*(*i*)	WGM(*k*)	Fine mesh ratio (presently = 1 always) in each coarse mesh for (x,y,z), (r,z,θ), or (r,φ,θ)
sx(*i*), *sy*(*i*), *sz*(*i*)	WGM(*k*)	Number of fine meshes in each coarse mesh for (x,y,z), (r,z,θ), or (r,φ,θ)
t(*i*,*j*)	WWT1(KP,*j*)	Upper time bounds for particle *i*, bin *j* (given only if *nt*(*i*)>1)
e(*i*,*j*)	WWE1(KP,*j*)	Upper energy bounds for particle *i*, bin *j*
nft	NWWM	Total number of fine meshes (*nfx*∗*nfy*∗*nfz*)
w(*i*,*j*,*k*,*l*,1)	WWF(KP,*j*,*k*,*l*,1)	Weight-window lower bounds. These are written in blocks of *j*=1:NWWMA geometry meshes for each energy *k*=1,NGWW(KP) and for each time *l*=1,MWWTG(KP)

Table 8-3. Correspondence of Variable Names

WWINP	WWOUT / WWONE	DESCRIPTION
Ip	*ip*	Particle type
Ic	*ic*	Mesh cell index
Ie	*ie*	Energy index
It	*it*	Time index
Ia	*ia*	Angle index (for multigroup)
Im	*im*	Multitasking index
NWGM	NWGMA	Length of WGM/WGMA
NWWM	NWWMA	Total number of fine meshes
MWWTF(*ip*)	MWWTG(*ip*)	Time bins
NWW(*ip*)	NGWW(*ip*)	Energy bins
WWM(26)	WWMA(26)	Geometry description
WGM(*i*)	WGMA(*i*)	Geometry boundaries, fine
WWE1(*ip*,*ie*)	WWGE(*ip*,*ie*)	Energy bounds
WWT1(*ip*,*it*)	WWGT(*ip*,*it*)	Time bounds

WWINP	**WWOUT / WWONE**	**DESCRIPTION**
WWF(*ip*,*ic*,*ie*,*it*,*ia*)	WWFA(*ip*,*ic*,*ie*,*it*,*im*	Weight-window lower bounds

Example:

Input file mesh description:

```
mesh geom=rzt ref= -4.2419 4.2419 -2
     origin 0 0 -9.0001
     imesh  3.02  6.0001
     iints  3  5
     jmesh 8.008 14.002
     jints  4  3
     kmesh .25 .50 .75  1
     kints  2   1   2   3
```

Resultant WWINP, WWOUT and WWONE file:

```
         1         1         1        16
         1
   6.0000      7.0000      8.0000      0.0000      0.0000     -9.0001
   2.0000      2.0000      4.0000      0.0000      0.0000      5.0001
   6.0001      0.0000     -9.0001      2.0000
   0.0000      3.0000      3.0200      1.0000      5.0000      6.0001
   1.0000
   0.0000      4.0000      8.0080      1.0000      3.0000      14.002
   1.0000
   0.0000      2.0000     0.25000      1.0000      1.0000     0.50000
   1.0000      2.0000     0.75000      1.0000      3.0000      1.0000
   1.0000
   100.00
   0.0000      0.0000      1.1924     0.48566     0.60746      1.0653
  0.10454      0.9993     0.11065     0.16738     0.37556     0.94980
...
...
```

9 APPENDIX C FISSION SPECTRA CONSTANTS

9.1 CONSTANTS FOR FISSION SPECTRA

The following is a list of recommended parameters for use with the MCNP6 source fission spectra and the SP input card described in Section 3.3.4.3. The constants for neutron-induced fission are taken directly from the ENDF/B-V library. For each fissionable isotope, constants are given for either the Maxwell spectrum or the Watt spectrum, but not both. The Watt fission spectrum is preferred to the Maxwell fission spectrum. The constants for spontaneously fissioning isotopes are supplied by Madland of Group T-16. If you desire constants for isotopes other than those listed below, contact XCP-Division. Note that both the Watt and Maxwell fission spectra are approximations. A more accurate representation has been developed by Madland in T-16. If you are interested in this spectrum, contact XCP-Division.

9.1.1 Constants for the Maxwell Fission Spectrum (neutron-induced)

$$f(E) = CE^{1/2}\exp(-E/a)$$

	Incident Neutron Energy (MeV)	***a*** **(MeV)**
n + ^{233}Pa	Thermal	1.3294
	1	1.3294
	14	1.3294
n + ^{234}U	Thermal	1.2955
	1	1.3086
	14	1.4792
n + ^{236}U	Thermal	1.2955
	1	1.3086
	14	1.4792
n + ^{237}U	Thermal	1.2996
	1	1.3162
	14	1.5063
n + ^{237}Np	Thermal	1.315
	1	1.315
	14	1.315
n + ^{238}Pu	Thermal	1.330
	1	1.330
	14	1.330

	Incident Neutron Energy (MeV)	***a* (MeV)**
n + ^{240}Pu	Thermal	1.346
	1	1.3615
	14	1.547
n + ^{241}Pu	Thermal	1.3597
	1	1.3752
	14	1.5323
n + ^{242}Pu	Thermal	1.337
	1	1.354
	14	1.552
n + ^{241}Am	Thermal	1.330
	1	1.330
	14	1.330
n + ^{242m}Pu	Thermal	1.330
	1	1.330
	14	1.330
n + ^{243}Am	Thermal	1.330
	1	1.330
	14	1.330
n + ^{242}Cm	Thermal	1.330
	1	1.330
	14	1.330
n + ^{244}Cm	Thermal	1.330
	1	1.330
	14	1.330
n + ^{245}Cm	Thermal	1.4501
	1	1.4687
	14	1.6844
n + ^{246}Cm	Thermal	1.3624
	1	1.4075
	14	1.6412

9.1.2 Constants for the Watt Fission Spectrum

$$f(E) = C\exp(-E/a)\sinh\left(\sqrt{bE}\right)$$

9.1.2.1 NEUTRON-INDUCED FISSION

	Incident Neutron Energy (MeV)	*a* (MeV)	*b* (MeV^{-1})
n + ^{232}Th	Thermal	1.0888	1.6871
	1	1.1096	1.6316
	14	1.1700	1.4610
n + ^{233}U	Thermal	0.977	2.546
	1	0.977	2.546
	14	1.0036	2.6377
n + ^{235}U	Thermal	0.988	2.249
	1	0.988	2.249
	14	1.028	2.084
n + ^{238}U	Thermal	0.88111	3.4005
	1	0.89506	3.2953
	14	0.96534	2.8330
n + ^{239}Pu	Thermal	0.966	2.842
	1	0.966	2.842
	14	1.055	2.383

9.1.2.2 SPONTANEOUS FISSION

	a (MeV)	*b* (MeV^{-1})
^{232}Th	0.800000	4.00000
^{232}U	0.892204	3.72278
^{233}U	0.854803	4.03210
^{234}U	0.771241	4.92449
^{235}U	0.774713	4.85231
^{236}U	0.735166	5.35746
^{238}U	0.648318	6.81057
^{237}Np	0.833438	4.24147
^{238}Pu	0.847833	4.16933
^{239}Pu	0.885247	3.80269
^{240}Pu	0.794930	4.68927
^{241}Pu	0.842472	4.15150
^{242}Pu	0.819150	4.36668
^{241}Am	0.933020	3.46195
^{242}Cm	0.887353	3.89176
^{244}Cm	0.902523	3.72033
^{249}Bk	0.891281	3.79405
^{252}Cf	1.180000	1.03419

10 APPENDIX D PTRAC TABLES

Table 10-1 presents the format of the PTRAC output file. Table 10-2 on provide a detailed description of each variable in the output file. Note that capitalized variables with three or more characters refer to MCNP6 Fortran variables (except where noted).

Table 10-1. Format of the PTRAC Output File

Format	ASCII		Binary Record
	Line	Format	
-1	1	`(i5)`	1
KOD, VER, LODDAT, IDTM	2	`(a8,a5,a8,a19)`	2
AID	3	`(a128)`	3
m n_1 V_1^2 V_2^2 … V_{n1}^2 …	4	`(1x,10e12.4)`	4
. . .	K total lines of PTRAC input data (see Table 10-2)		
N_1 N_2 … N_{20}	4+K	`(1x,20i5)`	4+K
L_1 L_2 … L_{N1}	5+K	`(1x,30i4)`	5+K
L_1^1 L_2^1 … L_{N2+N3}^1			
. . .	M total Lines of variable IDs		
***************End of Header — Start NPS and Event Lines***************			
I_1^1 I_2^1 … I_{N1}^1	5+K+M	`(1x,5i10,e13.5)`	6+K
J_1^1 J_2^1 … $J_{N2,4,6,8,10}^1$	6+K+M	`(1x,8i10)`	7+K
P_1^1 P_2^1 … $P_{N3,5,7,9,11}^1$	7+K+M	`(1x,9e13.5)`	
J_1^2 J_2^2 … $J_{N2,4,6,8,10}^2$	8+K+M	`1x,8i10)`	8+K
P_1^2 P_2^2 … $P_{N3,5,7,9,11}^2$	9+K+M	`(1x,9e13.5)`	
. . .	Q total lines of event data for this history (see Table 10-3).		

Format		ASCII		Binary Record
		Line	Format	
$I_1^2\ I_2^2\ \ldots\ I_{N1}^2$		5+K+M+Q	(1x,5i10,e13.5)	6+K+Q/2
. . .				
See Table 10-3 for all possible values of N_2-N_{11}				
N_1	Number of variables on the NPS line ($I_1\ \ I_2\ \ldots$).			
N_2	Number of variables on 1st event line for an "src" event.			
N_3	Number of variables on 2nd event line for an "src" event.			
N_4	Number of variables on 1st event line for a "bnk" event.			
N_5	Number of variables on 2nd event line for a "bnk" event.			
N_6	Number of variables on 1st event line for a "sur" event.			
N_7	Number of variables on 2nd event line for a "sur" event.			
N_8	Number of variables on 1st event line for a "col" event.			
N_9	Number of variables on 2nd event line for a "col" event.			
N_{10}	Number of variables on 1st event line for a "ter" event.			
N_{11}	Number of variables on 2nd event line for a "ter" event.			
N_{12}	IPT for single particle transport, otherwise 0.			
N_{13}	4 for `real*4` output and 8 for `real*8` output			
N_{14}–N_{20}	not used.			
See Table 10-4 for definitions of variable IDs:				
$L_1\ L_2\ \ldots\ L_{N1}$	List of variable IDs for the NPS line.			
$L_1^1\ L_2^1\ \ldots\ L_{N2+N3}^1$	List of variable IDs for an "src" event.			
$L_1^2\ L_2^2\ \ldots\ L_{N4+N5}^2$	List of variable IDs for a "bnk" event.			
$L_1^3\ L_2^3\ \ldots\ L_{N6+N7}^3$	List of variable IDs for a "sur" event.			
$L_1^4\ L_2^4\ \ldots\ L_{N8+N9}^4$	List of variable IDs for a "col" event.			
$L_1^5\ L_2^5\ \ldots\ L_{N10+N11}^5$	List of variable IDs for a "ter" event.			
See Table 10-4 for corresponding variable IDs:				
I_1^1	NPS.			
I_2^1	Event type of the 1st event for this history (see Table 10-5).			

Format		ASCII Line	ASCII Format	Binary Record
I_3^1	Cell number if cell filtered, otherwise omitted.			
I_4^1	Surface number if surface filtered, otherwise omitted.			
I_5^1	Tally number if tally filtered, otherwise omitted.			
I_6^1	TFC bin tally if tally filtered, otherwise omitted.			
See Table 10-4 for definitions of J_1^1, J_2^1, ..., and P_1^1, P_2^1, ...				

Table 10-2. PTRAC Input Format

m n_1 V_1^1 V_2^1 … V_{n1}^1 n_2 V_1^2 V_2^2 … V_{n2}^2 ... n_{13} V_1^{13} V_2^{13} … V_{n1}^{13}

where m = Number of PTRAC keywords = 13

n_i = Number of entries for i^{th} keyword or 0 for no entries

V_1 V_2 … V_{ni} = 1^{st} entry, 2^{nd} entry, ..., for the i^{th} keyword (see below).

Index Keyword	Index Keyword	Index Keyword	Index Keyword
1 BUFFER	5 FILTER	9 SURFACE	13 WRITE
2 CELL	6 MAX	10 TALLY	
3 EVENT	7 MENP	11 TYPE	
4 FILE	8 NPS	12 VALUE	

Table 10-3. Event Line Variable IDs (See Table 10-4)†

Index	Type 1		Type 2		Type 3		Type 4	
	$N_{12}\neq0$ WRITE=pos		$N_{12}=0$ WRITE=pos		$N_{12}\neq0$ WRITE=all		$N_{12}=0$ WRITE=all	
	$N_2=5$ $N_3=3$	$N_{4,6,8,10}=6$ $N_{5,7,9,11}=3$	$N_2=6$ $N_3=3$	$N_{4,6,8,10}=7$ $N_{5,7,9,11}=3$	$N_2=6$ $N_3=9$	$N_{4,6,8,10}=7$ $N_{5,7,9,11}=9$	$N_2=7$ $N_3=9$	$N_{4,6,8,10}=8$ $N_{5,7,9,11}=9$
J_1	7	7	7	7	7	7	7	7
J_2	8	8	8	8	8	8	8	8
J_3	9	10,12,10,14	9	10,12,10,14	9	10,12,10,14	9	10,12,10,14
J_4	17	11,13,11,15	16	11,13,11,15	17	11,13,11,15	16	11,13,11,15
J_5	18	17	17	16	18	17	17	16
J_6		18	18	17	19	18	18	17

Index	Type 1 $N_{12}\neq0$ `WRITE=pos` N_2=5 N_3=3	$N_{4,6,8,10}$=6 $N_{5,7,9,11}$=3	Type 2 N_{12}=0 `WRITE=pos` N_2=6 N_3=3	$N_{4,6,8,10}$=7 $N_{5,7,9,11}$=3	Type 3 $N_{12}\neq0$ `WRITE=all` N_2=6 N_3=9	$N_{4,6,8,10}$=7 $N_{5,7,9,11}$=9	Type 4 N_{12}=0 `WRITE=all` N_2=7 N_3=9	$N_{4,6,8,10}$=8 $N_{5,7,9,11}$=9
J_7				18		19	19	18
J_8								19
P_1	20	20	20	20	20	20	20	20
P_2	21	21	21	21	21	21	21	21
P_3	22	22	22	22	22	22	22	22
P_4					23	23	23	23
P_5					24	24	24	24
P_6					25	25	25	25
P_7					26	26	26	26
P_8					27	27	27	27
P_9					28	28	28	28

† For a "bnk" event (N_4, N_5), interpret J_1 ... J_4 = 7,8,10,11
For a "sur" event (N_6, N_7), interpret J_1 ... J_4 = 7,8,12,13
For a "col" event (N_8, N_9), interpret J_1 ... J_4 = 7,8,10,11
For a "ter" event (N_{10}, N_{11}), interpret J_1 ... J_4 = 7,8,14,15

Table 10-4. Description of Variable IDs

Variable ID	MCNP6 Name	Description
NPS LINE		
1	`NPS`	Count of source particles started
2	`---`	Event type of 1st event (see Table 10-5)
3	`NCL(PBL%I%ICL)`	Problem numbers of the cells.
4	`NSF(PBL%I%JSU)`	Problem transformation of the surfaces.
5	`JPTAL(1,ITAL)`	Basic tally information
6	`TAL(JPTAL(7,ITAL))`	Tally scores accumulation
EVENT LINE		
7		Event type of next event (see Table 10-5)
8	`PBL%I%NODE`	Number of nodes in track from source to here
9	`NSR`	Source type
10	`NXS(2,IEX)`	Blocks of descriptors of cross section tables
11	`NTYN/PBL%I%MTP`	Reaction type (see table 10-8). `NTYN` for bank event; `MTP` for collision event
12	`NSF(PBL%I%JSU)`	Surface number

Variable ID	MCNP6 Name	Description
13		Angle with surface normal (degrees)
14	`NTER`	Termination type (see table 10-7)
15		Branch number for this history
16	`PBL%I%IPT`	Particle type
17	`NCL(PBL%I%ICL)`	Problem numbers of the cells.
18	`MAT(PBL%I%ICL)`	Material numbers of the cells.
19	`PBL%I%NCP`	Count of collisions per track
20	`PBL%R%X`	X coordinate of the particle position
21	`PBL%R%Y`	Y coordinate of the particle position
22	`PBL%R%Z`	Z coordinate of the particle position
23	`PBL%R%U`	Particle direction cosine with x axis
24	`PBL%R%V`	Particle direction cosine with y axis
25	`PBL%R%W`	Particle direction cosine with z axis
26	`PBL%R%ERG`	Particle energy
27	`PBL%R%WGT`	Particle weight
28	`PBL%R%TME`	Time at the particles position

Table 10-5. Event-Type Description

Location	Variable ID	Event Type src	bnk‡	sur	col	ter	Flag†
I_2 or J_1	7	1000	±(2000+L)	3000	4000	5000	9000

† When I_2 or J_1 = 9000, this event is the last event for this history.
‡ When I_2 or J_1 < 0, the next event has been rejected and is included for creation information only. The value L is given in Table 10-6.

Table 10-6. Bank Event Descriptions

L Value	Description	MCNP6 Subroutine	`NXS` & `NTYN` Provided
1	DXTRAN Track	DXTRAN	Y
2	Energy Split	ERGIMP	N
3	Weight-Window Surface Split	WTWNDO	N
4	Weight-Window Collision Split	WTWNDO	Y
5	Forced Collision-Uncollided Part	FORCOL	N
6	Importance Split	SURFAC	N
7	Neutron from Neutron (*n*,*xn*) (*n*,*f*) and Secondary Particles from Library Protons	COLIDN	Y
8	Photon from Neutron	ACEGAM	Y

L Value	Description	MCNP6 Subroutine	NXS & NTYN Provided
9	Photon from Double Fluorescence	COLIDP	Y
10	Photon from Annihilation	COLIDP	N
		ELECTR	
11	Electron from Photoelectric	EMAKER	Y
12	Electron from Compton	EMAKER	Y
13	Electron from Pair Production	EMAKER	Y
14	Auger Electron from Photon/X-ray	EMAKER	Y
15	Positron from Pair Production	EMAKER	N
16	Bremsstrahlung from Electron	TTBR	N
		BREMS	
17	Knock-on Electron	KNOCK	N
18	X-rays from Electron	KXRAY	N
19	Photon from Neutron – Multigroup	MGCOLN	Y
20	Neutron (*n*,*f*) – Multigroup	MGCOLN	Y
21	Neutron (*n*,*xn*) k- Multigroup	MGCOLN	Y
22	Photo from Photon – Multigroup	MGCOLN	Y
23	Adjoint Weight Split – Multigroup	MGACOL	N
24	Weight-Window Pseudo-Collision Split	WTWNDO	N
25	Secondary Particles from Photonuclear	COLLPN	Y
26	DXTRAN annihilation photon from pulse-height tally variance reduction	DXTRAN	Y
30	Light Ions from Neutrons	ACECP / LRECOIL / ACEION	Y
31	Light Ions from Protons	LRECOIL	Y
32	Library Neutrons from Model Neutrons	INTRCT	N
33	Secondary Particles from Inelastic Nuclear Interactions	UPDAT1	N
34	Secondary Particles from Elastic Nuclear Interactions	UPDATE	N
35	Delayed neutron	DNG_MODEL	N
36	Delayed photon	DNG_MODEL	N
37	Delayed electron	DNG_MODEL	N
38	Delayed alpha	DNG_MODEL	N
39	Delayed positron	DNG_MODEL	N

Table 10-7 NTER Variable Descriptions

NTER	Named Constant	Description
1	ALL_PARS_LOSS_ESCAPE	Escape
2	ALL_PARS_LOSS_ENERGY_CUTOFF	Energy cutoff
3	ALL_PARS_LOSS_TIME_CUTOFF	Time cutoff
4	ALL_PARS_LOSS_WEIGHT_WINDOW	Weight window
5	ALL_PARS_LOSS_CELL_IMPORTANCE	Cell importance
6	ALL_PARS_LOSS_WEIGHT_CUTOFF	Weight cutoff
7	ALL_PARS_LOSS_E_OR_T_IMPORTANCE	Energy/time importance
8	ALL_PARS_LOSS_DXTRAN	Dxtran
9	ALL_PARS_LOSS_FORCED_COLLISIONS	Forced collisions
10	ALL_PARS_LOSS_EXP_TRANSFORM	Exponential transform
Neutrons		
12	NEUTRON_LOSS_CAPTURE	Capture
13	NEUTRON_LOSS_LOSS_TO_N_XN	Loss to (n,xn)
14	NEUTRON_LOSS_LOSS_TO_FISSION	Loss to fission
15	NEUTRON_LOSS_NUCL_INTERACTION	Nuclear interaction
16	NEUTRON_LOSS_PARTICLE_DECAY	Particle decay
17	NEUTRON_LOSS_TABULAR_BOUNDARY	Tabular boundary
Photons		
12	PHOTON_LOSS_CAPTURE	Capture
13	PHOTON_LOSS_PAIR_PRODUCTION	Pair production
14	PHOTON_LOSS_PHOTONUCLEAR_ABS	Photonuclear absorption
15	PHOTON_LOSS_PHOTOFISSION	Loss to photofission

Electrons		
13	ELECTRON_LOSS_P_ANNIHILATION	Positron annihilation
17	ELECTRON_LOSS_ERG_REJECTION	Energy rejection > emax
Other neutral particles		
11	NEUTRAL_LOSS_NUCL_INTERACTION	Nuclear interaction
13	NEUTRAL_LOSS_PARTICLE_DECAY	Particle decay
Other charged particles		
13	CHARGED_LOSS_NUCL_INTERACTION	Nuclear interaction
15	CHARGED_LOSS_PARTICLE_DECAY	Particle decay
16	CHARGED_LOSS_CAPTURE	Capture
17	CHARGED_LOSS_TABULAR_SAMPLING	Tabular sampling
18	CHARGED_LOSS_COSY_APERTURE_HIT	Cosy aperture hit
19	CHARGED_LOSS_COSY_FAULTS	Cosy faults
20	CHARGED_LOSS_ERG_REJECTION	Energy rejection > emax

Table 10-8 NTYN/MTP Variable Descriptions

MTP	**NTYN**	**Description**
NEUTRON		
4	1	Inelastic $S(\alpha,\beta)$
-2	2	Elastic $S(\alpha,\beta)$
>0	-99	Elastic scatter / Inelastic scatter
	>5	ENDF Reaction ID
PHOTON		
-1	1	Incoherent scatter
-2	2	Coherent scatter

MTP	NTYN	Description
-3	3	Fluorescence
-4	4	Pair production

11 APPENDIX E XSDIR DATA DIRECTORY FILE

A cross-section directory file, commonly referred to as XSDIR, is used to locate and read the ACE-formatted data files. The particular default XSDIR file provided with MCNP6 (Version 2) is named xsdir_mcnp6.2. MCNP6 uses two *types* and fifteen *classes* of data. These data are kept in individual *tables* that are often organized into *libraries*. These terms and tables are described in this appendix.

MCNP6 reads fifteen *classes* of data from two *types* of data tables. The two types of data tables are the following:

1. Type 1—standard formatted tables (sequential, up to 128 characters per record). These portable libraries are used to transmit data from one installation to another. They are bulky and slower to read. Often installations generate Type 2 tables from Type 1 tables using the MAKXSF code [BRO06].
2. Type 2—standard unformatted tables (direct-access, binary) locally generated from Type 1 tables. They are generally not portable between different systems. Type 2 tables are used mostly because they are more compact and faster to read than Type 1 tables.

Data tables exist for fifteen *classes* of data. These classes are identified by the last letter of the ZAID suffix

Table 11-1 MCNP6 Data Classes

Class description	**ZAID suffix**
$S(\alpha,\beta)$ data tables	t
Continuous-energy neutron data libraries	c
Discrete-energy neutron data libraries	d
Coupled neutron-photon data multigroup library—neutron	m
Coupled neutron-photon data multigroup library—photon	g
Photoatomic data libraries	p
Photonuclear data libraries	u
Dosimetry data libraries	y
Electron data libraries	e
Proton data libraries	h
Photoatomic data libraries with atomic relaxation data	p
Deuteron data libraries	o
Triton data libraries	r
Helion data libraries	s
Alpha data libraries	a

A user should think of a data table as an entity that contains evaluation-dependent information about one of the fifteen *classes* of data for a specific target isotope, isomer, element, or material. For how the data are used in MCNP6, a user does not need to know whether a particular table is in Type 1 or Type 2. For a given ZAID, the data contained on Type 1 and Type 2 tables are identical. Problems run with one data type will track problems run with the same data in another format type.

When we refer to data libraries, we are talking about a series of data tables concatenated into one file. All tables on a single library must be of the same *type* but not necessarily of the same *class*. There is no reason, other than convenience, for having data libraries; MCNP6 could read exclusively from individual data tables not in libraries.

MCNP6 determines where to find data tables for each ZAID in a problem based on information contained in a system-dependent cross-section directory (or XSDIR) file. (The specific directory file supplied with the MCNP6 (Version 2) distribution is named xsdir_mcnp6.2.) The directory file is a sequentially formatted ASCII file containing free-field entries delimited by blanks.
The XSDIR file has three sections. In the first section, the first line is an optional entry of the form

`DATAPATH =` *`datapath`*

where the word DATAPATH (case insensitive) must start in columns 1–5. The "=" sign is optional. The directory where the data libraries are stored is named *datapath*. The XSDIR directory file can be renamed on the MCNP6 execution line (see Table 1-2). The search hierarchy to find XSDIR and/or the data libraries is the following:

1. XSDIR=*file_name* on the MCNP6 execution line, where "*file_name* " is the name of a cross-section directory file
2. `DATAPATH =` *`datapath`* in the INP file message block,
3. the current working directory,
4. the `DATAPATH` entry on the first line of the XSDIR file,
5. the system environment variable `DATAPATH`, or

the individual data table line in the XSDIR file (see below under Access Route).The second section of the XSDIR file is the atomic weight ratios. This section starts with the words “ATOMIC WEIGHT RATIOS” (case insensitive) beginning in columns 1–5. The following lines are free-format pairs of ZAID AWR, where ZAID is an integer of the form ZZAAA and AWR is the atomic weight ratio. These atomic weight ratios are used for converting from weight fractions to atom fractions and for getting the average Z in computing electron stopping powers. If the atomic weight ratio is missing for any nuclide requested on an M*m* card, it must be provided on the AWTAB card.

The third section of the XSDIR file is the listing of available data tables. This section starts with the word “DIRECTORY” (case insensitive) beginning in columns 1–5. The lines following consist of the seven– to ten–entry description of each table. The ZAID of each table must be the first entry. If a table requires more than one line, the continuation is indicated by a □□ at the end of the line. A zero indicates the entry is not applicable. Unneeded entries at the end of the line can be omitted.

The directory file has seven to eleven entries for each table. They are the following:

1.	Name of the Table	character * 10
2.	Atomic Weight Ratio	real
3.	File Name	character * 60
4.	Access Route	character * 70
5.	File Type	integer
6.	Address	integer
7.	Table Length	integer
8.	Record Length	integer
9.	Number of Entries per Record	integer
10.	Temperature	real
11.	Probability Table Flag	character * 6

1. Name of the Table. This is usually the 10-character ZAID with 3 characters for Z, 3 characters for A, a decimal point, 2 characters for evaluation identification, and a tenth character to identify the class. For the S(α,β) tables, the first 6 characters contain a mnemonic character string, such as LWTR.01T.

2. Atomic Weight Ratio. This is the atomic mass divided by the mass of a neutron. The atomic weight ratio here is used only for neutron kinematics and should be the same as it appears in the cross-section table so that threshold reactions are correct. It is the quantity *A* used in all the neutron interaction equations of Section 2. This entry is used only for neutron tables.

3. File Name. The file name is the name of the library that contains the table. The file name can include a directory path.

4. Access Route. The access route is a string of up to 70 characters that tells how to access the file if it is not already accessible, such as a directory path. If there is no access route, this entry is zero

5. File Type. Either 1 for Type 1 files or 2.for Type 2.

6. Address. For Type 1 files, the address is the line number in the file where the table starts. For Type 2 files, it is the record number of the first record of the table.

7. Table Length. A data table consists of two blocks of information. The first block is a collection of pointers, counters, and character information. The second block is a solid sequence of numbers. For Type 1 and Type 2 tables, the table length is the length (total number of words) of the second block.

8. Record Length. This entry is unused for Type 1 files and therefore is zero. For Type 2 direct access files, it is a compiler-dependent attribute.

9. Number of Entries per Record. This is unused for Type 1 files and therefore is zero. For Type 2 files it is the number of entries per record. Usually this entry is set to 512.

10. Temperature. This is the temperature in MeV at which a neutron table is processed. This entry is used only for neutron data.

11. Probability Table Flag. The character word “ptable” indicates a continuous-energy neutron nuclide has unresolved resonance range probability tables.

12 APPENDIX F SUPPLEMENTAL PHYSICS INFORMATION

Table 12-1 identifies those heavy ions that may be transported.

Table 12-1. Heavy Ions Available for Transport

Z = 2 ***** Helium *****									
2005	2006	2007	2008						
Z = 3 ***** Lithium *****									
3005	3006	3007	3008	3009	3010	3011			
Z = 4 ***** Beryllium *****									
4006	4007	4008	4009	4010	4011	4012	4013	4014	
Z = 5 ***** Boron *****									
5008	5009	5010	5011	5012	5013	5014	5015	5016	5017
Z = 6 ***** Carbon *****									
6008	6009	6010	6011	6012	6013	6014	6015	6016	6017
6018	6019	6020							
Z = 7 ***** Nitrogen *****									
7011	7012	7013	7014	7015	7016	7017	7018	7019	7020
7021	7022	7023							
Z = 8 ***** Oxygen *****									
8013	8014	8015	8016	8017	8018	8019	8020	8021	8022
8023	8024								
Z = 9 ***** Fluorine *****									
9015	9016	9017	9018	9019	9020	9021	9022	9023	9024
9025	9026	9027							
Z = 10 ***** Neon *****									
10017	10018	10019	10020	10021	10022	10023	10024	10025	10026
10027	10028								

Z = 11 ***** Sodium *****									
11019	11020	11021	11022	11023	11024	11025	11026	11027	11028
11029	11030	11031	11032	11033	11034	11035			
Z = 12 ***** Magnesium *****									
12020	12021	12022	12023	12024	12025	12026	12027	12028	12029
12030	12031	12032	12033	12034					
Z = 13 ***** Aluminum *****									
13022	13023	13024	13025	13026	13027	13028	13029	13030	13031
13032	13033	13034	13035						
Z = 14 ***** Silicon *****									
14024	14025	14026	14027	14028	14029	14030	14031	14032	14033
14034	14035	14036	14037	14038	14039				
Z = 15 ***** Phosphorus *****									
15026	15027	15028	15029	15030	15031	15032	15033	15034	15035
15036	15037	15038	15039	15040	15041	15042			
Z = 16 ***** Sulfur *****									
16029	16030	16031	16032	16033	16034	16035	16036	16037	16038
16039	16040	16041	16042	16043	16044				
Z = 17 ***** Chlorine *****									
17031	17032	17033	17034	17035	17036	17037	17038	17039	17040
17041	17042	17043	17044	17045					
Z = 18 ***** Argon *****									
18032	18033	18034	18035	18036	18037	18038	18039	18040	18041
18042	18043	18044	18045	18046					
Z = 19 ***** Potassium *****									
19035	19036	19037	19038	19039	19040	19041	19042	19043	19044
19045	19046	19047	19048	19049	19050	19051			
Z = 20 ***** Calcium *****									
20036	20037	20038	20039	20040	20041	20042	20043	20044	20045
20046	20047	20048	20049	20050	20051				

Z = 21 ***** Scandium *****									
21040	21041	21042	21043	21044	21045	21046	21047	21048	21049
21050	21051								
Z = 22 ***** Titanium *****									
22041	22042	22043	22044	22045	22046	22047	22048	22049	22050
22051	22052	22053	22054						
Z = 23 ***** Vanadium *****									
23044	23045	23046	23047	23048	23049	23050	23051	23052	23053
23054	23055	23056							
Z = 24 ***** Chromium *****									
24045	24046	24047	24048	24049	24050	24051	24052	24053	24054
24055	24056	24057	24058	24059					
Z = 25 ***** Manganese *****									
25049	25050	25051	25052	25053	25054	25055	25056	25057	25058
25059	25060	25061	25062						
Z = 26 ***** Iron *****									
26049	26050	26051	26052	26053	26054	26055	26056	26057	26058
26059	26060	26061	26062	26063	26064				
Z = 27 ***** Cobalt *****									
27053	27054	27055	27056	27057	27058	27059	27060	27061	27062
27063	27064								
Z = 28 ***** Nickel *****									
28053	28054	28055	28056	28057	28058	28059	28060	28061	28062
28063	28064	28065	28066	28067	28068				
Z = 29 ***** Copper *****									
29057	29058	29059	29060	29061	29062	29063	29064	29065	29066
29067	29068	29069	29070	29071	29072	29073			
Z = 30 ***** Zinc *****									
30057	30058	30059	30060	30061	30062	30063	30064	30065	30066
30067	30068	30069	30070	30071	30072	30073	30074	30075	30076
30077	30078								

Z = 31 ***** Gallium *****									
31062	31063	31064	31065	311066	31067	31068	31069	31070	31071
31072	31073	31074	31075	31076	31077	31078	31079	31080	31081
31082	31083								
Z = 32 ***** Germanium *****									
32061	32062	32063	32064	32065	32066	32067	32068	32069	32070
32071	32072	32073	32074	32075	32076	32077	32078	32079	32080
32081	32082	32083	32084						
Z = 33 ***** Arsenic *****									
33066	33067	33068	33069	33070	33071	33072	33073	33074	33075
33076	33077	33078	33079	33080	33081	33082	33083	33084	33085
33086	33087								
Z = 34 ***** Selenium *****									
34068	34069	34070	34071	34072	34073	34074	34075	34076	34077
34078	34079	34080	34081	34082	34083	34084	34085	34086	34087
34088	34089	34090	34091						
Z = 35 ***** Bromine *****									
35070	35071	35072	35073	35074	35075	35076	35077	35078	35079
35080	35081	35082	35083	35084	35085	35086	35087	35088	35089
35090	35091	35092							
Z = 36 ***** Krypton *****									
36071	36072	36073	36074	36075	36076	36077	36078	36079	36080
36081	36082	36083	36084	36085	36086	36087	36088	36089	36090
36091	36092	36093	36094	36095	36096	36097			
Z = 37 ***** Rubidium *****									
37074	37075	37076	37077	37078	37079	37080	37081	37082	37083
37084	37085	37086	37087	37088	37089	37090	37091	37092	37093
37094	37095	37096	37097	37098	37099	37100			
Z = 38 ***** Strontium *****									
38077	38078	38079	38080	38081	38082	38083	38084	38085	38086
38087	38088	38089	38090	38091	38092	38093	38094	38095	38096
38097	38098	38099	38100						

Z = 39 ***** Yttrium *****									
39080	39081	39082	39083	39084	39085	39086	39087	39088	39089
39090	39091	39092	39093	39094	39095	39096	39097	39098	39099
39100	39101	39102							
Z = 40 ***** Zirconium *****									
40081	40082	40083	40084	40085	40086	40087	40088	40089	40090
40091	40092	40093	40094	40095	40096	40097	40098	40099	40100
40101	40102								
Z = 41 ***** Niobium *****									
41084	41085	41086	41087	41088	41089	41090	41091	41092	41093
41094	41095	41096	41097	41098	41099	41100	41101	41102	41103
41104	41105	41106							
Z = 42 ***** Molybdenum *****									
42087	42088	42089	42090	42091	42092	42093	42094	42095	42096
42097	42098	42099	42100	42101	42102	42103	42104	42105	42106
42107	42108								
Z = 43 ***** Technetium *****									
43090	43091	43092	43093	43094	43095	43096	43097	43098	43099
43100	43101	43102	43103	43104	43105	43106	43107	43108	43109
43110									
Z = 44 ***** Ruthenium *****									
44092	44093	44094	44095	44096	44097	44098	44099	44100	44101
44102	44103	44104	44105	44106	44107	44108	44109	44110	44111
44112	44113								
Z = 45 ***** Rhodium *****									
45094	45095	45096	45097	45098	45099	45100	45101	45102	45103
45104	45105	45106	45107	45108	45109	45110	45111	45112	45113
45114									
Z = 46 ***** Palladium *****									
46096	46097	46098	46099	46100	46101	46102	46103	46104	46105
46106	46107	46108	46109	46110	46111	46112	46113	46114	46115
46116	46117	46118							

Z = 47 ***** Silver *****									
47096	47097	47098	47099	47100	47101	47102	47103	47104	47105
47106	47107	47108	47109	47110	47111	47112	47113	47114	47115
47116	47117	47118	47119	47120	47121	47122	47123		
Z = 48 ***** Cadmium *****									
48097	48098	48099	48100	48101	48102	48103	48104	48105	48106
48107	48108	48109	48110	48111	48112	48113	48114	48115	48116
48117	48118	48119	48120	48121	48122	48123	48124	48125	48126
Z = 49 ***** Indium *****									
49100	49101	49102	49103	49104	49105	49106	49107	49108	49109
49110	49111	49112	49113	49114	49115	49116	49117	49118	49119
49120	49121	49122	49123	49124	49125	49126	49127	49128	49129
49130	49131	49132							
Z = 50 ***** Tin *****									
50103	50104	50105	50106	50107	50108	50109	50110	50111	50112
50113	50114	50115	50116	50117	50118	50119	50120	50121	50122
50123	50124	50125	50126	50127	50128	50129	50130	50131	50132
50133	50134								
Z = 51 ***** Antimony *****									
51108	51109	51110	51111	51112	51113	51114	51115	51116	51117
51118	51119	51120	51121	51122	51123	51124	51125	51126	51127
51128	51129	51130	51131	51132	51133	51134	51135	51136	
Z = 52 ***** Tellurium *****									
52106	52107	52108	52109	52110	52111	52112	52113	52114	52115
52116	52117	52118	52119	52120	52121	52122	52123	52124	52125
52126	52127	52128	52129	52130	52131	52132	52133	52134	52135
52136	52137	52138							
Z = 53 ***** Iodine *****									
53110	53111	53112	53113	53114	53115	53116	53117	53118	53119
53120	53121	53122	53123	53124	53125	53126	53127	53128	53129
53130	53131	53132	53133	53134	53135	53136	53137	53138	53139
53140	53141	53142							

Z = 54 ***** Xenon *****									
54110	54111	54112	54113	54114	54115	54116	54117	54118	54119
54120	54121	54122	54123	54124	54125	54126	54127	54128	54129
54130	54131	54132	54133	54134	54135	54136	54137	54138	54139
54140	54141	54142	54143	54144	54145				
Z = 55 ***** Cesium *****									
55114	55115	55116	55117	55118	55119	55120	55121	55122	55123
55124	55125	55126	55127	55128	55129	55130	55131	55132	55133
55134	55135	55136	55137	55138	55139	55140	55141	55142	55143
55144	55145	55146	55147	55148					
Z = 56 ***** Barium *****									
56117	56118	56119	56120	56121	56122	56123	56124	56125	56126
56127	56128	56129	56130	56131	56132	56133	56134	56135	56136
56137	56138	56139	56140	56141	56142	56143	56144	56145	56146
56147	56148								
Z = 57 ***** Lanthanum *****									
57123	57124	57125	57126	57127	57128	57129	57130	57131	57132
57133	57134	57135	57136	57137	57138	57139	57140	57141	57142
57143	57144	57145	57146	57147	57148	57149			
Z = 58 ***** Cerium *****									
58124	58125	58126	58127	58128	58129	58130	58131	58132	58133
58134	58135	58136	58137	58138	58139	58140	58141	58142	58143
58144	58145	58146	58147	58148	58149	58150	58151		
Z = 59 ***** Praseodymium *****									
59129	59130	59131	59132	59133	59134	59135	59136	59137	59138
59139	59140	59141	59142	59143	59144	59145	59146	59147	59148
59149	59150	59151	59152						
Z = 60 ***** Neodymium *****									
60129	60130	60131	60132	60133	60134	60135	60136	60137	60138
60139	60140	60141	60142	60143	60144	60145	60146	60147	60148
60149	60150	60151	60152	60153	60154				

Z = 61 ***** Promethium *****									
61132	61133	61134	61135	61136	61137	61138	61139	61140	61141
61142	61143	61144	61145	61146	61147	61148	61149	61150	61151
61152	61153	61154	61155						
Z = 62 ***** Samarium *****									
62133	62134	62135	62136	62137	62138	62139	62140	62141	62142
62143	62144	62145	62146	62147	62148	62149	62150	62151	62152
62153	62154	62155	62156	62157	62158				
Z = 63 ***** Europium *****									
63138	63139	63140	63141	63142	63143	63144	63145	63146	63147
63148	63149	63150	63151	63152	63153	63154	63155	63156	63157
63158	63159	63160							
Z = 64 ***** Gadolinium *****									
64142	64143	64144	64145	64146	64147	64148	64149	64150	64151
64152	64153	64154	64155	64156	64157	64158	64159	64160	64161
64162	64163								
Z = 65 ***** Terbium *****									
65144	65145	65146	65147	65148	65149	65150	65151	65152	65153
65154	65155	65156	65157	65158	65159	65160	65161	65162	65163
65164	65165								
Z = 66 ***** Dysprosium *****									
66145	66146	66147	66148	66149	66150	66151	66152	66153	66154
66155	66156	66157	66158	66159	66160	66161	66162	66163	66164
66165	66166	66167	66168						
Z = 67 ***** Holmium *****									
67147	67148	67149	67150	67151	67152	67153	67154	67155	67156
67157	67158	67159	67160	67161	67162	67163	67164	67165	67166
67167	67168	67169	67170						
Z = 68 ***** Erbium *****									
68147	68148	68149	68150	68151	68152	68153	68154	68155	68156
68157	68158	68159	68160	68161	68162	68163	68164	68165	68166
68167	68168	68169	68170	68171	68172	68173			

Z = 69 ***** Thulium *****									
69151	69152	69153	69154	69155	69156	69157	69158	69159	69160
69161	69162	69163	69164	69165	69166	69167	69168	69169	69170
69171	69172	69173	69174	69175	69176				
Z = 70 ***** Ytterbium *****									
70153	70154	70155	70156	70157	70158	70159	70160	70161	70162
70163	70164	70165	70166	70167	70168	70169	70170	70171	70172
70173	70174	70175	70176	70177	70178	70179			
Z = 71 ***** Lutetium *****									
71151	71152	71153	71154	71155	71156	71157	71158	71159	71160
71161	71162	71163	71164	71165	71166	71167	71168	71169	71170
71171	71172	71173	71174	71175	71176	71177	71178	71179	71180
71181	71182	71183							
Z = 72 ***** Hafnium *****									
72154	72155	72156	72157	72158	72159	72160	72161	72162	72163
72164	72165	72166	72167	72168	72169	72170	72171	72172	72173
72174	72175	72176	72177	72178	72179	72180	72181	72182	72183
72184									
Z = 73 ***** Tantalum *****									
73157	73158	73159	73160	73161	73162	73163	73164	73165	73166
73167	73168	73169	73170	73171	73172	73173	73174	73175	73176
73177	73178	73179	73180	73181	73182	73183	73184	73185	73186
Z = 74 ***** Tungsten *****									
74158	74159	74160	74161	74162	74163	74164	74165	74166	74167
74168	74169	74170	74171	74172	74173	74174	74175	74176	74177
74178	74179	74180	74181	74182	74183	74184	74185	74186	74187
74188	74189	74190							
Z = 75 ***** Rhenium *****									
75161	75162	75163	75164	75165	75166	75167	75168	75169	75170
75171	75172	75173	75174	75175	75176	75177	75178	75179	75180
75181	75182	75183	75184	75185	75186	75187	75188	75189	75190
75191	75192								

Z = 76 ***** Osmium *****									
76163	76164	76165	76166	76167	76168	76169	76170	76171	76172
76173	76174	76175	76176	76177	76178	76179	76180	76181	76182
76183	76184	76185	76186	76187	76188	76189	76190	76191	76192
76193	76194	76195	76196						
Z = 77 ***** Iridium *****									
77166	77167	77168	77169	77170	77171	77172	77173	77174	77175
77176	77177	77178	77179	77180	77181	77182	77183	77184	77185
77186	77187	77188	77189	77190	77191	77192	77193	77194	77195
77196	77197	77198							
Z = 78 ***** Platinum *****									
78168	78169	78170	78171	78172	78173	78174	78175	78176	78177
78178	78179	78180	78181	78182	78183	78184	78185	78186	78187
78188	78189	78190	78191	78192	78193	78194	78195	78196	78197
78198	78199	78200	78201						
Z = 79 ***** Gold *****									
79175	79176	79177	79178	79179	79180	79181	79182	79183	79184
79185	79186	79187	79188	79189	79190	79191	79192	79193	79194
79195	79196	79197	79198	79199	79200	79201	79202	79203	79204
Z = 80 ***** Mercury *****									
80177	80178	80179	80180	80181	80182	80183	80184	80185	80186
80187	80188	80189	80190	80191	80192	80193	80194	80195	80196
80197	80198	80199	80200	80201	80202	80203	80204	80205	80206
Z = 81 ***** Thallium *****									
81184	81185	81186	81187	81188	81189	81190	81191	81192	81193
81194	81195	81196	81197	81198	81199	81200	81201	81202	81203
81204	81205	81206	81207	81208	81209	81210			
Z = 82 ***** Lead *****									
82183	82184	82185	82186	82187	82188	82189	82190	82191	82192
82193	82194	82195	82196	82197	82198	82199	82200	82201	82202
82203	82204	82205	82206	82207	82208	82209	82210	82211	82212
82213	82214								

Z = 83 ***** Bismuth *****									
83188	83189	83190	83191	83192	83193	83194	83195	83196	83197
83198	83199	83200	83201	83202	83203	83204	83205	83206	83207
83208	83209	83210	83211	83212	83213	83214	83215		
Z = 84 ***** Polonium *****									
84192	84193	84194	84195	84196	84197	84198	84199	84200	84201
84202	84203	84204	84205	84206	84207	84208	84209	84210	84211
84212	84213	84214	84215	84216	84217	84218			
Z = 85 ***** Astatine *****									
85196	85197	85198	85199	85200	85201	85202	85203	85204	85205
85206	85207	85208	85209	85210	85211	85212	85213	85214	85215
85216	85217	85218	85219						
Z = 86 ***** Radon *****									
86199	86200	86201	86202	86203	86204	86205	86206	86207	86208
86209	86210	86211	86212	86213	86214	86215	86216	86217	86218
86219	86220	86221	86222	86223	86224	86225	86226		
Z = 87 ***** Francium *****									
87201	87202	87203	87204	87205	87206	87207	87208	87209	87210
87211	87212	87213	87214	87215	87216	87217	87218	87219	87220
87221	87222	87223	87224	87225	87226	87227	87228	87229	
Z = 88 ***** Radium *****									
88206	88207	88208	88209	88210	88211	88212	88213	88214	88215
88216	88217	88218	88219	88220	88221	88222	88223	88224	88225
88226	88227	88228	88229	88230					
Z = 89 ***** Actinium *****									
89209	89210	89211	89212	89213	89214	89215	89216	89217	89218
89219	89220	89221	89222	89223	89224	89225	89226	89227	89228
89229	89230	89231	89232						
Z = 90 ***** Thorium *****									
90212	90213	90214	90215	90216	90217	90218	90219	90220	90221
90222	90223	90224	90225	90226	90227	90228	90229	90230	90231
90232	90233	90234	90235	90236					

Z = 91 ***** Protactinium *****									
91215	91216	91217	91218	91219	91220	91221	91222	91223	91224
91225	91226	91227	91228	91229	91230	91231	91232	91233	91234
91235	91236	91237	91238						
Z = 92 ***** Uranium *****									
92222	92223	92224	92225	92226	92227	92228	92229	92230	92231
92232	92233	92234	92235	92236	92237	92238	92239	92240	92241
92242									
Z = 93 ***** Neptunium *****									
93227	93228	93229	93230	93231	93232	93233	93234	93235	93236
93237	93238	93239	93240	93241	93242				
Z = 94 ***** Plutonium *****									
94232	94233	94234	94235	94236	94237	94238	94239	94240	94241
94242	94243	94244	94245	94246					
Z = 95 ***** Americium *****									
95232	95233	95234	95235	95236	95237	95238	95239	95240	95241
95242	95243	95244	95245	95246	95247				
Z = 96 ***** Curium *****									
96238	96239	96240	96241	96242	96243	96244	96245	96246	96247
96248	96249	96250	96251						
Z = 97 ***** Berkelium *****									
97240	97241	97242	97243	97244	97245	97246	97247	97248	97249
97250	97251								
Z = 98 ***** Californium *****									
98239	98240	98241	98242	98243	98244	98245	98246	98247	98248
98249	98250	98251	98252	98253	98254	98255	98256		
Z = 99 ***** Einsteinium *****									
99243	99244	99245	99246	99247	99248	99249	99250	99251	99252
99253	99254	99255	99256						
Z = 100 ***** Fermium *****									
100242	100243	100244	100245	100246	100247	100248	100249	100250	100251
100252	100253	100254	100255	100256	100257	100258	100259		