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MCNPX 2.6.0 – New Features Demonstrated

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Outline

- Overview
- Development History
- User Base
- New 2.6.0 Features
- Future Development

Overview

- Monte Carlo radiation transport code
  - Extends MCNP4C to virtually all particles and energies
  - 34 particles (n,p,e, …) + 2205 heavy ions
  - Continuous energy (roughly 0-1000 GeV)
  - Data libraries below ~ 150 MeV (n,p,e,h) & models otherwise
- General 3-D geometry
  - 1st & 2nd degree surfaces, tori, 10 macrobodies, lattices
- General sources and tallies
  - Interdependent source variables, 7 tally types, many modifiers
- Supported on virtually all computer platforms
  - Unix, Linux, Windows, OS X (parallel with MPI)

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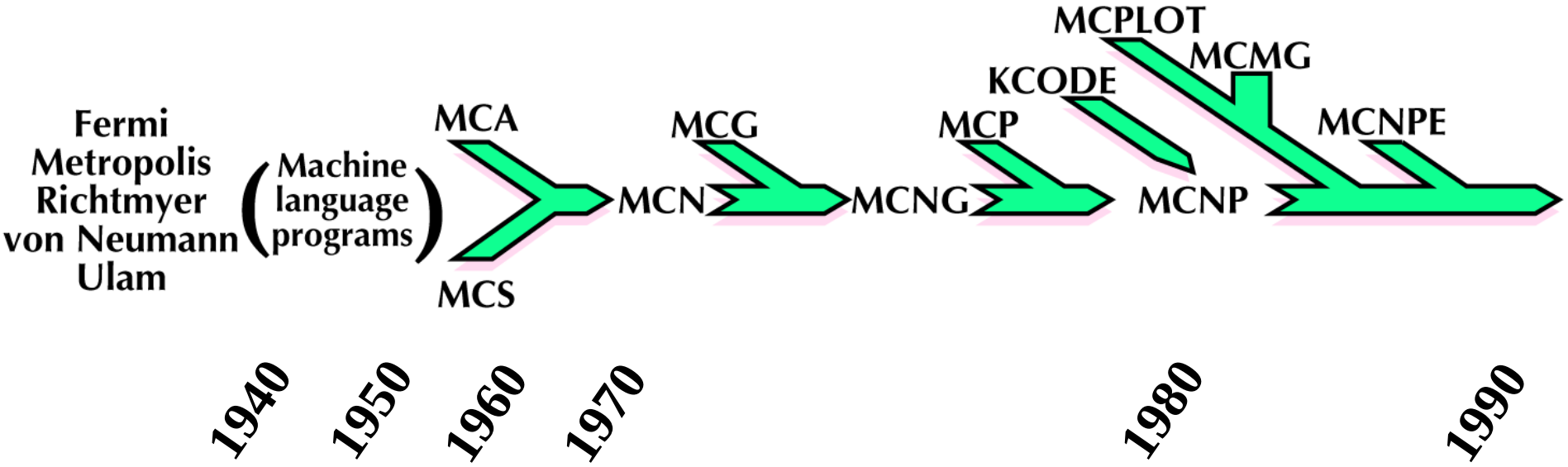
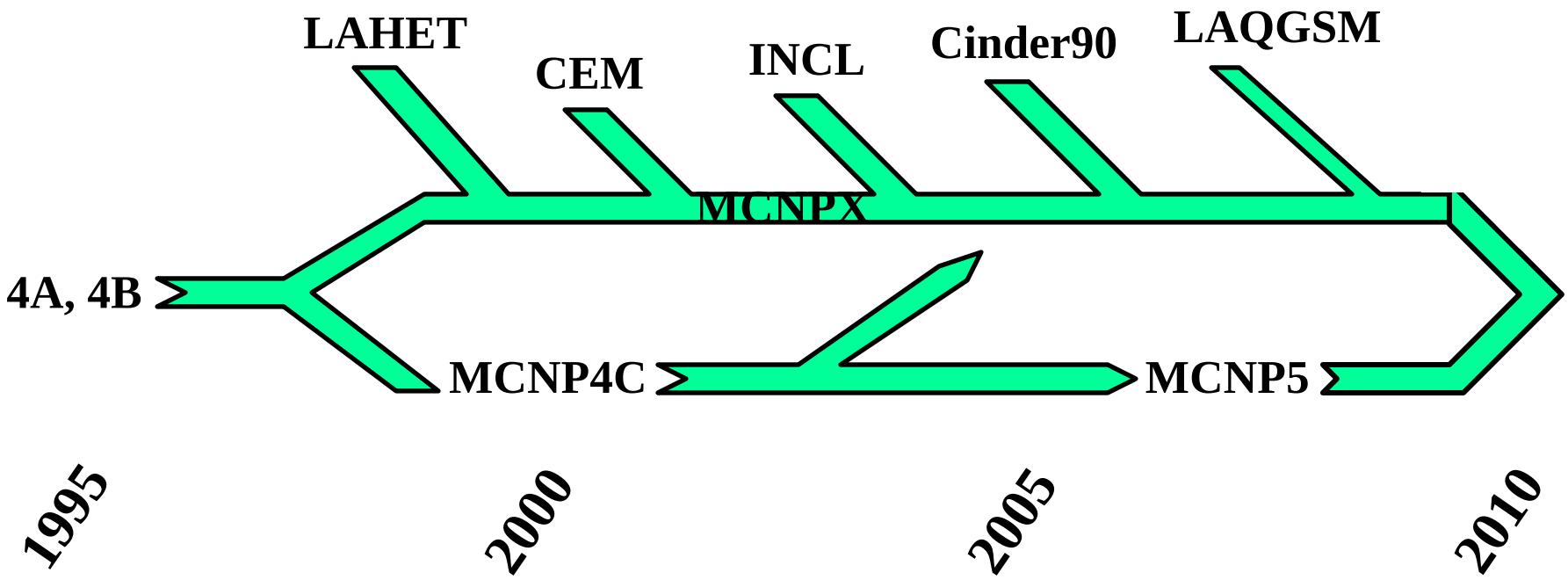
History of MCNP



History of MCNP/MCNPX



History of MCNPX

1992-1993 LAHET and Superhet
Superconducting Super Collider
1994-1995 Start of the APT program
Version 1.0 April 22, 1997
Version 2.0 October 1, 1997
Version 2.1.3 April 17, 1998
HISTP writing, compatible with HTAPE, collisional energy loss model
Version 2.1.4 July 24, 1998
Mesh & radiography tallies, gridconv, bertin & phtlib binary support
Version 2.1.5 **Nov 14, 1999**
CEM, HTAPE3X, User's Manual, Beta test team
Version 2.1.6 September 14, 1999
Proton libraries (internal user only)
Version 2.3.0 **April 27, 2002**

History of MCNPX

Version 2.4.0 **August 01, 2002**

Update to MCNP4C3, F90, Windows PC, New user's manual

Version 2.5.C April, 2003

MPI Multiprocessing, Mix & Match, CEM2K

Version 2.5.D August, 2003

INCL4/ABLA physics models, Multiple particles on SDEF card, READ card

Version 2.5.E February, 2004

MPI KCODE speedup, 64-bit integers, G5 support, 2-D color contour plots

Version 2.5.0 **March, 2005**

Mesh tally contour plots, Pulse-height tally with VR, PN improvements

History of MCNPX

Version 2.6.A	December, 2005
Transmutation, Long file names, STOP card	
Version 2.6.B	June, 2006
CEM 03, new PHTLIB, predictor-corrector for burnup	
Version 2.6.C	December, 2006
Spherical weight windows, delayed particle production	
Version 2.6.D	June, 2007
Coupled energy-time weight windows, activation	
Version 2.6.E	November, 2007
Heavy-ion transport, muon capture physics, photofission yields	
Version 2.6.F	March, 2008
Spontaneous photons, dynamic material burnup	
Version 2.6.0	**April, 2008**
Version 2.7.A	November, 2008
Pulsed sources, tally tagging, CEM upgrade to 03.02	

History of MCNPX – Version 2.6.A

- Transmutation using Cinder90 (BURN card)
  - Several keywords of options (MAT, POWER, etc.)
  - Automatic updating of material atom densities
- Long file names (40 vs. 8 characters)
- STOP card - terminate tallies at desired precision
- Corrections/enhancements/extensions
  - Proton step size control (HSTEP on M card)
  - New S(α,β) scattering law
  - Differential data tallies extended to table physics
  - Separate printout of induced fission multiplicity

History of MCNPX – Version 2.6.B

- Transmutation improvements (BURN card)
  - Predictor/corrector
  - Automatic selection of FP dist. (thermal, fast, high)
- CEM INC model upgrade (from 2K to 03)
- FIELD card–planetary gravity effects for neutrons
- Corrections/enhancements/extensions
  - New photon emission data: PHTLIB
  - Geometry plot basis vectors
  - Extend ZAID identifiers

History of MCNPX – Version 2.6.C

- Transmutation improvements (BURN card)
  - Support for continue-runs & parallel execution
  - Printing of reaction rates sent to Cinder90
  - Reduced memory requirements
- Spherical weight windows
- Delayed neutrons & gammas
  - ~1000 nuclides treated with gamma line data
- Photon tally tagging
- Model treatment for library absorption reactions

History of MCNPX – Version 2.6.D

- Transmutation improvements (BURN card)
  - Time-dependent material changes (CONC keyword)
  - Repeated-structures power norm. (VOL keyword)
  - Fission-product tier improvements
- Coupled space-energy-time weight windows
- Activation neutrons and gammas
- Photon tally tagging

History of MCNPX – Version 2.6.E

- Transmutation improvements (BURN card)
  - Additional printout information
  - Multiple Cinder iterations per time step
- Muon capture physics
- Heavy-ion transport (via LAQGSM)
- Photofission yields
- Spherical mesh plotting
- Activation enhancements

History of MCNPX – Version 2.6.F

- Transmutation improvements (BURN card)
  - Time-dependent material loading/unloading
  - May be used to simulate control-rod/poison effects
- Spontaneous photons (SDEF par=sp, erg=0)
  - Unstable nuclides in a material (SDEF PAR=sp)
  - Directly as a source (SDEF PAR=7016, ERG=0)
- Photonuclear data
- Corrections & misc. enhancements

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User Base

- ~2500 users world wide
  - Provide 6-8 workshops per year (4-6 US, ~2 international)
  - 150 workshop participants per year
  - Access to RSICC/NEA released versions only
    - http://www-rsicc.ornl.gov/ (C00746) 2.6.0
    - http://www.nea.fr/html/dbprog/ (CCC-0746) 2.6.0
  - Limited access to MCNPX web site
    - http://mcnpx.lanl.gov (some documentation)
- ~2000 registered Beta Testers
  - Full access to MCNPX web site
  - Access to intermediate versions
  - Increased user support

Application	# Groups	Percent
Medical (BNCT, proton therapy, etc.)	**50**	**15**
Spacecraft, Cosmic Rays, SEE, propulsion	**42**	**12**
Detectors, experiments, Threat Reduction	**39**	**11**
ATW, ADS, Energy Amplifiers	**37**	**11**
Fuel cycles, beginning to end, including storage	**32**	**9**
Accelerator Shielding and Health Physics	**28**	**8**
Theoretical Physics	**23**	**7**
Neutron Production for Scattering	**21**	**6**
Isotope Production	**14**	**4**
Radiography	**12**	**4**
MCNPX/MCNP code development	**11**	**3**
Homeland Security	**10**	**3**
Materials studies (IFMIF)	**6**	**2**
Radioactive Ion Beams	**5**	**1**
Irradiation Facilities	**4**	**1**
Neutrino Targets	**4**	**1**
Light Sources, electron machines	**3**	**1**

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New 2.6.0 Features

- **User-interface enhancements (14)**
  - 3 new source options
  - 4 new tally options
  - 3 new variance reduction options
  - 4 other miscellaneous improvements
- **Physics enhancements (10)**
  - 7 new model physics features
  - 2 new neutron physics features
  - 1 new photon physics features

User-Interface Enhancements

- **Three new source options**
  - Transmutation for eigenvalue problems
  - Spontaneous photon sources
  - Enhanced eigenfunction convergence

Transmutation for eigenvalue problems

```
GODIVA burn for 4 days @ 1 MW
1    1  -18.74  -1 imp:n=1
2    0            1 imp:n=0

1    sph 0 0 0    8.741

kcode 10000 1 20 50
ksrc  0 0 0
BURN  TIME=1,3  $ Days
      POWER=1.0 $ MW
vol   2797.512 0
m1    92235 -94.73  92238 -5.27
```

Transmutation for eigenvalue problems

1burnup summary table by material print table 210

step	duration (days)	time (days)	power (MW)	keff	flux	ave. nu	ave. q	burnup (GWd/MTU)	source (nts/sec)
0	0.000E+00	0.000E+00	1.000E+00	1.00157	1.951E+14	2.599	200.962	0.000E+00	8.071E+16
1	1.000E+00	1.000E+00	1.000E+00	0.99984	1.949E+14	2.598	200.962	1.908E-02	8.069E+16
2	3.000E+00	4.000E+00	1.000E+00	1.00340	1.951E+14	2.599	200.962	7.631E-02	8.072E+16

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actinide inventory for material 1 at end of step 2, time 4.000E+00 (days), power 1.000E+00 (MW)

no.	zaid	mass (gm)	activity (Ci)	spec.act. (Ci/gm)	atom den. (a/b-cm)	atom fr.	mass fr.
1	92235	4.966E+04	1.073E-01	2.161E-06	4.548E-02	9.479E-01	9.473E-01
2	92238	2.763E+03	9.286E-04	3.361E-07	2.498E-03	5.207E-02	5.270E-02
3	92236	4.740E-01	3.065E-05	6.467E-05	4.322E-07	9.009E-06	9.041E-06
4	92234	2.659E-02	1.653E-04	6.217E-03	2.446E-08	5.097E-07	5.072E-07
5	93239	1.008E-02	2.338E+03	2.319E+05	9.079E-09	1.892E-07	1.923E-07
6	94239	6.994E-03	4.338E-04	6.203E-02	6.298E-09	1.313E-07	1.334E-07
7	92237	1.564E-03	1.277E+02	8.160E+04	1.421E-09	2.961E-08	2.984E-08
8	93237	3.403E-04	2.398E-07	7.047E-04	3.090E-10	6.441E-09	6.491E-09
9	92239	1.016E-04	3.405E+03	3.351E+07	9.150E-11	1.907E-09	1.938E-09
	totals	5.242E+04	5.871E+03	1.120E-01	4.798E-02	1.000E+00	1.000E+00

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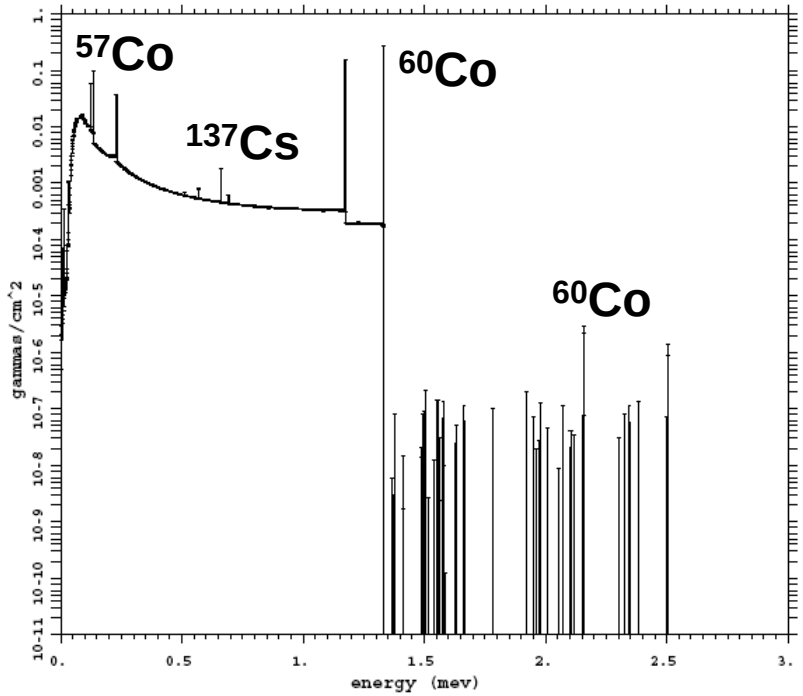
Spontaneous photon sources

```
Co-57, Co-60, & Cs-137 mixed in soil
1  1  -1.6   -1  imp:p=1
2  0          1  imp:p=0

1  so  100.0

mode p #
m1    1001 -.002  8016 -.527 11023 -.021
     13027 -.061 14028 -.345 19000 -.029
     26056 -.016 27057 -.00000001
     27060 -.000001 55137 -.000323
sdef par=sp pos=0 0 0 rad=d2
si2   0 100
sp2   -21 2
nps  100000000
phys:p 5j -102
f14:p 1
e14   0 999i 10
```

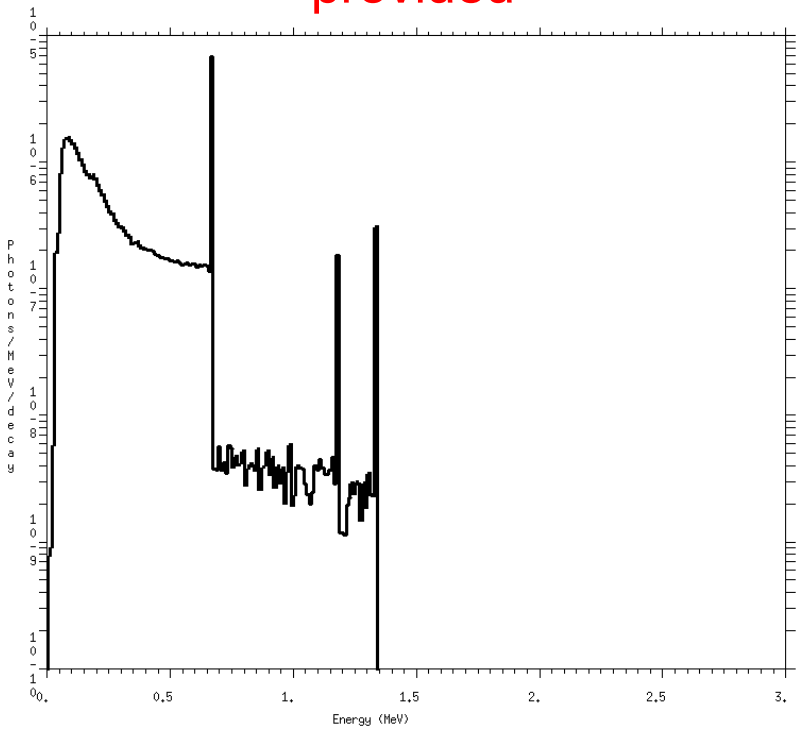
Source strength calculated automatically



Spontaneous photon sources

```
Co-57, Co-60, & Cs-137 using SDEF card
1  1  -1.6   -1  imp:p=1
2  0         1  imp:p=0

1  so  100.0

mode p #
m1    1001 -.002  8016 -.527 11023 -.021
     13027 -.061 14028 -.345 19000 -.029
     26056 -.016
sdef par=d1 erg=0 pos=0 0 0 rad=d2
si1 L      27057       27060       55137
sp1   0.00003086  0.00308632  0.99688281
si2   0 100
sp2   -21 2
nps  100000000
phys:p 5j -102
f14:p 1
e14   0 999i 10
```

Source strength must be provided



Spontaneous photon sources

heavy_ion creation	tracks	weight (per source	energy particle)
source	45312	4.5312E-02	0.
nucl. interaction	0	0.	0.
particle decay	0	0.	0.
weight window	0	0.	0.
cell importance	0	0.	0.
weight cutoff	0	0.	0.
energy importance	0	0.	0.
dxtran	0	0.	0.
forced collisions	0	0.	0.
exp. transform	0	0.	0.
tabular sampling	0	0.	0.
photonuclear	0	0.	0.
elastic recoil	0	0.	0.
(gamma,xgen_chg)	0	0.	0.
total	45312	4.5312E-02	0.0000E+00

heavy_ion loss	tracks	weight (per source	energy particle)
escape	0	0.	0.
energy cutoff	0	0.	0.
time cutoff	0	0.	0.
weight window	0	0.	0.
cell importance	0	0.	0.
weight cutoff	0	0.	0.
energy importance	0	0.	0.
dxtran	0	0.	0.
forced collisions	0	0.	0.
exp. transform	0	0.	0.
multiple scatter	0	0.	0.
bremsstrahlung	0	0.	0.
nucl. interaction	0	0.	0.
elastic scatter	0	0.	0.
particle decay	45312	4.5312E-02	0.
capture	0	0.	0.
tabular sampling	0	0.	0.
total	45312	4.5312E-02	0.0000E+00

Spontaneous photon sources

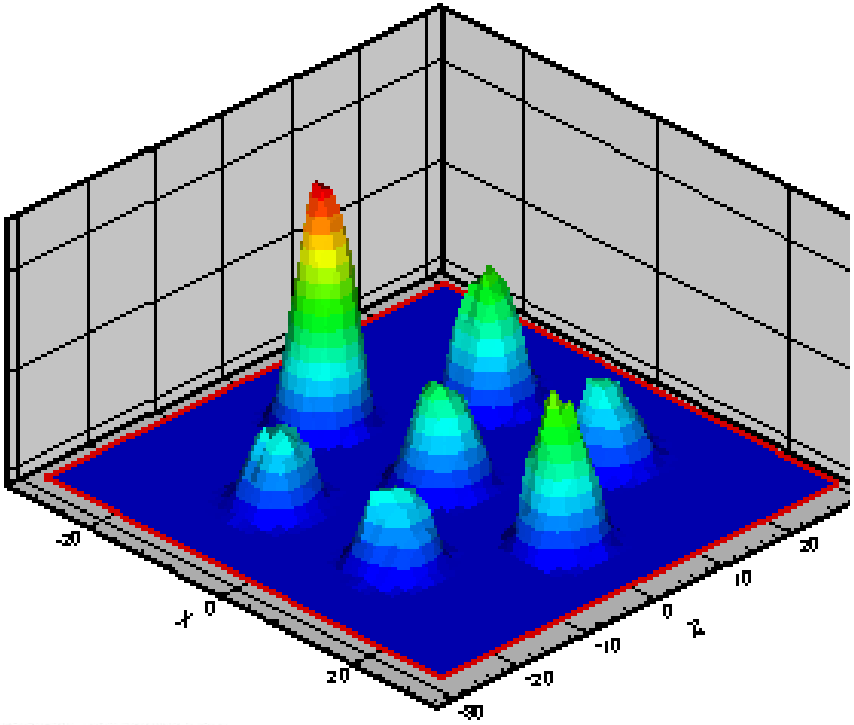
photon creation	tracks	weight (per source	energy particle)	photon loss	tracks	weight (per source	energy particle)
source	0	0.	0.	escape	8615	8.6150E-03	3.4762E+03
nucl. interaction	0	0.	0.	energy cutoff	0	0.	9.0169E-01
particle decay	45331	4.5331E-02	2.7777E+04	time cutoff	0	0.	0.
weight window	0	0.	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.
energy importance	0	0.	0.	energy 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.
from neutrons	0	0.	0.	compton scatter	0	0.	2.1672E+04
bremsstrahlung	2852	2.8520E-03	5.0258E+01	capture	44073	4.4073E-02	2.7188E+03
p-annihilation	6	6.0000E-06	3.0660E+00	pair production	3	3.0000E-06	3.9975E+00
photonuclear	0	0.	0.	photonuclear abs	0	0.	0.
electron x-rays	0	0.	0.				
1st fluorescence	4424	4.4240E-03	4.1110E+01				
2nd fluorescence	78	7.8000E-05	3.4098E-01				
(gamma,xgamma)	0	0.	0.				
tabular sampling	0	0.	0.				
total	52691	5.2691E-02	2.7872E+04	total	52691	5.2691E-02	2.7872E+04

Enhanced eigenfunction convergence

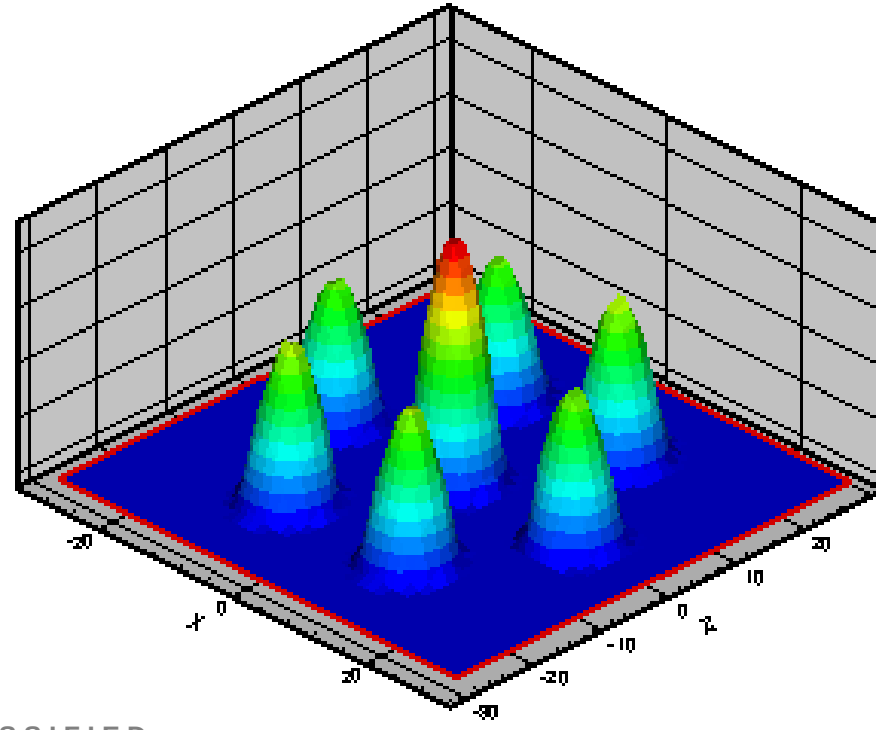
```
HEU fluid in 7 cans
1 1 -8.4      -1      u=1    imp:n=1
2 0           -2      u=1    imp:n=1
3 2 -2.7      -3 1 2  u=1    imp:n=1
4  3 -.001     3      u=1    imp:n=1
10 3 -.001    -6 lat=2 u=2   imp:n=1 fill=-2:2 -2:2 0:0 2 6r 1 1 2 2 1 1 1 2 2 1 1 2 6r
11 0          -8             imp:n=1 fill=2
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

kcode 1000 1 30 100
ksrc  0 6 0  18 6 0  -18 6 0  9 6 15  -9 6 15  9 6 -15  -9 6 -15
dbcn  23j 2  $ Remove this for default convergence
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
tmesh
rmesh12  n
 cora12  -30. 53i 30.
 corb12    0.     12.
 corc12  -30. 35i 30.
endmd
```

Enhanced eigenfunction convergence

- Default power series
- 1,000 particles/cycle
- 100 active cycles (30 settle)
- Factor 3-4 flux tilt



- Enhanced convergence
- 1,000 particles/cycle
- 100 active cycles (30 settle)
- ~10% flux tilt



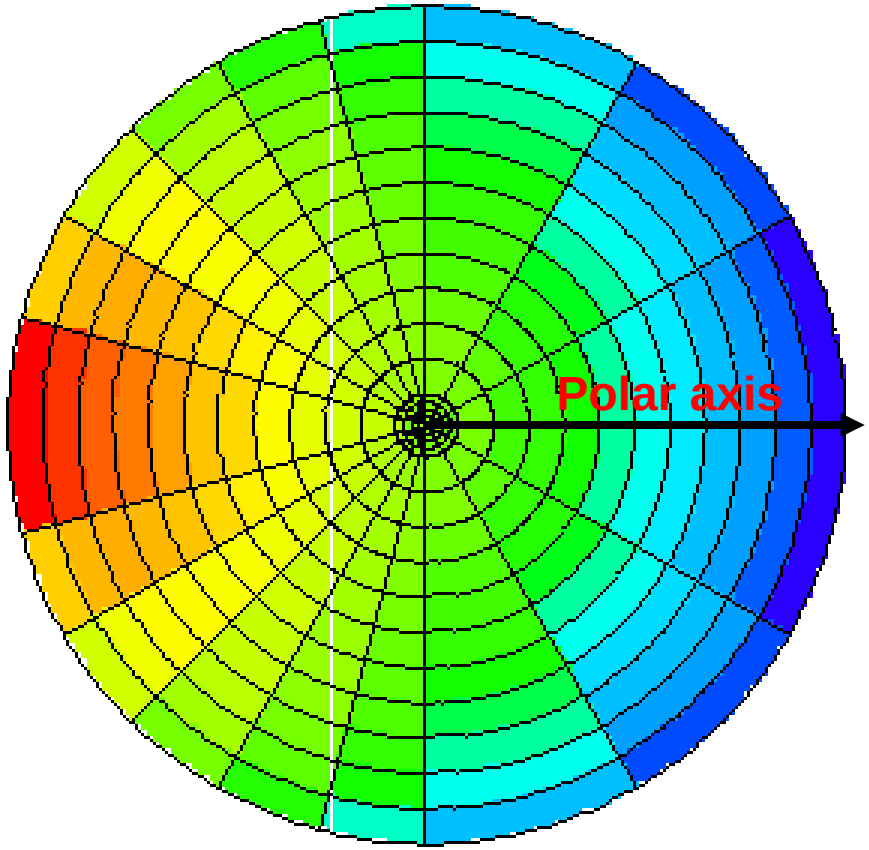
User-Interface Enhancements

- **Four new tally options**
  - Spherical mesh tallies
  - Tally tagging
  - Differential tallies for library interactions
  - Termination based on tally precision

Spherical mesh tallies

```
Neutrons into spherical tank – rotated mesh tally
1  1  -10.0   -1       imp:n=1
2  2   -1.0    1 -2    imp:n=1
3  0              2    imp:n=0

1 sph 0 0 0   3
2 sph 0 0 0  40

sdef  erg=14 par=n pos=-39.999 0 0
m1    92235 .5  92238 .5 nlib=.66c
m2    1001 200  8016 99.762  8017 .038
      8018 .200 nlib=.66c
nps   1000000
*tr1  0 0 0 90 90 180  90 0 90  0 90 90
tmesh
 smesh1:n flux trans 1
 cora1  0 3i 3.01 10i 40.01
 corb1  30 60 90 5i 180
 corc1  360
endmd
```

Mesh tally results overlaid on the geometry

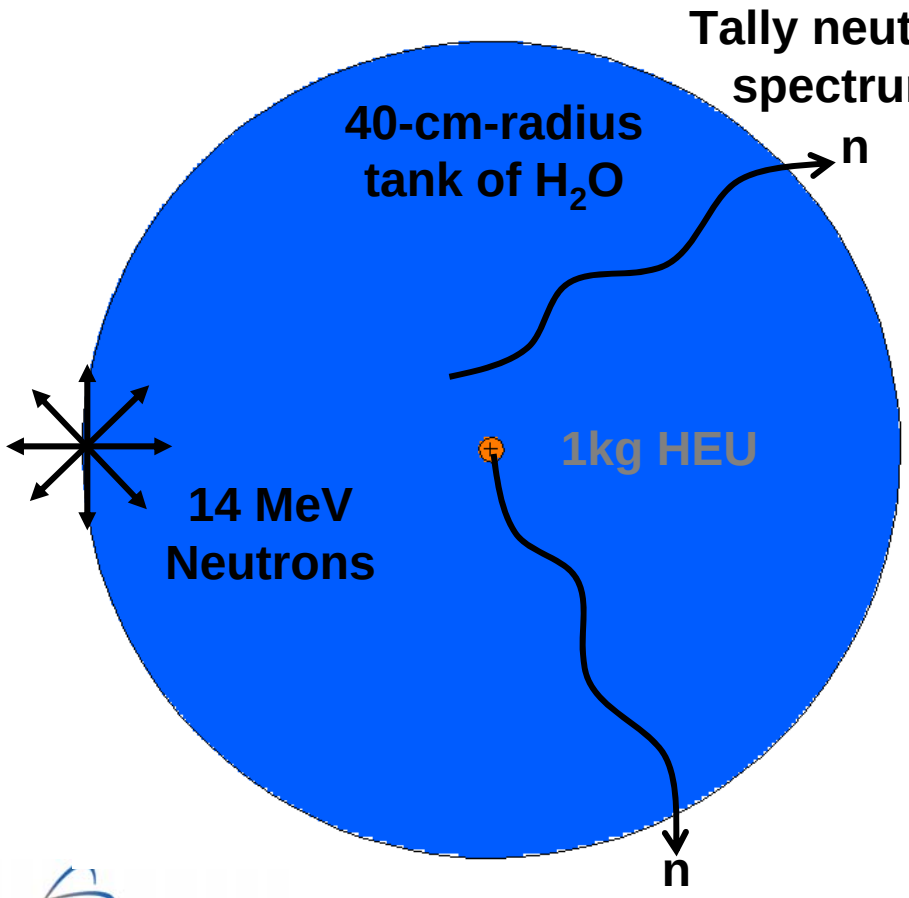


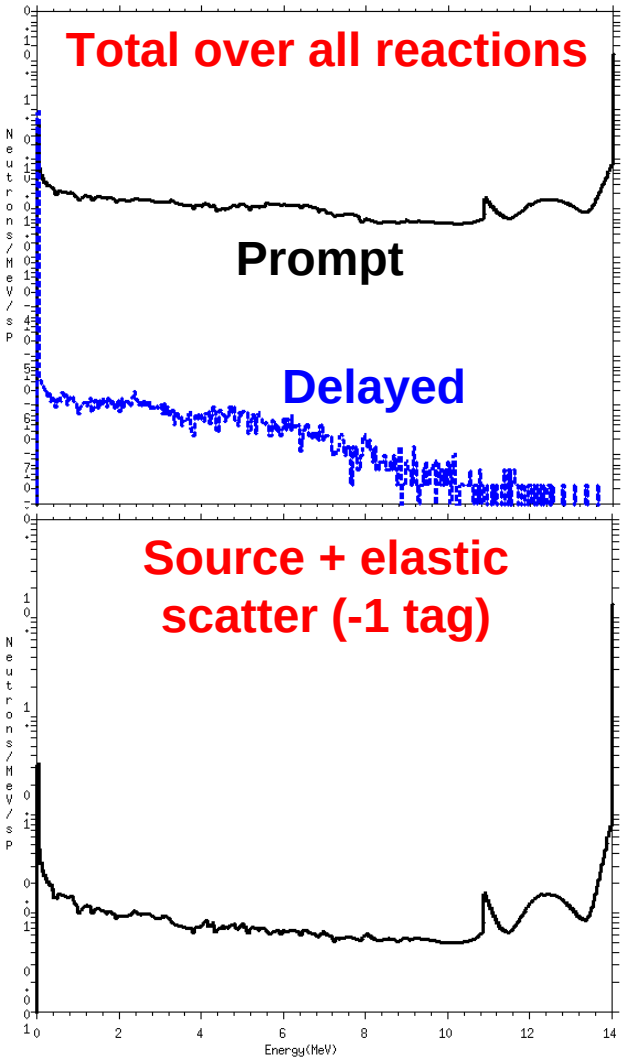
Tally tagging

```
Neutron activation of water + HEU
1  2  -10.0   -1       imp:n=1
2  1   -1.0    1 -2    imp:n=1
3  0              2    imp:n=0

1 sph 0 0 0   3
2 sph 0 0 0  40

mode n
cut:n   2j 0 0
phys:n  3j -1
sdef  erg=14 par=n pos=-39.999 0 0
m1    1001 200.0
      8016  99.762
      8017   0.038
      8018   0.200
      nlib=.66c
m2    92235  0.5
      92238  0.5
      nlib=.66c
nps   100000
```

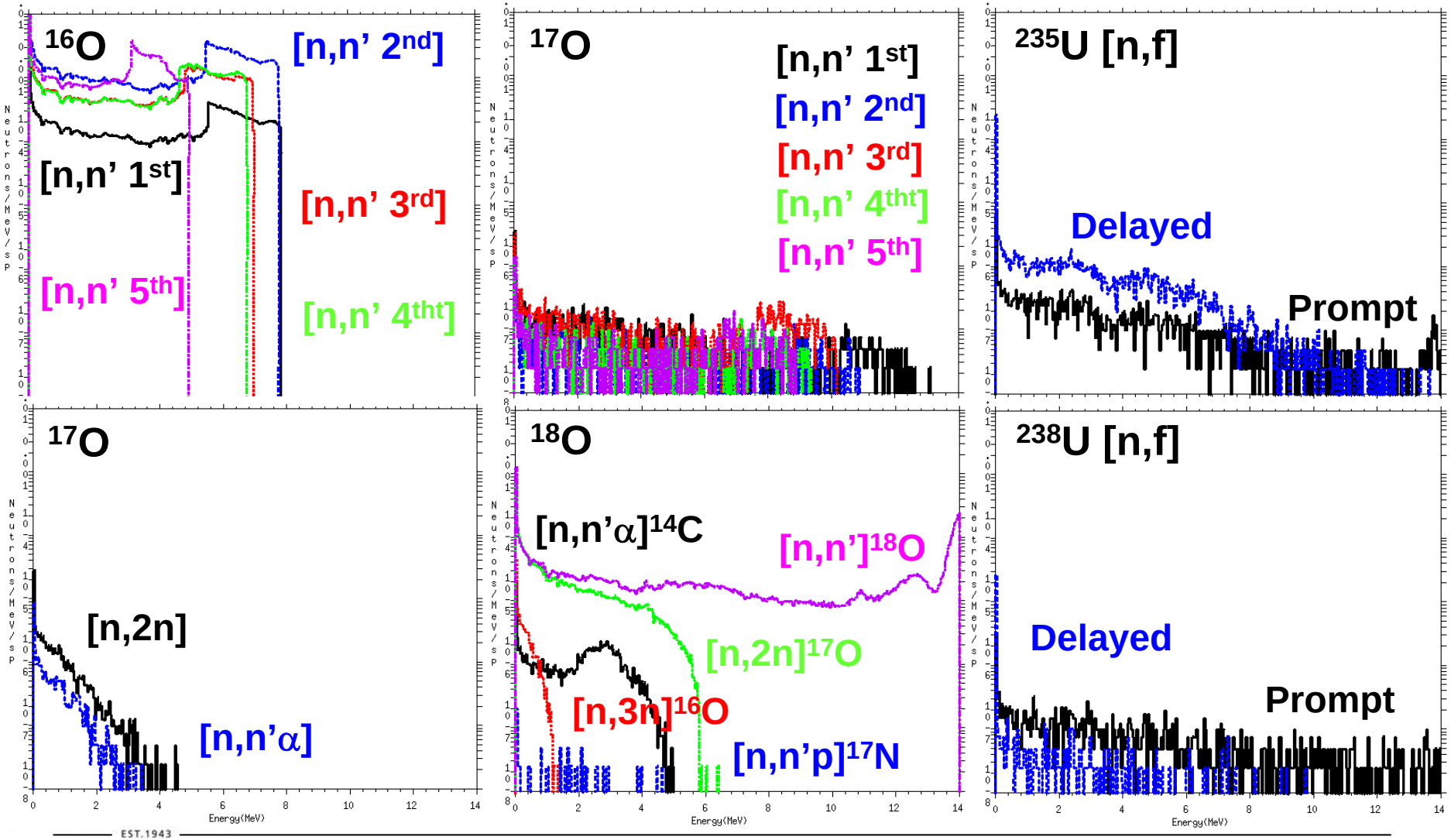
```
f31:n 2
ft31  tag 3
fu31  -1.0
      1001.0
      8016.00011 8016.00016 8016.00017 8016.00022
      8016.00023 8016.00024 8016.00025 8016.00028
      8016.00029 8016.00030 8016.00032 8016.00033
      8016.00034 8016.00035 8016.00036 8016.00037
      8016.00041 8016.00042 8016.00043 8016.00044
      8016.00051 39i        8016.00091 8016.0
      8017.00011 8017.00016 8017.00017 8017.00022
      8017.00023 8017.00024 8017.00025 8017.00028
      8017.00029 8017.00030 8017.00032 8017.00033
      8017.00034 8017.00035 8017.00036 8017.00037
      8017.00041 8017.00042 8017.00043 8017.00044
      8017.00051 39i        8017.00091 8017.0
      8018.06012 8018.06013 8018.06014
      8018.07014 8018.07015 8018.07016 8018.07017
      8018.08015 8018.08016 8018.08017 8018.08018
      8018.08019 8018.0
      92235.99999 92235.00000
      92238.99999 92238.00000
      1e10
t31   100 1e15  $ Prompt and delayed time bins
e31   0 499i 20
```

Tally tagging





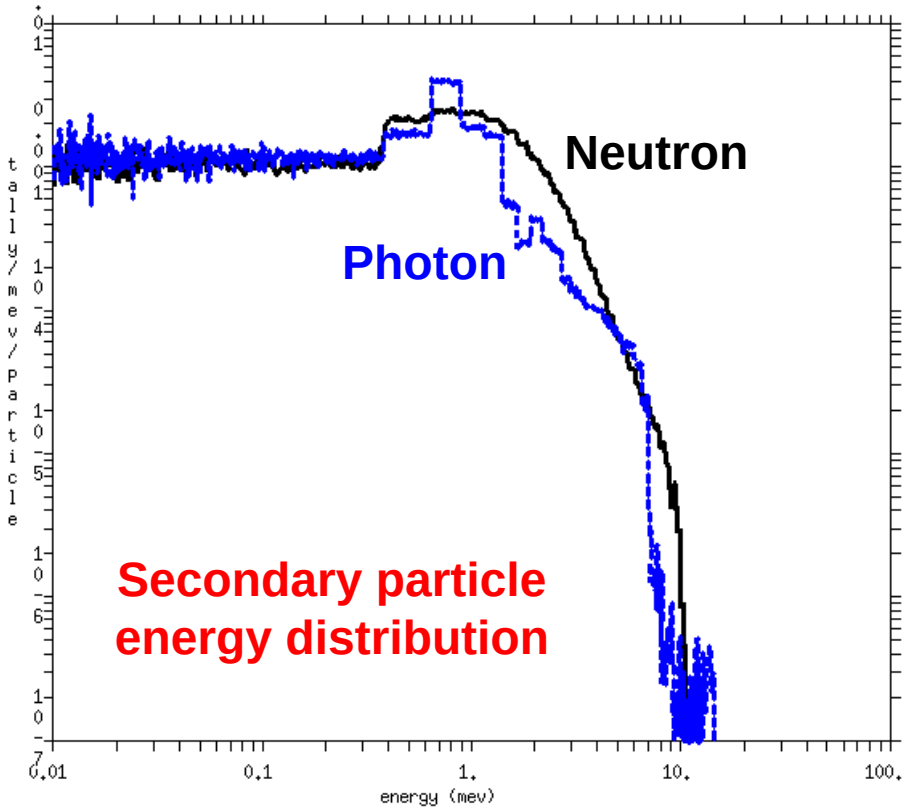
Tally tagging

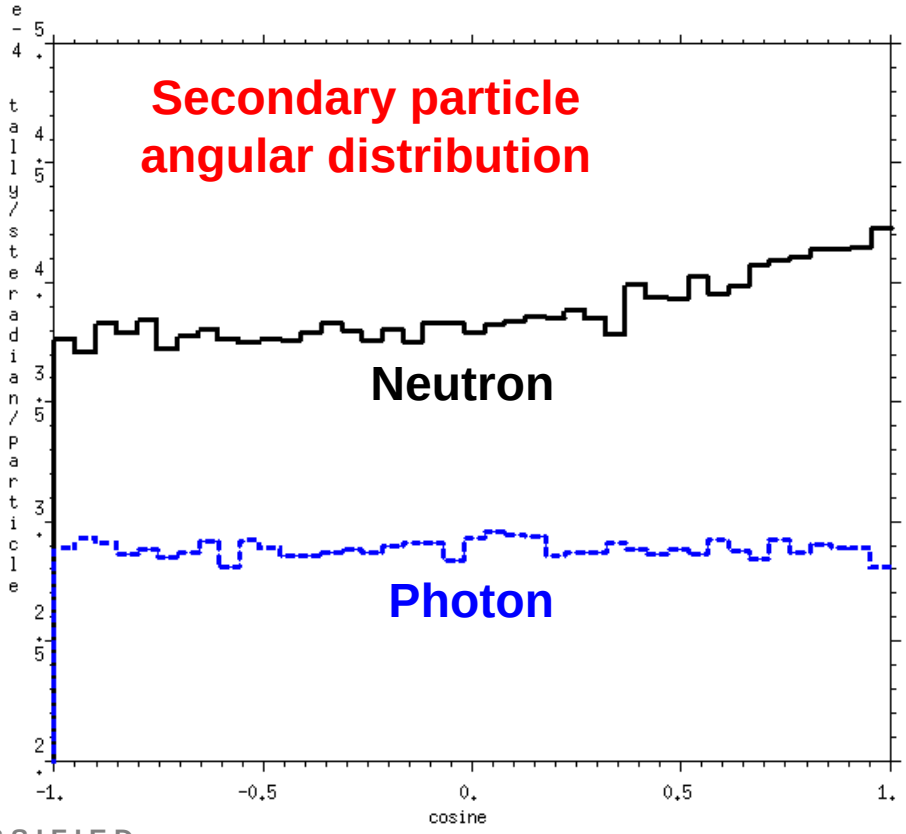


Differential tallies for library interactions

```
Protons into lead - differential secondary spectra
1  1  -1.0   -1       imp:n=1
2  0          1       imp:n=0

1 sph 0 0 0   1

mode  n p h
sdef  erg=14 par=h vec=1 0 0 dir=1
m1    82208 1 hlib=.24h
nps   100000000
lca   7j -2  $ First interaction only
f1:n  1
e1    1e-8 999log 14.1
f11:n 1
c11   -.95 39i 1
ft11  frv 1 0 0
f21:p 1
e21   1e-3 999log 14.1
f31:p 1
c31   -.95 39i 1
ft31  frv 1 0 0
```

Differential tallies for library interactions





Termination based on tally precision

```
Protons into lead - differential secondary spectra
1  1  -1.0   -1       imp:n=1
2  0          1       imp:n=0

1 sph 0 0 0   1

mode  n p h
sdef  erg=14 par=h vec=1 0 0 dir=1
m1    82208 1 hlib=.24h
lca   7j -2
f1:n  1
e1    1e-8 999log 14.1
f11:n 1
c11   -.95 39i 1
ft11  frv 1 0 0
f21:p 1
e21   1e-3 999log 14.1
f31:p 1
c31   -.95 39i 1
ft31  frv 1 0 0
stop  nps 1000000000 ctme 200 f11 .01 f31 .01
```

Termination based on tally precision

1tally fluctuation charts

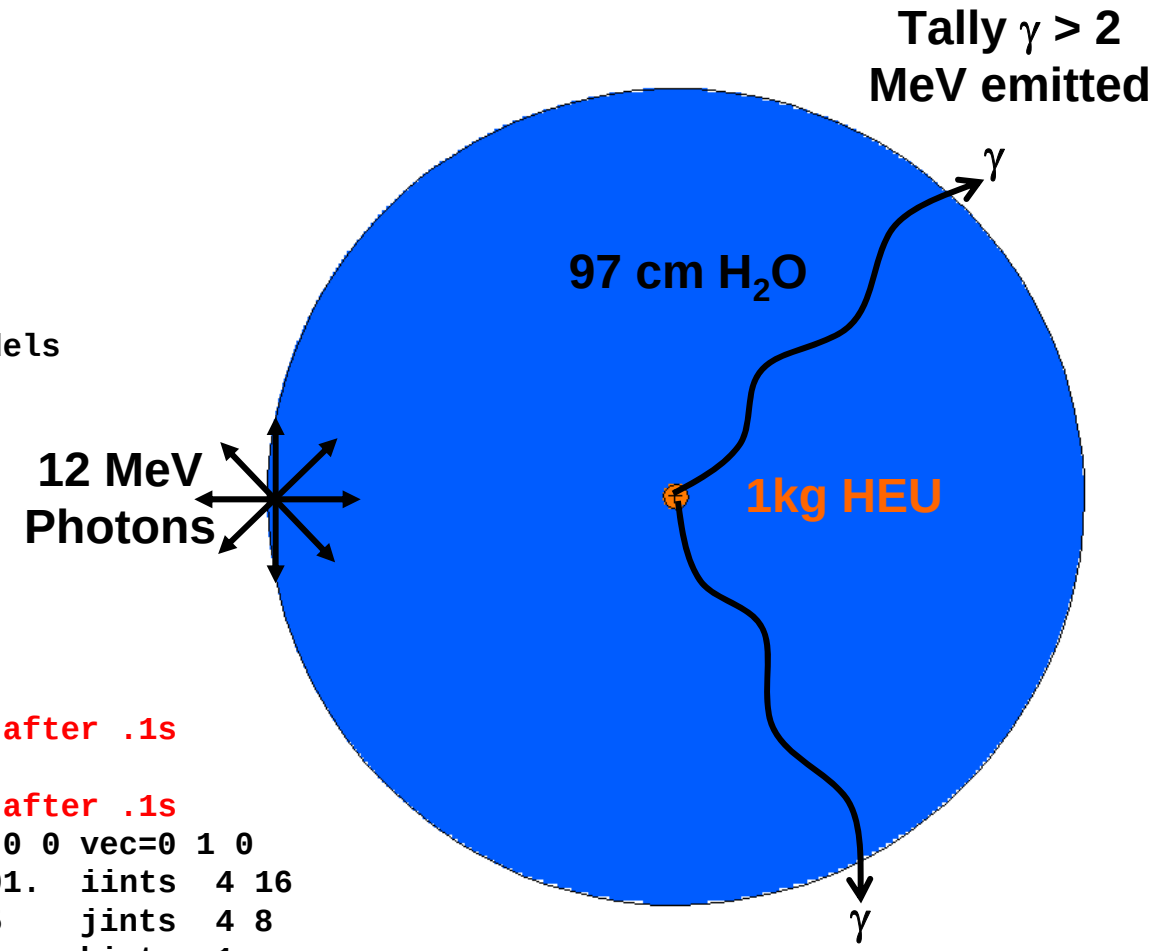
	tally 1					tally 11				
nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom
4096000	4.8838E-03	0.0071	0.0000	10.0	37555	1.3525E-04	0.0425	0.0018	10.0	1035
8192000	4.8960E-03	0.0050	0.0000	10.0	37738	1.3416E-04	0.0302	0.0009	10.0	1029
12288000	4.8829E-03	0.0041	0.0000	10.0	37678	1.3192E-04	0.0248	0.0006	10.0	1013
16384000	4.8763E-03	0.0035	0.0000	10.0	37609	1.3049E-04	0.0216	0.0005	10.0	1002
20480000	4.8860E-03	0.0032	0.0000	10.0	37718	1.3145E-04	0.0193	0.0004	10.0	1010
24576000	4.8831E-03	0.0029	0.0000	10.0	37716	1.2980E-04	0.0177	0.0003	10.0	998
28672000	4.8832E-03	0.0027	0.0000	10.0	37429	1.2960E-04	0.0164	0.0003	10.0	989
32768000	4.8802E-03	0.0025	0.0000	10.0	37200	1.2949E-04	0.0154	0.0002	10.0	982
36864000	4.8795E-03	0.0024	0.0000	10.0	37059	1.2912E-04	0.0145	0.0002	10.0	976
40960000	4.8809E-03	0.0022	0.0000	10.0	36959	1.2905E-04	0.0138	0.0002	10.0	973
45056000	4.8823E-03	0.0021	0.0000	10.0	36878	1.2944E-04	0.0131	0.0002	10.0	973
49152000	4.8865E-03	0.0020	0.0000	10.0	36835	1.2933E-04	0.0125	0.0002	10.0	970
53248000	4.8858E-03	0.0020	0.0000	10.0	36768	1.2983E-04	0.0120	0.0001	10.0	972
57344000	4.8847E-03	0.0019	0.0000	10.0	36703	1.3041E-04	0.0116	0.0001	10.0	975
61440000	4.8864E-03	0.0018	0.0000	10.0	36672	1.2980E-04	0.0112	0.0001	10.0	970
65536000	4.8859E-03	0.0018	0.0000	10.0	36625	1.2990E-04	0.0108	0.0001	10.0	969
69632000	4.8827E-03	0.0017	0.0000	10.0	36558	1.3014E-04	0.0105	0.0001	10.0	970
73728000	4.8802E-03	0.0017	0.0000	10.0	36523	1.3010E-04	0.0102	0.0001	10.0	969
77824000	4.8804E-03	0.0016	0.0000	10.0	36590	1.3031E-04	0.0099	0.0001	10.0	972

User-Interface Enhancements

- **Three new variance reduction options**
  - Coupled space-energy-time weight windows
  - Spherical weight windows
  - Additional weight window controls

Coupled space-energy-time weight windows

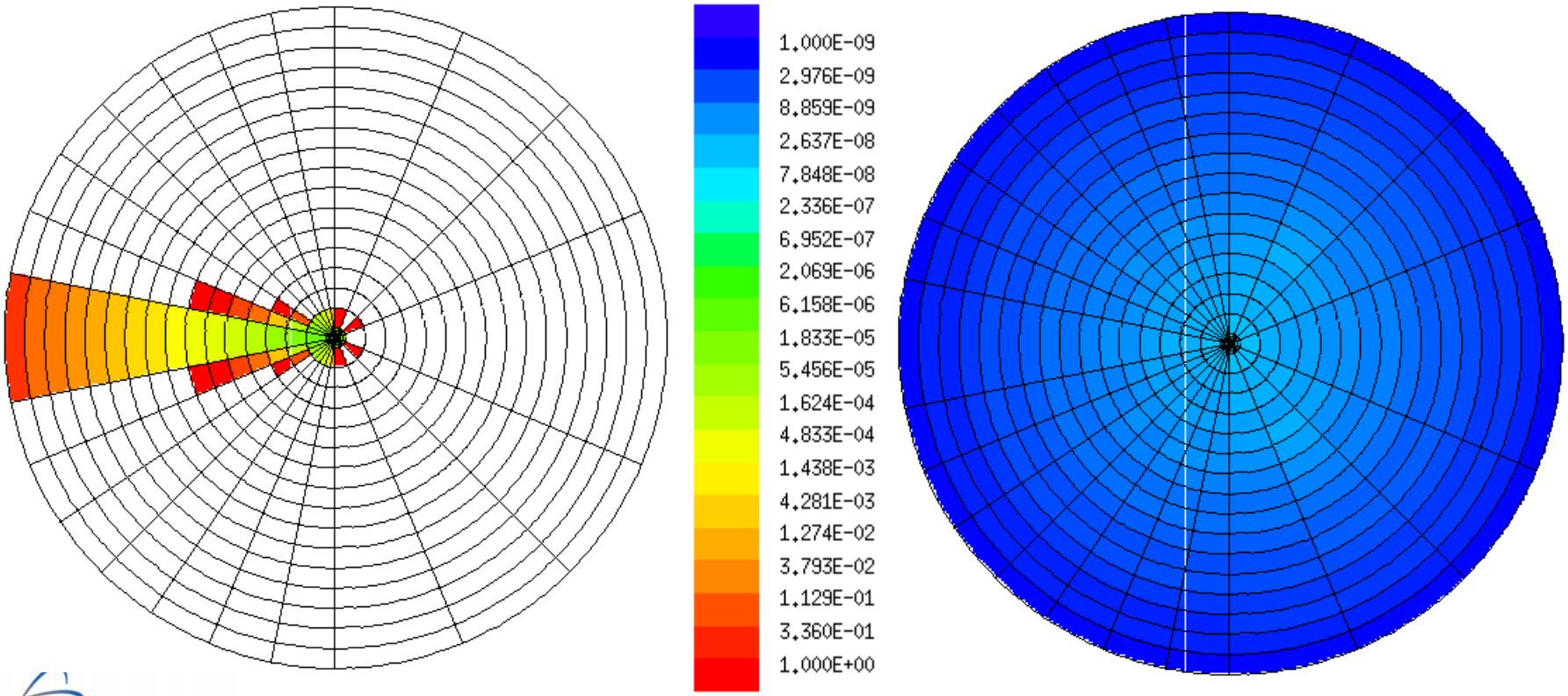
```
12 MeV photons into water with HEU
1  1  -10.0   -1    imp:n,p=1
2  2  -1.0    +1 -2 imp:n,p=1
3  0             +2 imp:n,p=0

1 sph 0 0 0  3
2 sph 0 0 0  100

mode n p
phys:n 3j  101  $ DN with models
phys:p 3j 1 j -101  $ DG with models
sdef par=p erg=12 pos -99 .1 .1
m1   92235 .5 92238 .5
m2   1001 2 8016 1
nps  200000
f1:p 2
e1   2  100 nt
t1   0.1e8 1e15 nt
wwg  1 0 6j 100
wwge:p  2.0    100.0
wwgt:p  0.1e8  1.0e15  $ Delayed after .1s
wwge:n  1.0e-6 100.0
wwgt:n  0.1e8  1.0e15  $ Delayed after .1s
mesh geom=rpt origin=0 0 0 axs=1 0 0 vec=0 1 0
     ref=-99 .1 .1 imesh  3.01 101.  iints  4 16
                   jmesh   .25 .5    jints  4 8
                   kmesh   1         kints  1
```



Coupled space-energy-time weight windows

High energy prompt photon WW

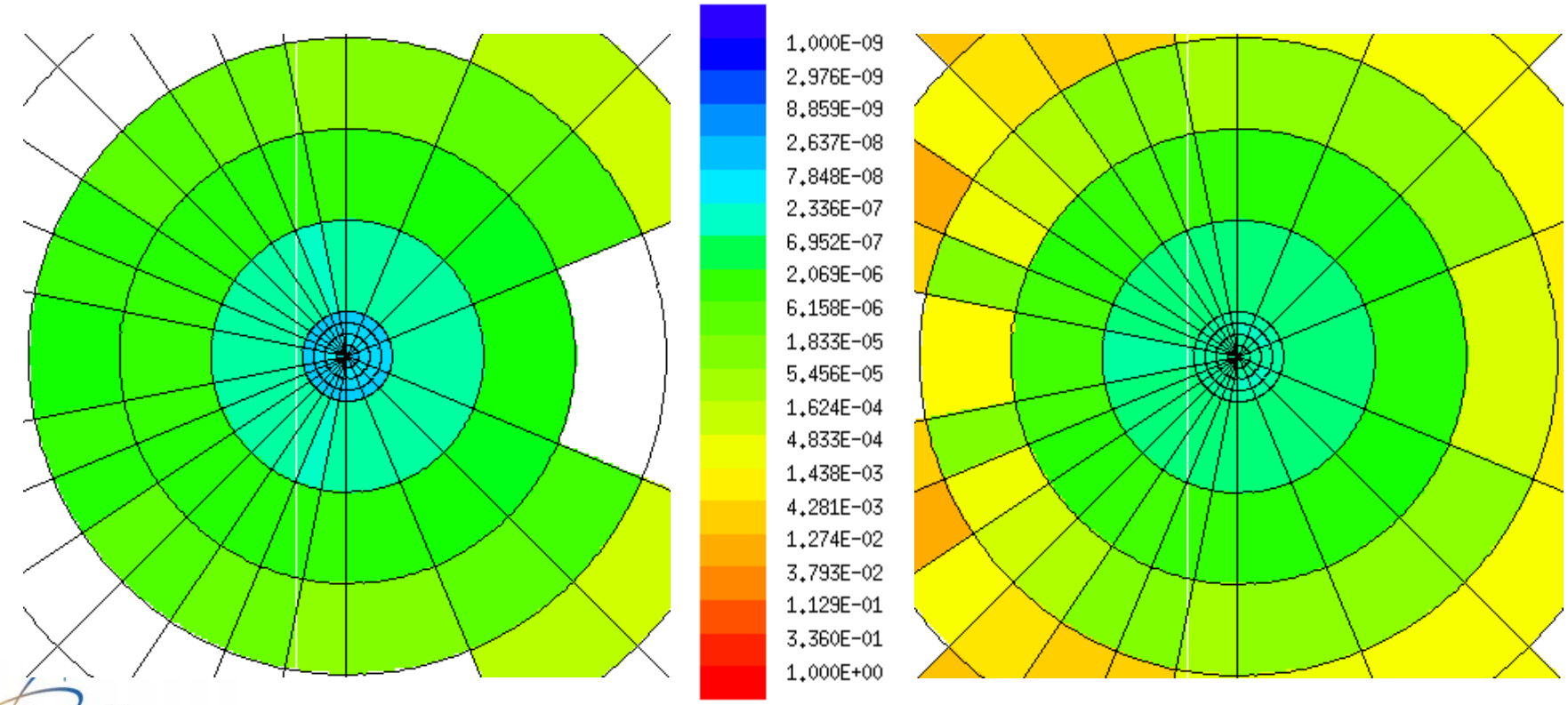
High energy delayed photon WW



Coupled space-energy-time weight windows

Low energy prompt neutron WW

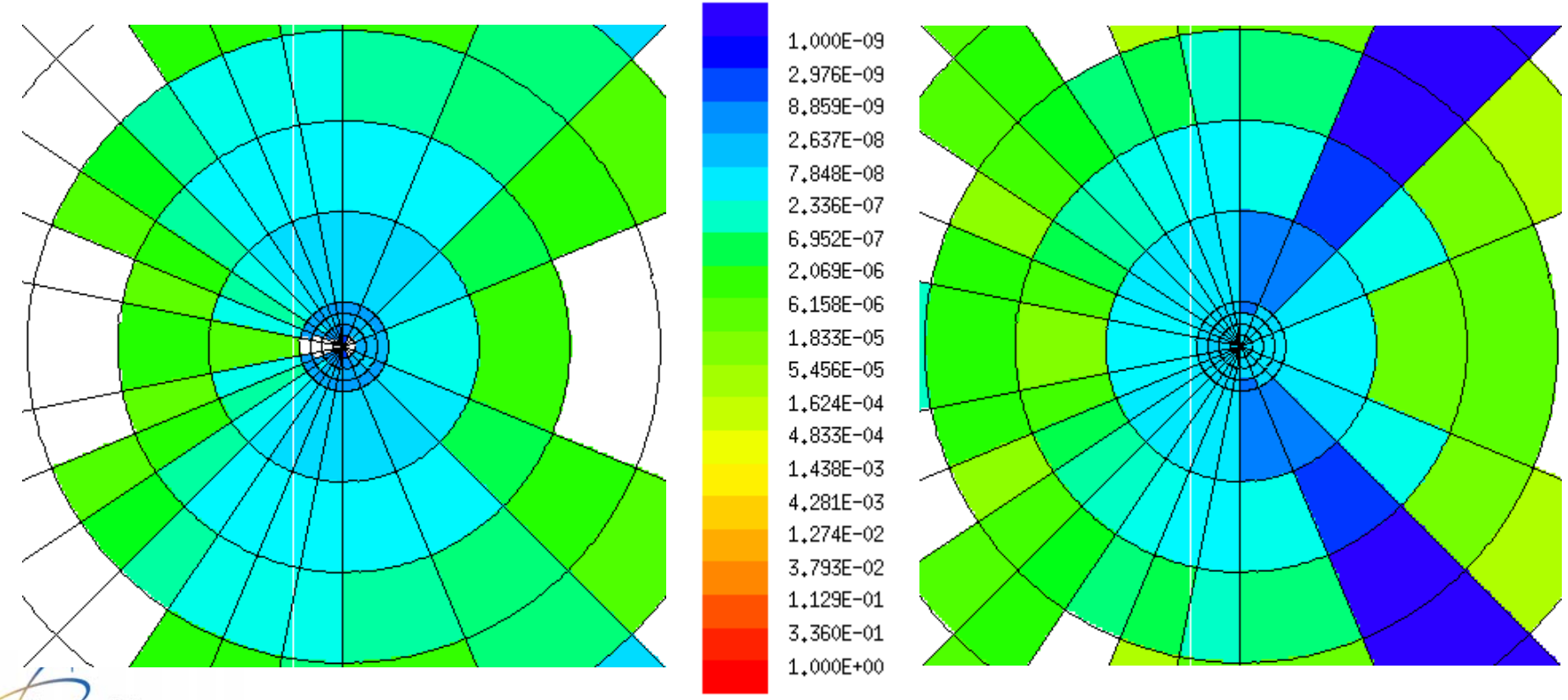
High energy prompt neutron WW



Coupled space-energy-time weight windows

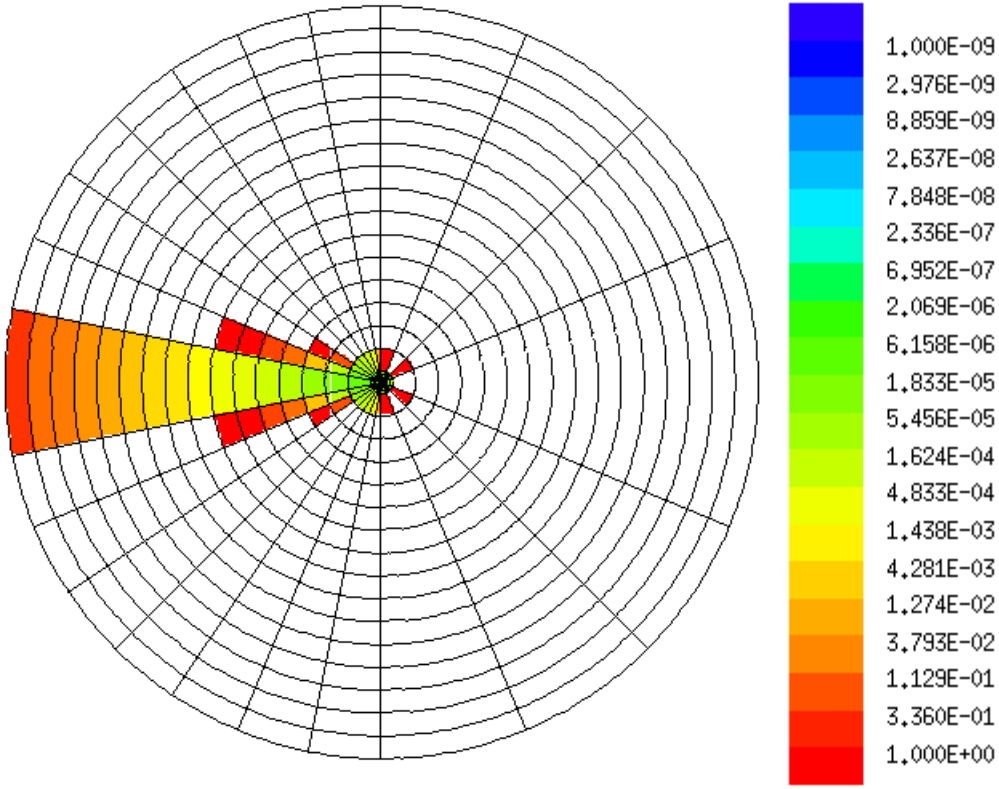
Low energy delayed neutron WW

High energy delayed neutron WW



Spherical weight windows

```
12 MeV photons into water with HEU
1  1  -10.0   -1    imp:n,p=1
2  2  -1.0    +1 -2 imp:n,p=1
3  0             +2 imp:n,p=0

1 sph 0 0 0  3
2 sph 0 0 0  100

mode n p
phys:n 3j  101  $ DN with models
phys:p 3j 1 j -101  $ DG with models
sdef par=p erg=12 pos -99 .1 .1
m1   92235 .5 92238 .5
m2   1001 2 8016 1
nps  200000
f1:p 2
e1   2  100 nt
t1   0.1e8 1e15 nt
wwg  1 0 6j 100
mesh geom=rpt origin=0 0 0 axs=1 0 0
     vec=0 1 0 ref=-99 .1 .1
     imesh  3.01 101.  iints  4 16
     jmesh   .25 .5    jints  4 8
     kmesh   1         kints  1
```



Additional weight window controls

- New 9th entry on the WWP:<pl> card
  - Upper limit for all WW values applied to particle <pl>
  - Applied when WW values are read in from the WWINP file
  - Prevents undersampling of regions with high WW values
- Accept various units for azimuthal and polar WW mesh angles
  - Units can be in revolutions, radians, or degrees
  - Applies to KMESH entries for cylindrical meshes
  - Applies to JMESH & KMESH entries for spherical meshes
- Improved coloring of WW values overlaid on the geometry
  - White areas now indicate zero WW values (no WW game)
  - Logarithmic contouring applied for max./min. ratios > 100

User-Interface Enhancements

- **Four other miscellaneous improvements**
  - Output for induced-fission multiplicity
  - Proton sub-step control
  - Long input/output file names
  - Graphics enhancements

Output for induced-fission multiplicity

```
Spontaneous and induced fission in pu-239
1  1  -19.7  -1       imp:n=1
2  0          1       imp:n=0

1 sph 0 0 0   .1

mode   n
sdef   par=sf
m1     94239 1
phys:n 5j 1
nps    10000
```

Output for induced-fission multiplicity

1induced fission multiplicity and moments. print table 117

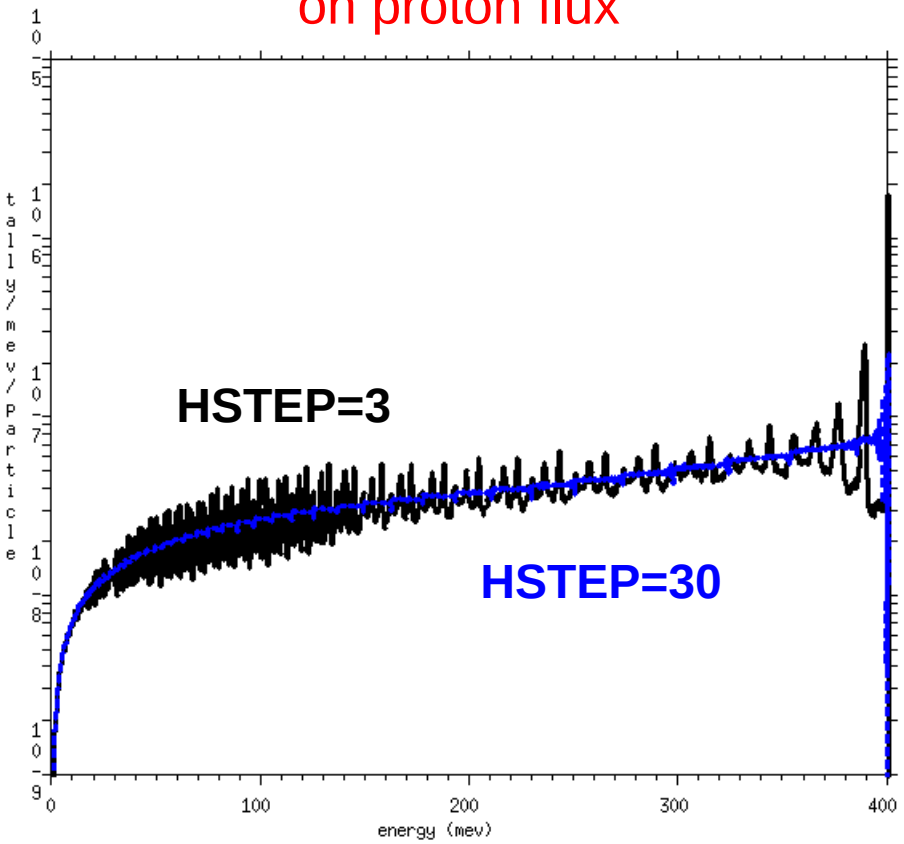
	by number			by weight			
	fissions	fission neutrons	multiplicity fraction	fissions	fission neutrons	multiplicity fraction	error
nu = 0	4	0	1.93237E-02	1.82917E-04	0.00000E+00	1.93098E-02	0.5000
nu = 1	14	14	6.76329E-02	6.41039E-04	6.41039E-04	6.76717E-02	0.2672
nu = 2	28	56	1.35266E-01	1.28035E-03	2.56070E-03	1.35161E-01	0.1889
nu = 3	83	249	4.00966E-01	3.79647E-03	1.13894E-02	4.00777E-01	0.1096
nu = 4	51	204	2.46377E-01	2.33604E-03	9.34416E-03	2.46606E-01	0.1399
nu = 5	23	115	1.11111E-01	1.05235E-03	5.26173E-03	1.11092E-01	0.2084
nu = 6	4	24	1.93237E-02	1.83616E-04	1.10169E-03	1.93835E-02	0.5000
total	207	662	1.00000E+00	9.47277E-03	3.02987E-02	1.00000E+00	0.0692

factorial moments	by number	by weight
nu	3.19807E+00 0.0258	3.19851E+00 0.0258
nu(nu-1)/2!	4.21739E+00 0.0529	4.21879E+00 0.0529
nu(nu-1)(nu-2)/3!	2.88406E+00 0.0929	2.88579E+00 0.0930
nu(nu-1) .... (nu-3)/4!	1.09179E+00 0.1583	1.09282E+00 0.1584
nu(nu-1) .... (nu-4)/5!	2.27053E-01 0.2660	2.27393E-01 0.2663
nu(nu-1) .... (nu-5)/6!	1.93237E-02 0.4951	1.93835E-02 0.4951

Proton sub-step control

```
400 MeV protons into water
1  1   -1.00   -1   imp:n=1
2  0             1   imp:n=0

1 sph 0 0 0 100

mode  n h
m1    1001 2  8016 1  $ hstep=30
sdef  par=9 erg=400
nps 50000
phys:n 500
f4:h   1
e4     1 999i 400
```

Effect of increasing HSTEP on proton flux



Long input/output file names

```
.\mcnpx inp=testlongname\mymcnpxinputfile na=testlongname\outp.

 mcnpx    ver=2.6.0 ld=Wed Apr 09 08:00:00 MST 2008   10/02/08 08:

 ************************************************************
 *                                                          *
 *                    MCNPX                                 *
 *                                                          *
 * Copyright 2007. Los Alamos National Security, LLC.       *
 * All rights reserved.                                     *
 *                                                          *
.
.
.
 Directory of E:\gwm\IEEE\testlongname

10/02/2008  08:54 AM    <DIR>          .
10/02/2008  08:54 AM    <DIR>          ..
10/02/2008  08:46 AM               195 mymcnpxinputfile
10/02/2008  08:54 AM            18,091 outp.o
10/02/2008  08:54 AM         5,224,518 outp.r
               3 File(s)      5,242,804 bytes
```

Physics Enhancements

- **Seven new model physics features**
  - Integration of Cinder90 transmutation code
  - Delayed particles from fission/activation
  - Integration of LAQGSM event generator
  - Heavy ion transport
  - Muon capture physics
  - Upgrade of the CEM event generator
  - Update of high-energy de-excitation data

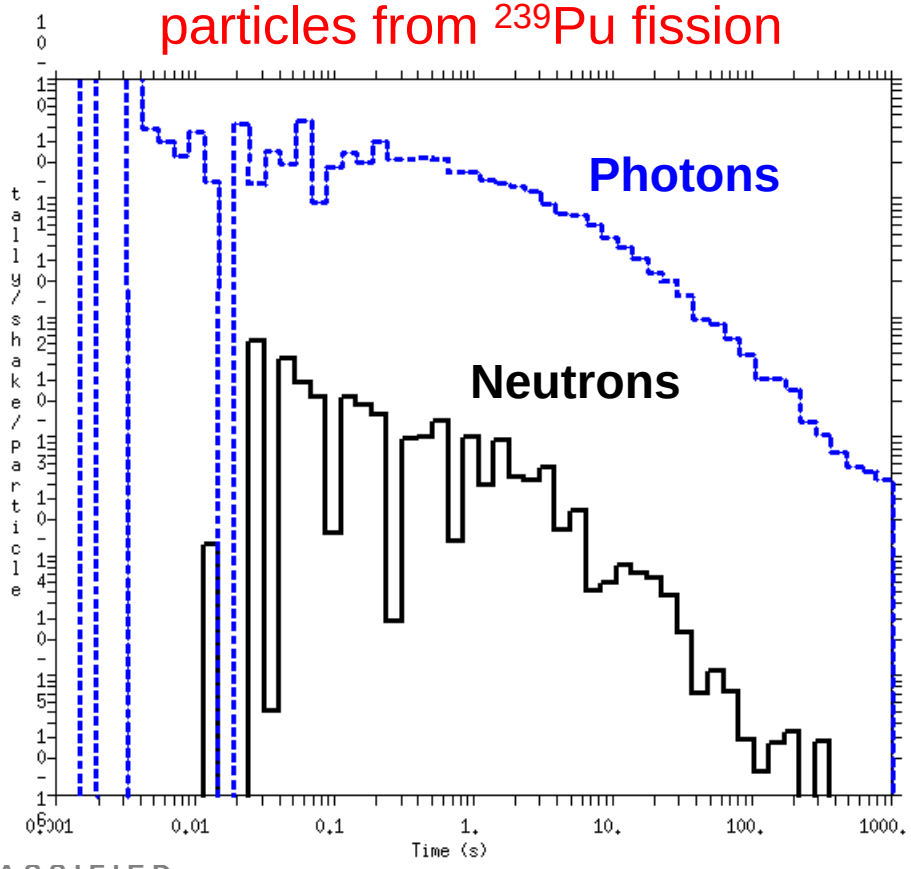
Integration of Cinder90 transmutation code

- Cinder is a transmutation code written at LANL
  - Has been under development for multiple decades
  - Has been released to RSICC for distribution
  - Is used in various transmutation packages (e.g., MONTEBURNS)
- Cinder90 is used within MCNPX for burnup
  - Integral reaction rates and 63-group fluxes are passed into Cinder
  - Isotopics are determined from buildup and depletion equations
  - Cinder is used twice in each time step (for prediction and correction)
- Cinder90 is also used for delayed particle production
  - A residual nucleus is passed into Cinder
  - A full decay-chain analysis is performed
  - Time & energy dependent distributions are returned to MCNPX

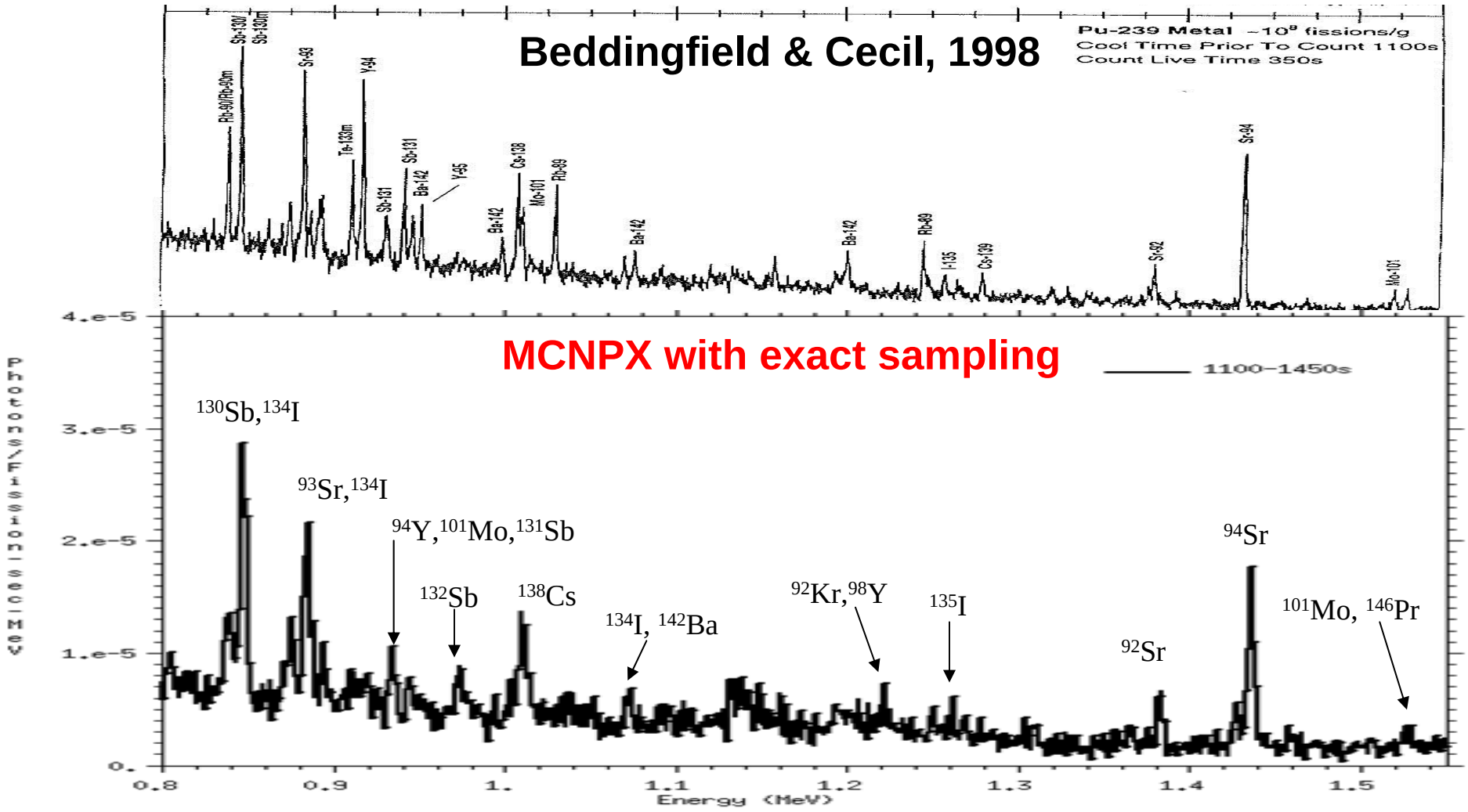
Delayed particles from fission/activation

```
Delayed neutrons and gammas from pu-239 fission
1  1  -19.7  -1        imp:n=1
2  0           1        imp:n=0

1 sph 0 0 0   .1

mode   n p
sdef   par=sf
m1     94239 1
phys:n 3j  101 j 1 $ Biased DN with models
phys:p 5j -102     $ Analog DG with models
nps    100000
f1:n   1
t1     1 99log 1e11
f11:p  1
t11    1 99log 1e11
```

Time distribution of delayed particles from ^{239}Pu fission



Delayed particles from fission/activation



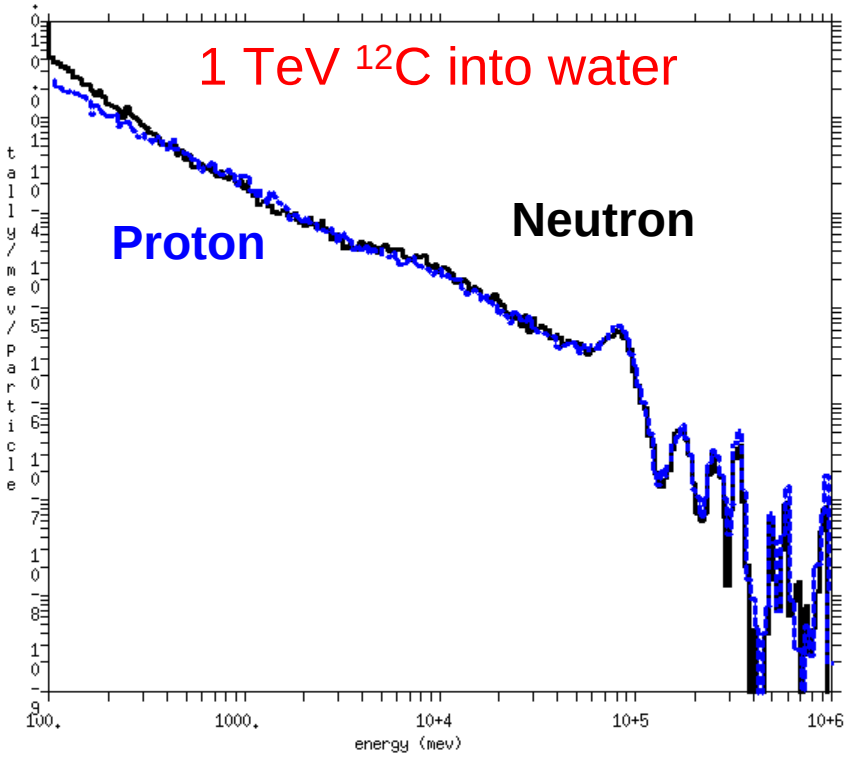
Integration of LAQGSM event generator

- LAQGSM is a high-energy event generator code from LANL
  - Has been under development for multiple decades
  - Is a collaboration between LANL and IAP (Moldova)
  - Can be run as a stand-alone code
- Version 03.01 is used within MCNPX for A+A interactions
  - Treats interactions from ~20 MeV/n to ~1 TeV/n
  - Projectiles can also include nucleons (eventually photons)
  - Includes a suite of physics models (DCM, QGSM, CEM, FB, and CM)
- Can be used in place of FLUKA89 (for most projectiles)
  - Always used for heavy ion interactions
  - 10^{th} entry on LCA card will turn on LAQGSM for nucleons (above INC)
  - Currently, some exotic particles still go to FLUKA89

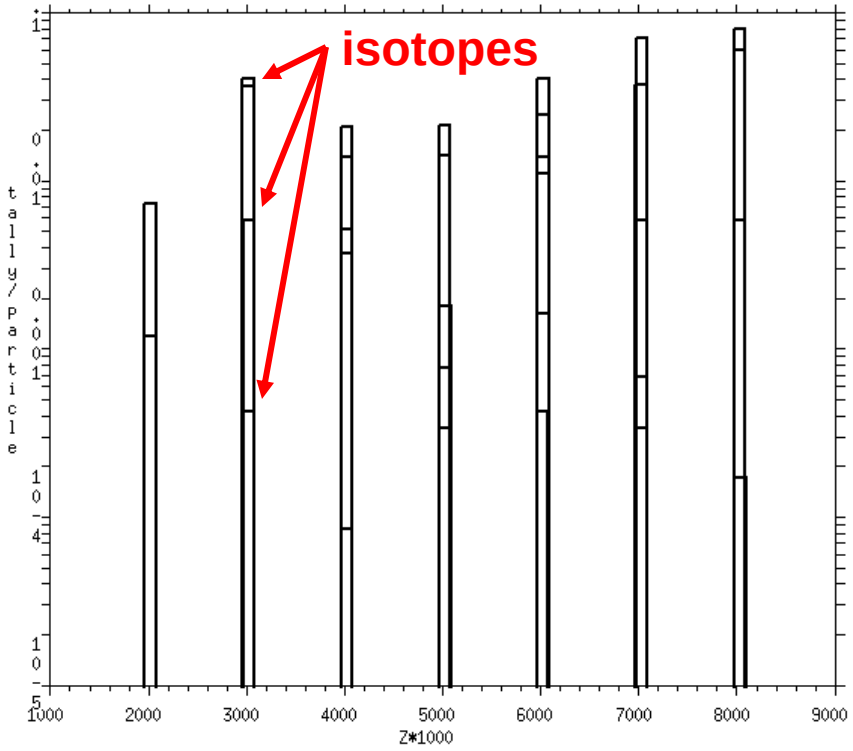
Heavy ion transport

```
1 TeV C-12 into water
1  1   -1.00   -1   imp:n=1
2  0            1   imp:n=0

1 sph 0 0 0 10

mode  # n h d t s a / z k % ^
m1    1001 2  8016 1
sdef  par=6012 erg=1000000
nps   50000
phys:n 1001000
f1:n   1
e1     100 199log 1000000
f11:h  1
e11    100 199log 1000000
f8:#   1
ft8    RES 1 10
```

Heavy ion transport

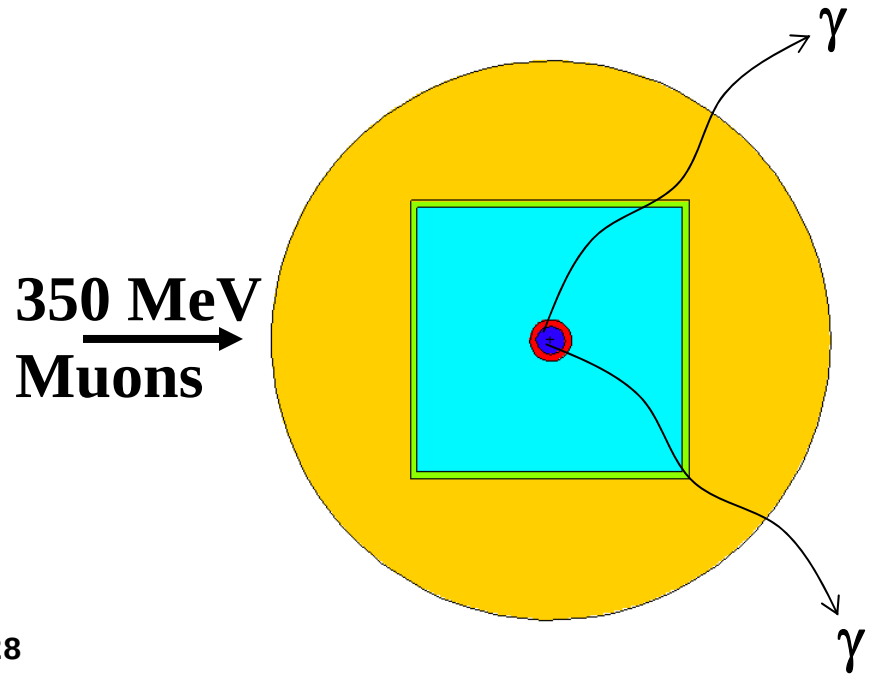


Residual distribution



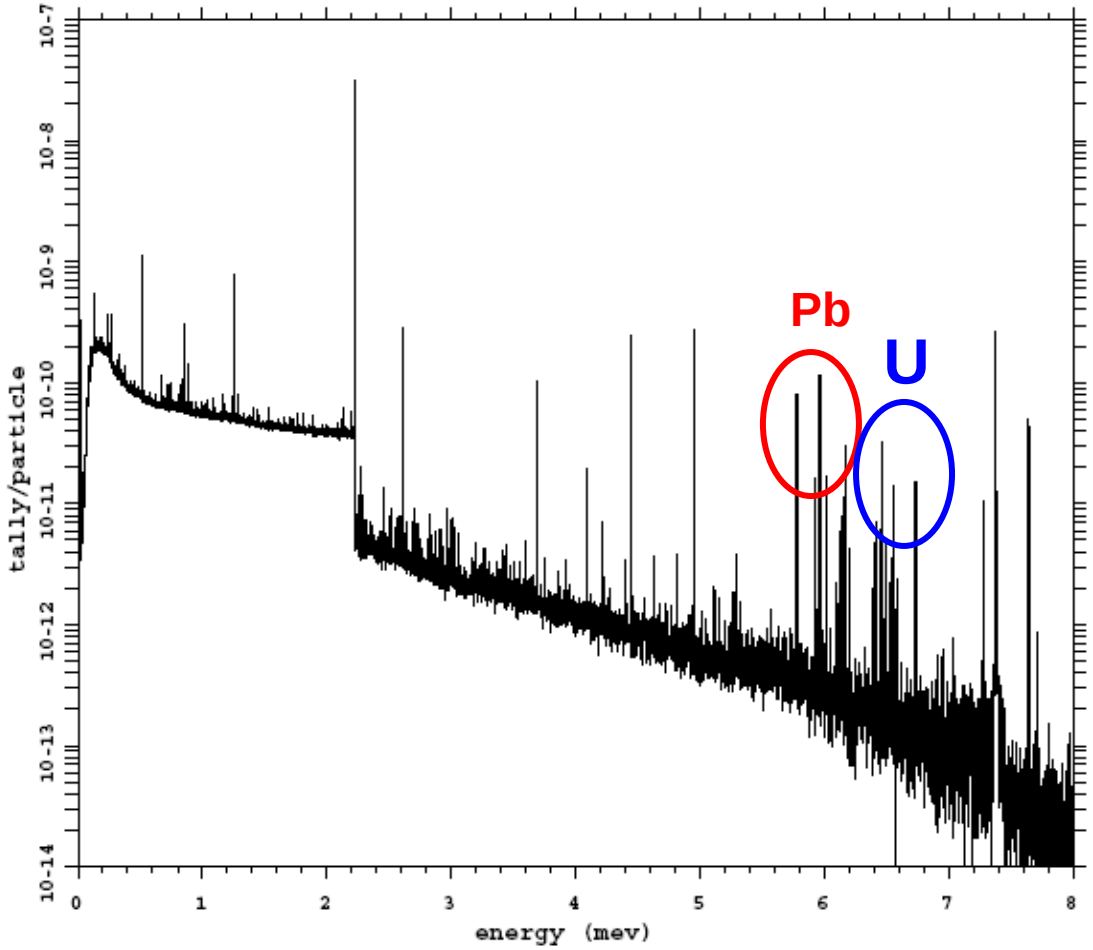
Muon capture physics

```
350 MeV muons into Pb surrounding HEU
1 1 -18.95  -1          imp:|,p=1
2 8 -11.35  1 -2        imp:|,p=1
3 3 -1.0  2 -3          imp:|,p=1
4 4 -7.8 3 -4           imp:|,p=1
5 5 -1.205e-3  4 -100   imp:|,p=1
100 0  100              imp:|,p=0

1 rcc -10.0 0.0 0.0 20.0 0.0 0.0 5.0
2 rcc -12.5 0.0 0.0 25.0 0.0 0.0 7.5
3 rpp -47.5 47.5 -47.5 47.5 -47.5 47.5
4 rpp -50.0 50.0 -50.0 50.0 -50.0 50.0
100 so   100.0

mode |  p
phys:|,p 350.0
sdef par=| erg=350.0 x=d1 y=d2 z=-60.0
     vec=0 0 1 dir=1
si1 -12.5 12.5
sp1 0  1
si2 -7.5 7.5
sp2 0  1
m1  92238 -.20 92235 -.80
m3  1001 2     6012 1
m4  26054 5.9 26056 91.72 26057 2.1 26058 .28
m5   1000 -6e-4 8000 -0.2353 7000 -0.7513
     18000 -0.0128
m8   82204 1.4   82206 24.1    82207 22.1
     82208 52.4
e2 0.0 9999i 10.0
f2:p 100
```



Muon capture physics

Muonic x-rays from U within Pb



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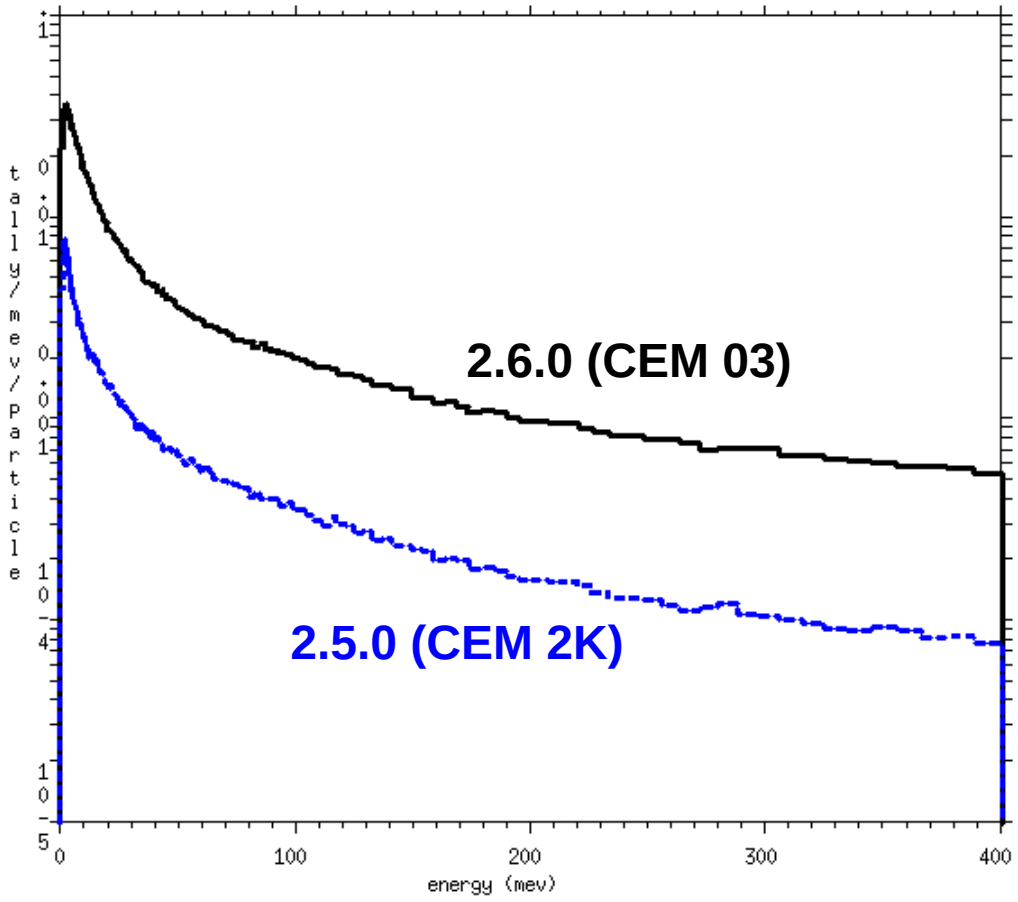
Upgrade of the CEM event generator

```
1 GeV protons into water
1  1   -1.00   -1   imp:n=1
2  0            1   imp:n=0

1 sph 0 0 0 100

mode  n h
m1    1001 2  8016 1
sdef  par=9 erg=1000
nps   1000000
phys:n 1010
lca    7j -2 1  $ Turn on CEM
f1:n   1
e1     1 199log 400
```

Neutron production from 1 GeV protons into water



Upgrade of the CEM event generator

Light-product yields (A<30)

Model	Proton energy (MeV)					
	300	500	750	1000	1500	2600
BERTINI	1035	26.1	50.5	13.8	4.93	3.35
ISABEL	---	256	49.1	17.0	5.99	4.02
INCL	233	215	51.5	38.1	26.1	12.1
CEM2K	---	12.6	21.1	7.83	4.87	4.02
CEM03	13.0	2.23	1.32	1.49	1.58	1.72

Heavy-product yields (A>30)

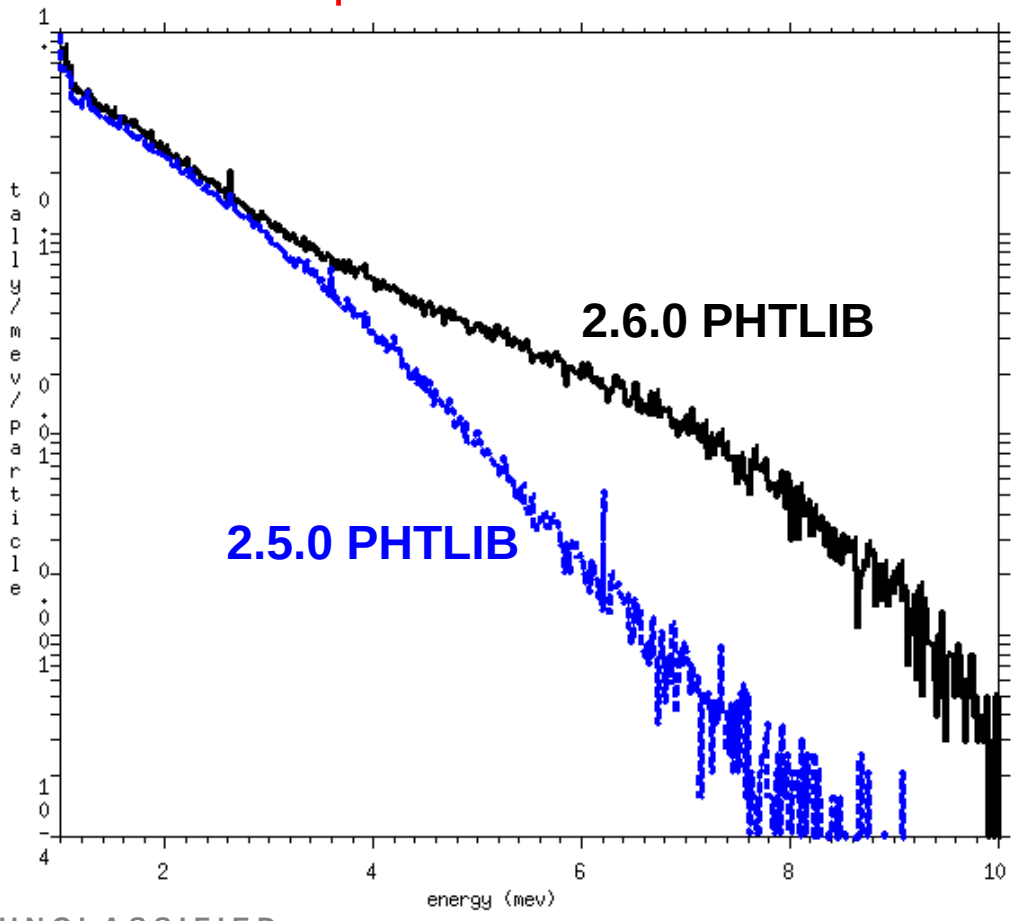
Model	Proton energy (MeV)						Ave. Dev.
	300	500	750	1000	1500	2600	
BERTINI	2.24	2.29	2.75	2.86	3.16	3.20	4.37
ISABEL	3.75	2.85	3.02	2.63	2.85	3.01	4.24
INCL	4.72	3.24	3.14	3.13	3.35	3.54	7.14
CEM2K	2.74	2.54	2.62	2.76	2.92	3.20	3.55
CEM03	1.84	1.89	1.89	1.92	2.04	3.17	2.26

Mean-squared deviation factors between model predictions and experimental data measured at ITEP.

Update of high-energy de-excitation data

```
1 GeV protons into lead
1  1   -11.4   -1   imp:p=1
2  0            1   imp:p=0

1 sph 0 0 0 100

mode  h p
m1    82208 1
sdef  par=9 erg=1000
nps   1000000
phys:h 1010
lca    7j -2 1  $ Turn on CEM
f1:p   1
e1     1 999i 20
```

Deexcitation gammas from 1 GeV protons into lead



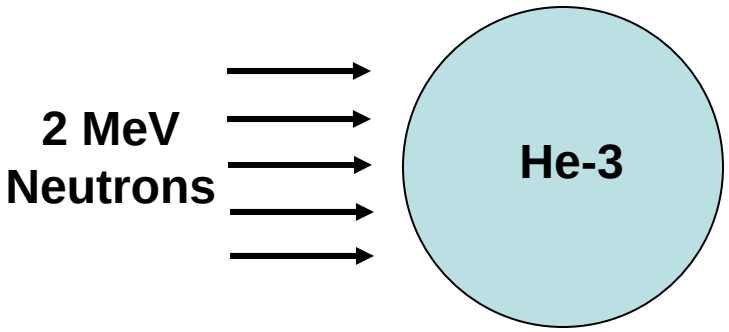
Physics Enhancements

- **Two new neutron physics features**
  - Light ion production from neutron capture
  - Gravity effects for planetary objects

Light-ion production from neutron capture

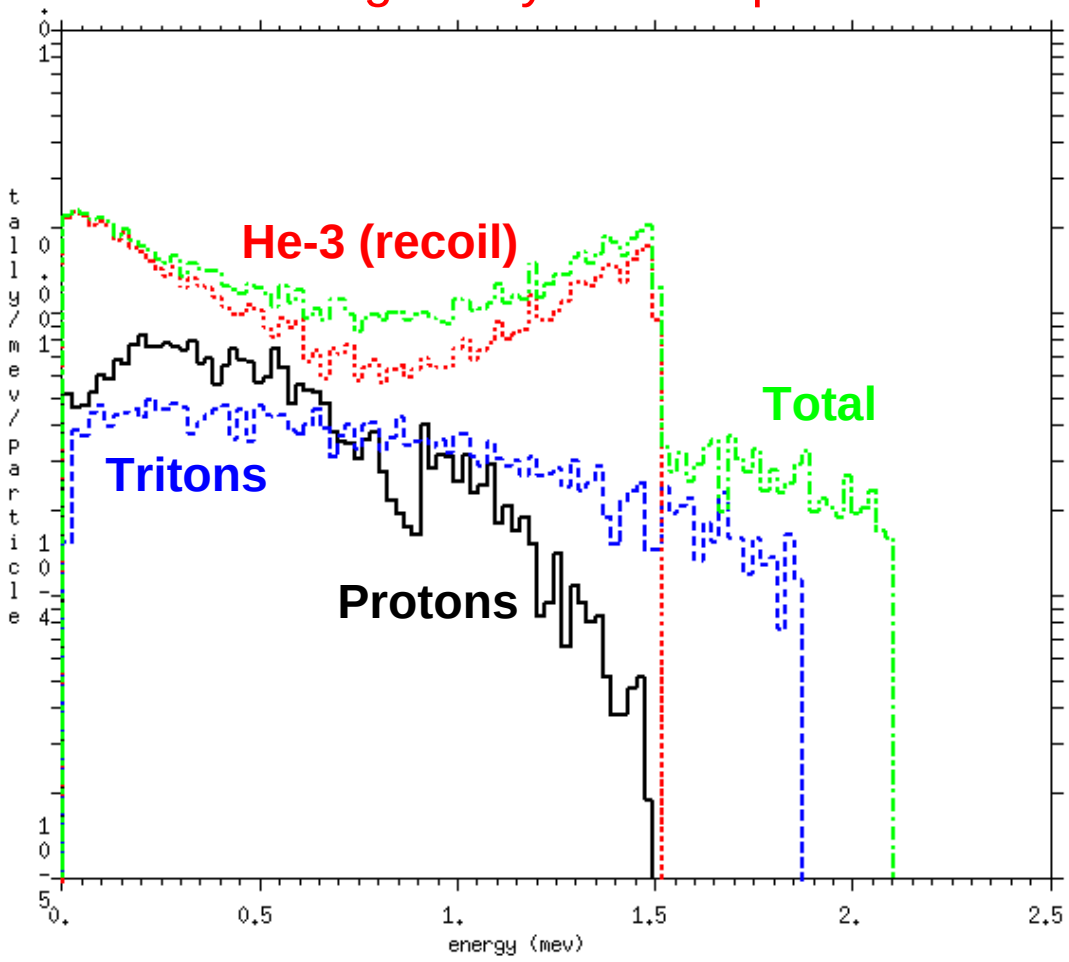
```
2 MeV neutrons into He-3
1  1 -5.3540E-4  -1    imp:n=1
2  0              1 -2 imp:n=1
3  0              2    imp:n=0

1  so 4.0
2  so 100.0

mode  n h d t s
sdef  par=n erg=2 pos=-5 0 0 rad=d1
      axs=1 0 0 ext=0 vec=1 0 0 dir=1
si1   0 3
sp1   -21 1
cut:n  2j 0 0
cut:h,d,t,s j .001
phys:n 6j 2
m1    2003.60c 1
nps   10000000
f6:h  1
f16:d 1
f26:t 1
f36:s 1
```

```
f8:n  1
e8    0. 99i 2.1
ft8   PHL 1  6 1 0
f18:n 1
e18   0. 99i 2.1
ft18  PHL 1 16 1 0
f28:n 1
e28   0. 99i 2.1
ft28  PHL 1 26 1 0
f38:n 1
e38   0. 99i 2.1
ft38  PHL 1 36 1 0
f58:n 1
e58   0. 99i 2.1
ft58  PHL 4 6 1 16 1 26 1 36 1 0
```



Light-ion production from neutron capture

Pulse height tally from all particles



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Gravity effects for planetary objects

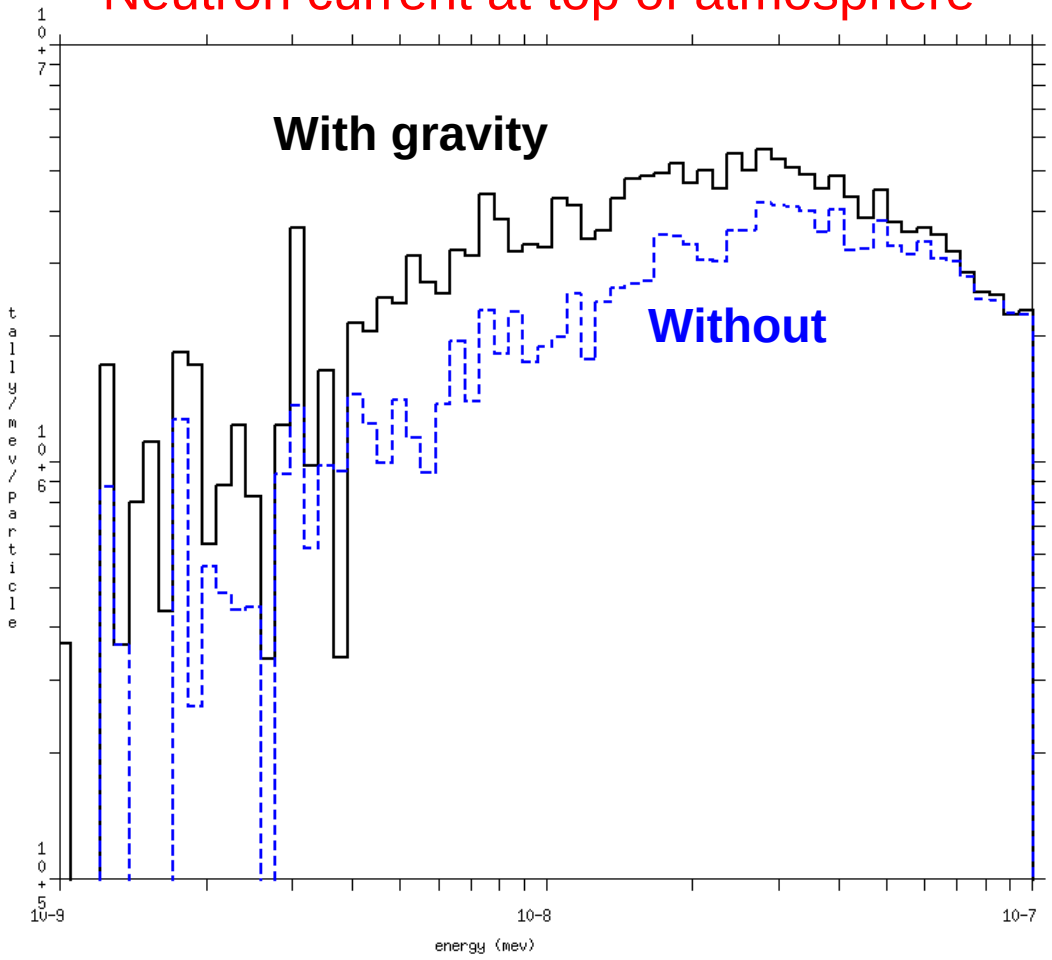
```
5 GeV protons into Mars, gravity reflection
1     1 -1.0         -1         imp:n=1
100   2 -1.35e-5     -101 +1    imp:n=1
101   2 -1.28e-5     -102 +101  imp:n=1
102   2 -1.22e-5     -103 +102  imp:n=1
103   2 -1.14e-5     -104 +103  imp:n=1
104   2 -1.08e-5     -105 +104  imp:n=1
105   2 -1.01e-5     -106 +105  imp:n=1
999   0              +106       imp:n=0

1     so 339000000.0
101   so 339060000.0
102   so 339110000.0
103   so 339180000.0
104   so 339240000.0
105   so 339310000.0
106   so 339380000.0

m1   8016.60c -0.6 14000.60c -0.3 26056.60c -0.1
m2   6000.60c -0.27 7014.60c -0.02 8016.60c -0.70
     18000.35c -0.01
FIELD GCUT=0.1320 GPAR=1 GRAD=3393.0 GSUR=106
mode  h n p z / d t s a
lca   8j 1  $ Use CEM
```

```
sdef  par=9 erg=5000 sur=106 nrm=-1
Nps   10000
phys:n 5010 j j j 20
f11:p 1
ft11  tag 1
e11   0. 1024i 10. 5000.
fu11  0. 8016.00051 8016.00052 8016.00053
      8016.00102  8016.
      14028.14027 14028.14026 14028.13027
      14028.13026 14000.
      26056.00051 26056.00052 26056.00053
      26056.00102 26056.
e21   1e-10 99log 1e-7
f21:n 105
```

Undocumented Feature

Gravity effects for planetary objects

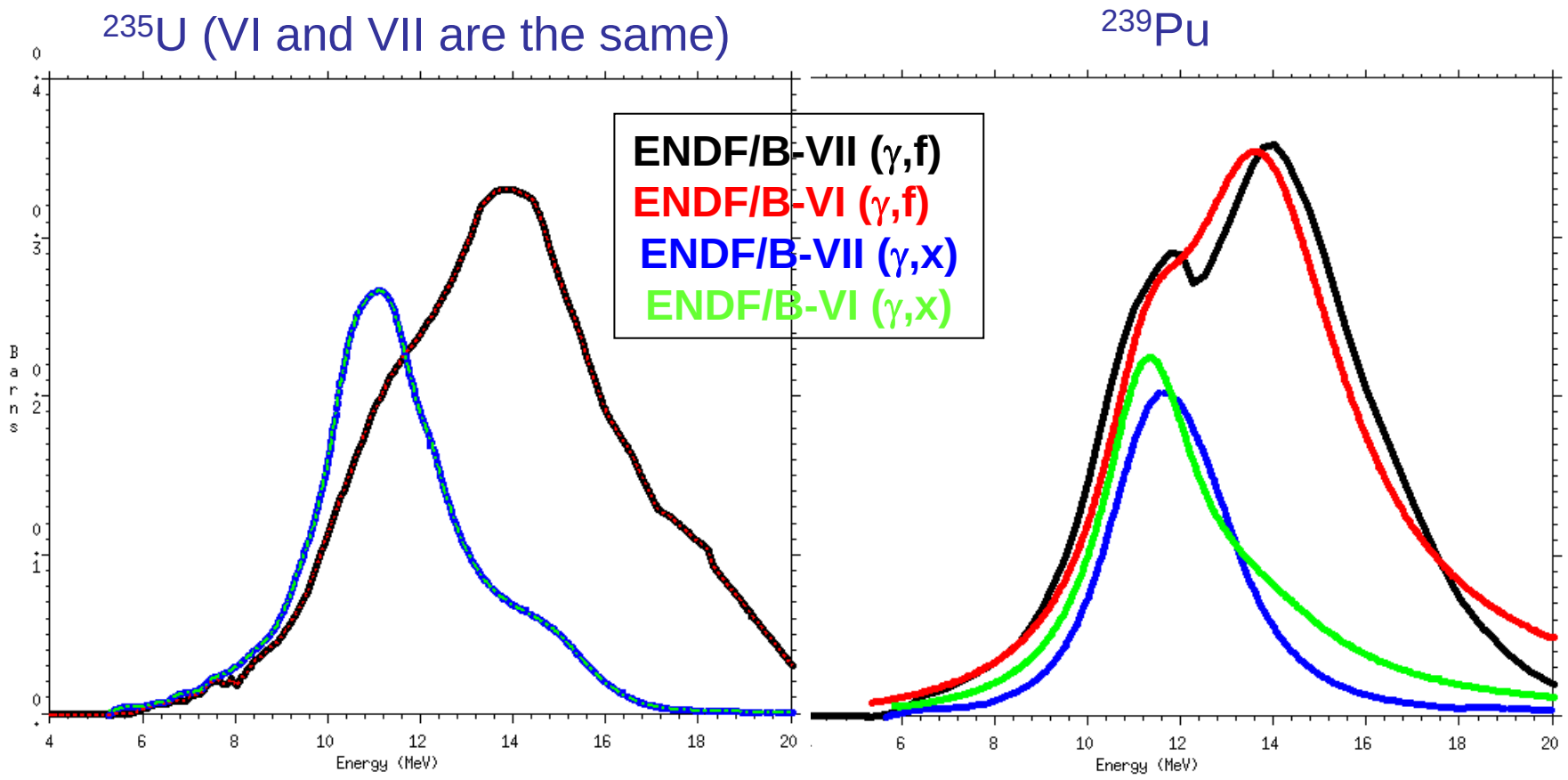
Neutron current at top of atmosphere



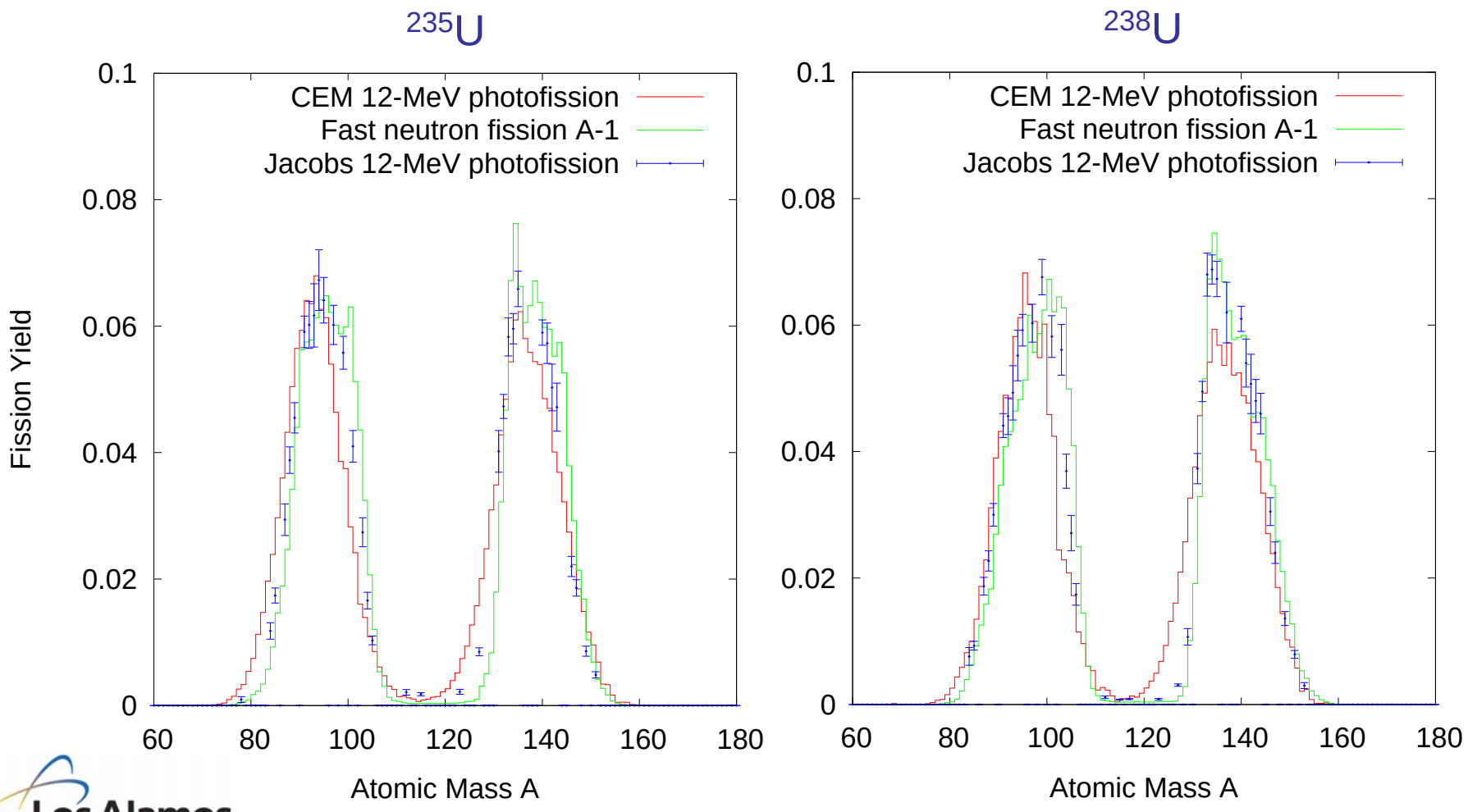
Physics Enhancements

- **One new photon physics feature**
  - Photofission yield data

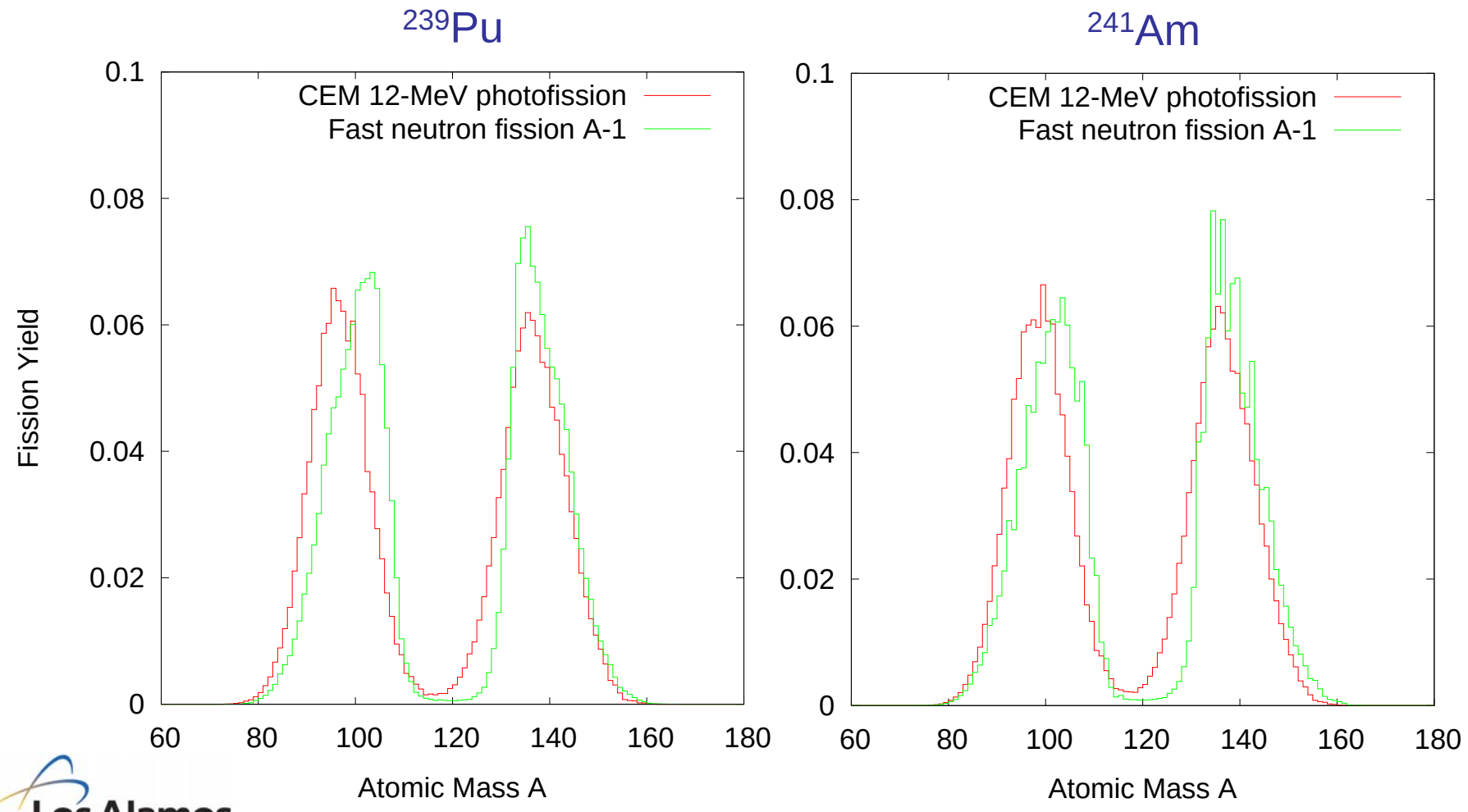
ENDF/B-VII photonuclear libraries



Photofission yield data



Photofission yield data



Outline

- **Overview**
- **Development History**
- **User Base**
- **New 2.6.0 Features**
- **Future Development**

Future Plans – Version 2.7.A

- Pulsed sources
  - Nested time distributions (TME=d10<d11<d12)
- Tally tagging (FT TAG option)
  - Segregates a tally based on particle creation mech.
- MCPLOT graphic enhancements
  - Improved axis labels
  - Logarithmic contours
  - Help package
- CEM upgrade (03.02)

Future Plans – Version 2.7.B

- MCPLOT arithmetic commands
  - Add, subtract, multiply, divide tallies
- Delayed gamma exact line sampling
  - ACT card to choose options
  - Generate line data for all unstable nuclides
- Improved proton stopping powers
  - ICRU-49 specification
- Additional special tally options
  - Flux vs. LET
  - Quality factors

Future Plans – Version 2.7.C

- Nuclear Resonance Fluorescence data
  - New version of photonuclear libraries
- Background source option
  - SDEF keyword for longitude, latitude, altitude
  - Automatic production of neutrons and photons
- Dynamic universes
  - Extension of the TRCL card
- Correlated secondary particles
  - For library interactions

MCNP/X Merger

- **Goal – combine all features of MCNP5 and MCNPX into a single code to be released as MCNP6**
- **Level of support: $3M**
  - **FY07: 2.5 FTE**
  - **FY08: 2.0 FTE**
  - **FY09: 2.0 FTE**
- **Strategy: Integrate MCNPX capabilities into MCNP5 / 6 subroutine by subroutine**
- **Planned Milestones:**
  - **MCNP6 at MCNP / MCNPX workshops (May 2008)**
  - **Alpha (internal release): October 2008**
  - **Beta (limited external release): April 2009**
  - **RSICC Release: October 2009**

MCNP/X Merger

Phase 1

- **Move MCNPX variables to MCNP6**
- **(reconcile particles, common, etc.)**

Phase 2

- **First half of IMCN (card reading)**

Phase 3

- **Second half of IMCN**
- **(geometry, tallies materials)**

Phase 4

- **XACT (Read / process cross sections,**
- **proton library, heating)**

Phase 5

- **MCRUN - particle transport**

Phase 6

- **MCRUN – sources and tallies**

Phase 7

- **Tally and cross section plots**

Phase 8

- **Geometry plot**

Phase 9

- **MCNPX 26 C, D, E, F, … upgrade**

Phase 10

- **Debug**
- **Quality control**
- **Documentation**