LA-UR-12-25775

MCNPX 2.7.0 – New Features Demonstrated

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IEEE NSS/MIC

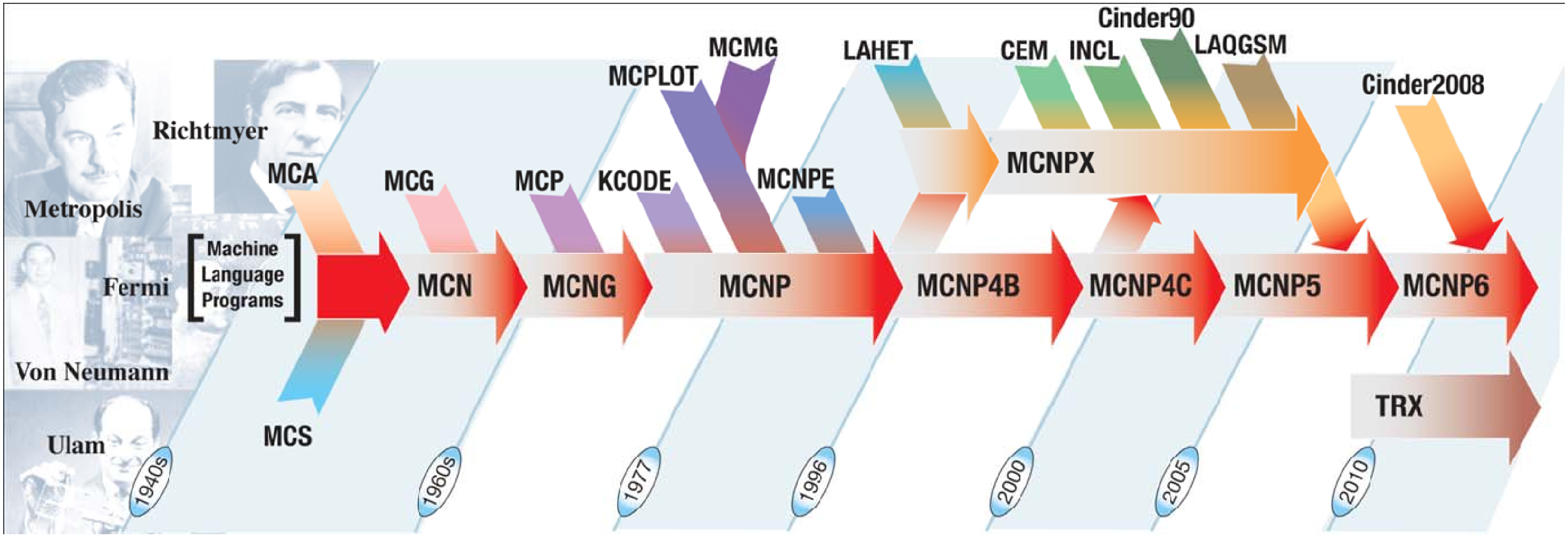
Anaheim, CA, October 29 - November 3, 2012

This work was sponsored by the US Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract/IAA HSHQDC-12-X-00251. This support does not constitute an express or implied endorsement on the part of the Government

MCNPX/MCNP6 are 3-D, all-particle, all-energy Monte Carlo transport codes

- **Monte Carlo radiation transport code**
  - Extends MCNP4C/MCNP5 to virtually all particles and energies
  - 34 different particle types + 2205 heavy ions
    - Neutrons, photons, electrons, protons, pions, muons, light-ions, etc.
  - Continuous energy (~0 -1 TeV/n)
  - 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)

MCNP has been under development for almost a century – final version of MCNPX was released in March 2011



MCNPX Public Versions

2.1.5, 1999

2.3.0 & 2.4.0, 2002

2.5.0, 2005

2.6.0, 2008

2.7.0, 2011

Resources for MCNP/X users

- **~5000 users world wide**
  - Provide ~10 workshops per year (75% US, 25% international)
  - 1-2 workshops per year have a HS emphasis
  - Access to RSICC released versions only
    - http://www-rsicc.ornl.gov/ (B00004 MNYCP 02) MCNPX/MCNP5/MCNP6
  - Limited access to MCNPX web site
    - http://mcnpx.lanl.gov (some documentation and data)
- **~2000 registered Beta Users**
  - Full access to MCNPX web site
  - Access to intermediate Beta versions
  - Increased user support

MCNPX public version 2.7.0 – thirty significant features over three years!

Physics Enhancements

CEM upgrade to 03.02
Adjustable stopping-power grid
LLNL photofission multiplicities
Delayed gamma exact sampling
LLNL neutron fission multiplicities
Muonic x-ray enhancements
Delayed neutron spectra
NRF data in ACE libraries
Improved photoatomic form factors
DG algorithm improvements
GEF photofission yields
LAQGSM upgrade to 03.03

Source Enhancements

Burnup enhancements
Pulsed sources
Beam source options
Natural background sources

Tally Enhancements

Tally tagging
LET tally option
Quality factor tally option
Cyclic tally binning
ROC curve tally option
Residual tally upgrades
Triple & quadruple coincidences
Time-dependent pulse-height tallies

Other Enhancements

MCPLOT graphics enhancements
Activation options (ACT card)
MCPLOT tally manipulations
Nested READ cards
Feature-based memory reduction
M & MX card extensions

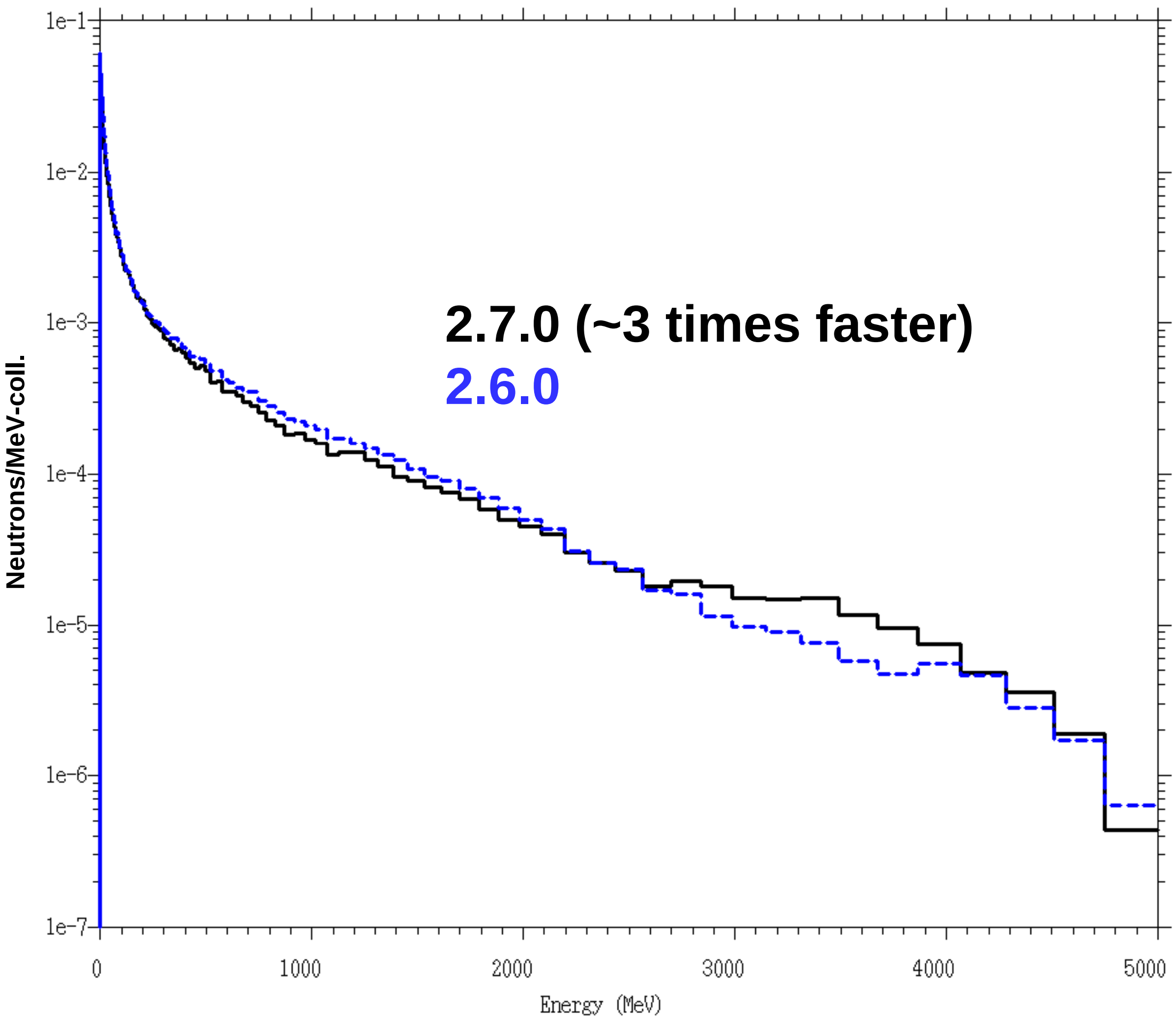
D. B. Pelowitz, editor, “MCNPX 2.7.0 Extensions,”
LANL report LA-UR-11-02295 (2011)

Physics: CEM & LAQGSM upgrades – neutron production for 1-5 GeV protons into N-14

```
1-5 GeV protons into N-14
1 1 -1    -1        imp:n,p=1
2 0        1        imp:n,p=0

1 so 10.0

mode   n h
m1     7014 1
lca    7j -2 1 1 $ Use CEM & LAQGSM
phys:n 5010
sdef   pos=0 0 0 par=h erg=d1
si1    1000 5000
sp1       0    1
f1:n   1
e1     1e-3 299log 5000
nps    100000
print
prdmp 2j 1
```



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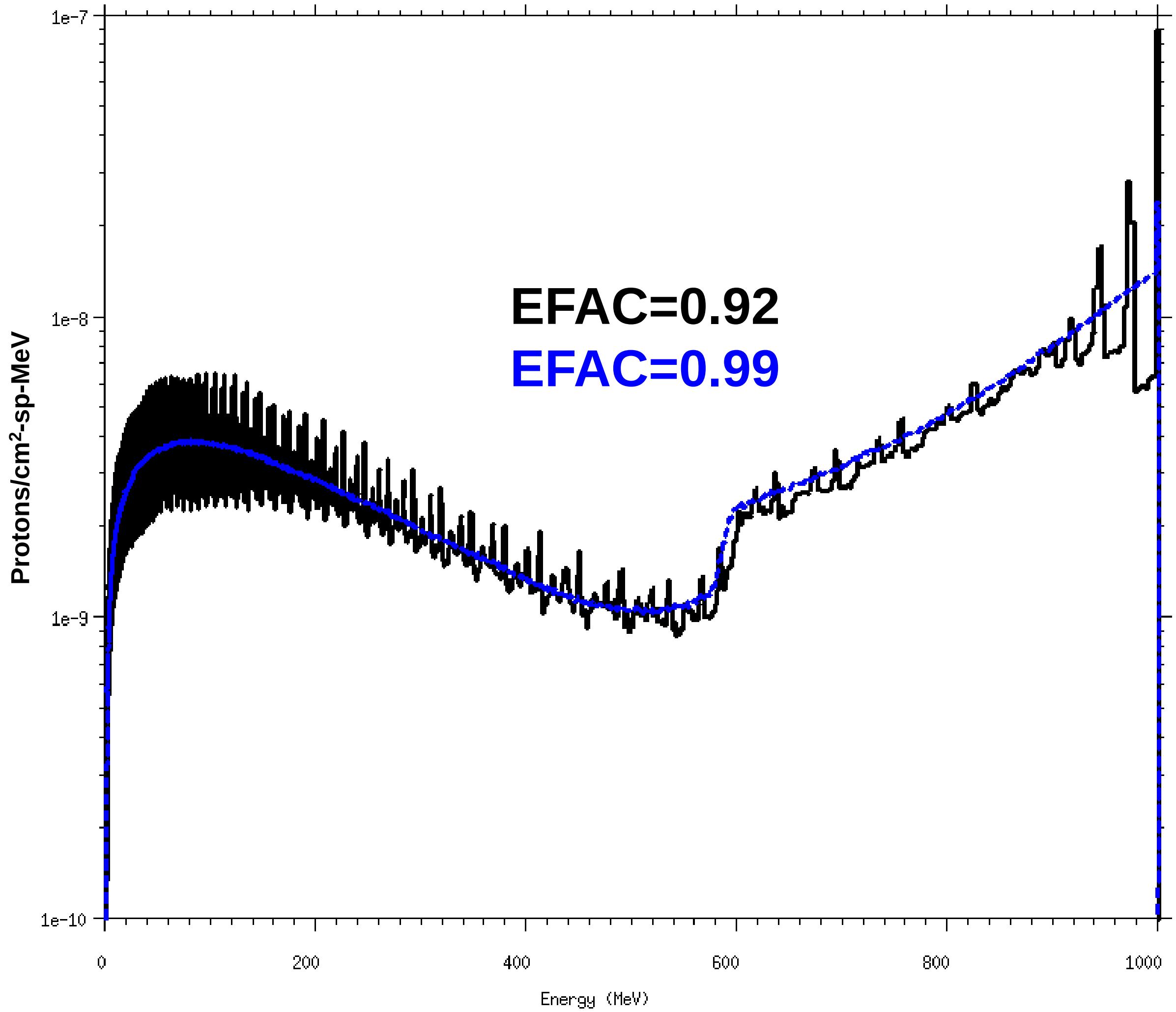
Physics: adjustable stopping-power grid – user can decrease energy steps to improve fidelity (PHYS:H card)

```
1 Gev protons into N-14
1  1  -1.0   -1   imp:n=1
2  0           1   imp:n=0

1  so  200.0

mode  n h d t s a
phys:n 1010
phys:h 1010 9j .99 $ Set EFAC
m1    7014 1
lca   8j 1
sdef  par=h erg=1000
f4:h  1
e4    1 2000log 1000
nps   10000000
print
```



Physics: LLNL fission multiplicity – benchmarking of neutron multiplicity from thermal neutron induced fission

Comparison to Measured Data (Holden, 1986)

	U-233	U-235	Pu-239	[illegible]41
P0	1.33%	7.11%	[illegible]	[illegible]
P1	3.60%	7.41%	[illegible]	0.30%
P2	1.67%	[illegible]	[illegible]	0.66%
P3	3.50%	[illegible]	0.03%	1.04%
P4	5.44%	[illegible]	0.21%	2.25%
P5	[illegible]	[illegible]	0.10%	1.69%
P6	[illegible]	19.70%	1.23%	13.37%
P7	[illegible]	45.90%	1.69%	30.89%
1st mom[illegible]	[illegible]	0.94%	0.10%	0.45%
2nd [illegible]	1.93%	1.58%	0.28%	0.89%
3rd m[illegible]	4.96%	0.43%	0.71%	1.17%

R. A. Weldon et al., "Testing the LLNL Multiplicity Capability in MCNPX 2.7.0," Proceedings of the ANS Winter Meeting, San Diego, CA, Nov. 11-15 (2012)

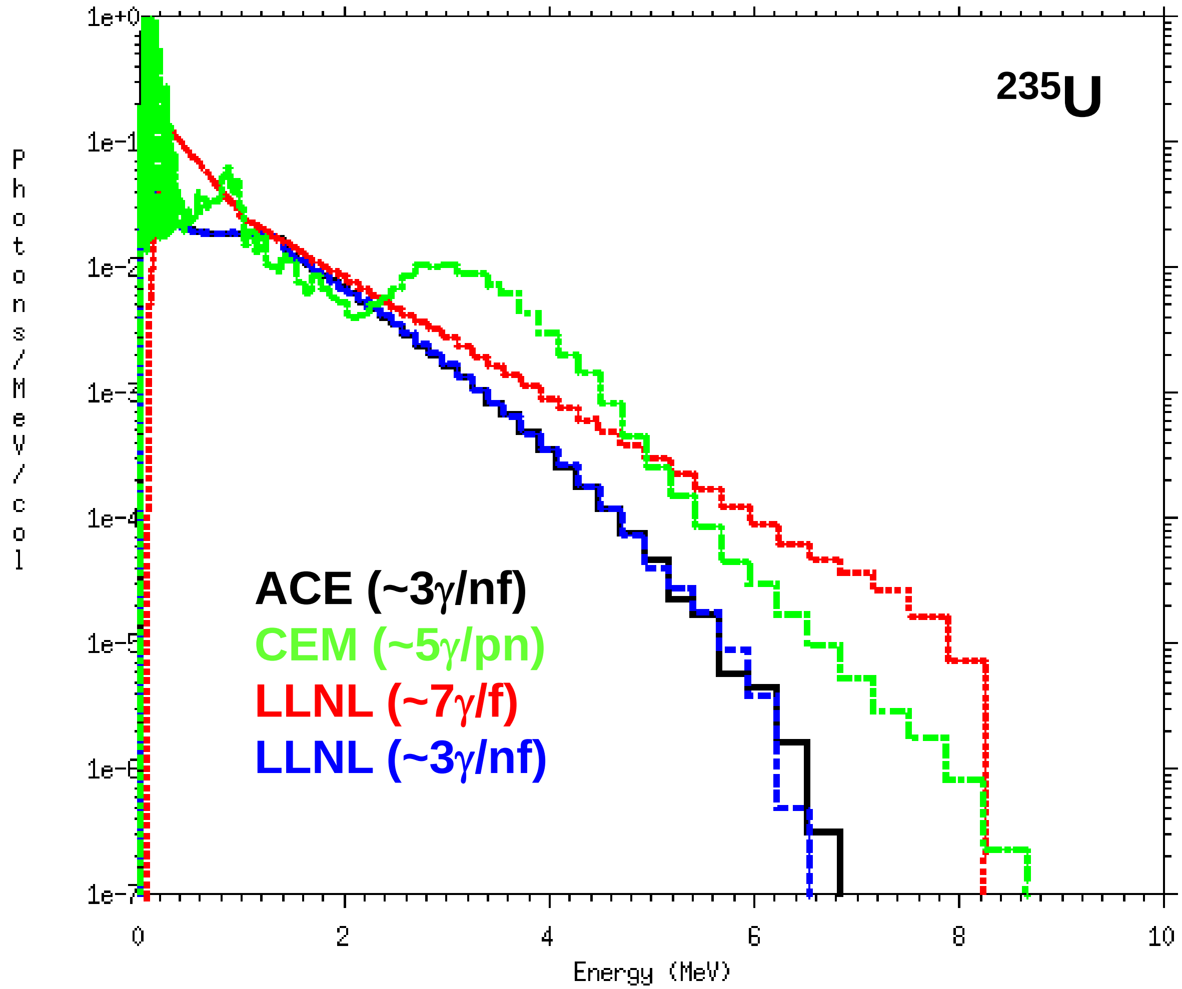
Physics: LLNL fission multiplicity – benchmarking of neutron multiplicity from spontaneous fission

Comparison to Measured Data (Holden, 1986)

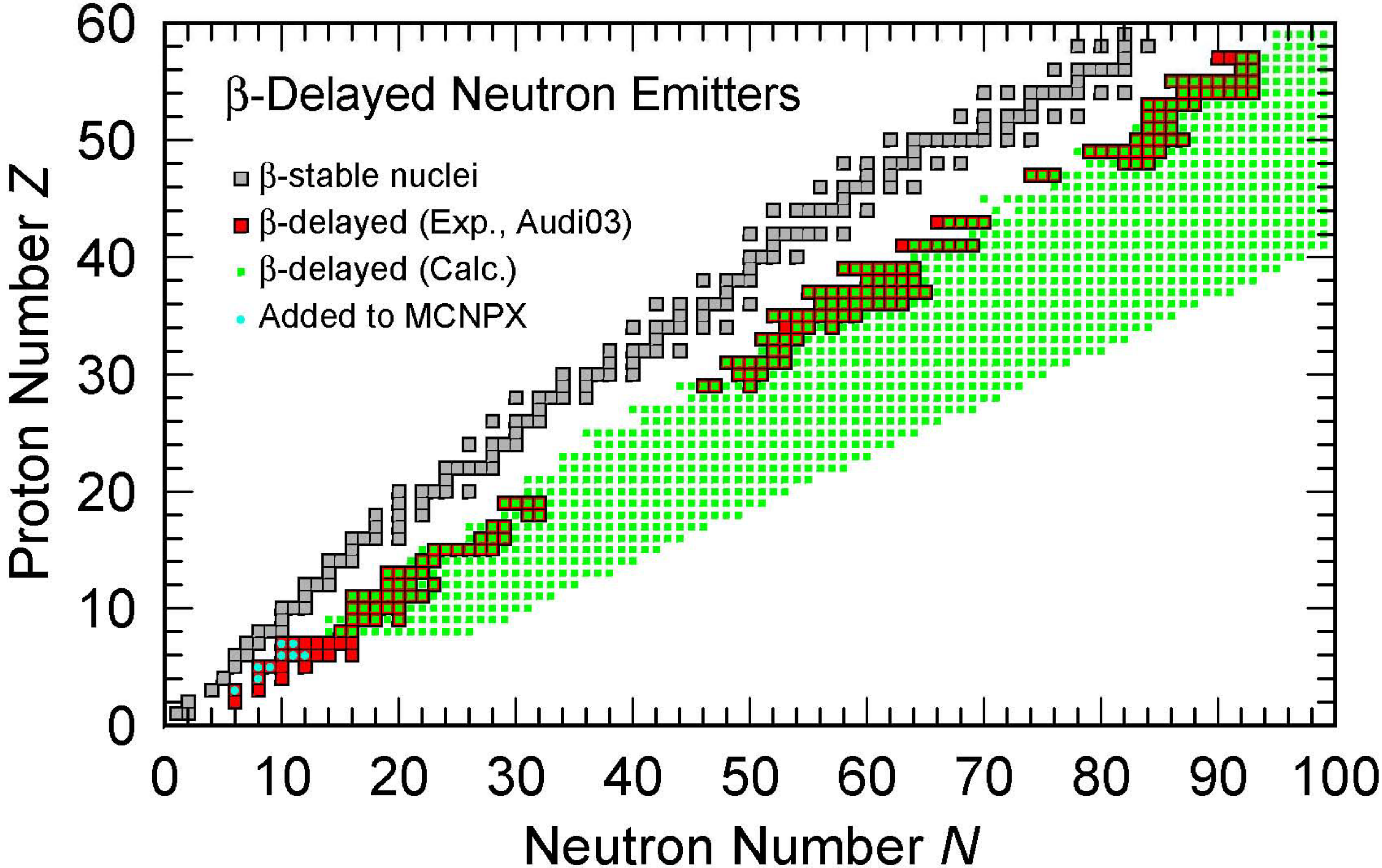
	U-238	Pu-238	Pu-240	Pu-242	Cm-242	Cm-244
P0	0.02%	4.14%	0.01%	1.55%	0.05%	0.05%
P1	0.00%	2.57%	0.00%	6.94%	0.01%	0.01%
P2	0.01%	0.13%	0.01%	3.03%	0.00%	0.00%
P3	0.01%	1.07%	0.01%	11.59%	0.00%	0.00%
P4	0.00%	2.94%	0.00%	49.57%	0.00%	0.00%
P5	0.05%	5.34%	0.03%	29.55%	0.01%	0.01%
P6			0.00%	99.92%	0.07%	0.07%
P7					0.07%	0.02%
P8					0.30%	
1st moment	0.00%	1.04%	0.00%	0.00%	0.00%	0.00%
2nd moment	0.00%	2.10%	0.00%	2.01%	0.00%	0.00%
3rd moment	0.00%	3.20%	0.00%	6.52%	0.00%	0.00%

Physics: LLNL fission multiplicity – provides prompt gammas from photofission (physics gap in ACE libraries)

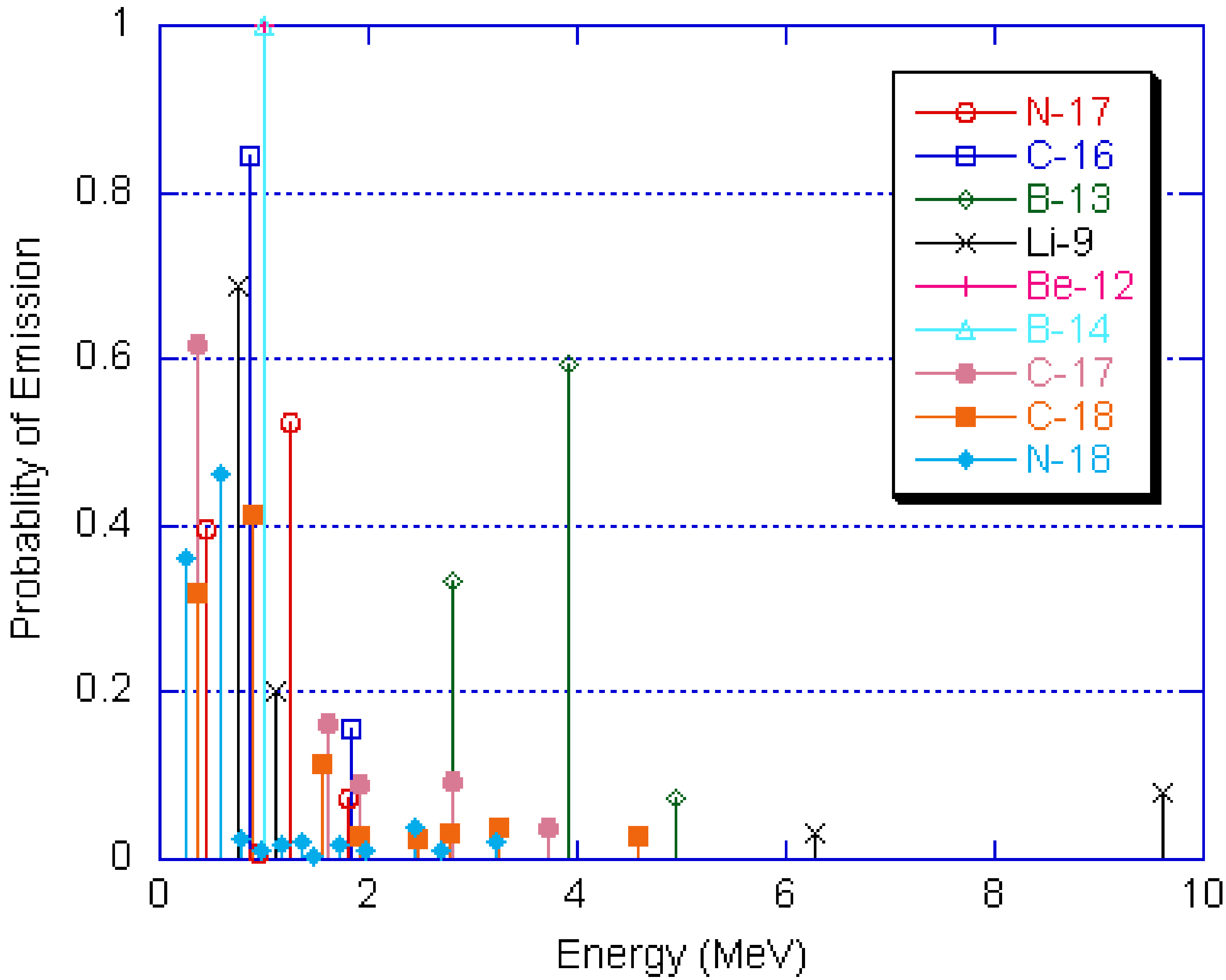
```
12-MeV photons into U-235
1  1  -19.0     -1  imp:n=1
2  0             1  imp:n=0

1  so  1.0

mode n p
m1   92235 1  pnlib=.70u
c  mx1:p  model $ CEM
PHYS:P j 1 j 1 2j 1 $ LLNL model
c  PHYS:P j 1 j 1 2j 0 $ ACE
sdef par=p erg=12
LCA  7j -2
f1:n  1
e1    1e-6 199log 12
f11:p 1
e11   1e-3 199log 12
ft11  tag 3
fu11  -1 0.00004 92000.00003
     92235.00005 92000.00005
     92235.00018 1e10
nps   1000000
print
```



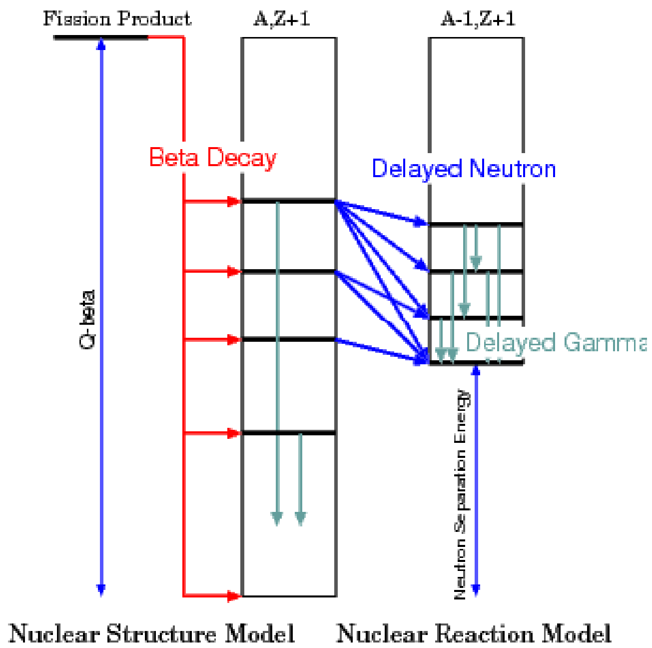
Physics: delayed particle production – delayed neutron spectra calculated for nearly all beta-unstable nuclei



Physics: delayed particle production – using measured delayed neutron spectra for low-Z nuclei

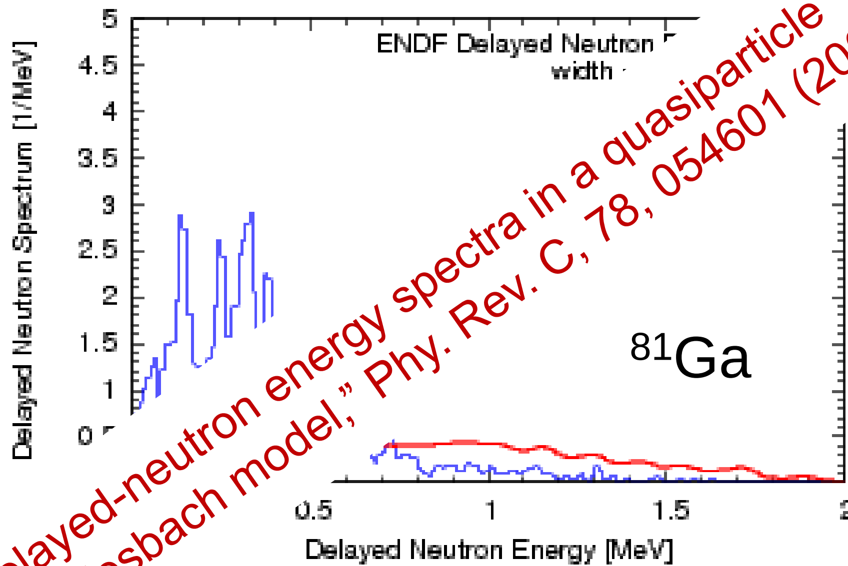


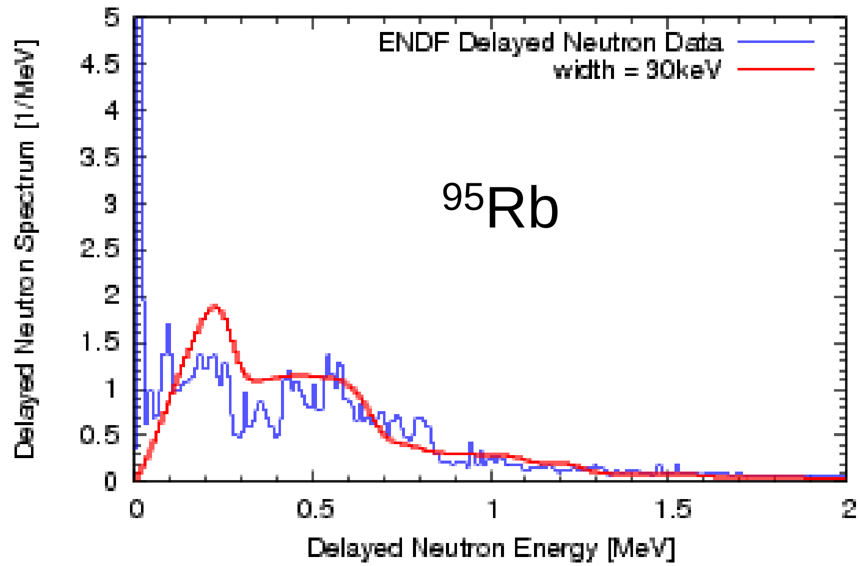
Physics: delayed particle production – using calculated delayed neutron spectra for 270 fission products



34 of the 270 ENDF DN … are based on meas… while the others use s… …ons. We have update… …a based on a LANL n… …ure model and a statistic… …er-Feshbach model.

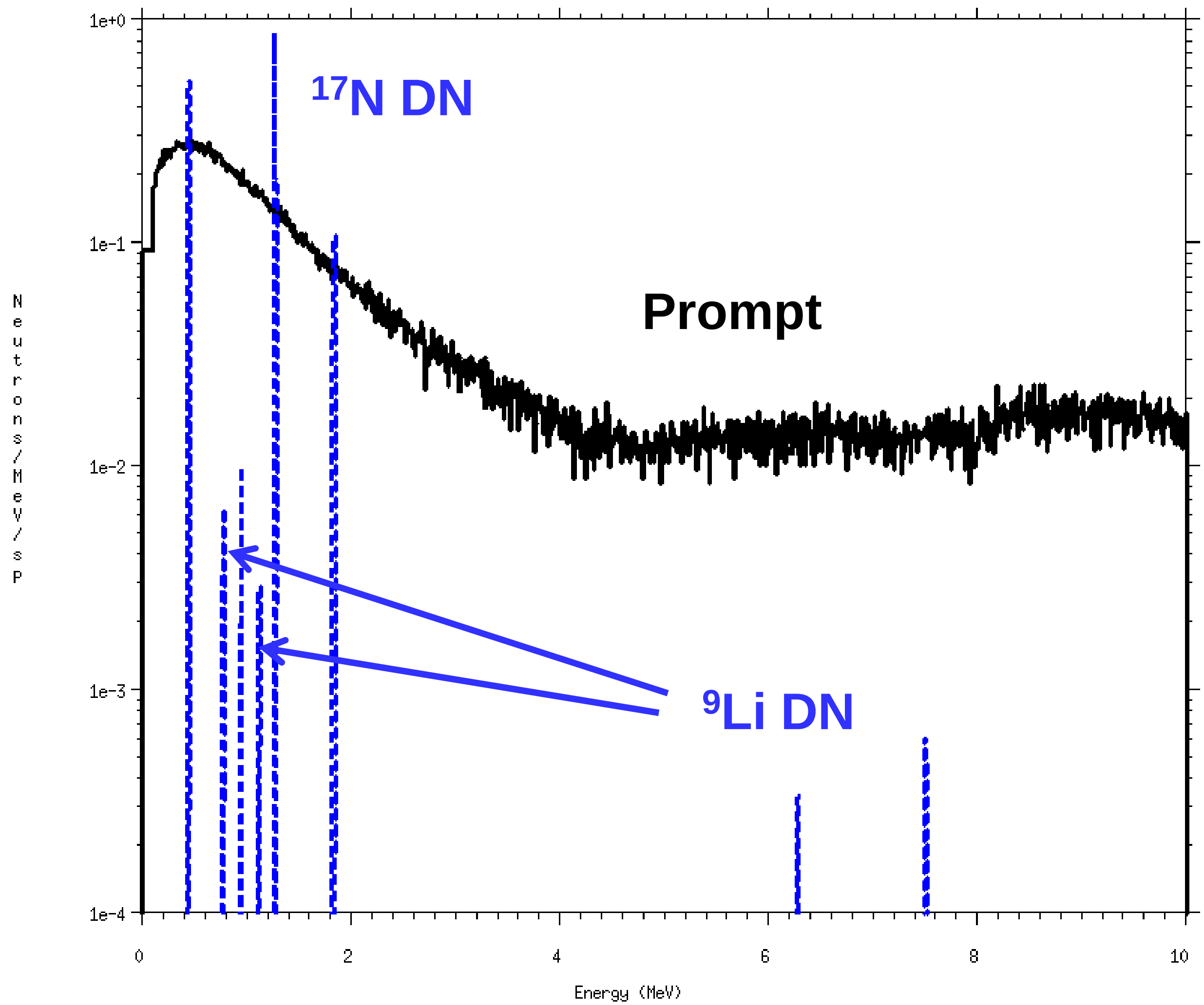
T. Kawano et al., “Calculation of delayed-neutron energy spectra in a quasiparticle random-phase approximation - Hauser-Fesbach model,” Phy. Rev. C, 78, 054601 (2008)





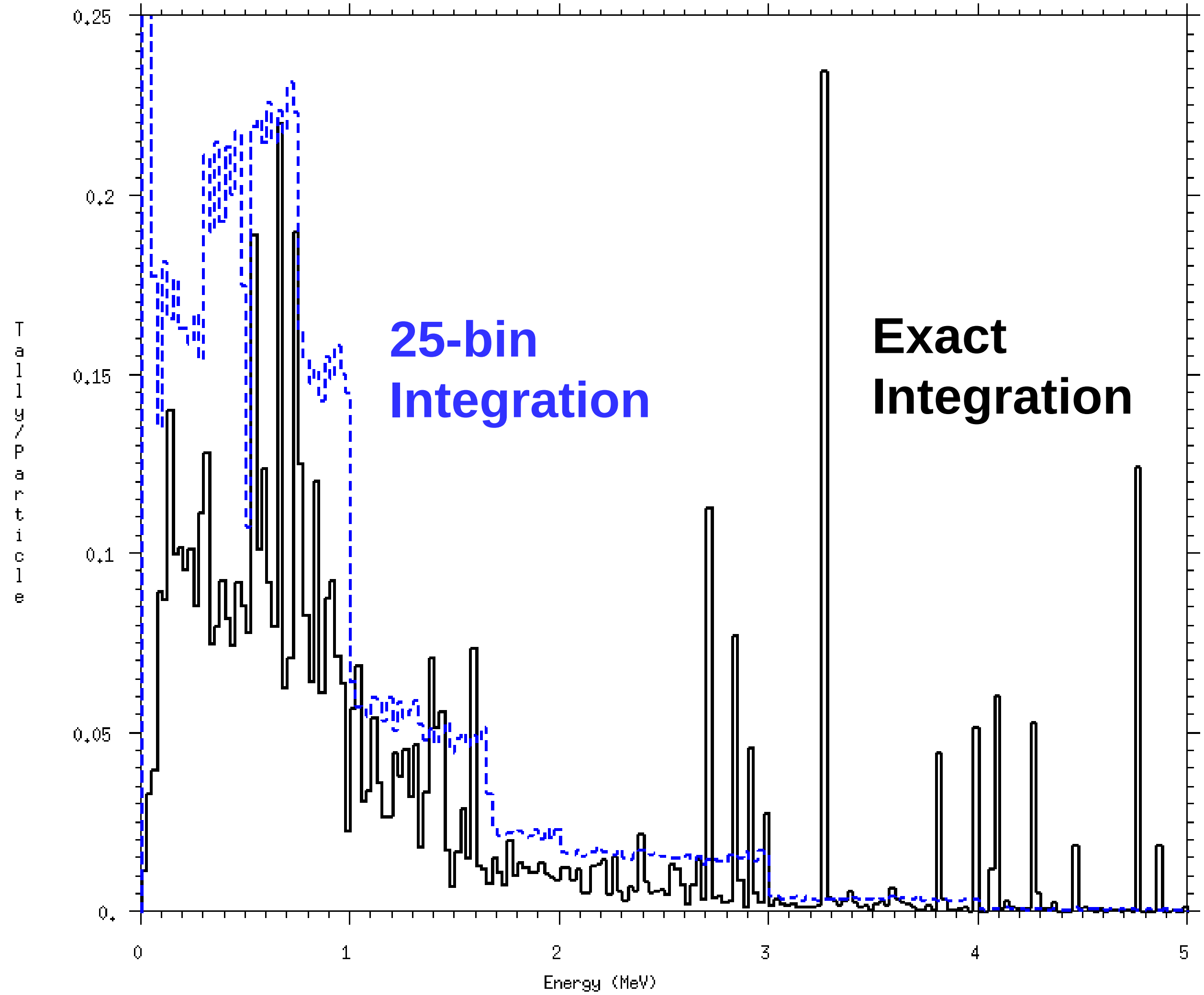
Physics: delayed particle production – a simple delayed neutron activation example

```
16-MeV neutrons into BeO
1   1   -1.0    -1     imp:n=1
2   0            1     imp:n=0

1 so   1.0

m1       4009 1 8017 1
sdef     par=n  erg=16
ACT      NONFISS=all DN=model
         DNBIAS=5
lca      7j -2
f1:n     1
e1       .1 999i 10.
t1       0.001000e8  1e30
nps      1000000
print
```

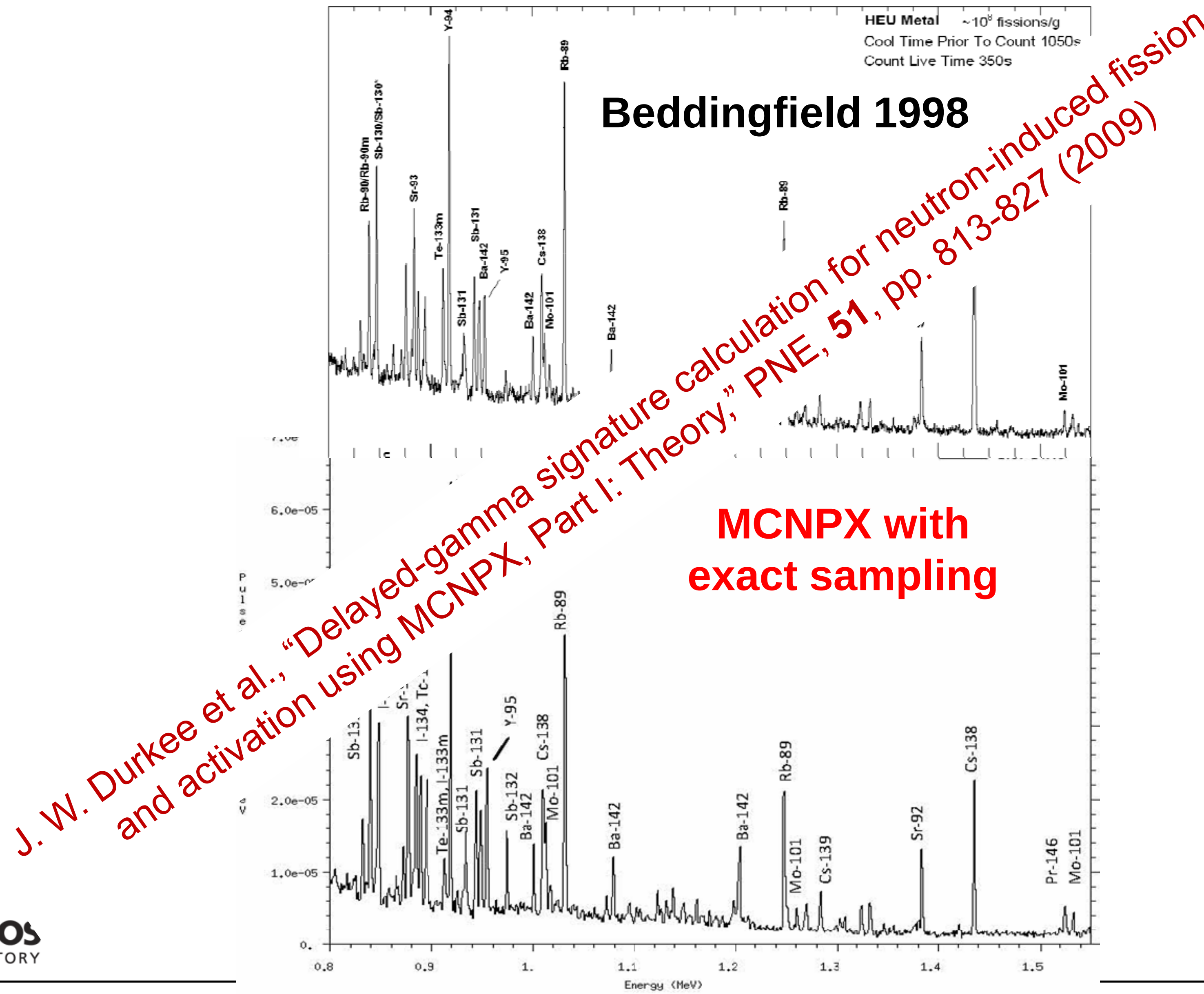


Physics: delayed particle production – new delayed gamma library with improved algorithms provide high fidelity

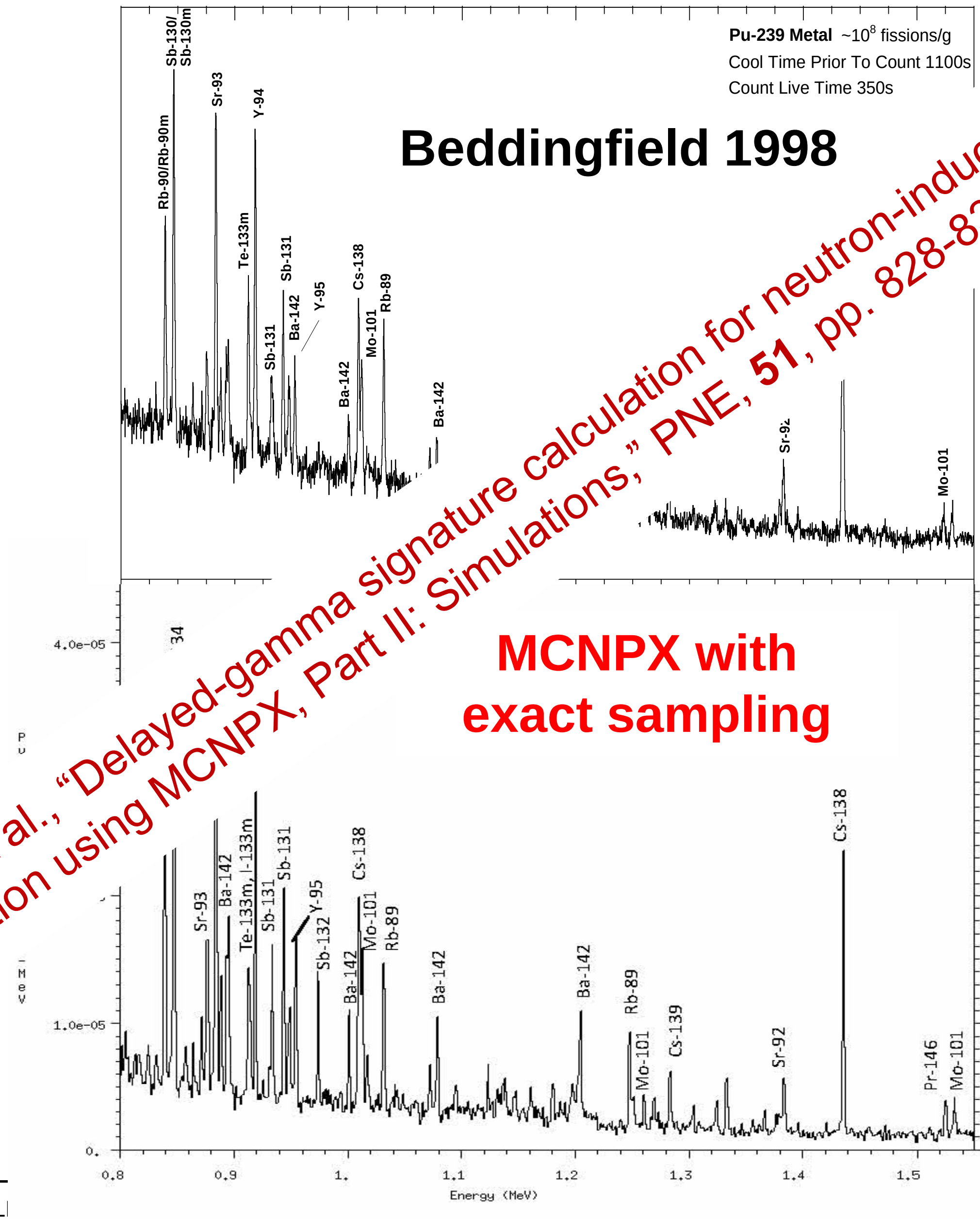
```
Thermal neutrons into U-235
1     1 -8.9     -1    imp:n=1
2     0           1    imp:n=0

1     so  1.0

m1      92235.70c  1.0
mode    n p
ACT     DG=lines $ Use line data
cut:n   j j 0 0
lca 7j  -2
sdef    par=n erg=2.54e-8
f1:p    1
e1      0.0 399i 10
sd1     1
t1      1e4  1e30
tf1     7j 2
nps     25000
print
```



Physics: delayed particle production - spectroscopic results from HEU fission agree with measured data



Physics: delayed particle production - spectroscopic results from ^{239}Pu fission agree with measured data



J. W. Durkee et al., "Delayed-gamma signature calculation for neutron-induced fission and activation using MCNPX, Part II: Simulations," PNE, **51**, pp. 828-836 (2009)

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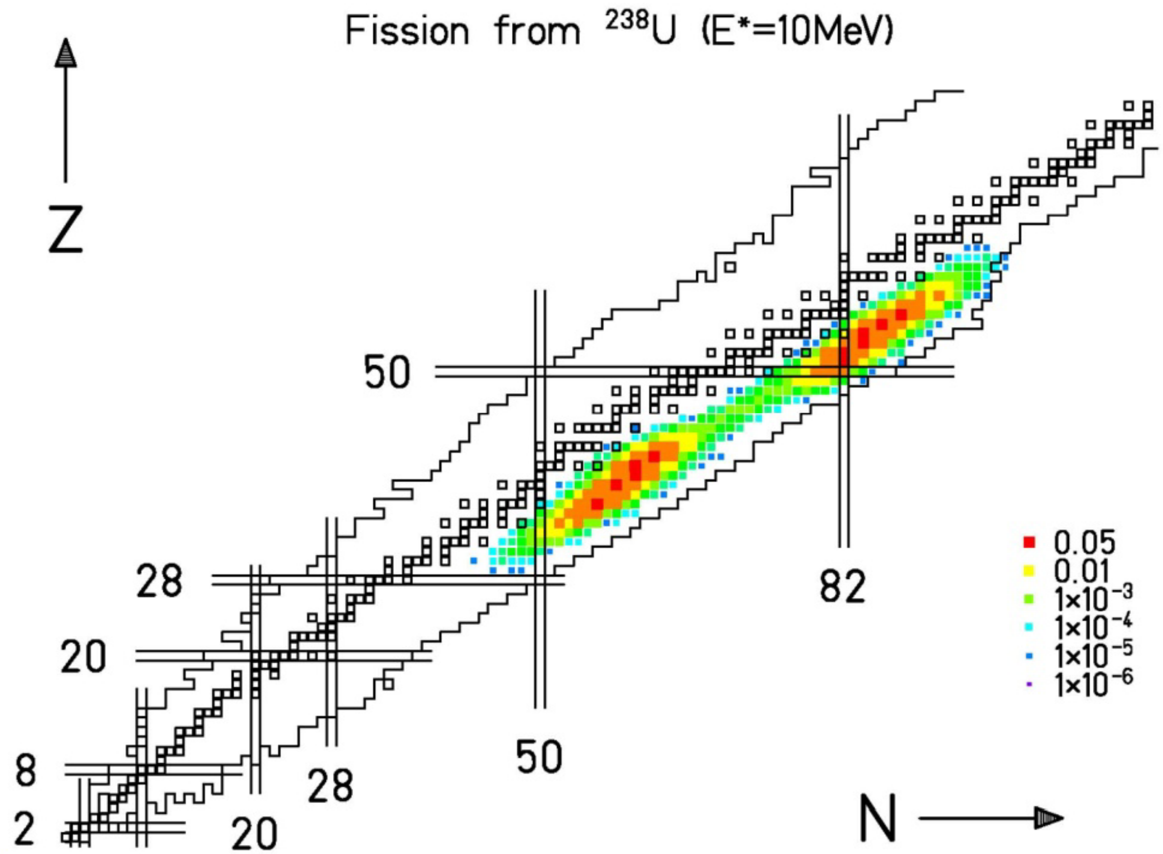
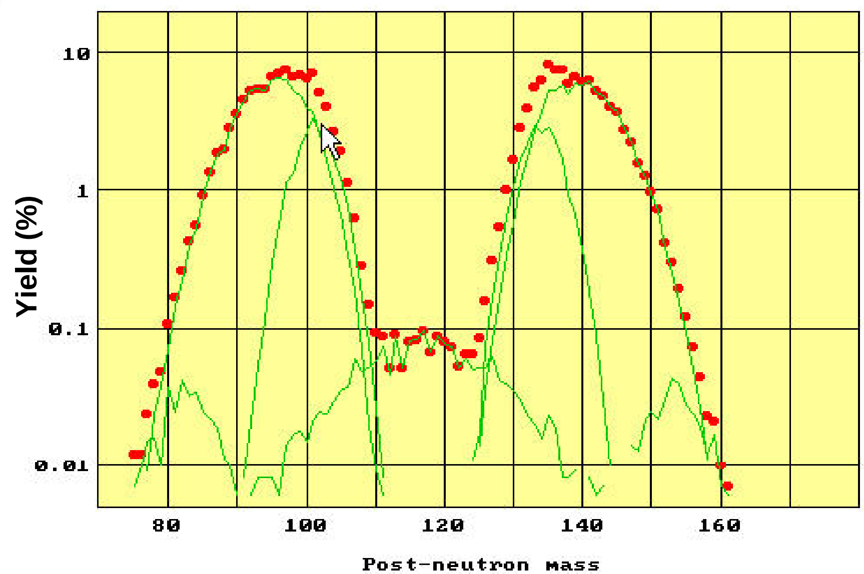
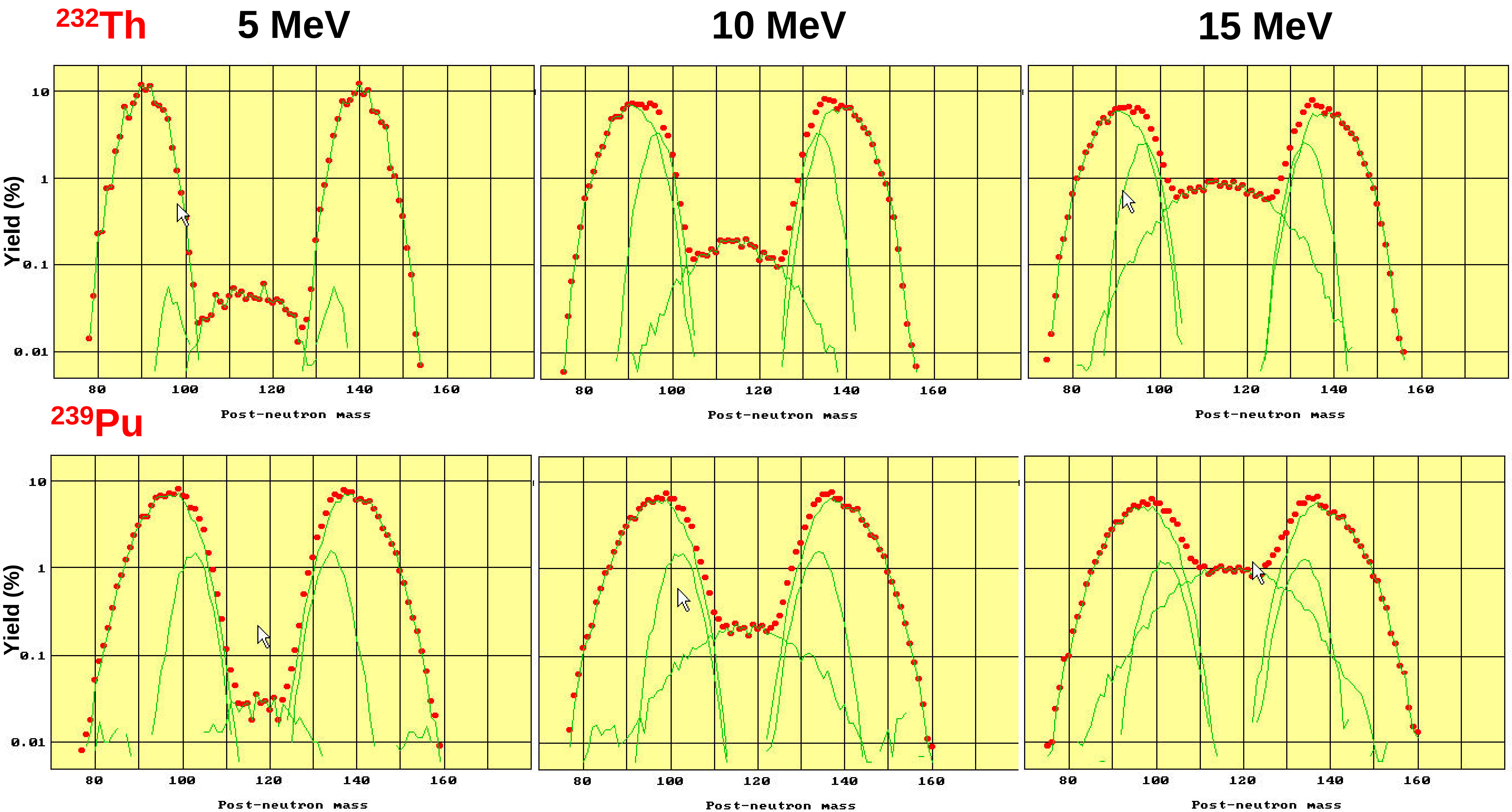
NNSA

Physics: photofission fission-product yields – French GEF code used to generate new actinide yield curves





Physics: photofission fission-product yields – French GEF code used to generate new actinide yield curves

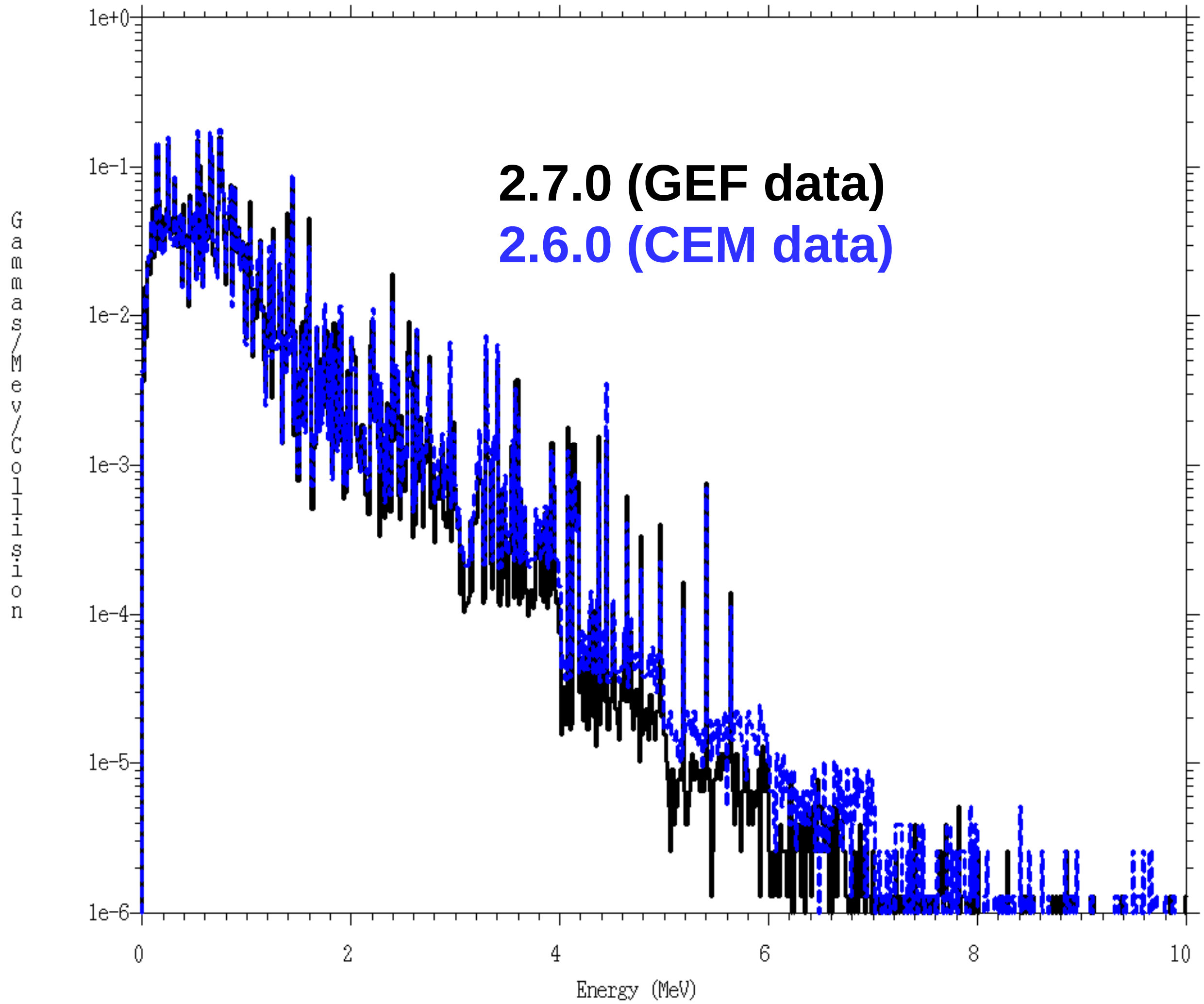


Physics: photofission fission-product yields – a simple photofission example of delayed gamma production

```
12-MeV photons into U-235
1  1  -19.0   -1  imp:n=1
2  0           1  imp:n=0

1  so 1.0

mode n p
m1  92235 1
phys:n  3j 105
phys:p  3j   1 j -102 $ Line data
sdef par=p erg=12.0
lca  7j -2
f1:n 1
e1   1.e-3 999i 15.0
t1   100  1e37
f11:p 1
e11  1.e-3 999i 15.0
t11  100  1e37
print
nps 1000000
```



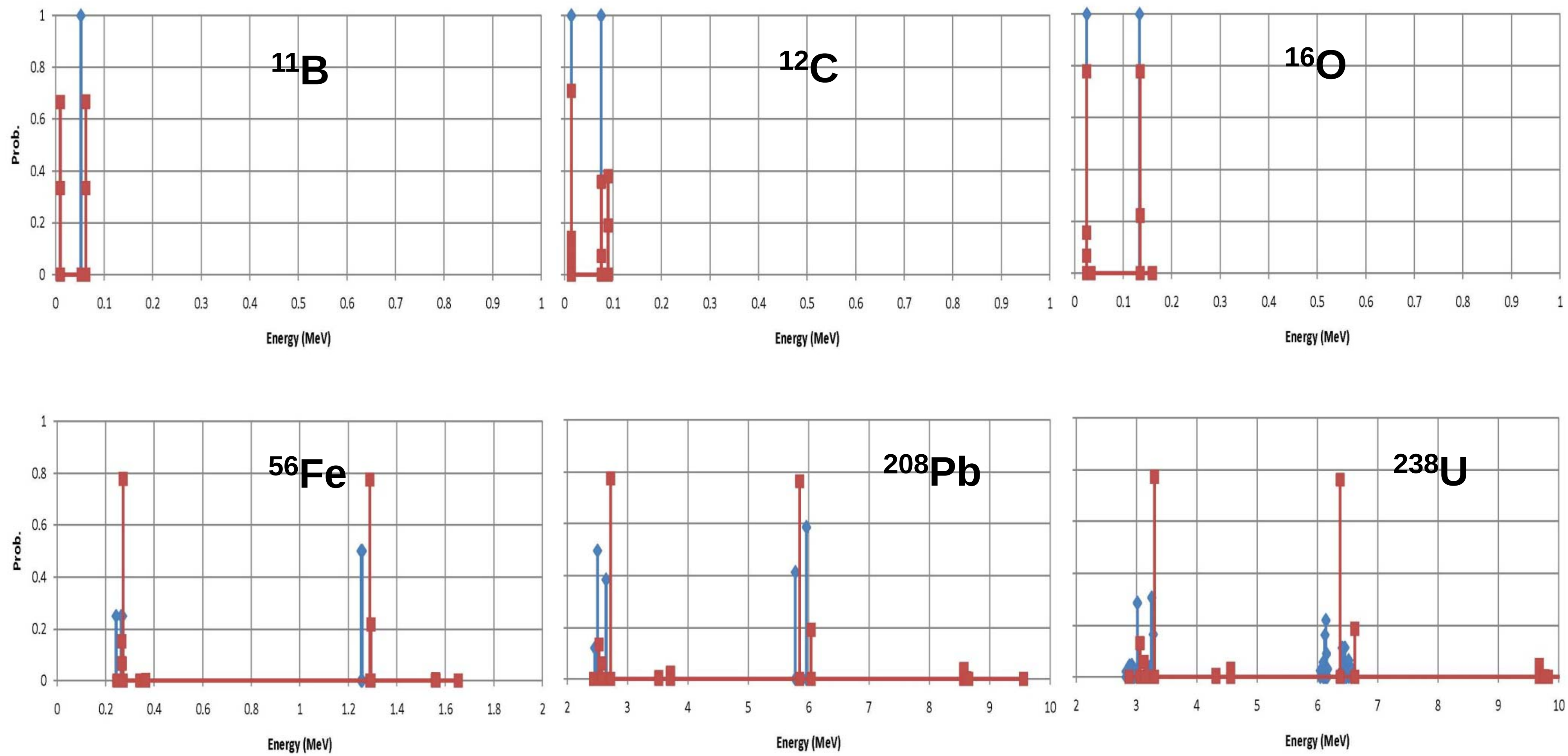
Physics: muonic x-ray production – MUON/RURP codes used to generate new library with 295 isotopes

Nuclide		L - Energy Levels			K - Energy Levels	
		Energy (MeV)	Probability		Energy (MeV)	Probability
He-3					[illegible]	[illegible]
He-4					[illegible]	1.00000
Li-6					[illegible]	1.00000
Li-7					[illegible]	1.00000
Be-9		0.00619	1.00000		[illegible]	1.00000
B-10		0.00970	0.33373		0.06223	0.33327
		0.00970	[illegible]		0.06223	0.66673
B-11		0.00971	[illegible]		0.06228	0.33327
		0.00971	[illegible]		0.06229	0.66673
C-12		[illegible]	[illegible]		0.07587	0.35847
		[illegible]	[illegible]		0.07589	0.07160
		[illegible]	0.04989		0.08984	0.18988
		[illegible]	0.09955		0.08984	0.37989
					0.08985	0.00014
C-13		[illegible]	0.14162		0.07591	0.35847
		0.01398	0.70890		0.07592	0.07161
		0.01402	0.04990		0.08989	0.18987
		0.01402	0.09957		0.08989	0.37989
					0.08989	0.00014

A. B. McKinney et al., “MCNPX Updated Muonic X-ray Library,” Proceedings of the ANS Winter Meeting, Washington, DC, Nov. 15-19 (2009)

Physics: muonic x-ray production – good agreement with previous data and measured data

New Data vs. Previous Data

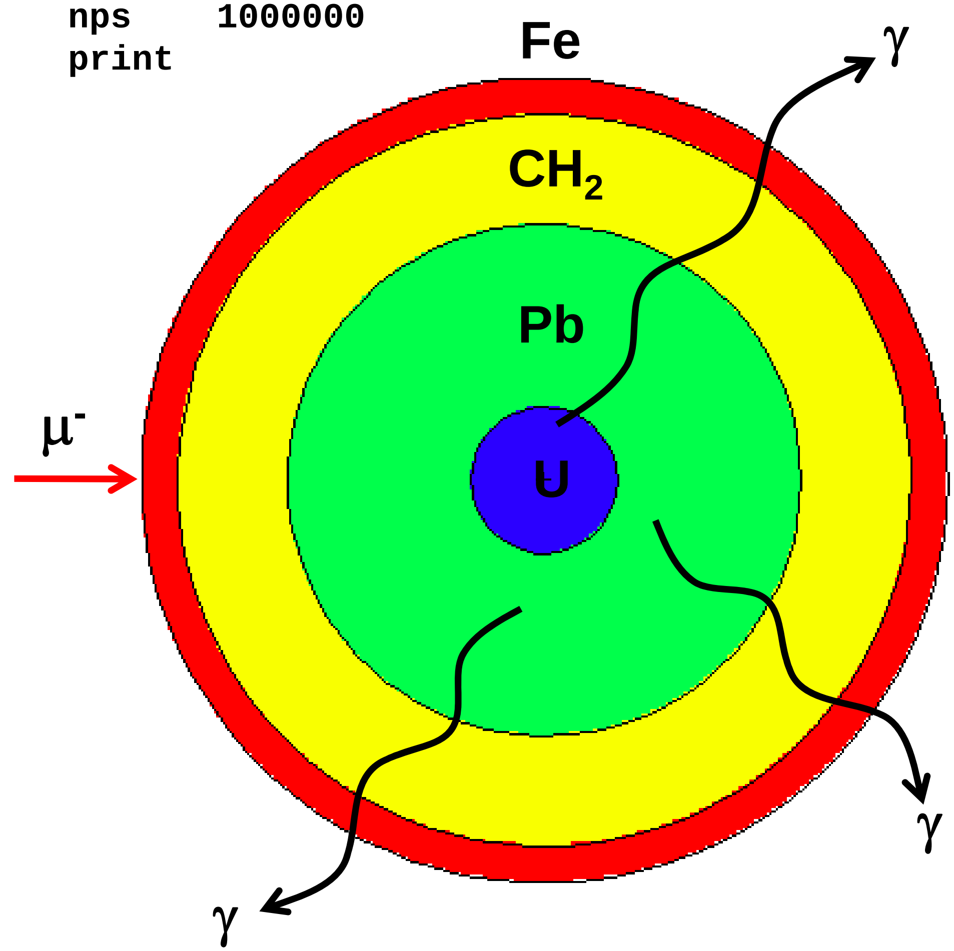


Physics: muonic x-ray production – a simple example of shielded HEU

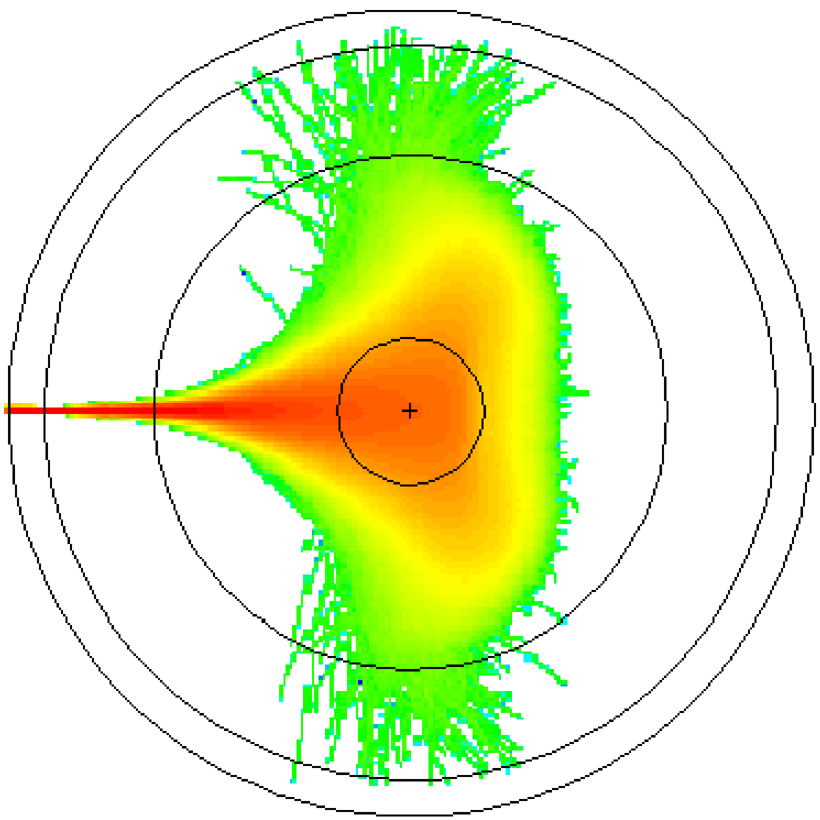
```
200 MeV muons into shielded HEU
1  1    -19.0      -1       imp:p=1
2  2    -11.35      1   -2  imp:p=1
3  3     -1.0       2   -3  imp:p=1
4  4     -7.9       3   -4  imp:p=1
5  0                4       imp:p=0

1  so 2.0
2  so 7.0
3  so 10.0
4  so 11.0

m1   92235 .5    92238 .5
m2   82204 .0140 82206 .2410 82207 .2210
     82208 .5240
m3   26054 .0585 26056 .9175 26057 .0212
     26058 .0028
m4   1001 2.00   6012 .99    6013 .01
mode  n p h d t s a / z |
phys:n 210
phys:| 6j  1 $ new data
sdef  par=| erg=200 pos=-10.999 0 0
      vec=1 0 0 dir=1
f1:p  4
e1    .001 999log 10
tmesh
rmesh11:| flux
cora11  -11.1 199i 11.1
corb11  -11.1      11.1
corc11  -11.1 199i 11.1
endmd
nps    1000000
print
```

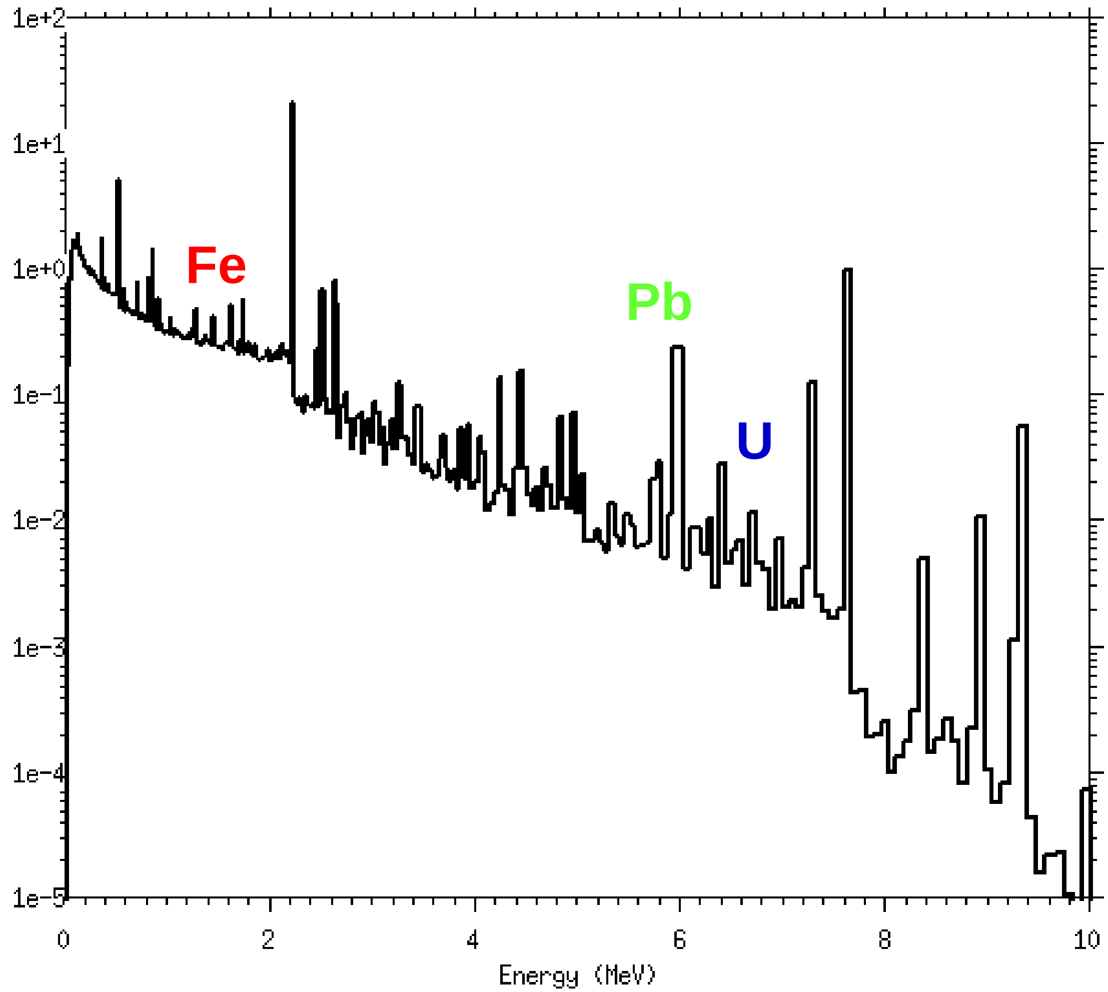


Physics: muonic x-ray production – a simple example of shielded HEU

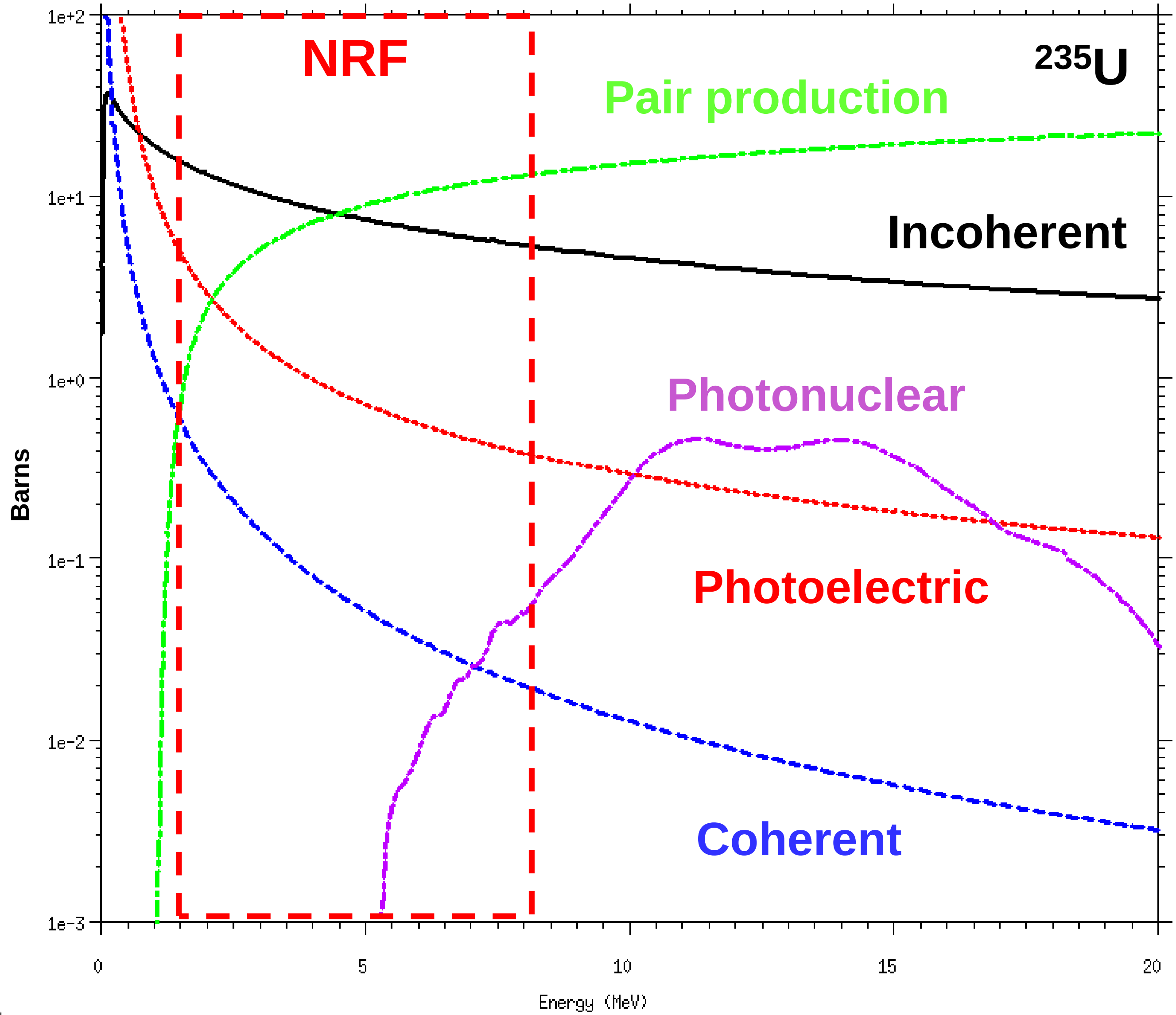


Muon flux within the stack

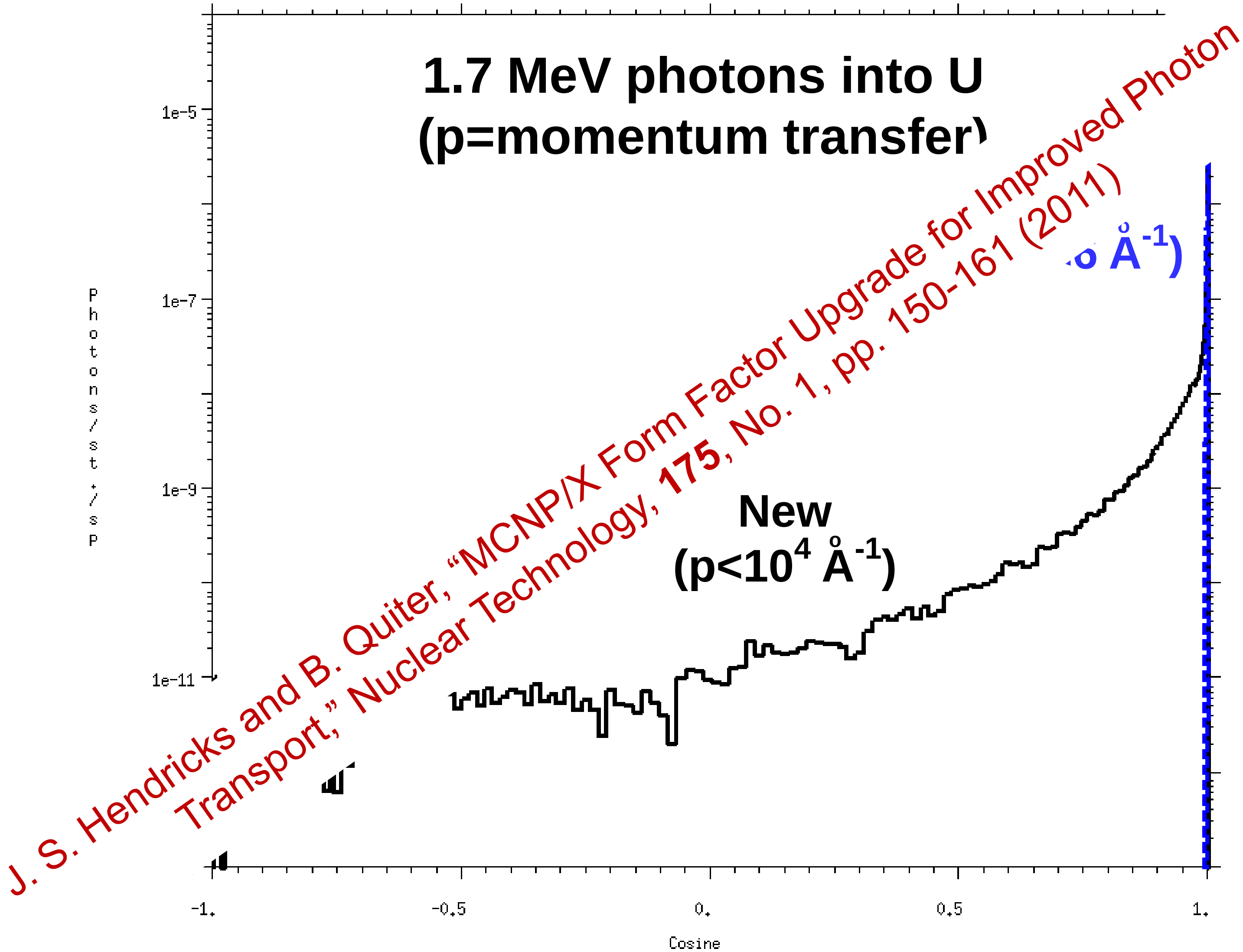
Photons escaping the shield



Physics: nuclear resonance fluorescence – improvements in photoatomic & photonuclear data libraries were needed



Physics: nuclear resonance fluorescence – coherent & incoherent form-factors were improved for all elements



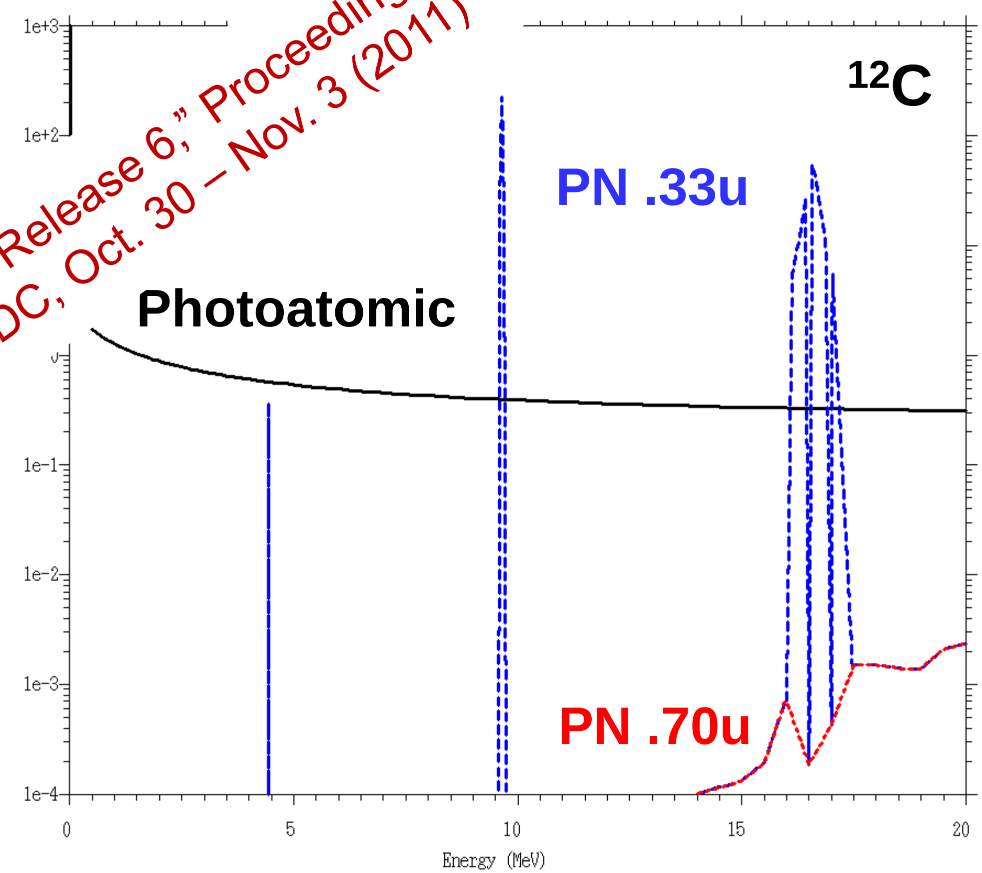
Physics: nuclear resonance fluorescence – new NRF photonuclear library (PN6-NRF) consists of 154 nuclei

```
Test of 6012.33u NRF data
1  1  -1.0    -1   imp:p=1
2  0            1   imp:p=0

1  so  1.0

mode p
m1  6012 1  pnlib=.33u
lca  7j -2
phys:p 3j 1
sdef   par=p erg=d1
si1 H  0.000000000000000 &
4.438830000000000 4.439030000000000 &
9.657920000000001 9.658120000000000 &
10.000000000000000
sp1    0 1 4r
print
nps  1000000000
f1:p 1
e1   1e-3 999log 12
```

T. A. Wilcox et al., "MCNPX NRF Library – Release 6," Proceedings of the ANS Winter Meeting, Washington, DC, Oct. 30 – Nov. 3 (2011)



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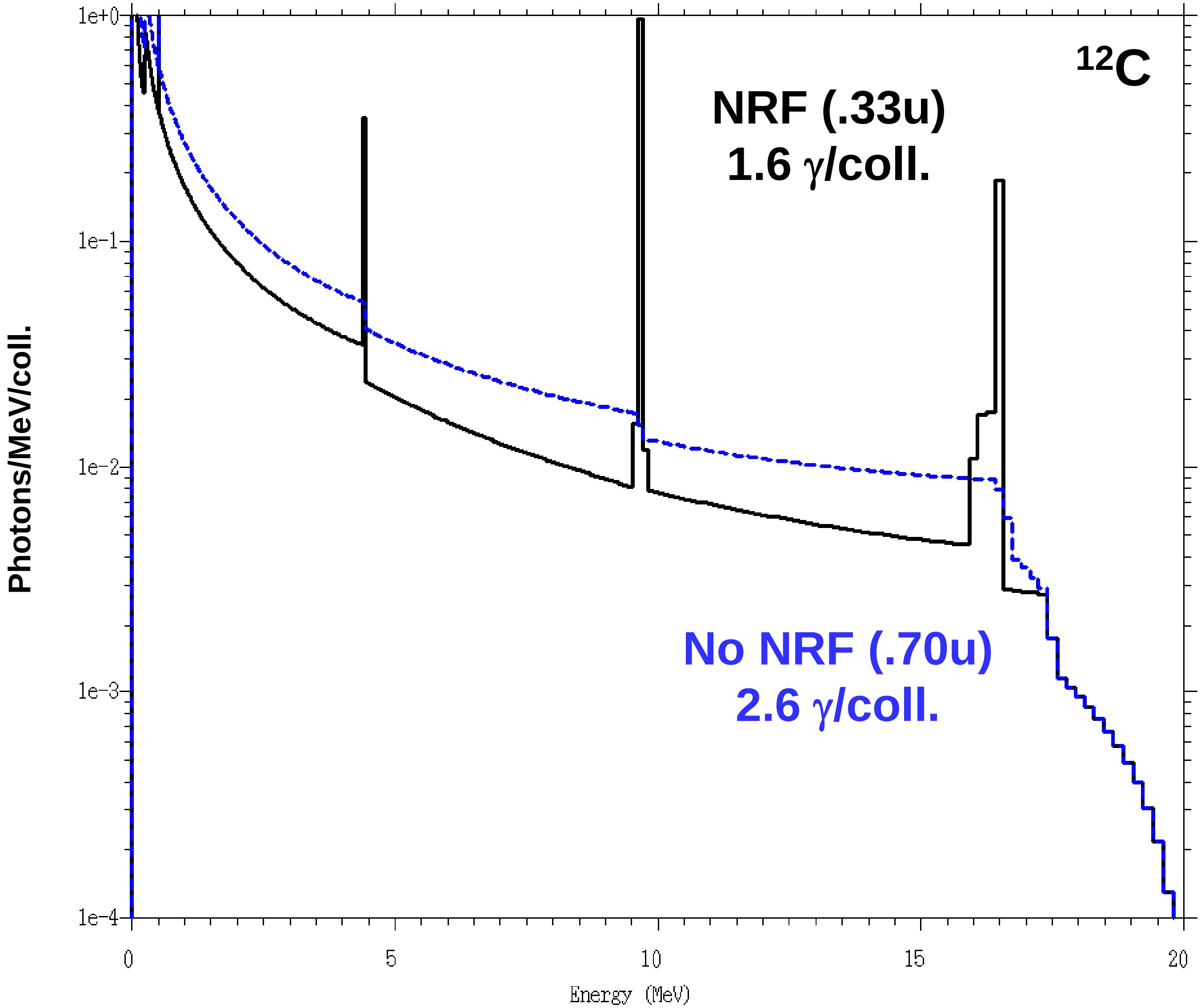
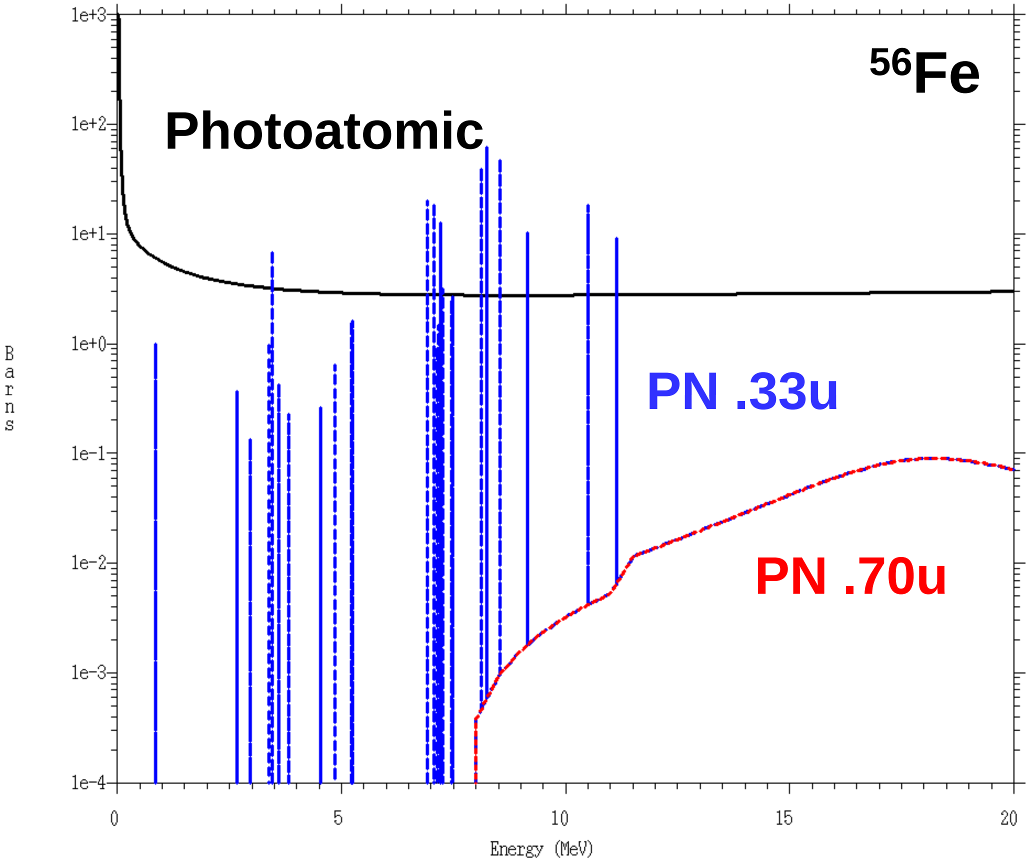
Physics: nuclear resonance fluorescence – new NRF photonuclear library (PN6-NRF) consists of 154 nuclei

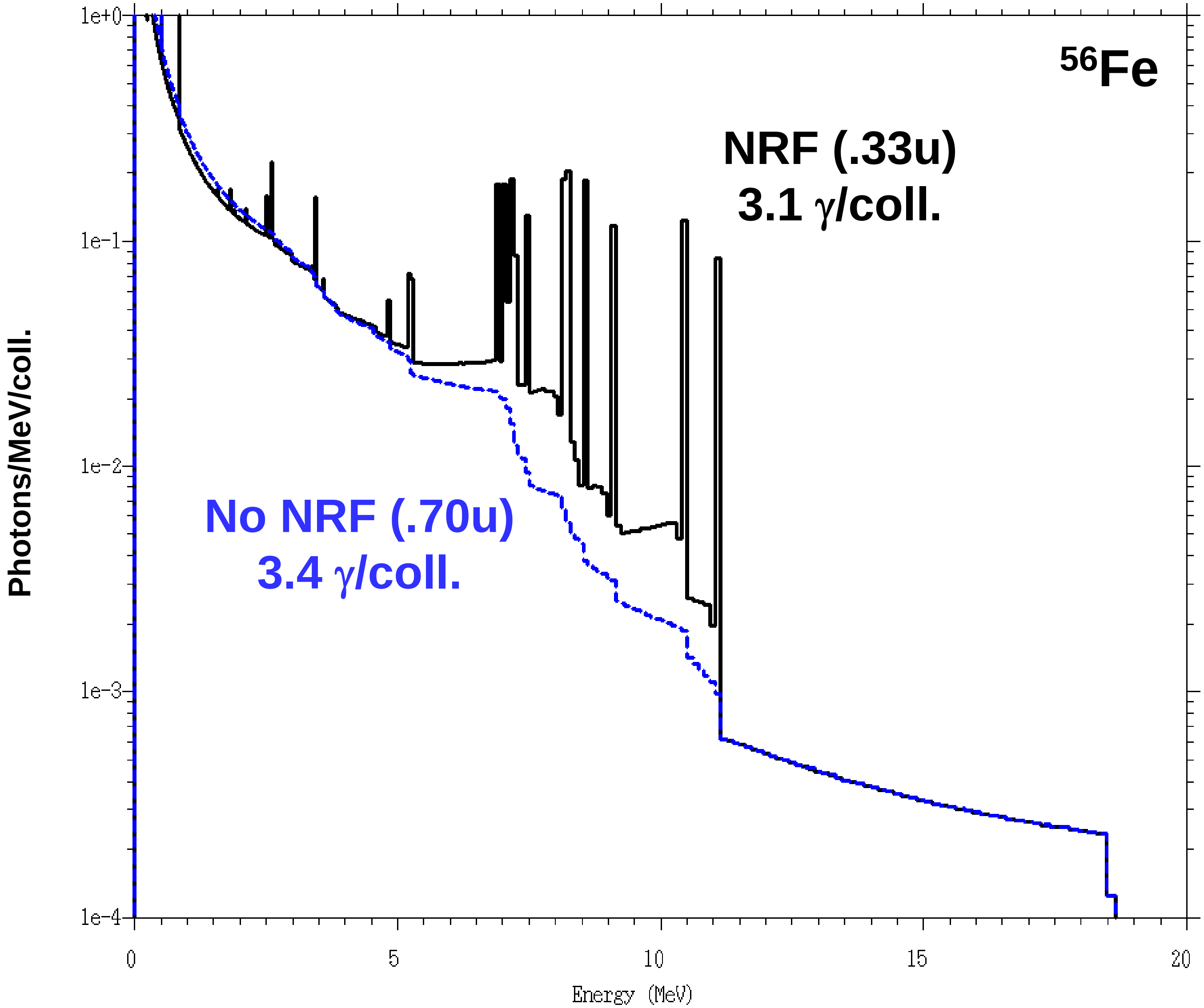


Physics: nuclear resonance fluorescence – new NRF photonuclear library (PN6-NRF) consists of 154 nuclei

```
Test of 26056.33u NRF data
1  1  -1.0    -1   imp:p=1
2  0           1   imp:p=0

1  so  1.0

mode p
m1  26056 1  pnlib=.33u
lca  7j -2
phys:p 3j 1
sdef   par=p erg=d1
si1 H    0.000000000000000 &
0.846680000000000  0.846880000000000 &
2.657460000000000  2.657660000000000 &
2.959820000000000  2.960020000000000 &
3.369640000000000  3.369840000000000 &
3.449200000000000  3.449400000000000 &
3.601910000000000  3.602110000000000 &
3.831910000000000  3.832110000000000 &
4.539410000000000  4.539610000000000 &
4.846910000000000  4.847110000000000 &
5.227210000000000  5.227410000000000 &
5.256910000000000  5.257110000000000 &
6.926410000000001  6.926610000000000 &
7.065910000000001  7.066110000000000 &
7.134910000000001  7.135110000000000 &
7.166910000000001  7.167110000000000 &
7.211410000000000  7.211609999999999 &
7.248410000000000  7.248609999999999 &
7.446410000000000  7.446610000000000 &
7.468410000000000  7.468610000000000 &
8.128510000000000  8.128710000000000 &
8.239610000000001  8.239810000000000 &
8.536610000000000  8.536809999999999 &
9.140210000000000  9.140409999999999 &
10.000000000000000
sp1  0 1 46r
nps  1000000000
f1:p 1
e1   1e-3 999log 12
```



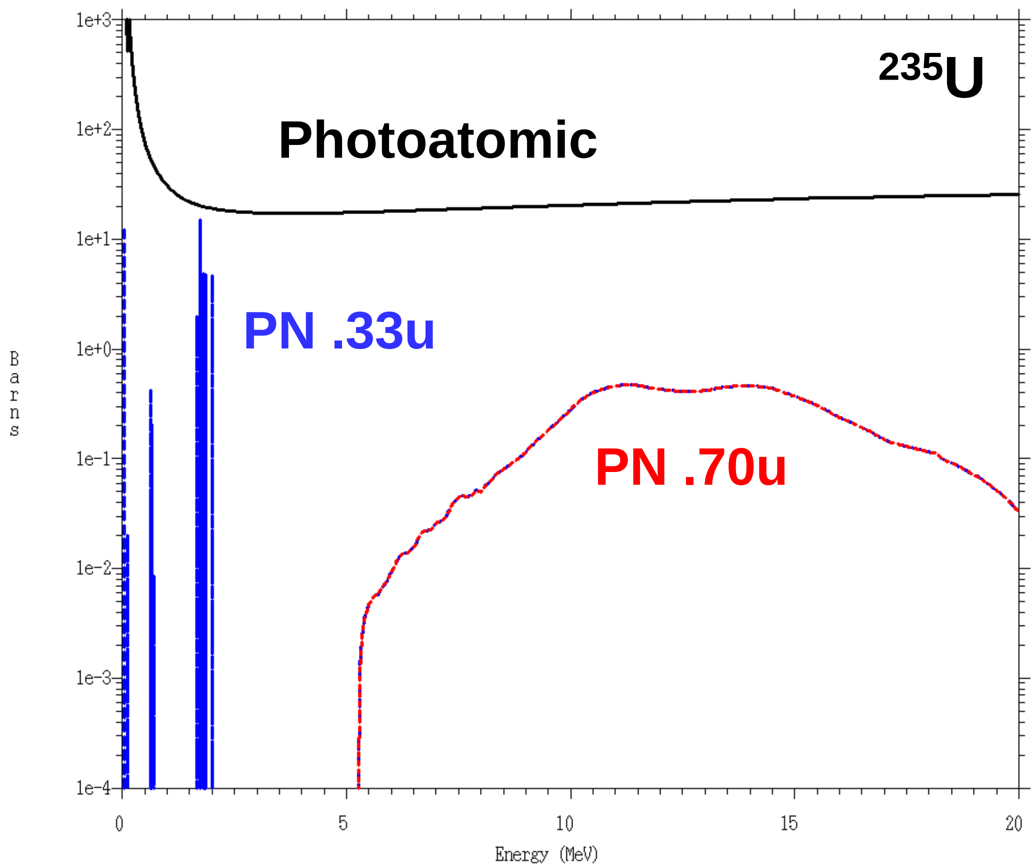
Physics: nuclear resonance fluorescence – new NRF photonuclear library (PN6-NRF) consists of 154 nuclei



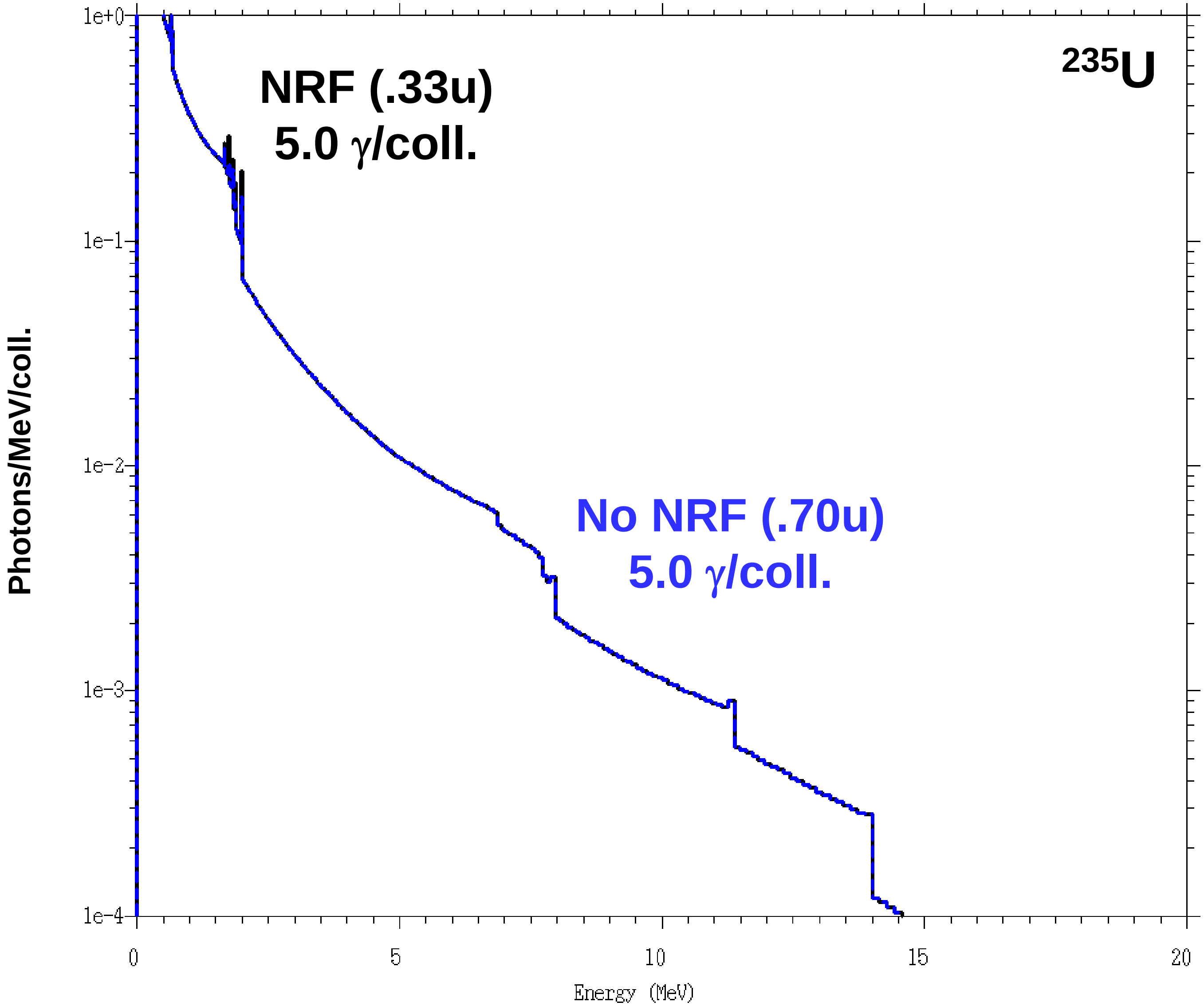
Physics: nuclear resonance fluorescence – new NRF photonuclear library (PN6-NRF) consists of 154 nuclei

```
Test of 92235.33u NRF data
1  1  -1.0    -1    imp:p=1
2  0           1    imp:p=0

1  so  1.0

mode p
m1  92235 1  pnlib=.33u
lca  7j -2
phys:p 3j 1
cut:n j j 0 0
sdef   par=p erg=d1
si1 H    0.000000000000000 &
0.046210000000000  0.046230000000000 &
0.103030000000000  0.103050000000000 &
0.633090000000000  0.633110000000000 &
0.637800000000000  0.637820000000000 &
0.664540000000000  0.664560000000000 &
1.656220000000000  1.656240000000000 &
1.733590000000000  1.733610000000000 &
1.815300000000000  1.815320000000000 &
1.827530000000000  1.827550000000000 &
1.862300000000000  1.862320000000000 &
2.003310000000000  2.003330000000000 &
2.006180000000000  2.006200000000000 &
6.799990000000000  6.800009999999999 &
7.659990000000001  7.660010000000000 &
7.959990000000000  7.960010000000000 &
11.359990000000000  11.360009999999999 &
13.959990000000001  13.960010000000000 &
20.000000000000000
```

```
sp1   0 1 34r
print
nps  1000000000
f1:p 1
e1   1e-3 999log 20
```

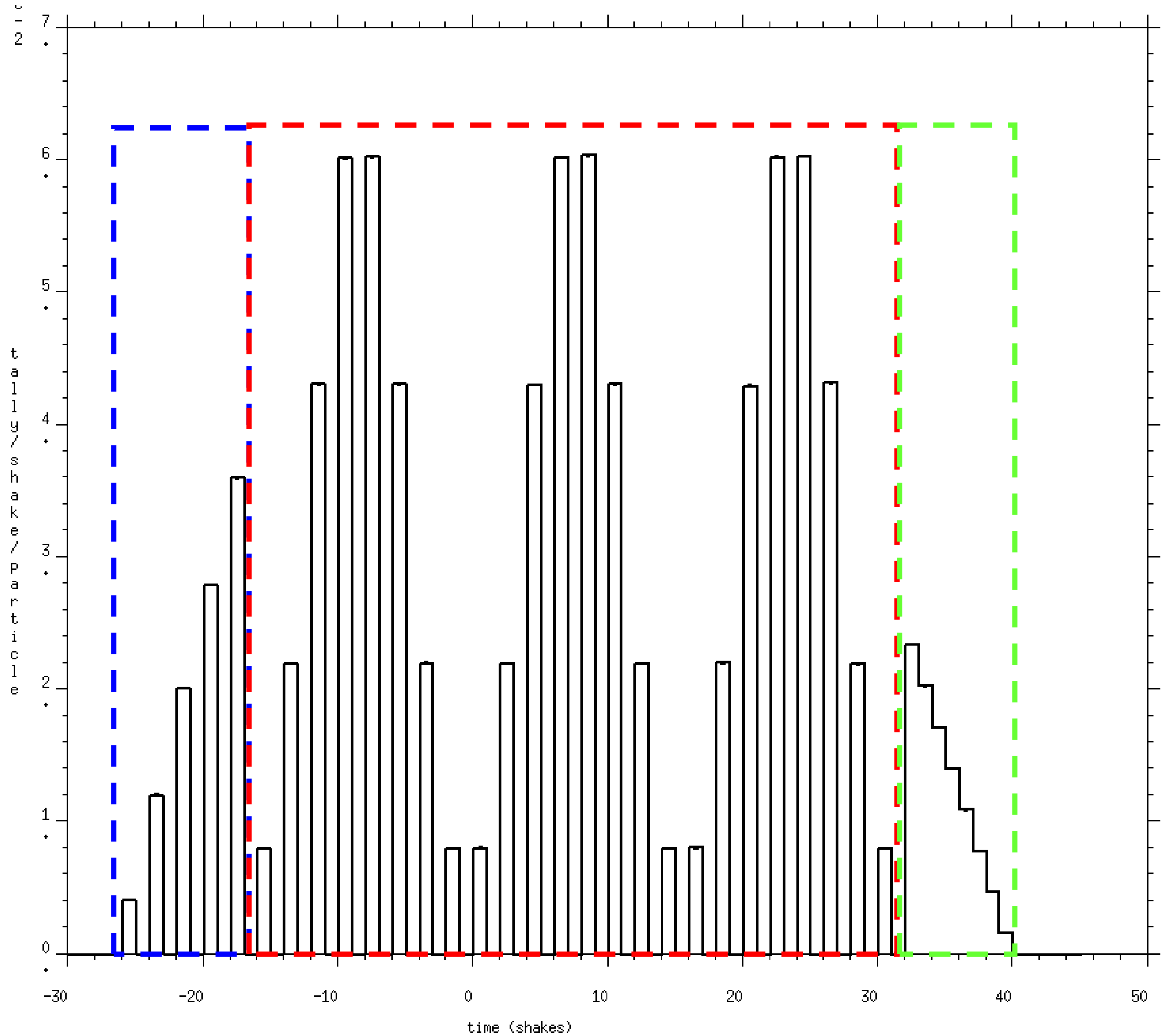


Physics: nuclear resonance fluorescence – new NRF photonuclear library (PN6-NRF) consists of 154 nuclei



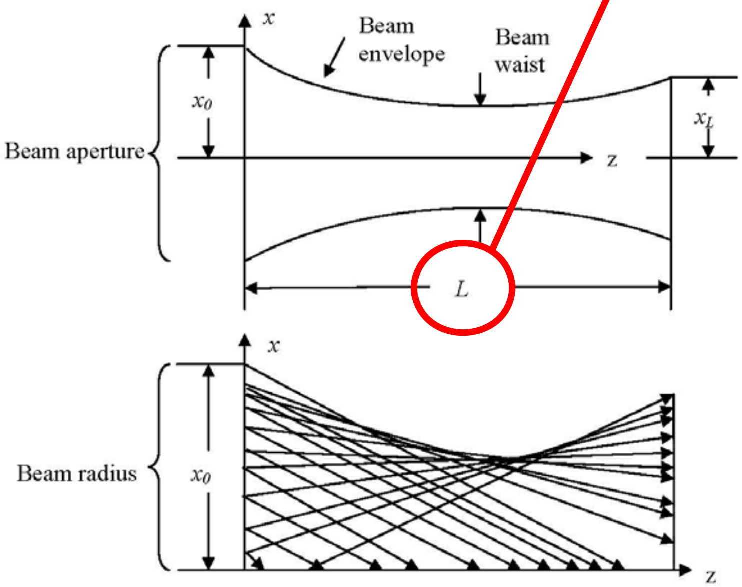
Sources: micro/macro beam pulse option – nesting of time distributions provides accurate beam modeling

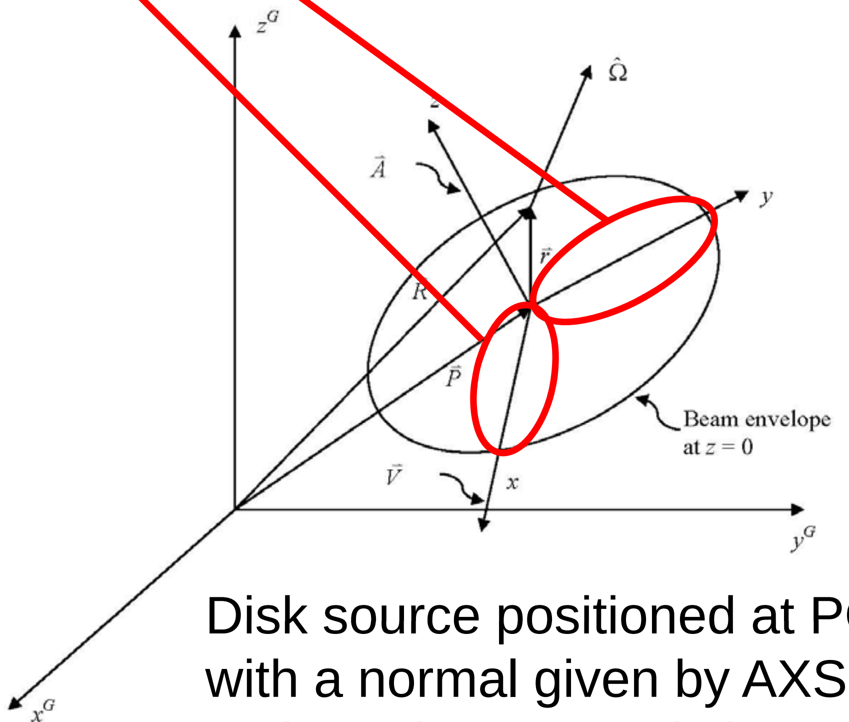
```
…
SDEF TME=D41
#       si41       sp41
          S          D
        51<52       .1
     (31<32<33)     .8
          61        .1
si51 H    0    1    2
sp51      0    1    0
si52 A -26  -16
sp52      0    1
si31      0    1    2
sp31      0    1    0
si32      0   16
sp32    -41    8    8
si33    -16   32
sp33      0    1
si61 A   32   40
sp61      1    0
```



Sources: beam profile source option – new user interface increases fidelity of spatial profiles

```
SDEF  PAR=| ERG=100 POS=0 0 0 AXS=0 0 1 VEC=1 0 0
      BEM=9.776e-3 9.776e-3 100 BAP=1.0 1.0 0
```

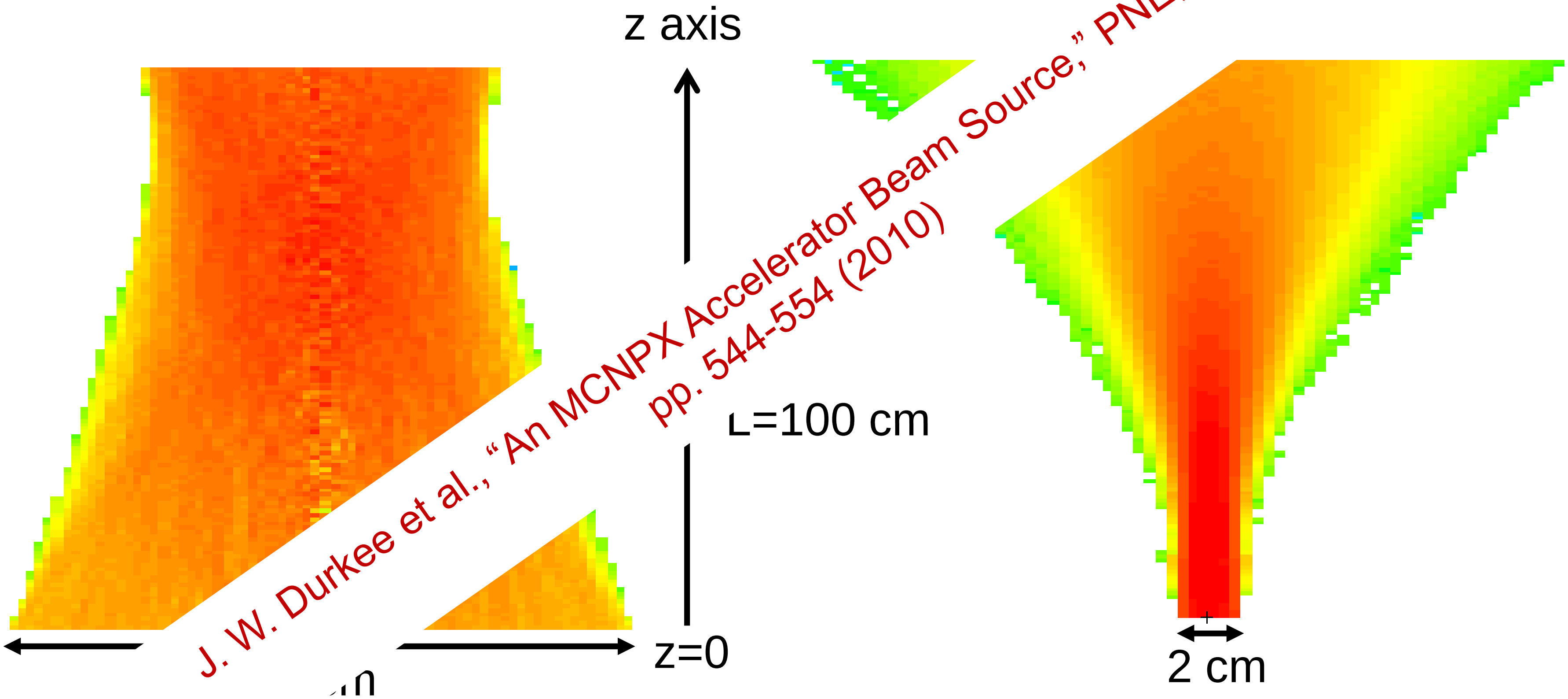




Disk source positioned at POS, with a normal given by AXS and a orthogonal axis by VEC

Sources: beam profile source option – new user interface increases fidelity of spatial profiles

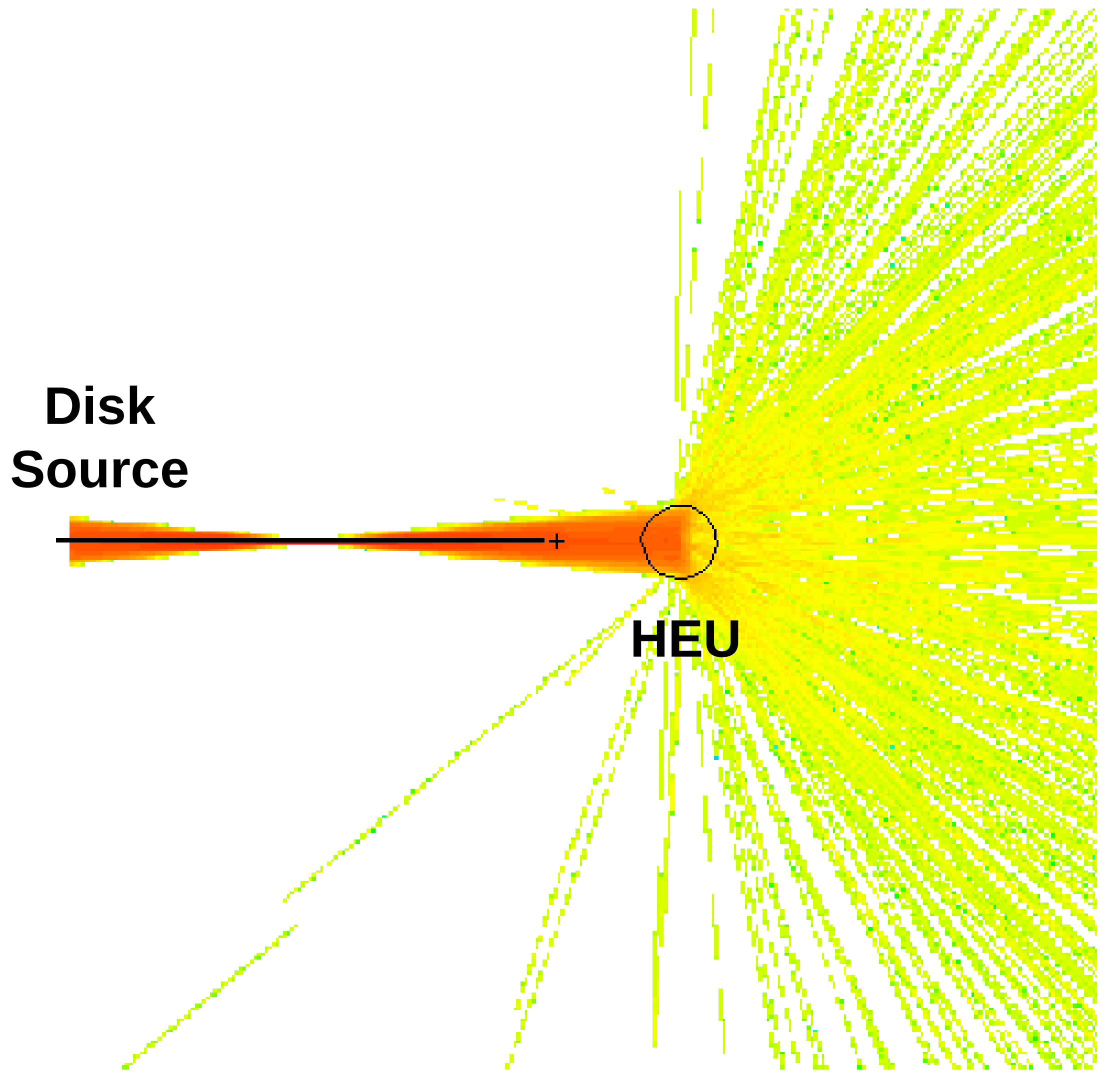
Beam transport in vacuum **Beam tra… …ir**



J. W. Durkee et al., “An MCNPX Accelerator Beam Source,” PNE, **52**, No. 6, pp. 544-554 (2010)

Sources: beam profile source option – a simple example for a 100-MeV muon beam

```
100 MeV muons in air
1  1 -0.0013  -1 2 3 imp:n=1
2  2 -19.0    -2     imp:n=1
3  1 -0.0013  -3     imp:n=1
4  0           1     imp:n=0

1  so  200
2  sph 50 0 0  3.0
3  rcc -1 0 0 40 0 0 .001

mode n p h |
m1   7014 .8  8016 .2
m2  92235 .5 92238 .5
phys:n 200
sdef par=| erg=100
     pos=0 0 0 axs=1 0 0 vec=0 1 0
     bem=9e-3 9e-3 20 bap=2.0 2.0 0
tmesh
rmesh1:|  flux
cora1 0 499i 100
corb1 -50 499i 50
corc1 -50 50
endmd
nps  1000000
print
```



Sources: natural background source option – new data file enables automatic sampling of background spectra

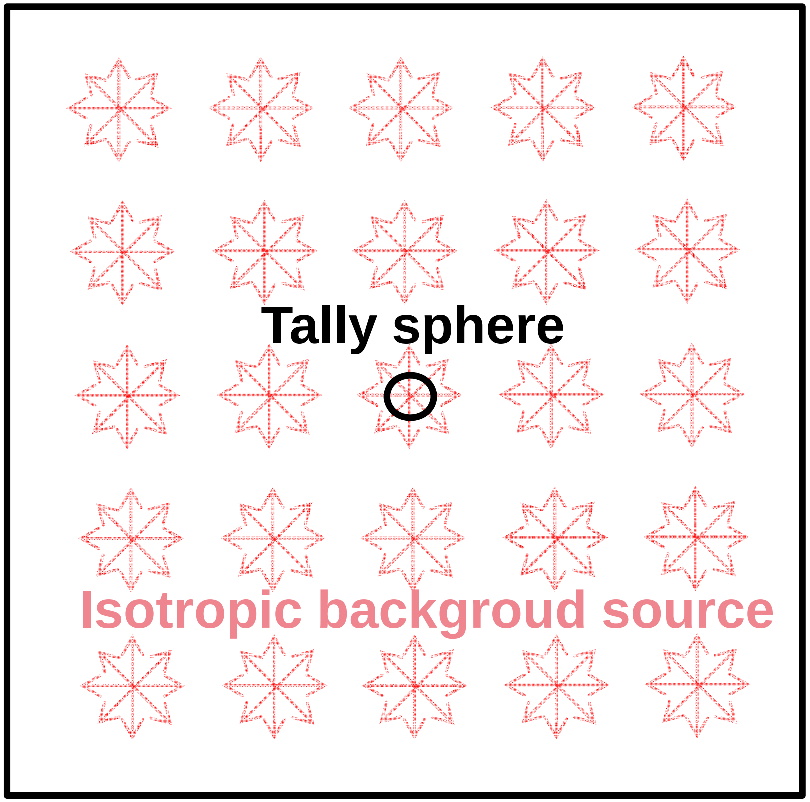
Routines from GADRAS, which implement the Goldhagen normalization technique for GCR neutron fluxes, were obtained and used to create integral flux values contained in the NBS file. A special flag indicates the existence of a specific spectrum for that location. Also shown is the generic photon spectrum currently provided.

```
Neutron flux from Goldhagen JEDEC No. 89A (2006)
                90.0            0.0            0.0          330
 flux (n/cm2/s)     0.1193E-01 flux (p/cm2/s)      0.1667E+00
          1.0593E-10     2.1270E+02     4.6400E-02     0.0000E+00
          1.1885E-10     2.3849E+02     4.6500E-02     1.4500E+01
          1.3335E-10     2.6743E+02     4.6600E-02     0.0000E+00
          1.4962E-10     3.0003E+02     [illegible].0100E-02     0.0000E+00
          1.6788E-10     3.3624E[illegible]     [illegible].0200E-02     1.4900E-01
          1.8836E-10     3.77[illegible]     5.0300E-02     0.0000E+00
          2.1135E-10     4[illegible]     5.3100E-02     0.0000E+00
          2.3714E-10     [illegible]02     5.3200E-02     1.2600E+00
          2.6607E-10     [illegible]1E+02     5.3300E-02     0.0000E+00
          2.9854E-[illegible]     [illegible]9510E+02     6.3200E-02     0.0000E+00
          3.349[illegible]     6.6707E+02     6.3300E-02     1.2500E+01
          3.[illegible]     7.4766E+02     6.3400E-02     0.0000E+00
                                 …
LP    [illegible]tude      Longitude      Altitude   # lines
                30.0          120.0            0.0            0
 [illegible] (n/cm2/s)     0.6866E-02 flux (p/cm2/s)      0.1667E+00
                                 …
NY     Latitude      Longitude      Altitude   # lines
                40.0           70.0            0.0            0
 flux (n/cm2/s)     0.8859E-02 flux (p/cm2/s)      0.1667E+00
                                 …
```

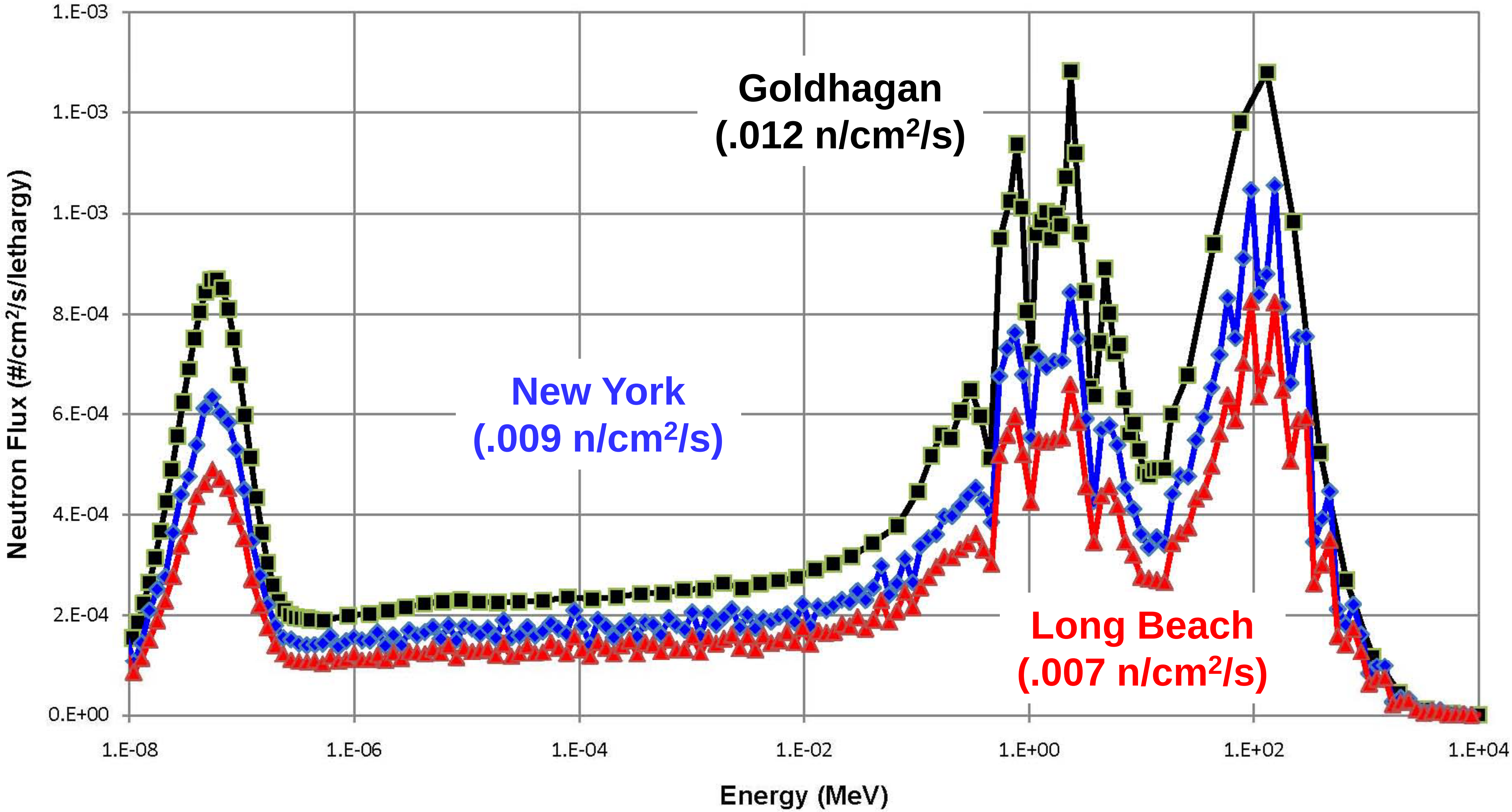
Undocumented feature in 2.7.0!

Sources: natural background source option – a simple example producing neutron spectra for NY and CA

```
Background source for NY & LB
1    0    -1 5 imp:n=1
5    0     -5  imp:n=1
99   0     1   imp:n=0

1   rpp   -100 100 -100 100 -100 100
5    s     0   0   0   5

mode   n p
phys:n 5e5
phys:p 1e5
sdef   X=d1 Y=d2 Z=d3  PAR=bg
       WGT=578.93565 LOC=40.78  73.97 0 $ NY
c      WGT=448.69310 LOC=33.77 118.18 0 $ LB
si1    -100 100
sp1      0  1
si2    -100 100
sp2      0  1
si3    -100 100
sp3      0  1
f4:n 5
e4 1e-8 199log 1e6
f14:p 5
e14 0 299i 10
nps    1000000000
print
```



Sources: natural background source option – a simple example producing neutron spectra for NY and CA

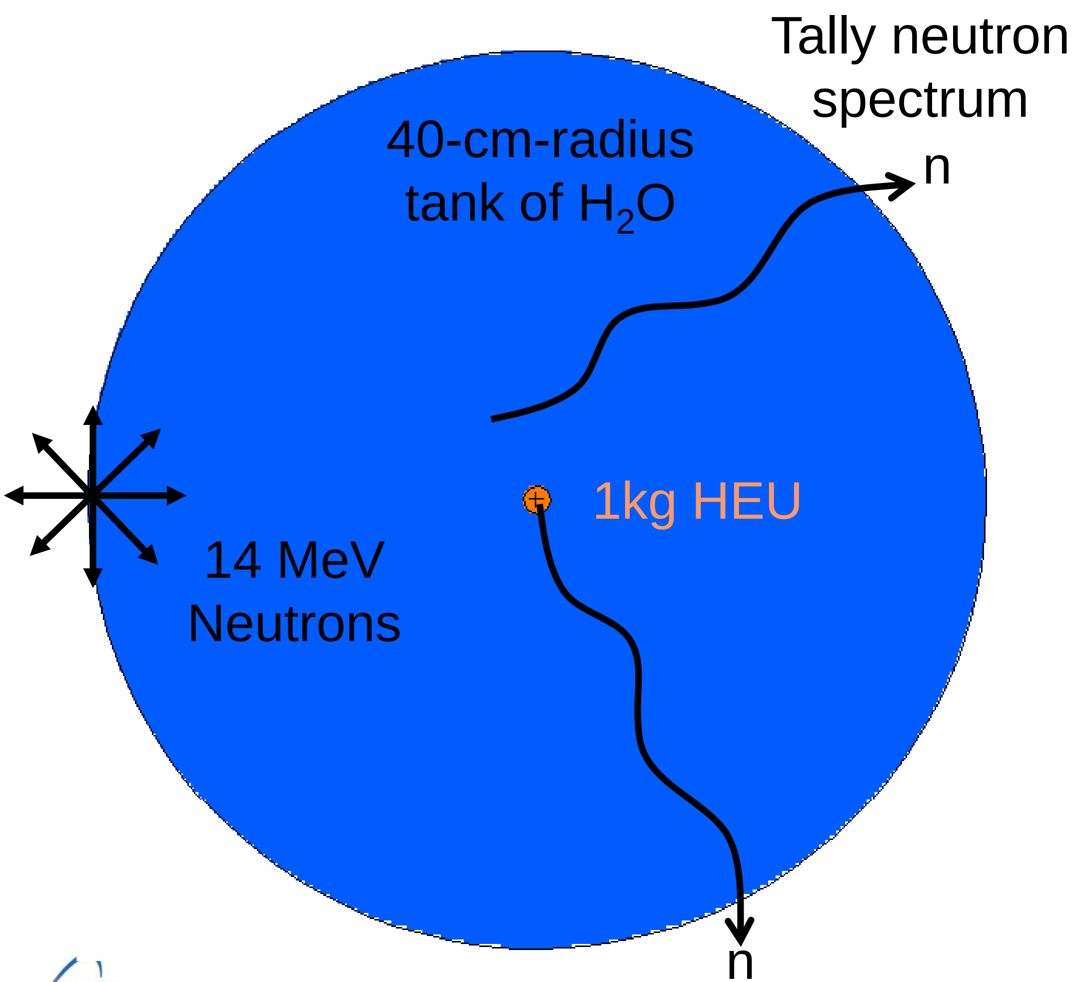


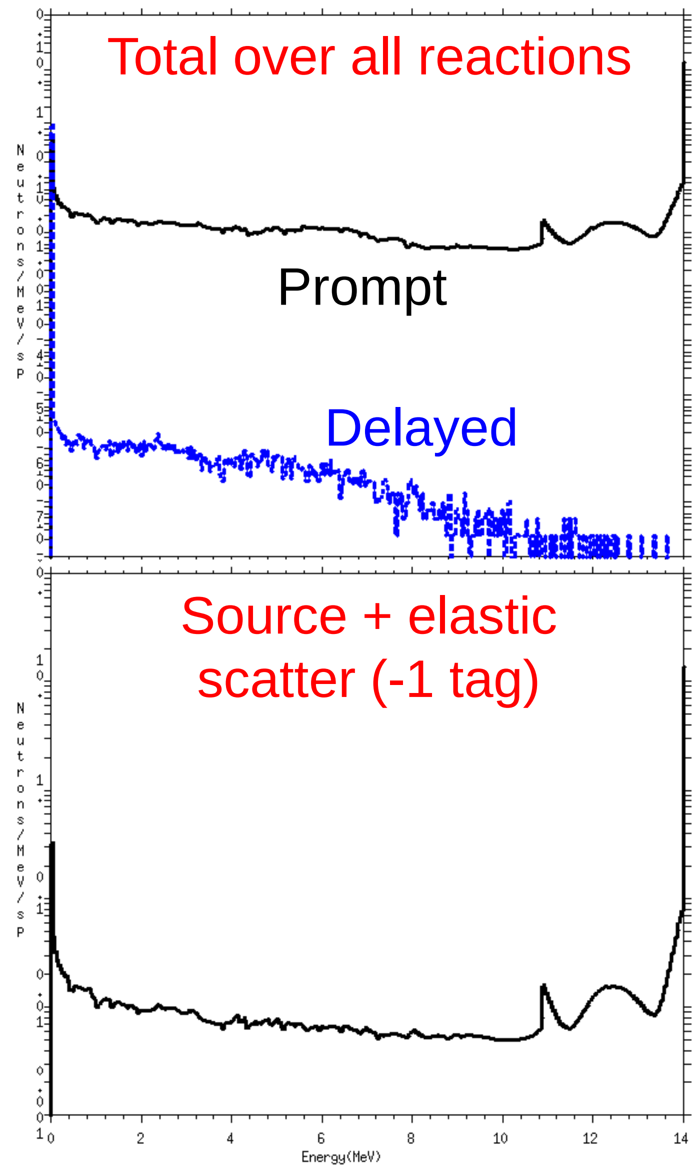
Tallies: tally tagging option – neutron activation of HEU surrounded by water

```
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
```

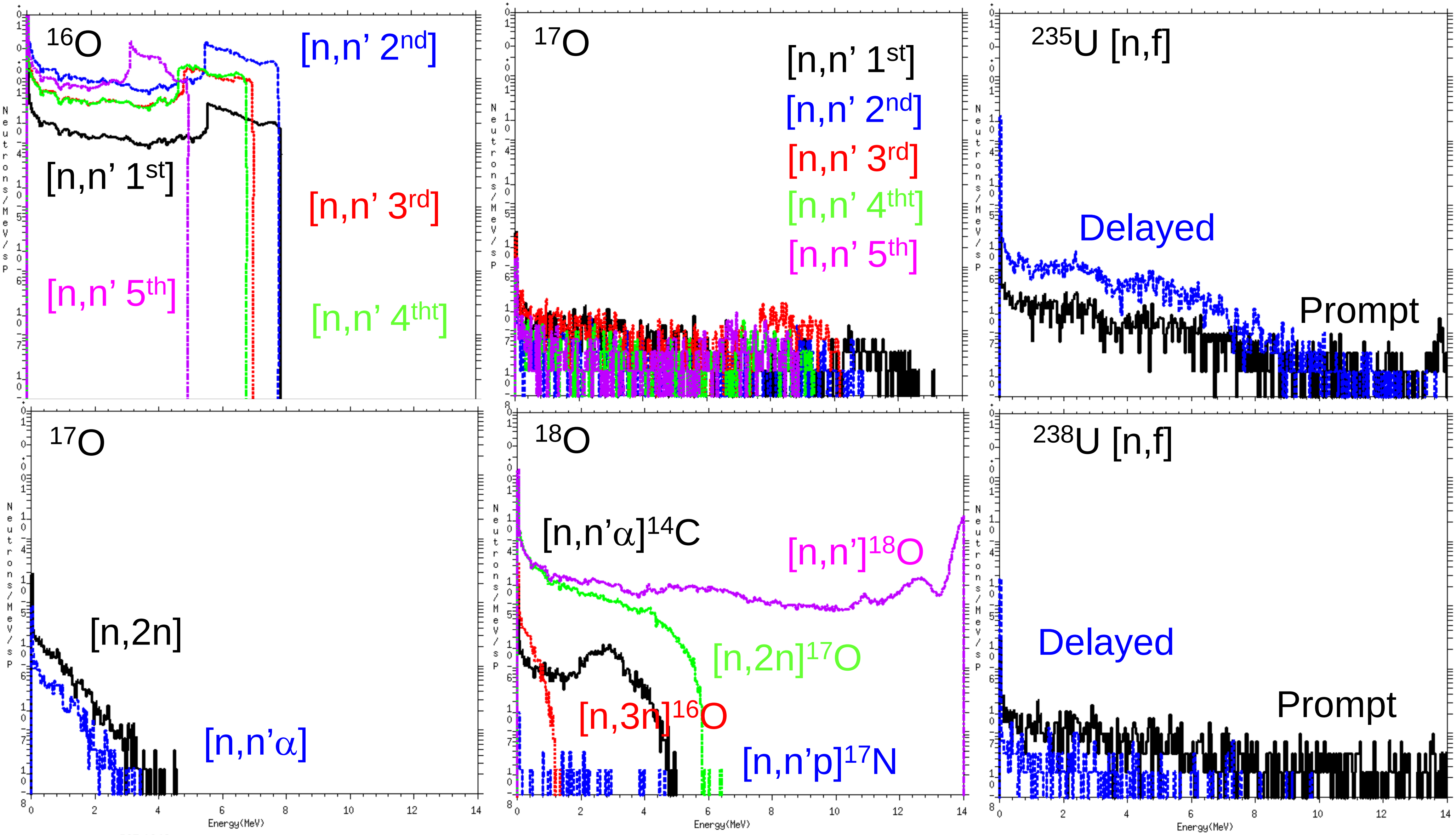
```
f31:n 2
ft31  tag 3
fu31  -1.0
      1001.0
      8016.00011 8016.00016 8016.00017 8016.00022
      8016.00023 8016.00024 8016.00025 8016.00028
      8016.00029 8016.00030 8016.00032 8016.00033
      8016.00034 8016.00035 8016.00036 8016.00037
      8016.00041 8016.00042 8016.00043 8016.00044
      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
```

Tallies: tally tagging option – neutron activation of HEU surrounded by water



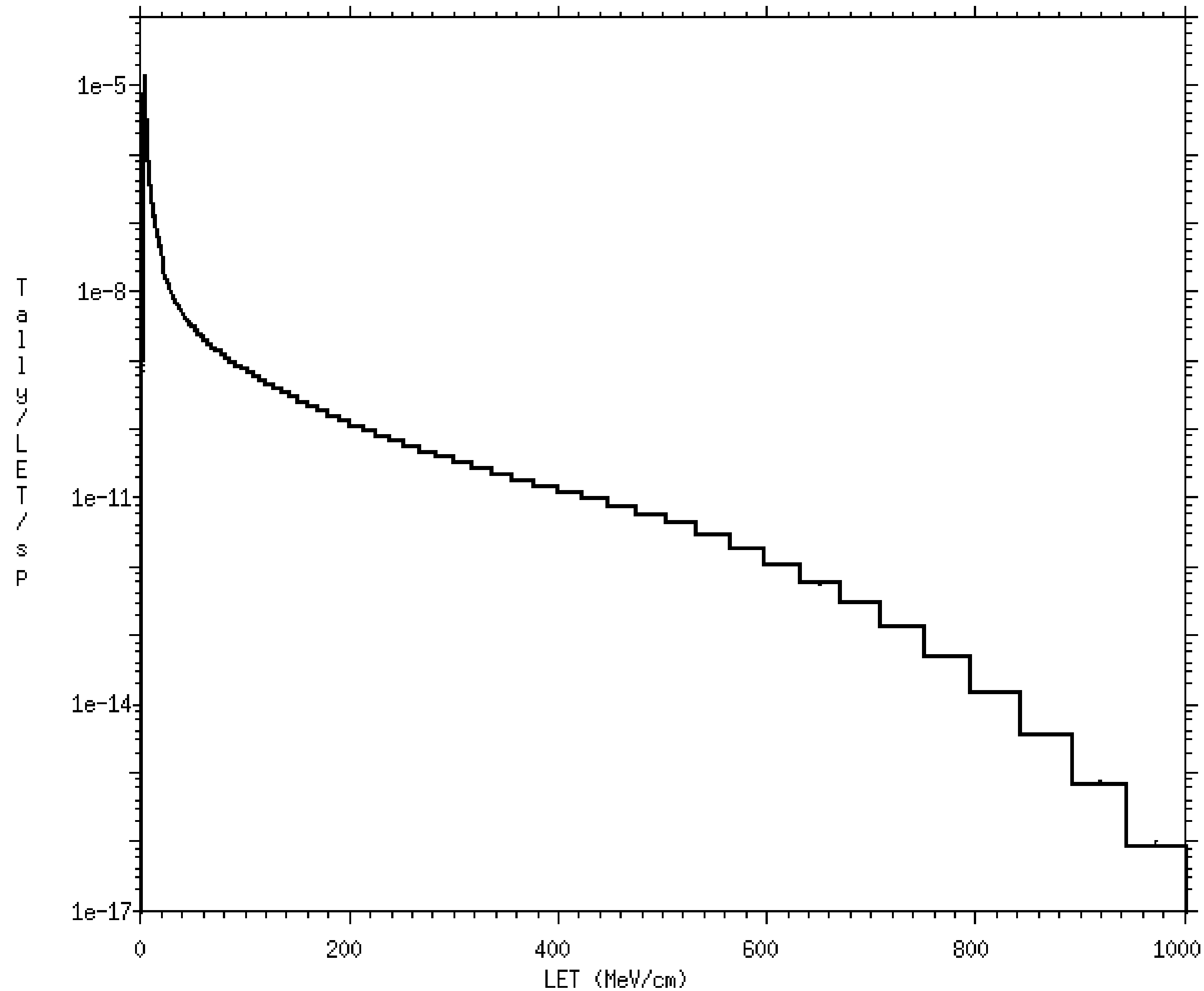


Tallies: tally tagging option – neutron activation of HEU surrounded by water



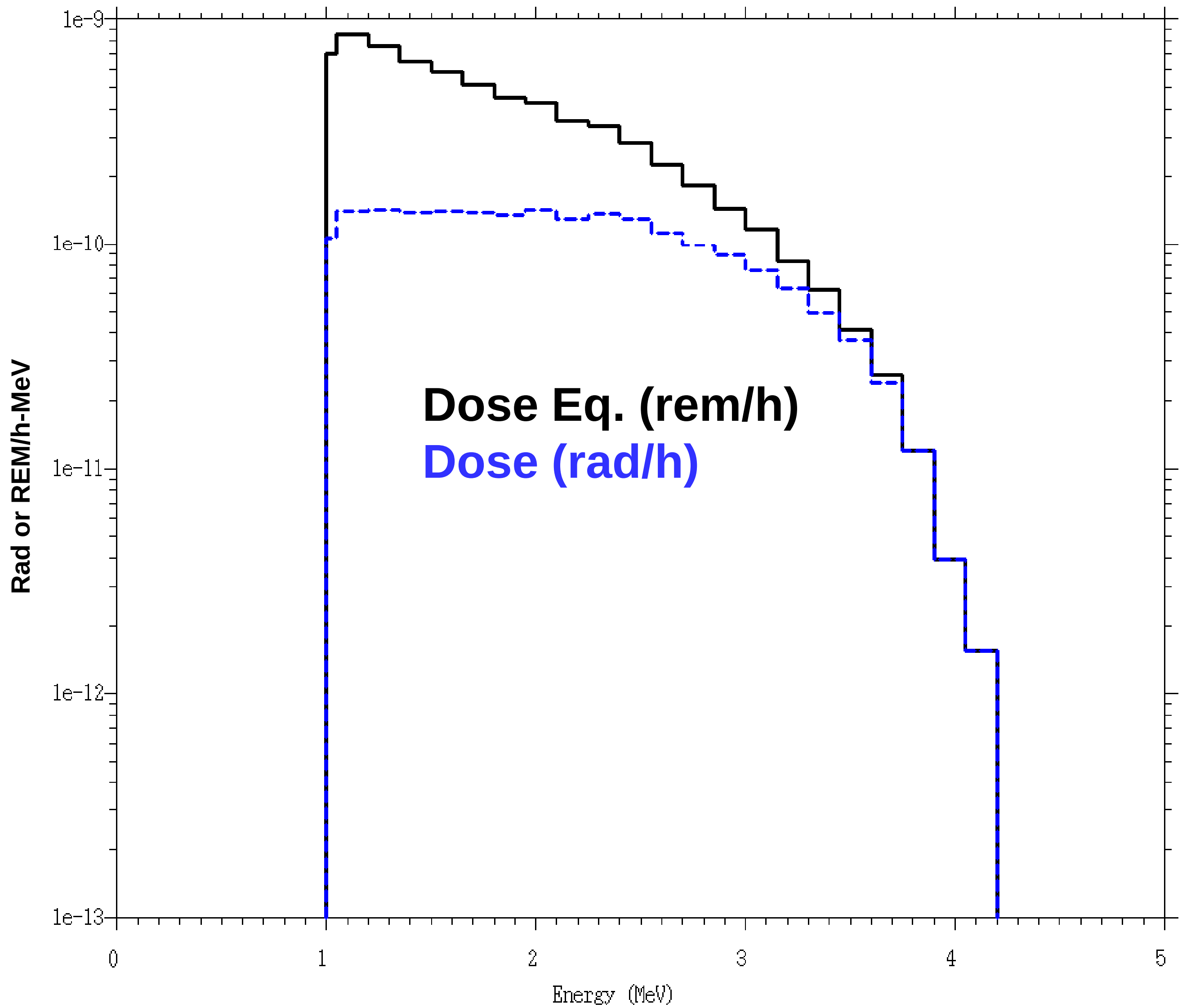
Tallies: LET tally option – flux LET spectrum for 1-MeV photons in Si

```
1 MeV photons into Si
1 1 -2.0 -1  imp:p,e=1
2 0        1  imp:p,e=0

1 so 10.0

MODE p e
M1  14028 1
sdef par=p erg=1
f4:e 1
e4   .01 199log 1000 $ MeV/cm
ft4  LET
nps  1000000
print
```



Tallies: Quality Factor tally option – proton dose equivalence based on stopping powers (ICRP-60)

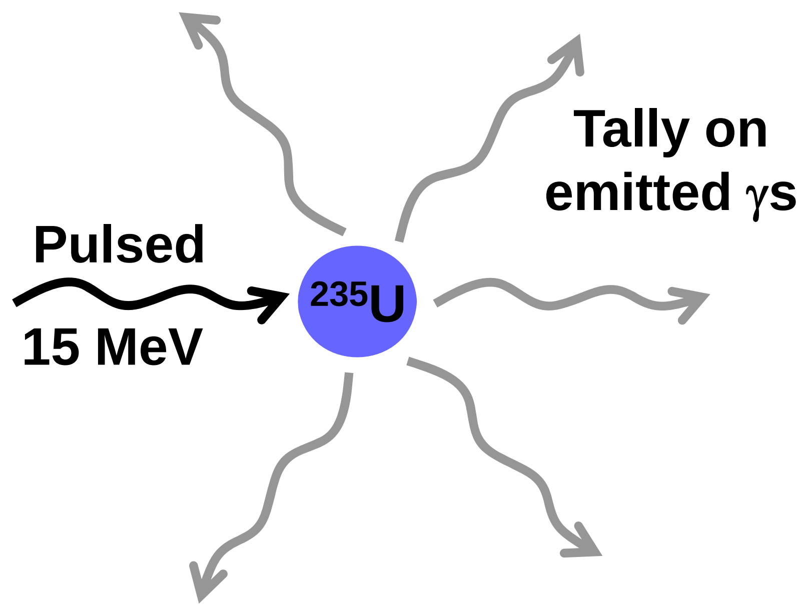
```
14-MeV neutrons into water
1     1 -1.0      -1     imp:n=1
2     0            1     imp:n=0

1     so  10.0

m1      1001 2 8016 1
mode    n h d t s a / z #
lca     8j 1 1
sdef    par=n erg=14
e0      0 99i 15
c
fc16 Dose equiv
f16:h   1
df16    ic=99 iu=1 fac=-3
c
fc116 Dose
f116:h 1
```



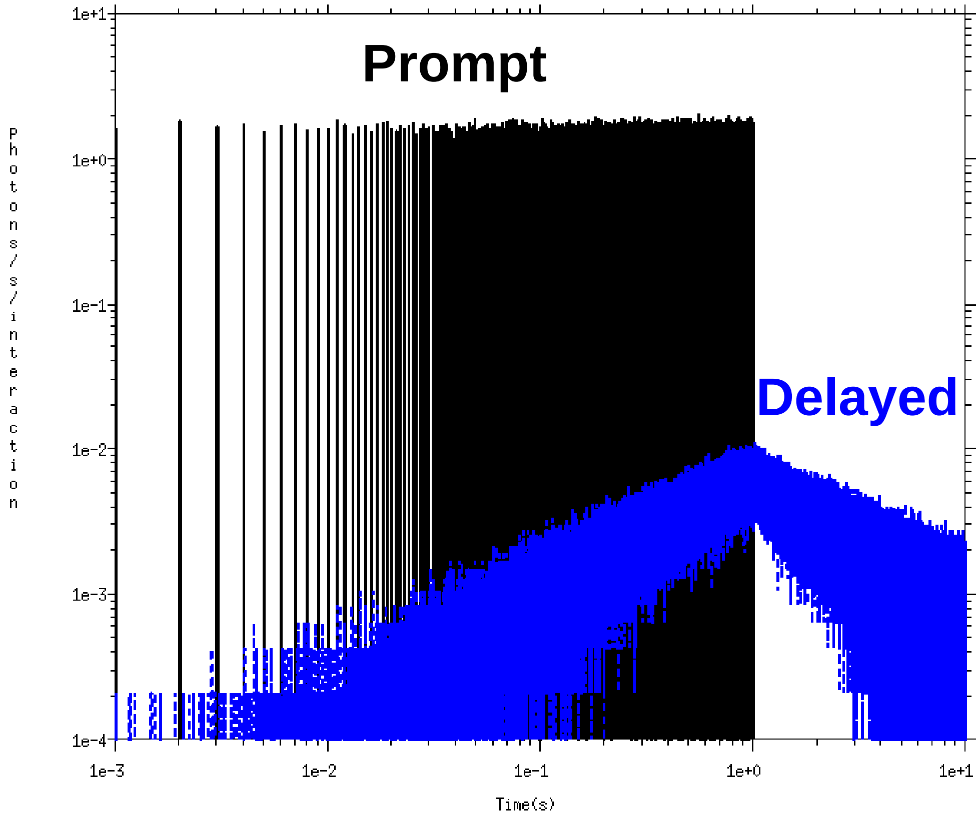
Tallies: cyclic-bin tally option – simplifies accumulation of tallies in pulsed applications

```
Pulsed 15-MeV gammas into U-235
1   1 -19.0     -1   imp:p=1
2   0            1   imp:p=0

1   so 10

m1    92235 1
mode p
phys:p 3j 1 j -101
lca   7j -2
sdef par=p erg=15 tme=d1<d2
si1   0 0.000001e8 .001e8
sp1   0          1       0
si2   0        1e8
sp2   0          1
f1:p 1
t1    CBEG=0.0 CFRQ=1000.e-8 COFI=0.000005e8
      CONI=0.0005e8 CSUB=5 $ CEND=1e8
ft1    tag 1
fu1    92235.99999 92000.0
nps    100000000
print
```

1 μs pulse every 1 ms out to 1s

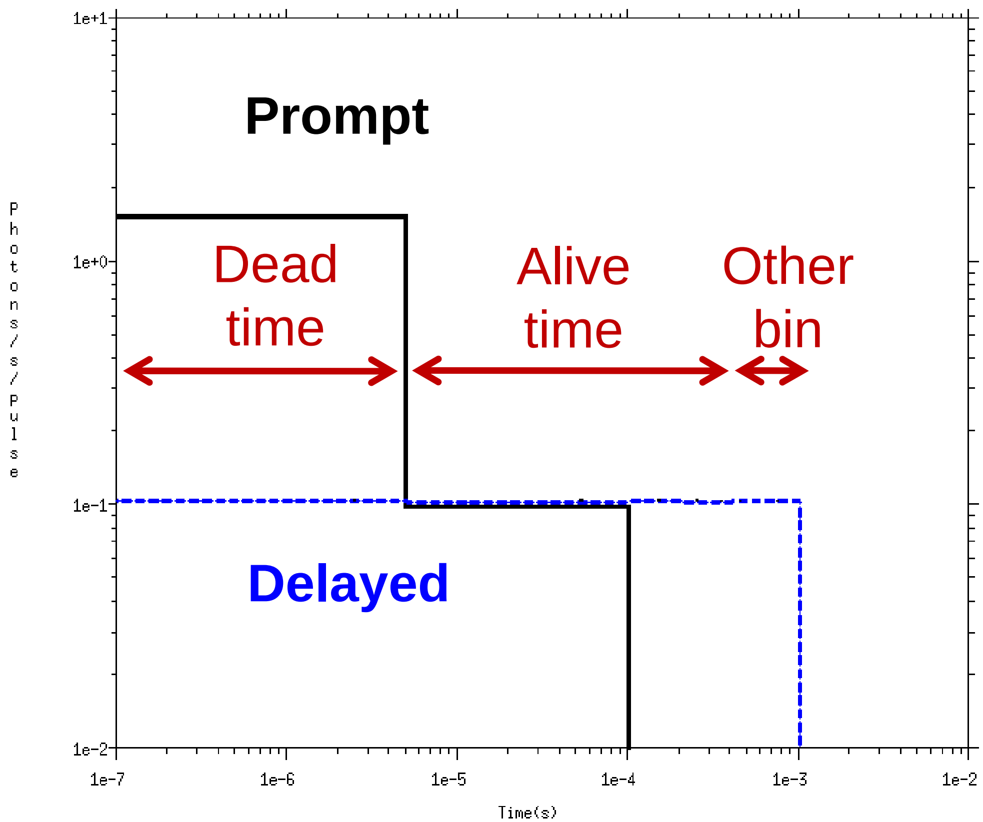


Tallies: cyclic-bin tally option – pulsed photon irradiation of ^{235}U

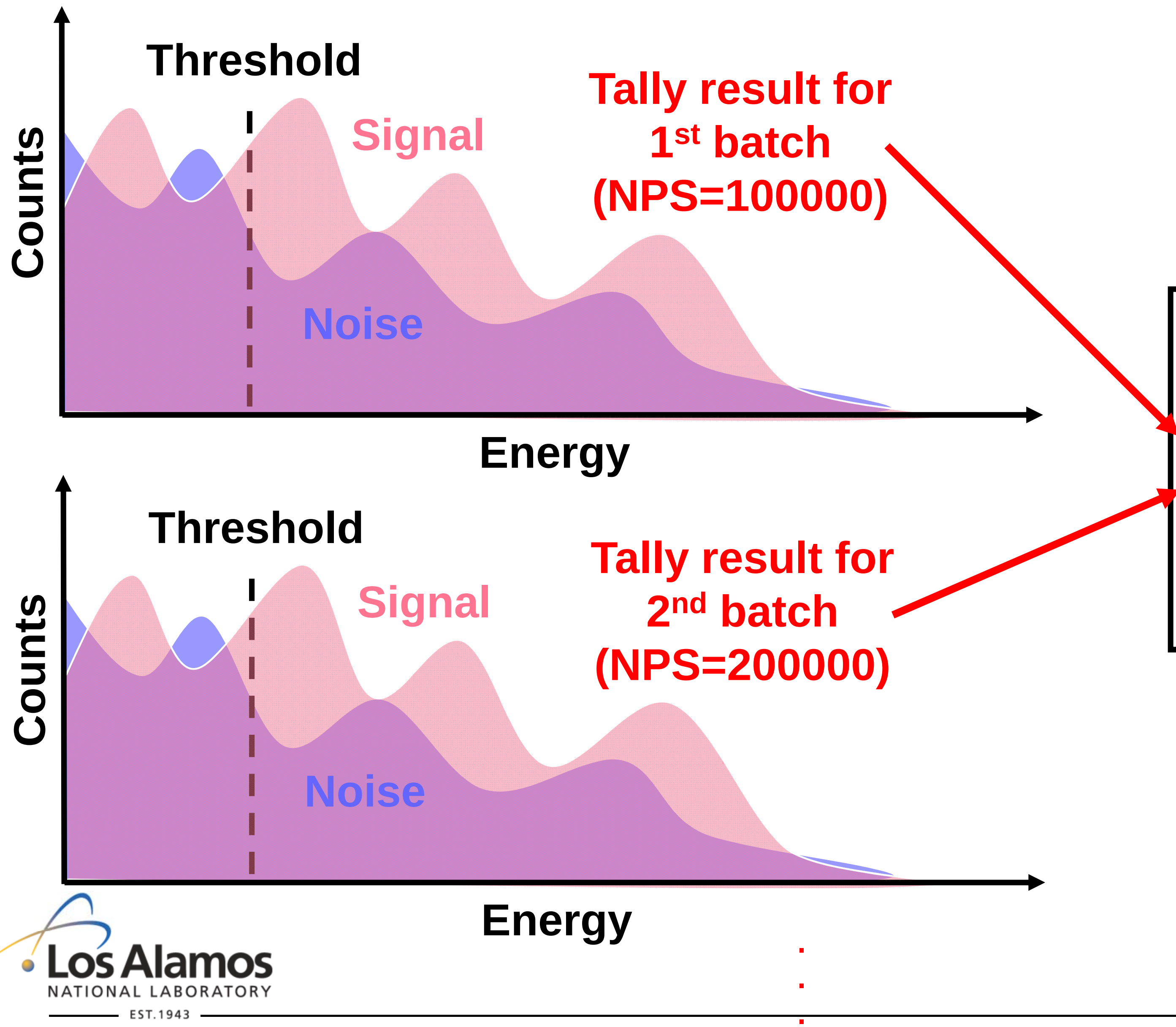


Full time-dependent behavior of 1000 pulses with dead/alive time bins repeated every 1 ms. Note decay after beam is turned off.

Cyclic time feature accumulates contributions across all 1000 repeated bins.



Tallies: ROC curve tally option – generates ROC curves from signal & noise tallies using batches of samples

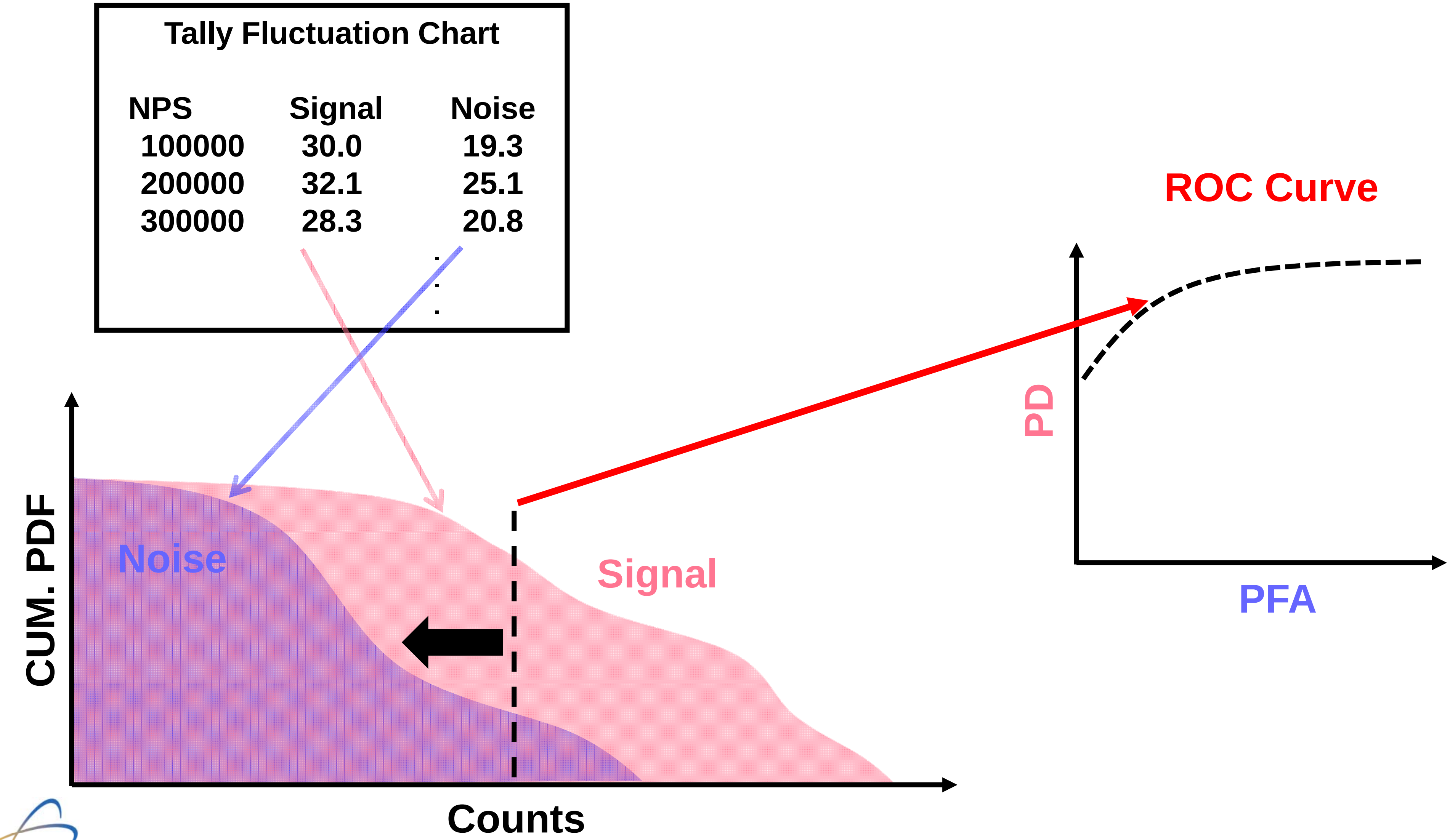


Tally Fluctuation Chart

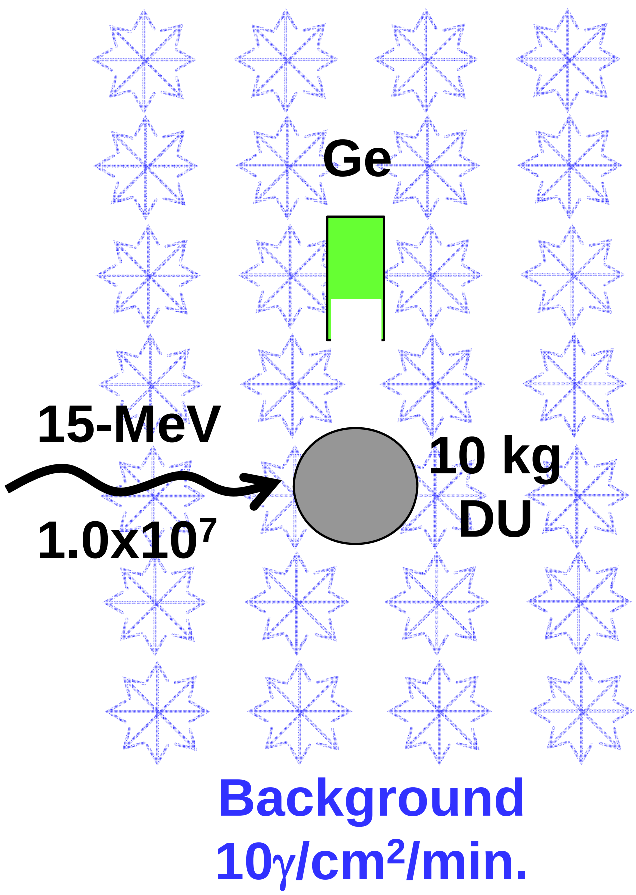
NPS	Signal	Noise
100000	30.0	19.3
200000	32.1	25.1
300000	28.3	20.8

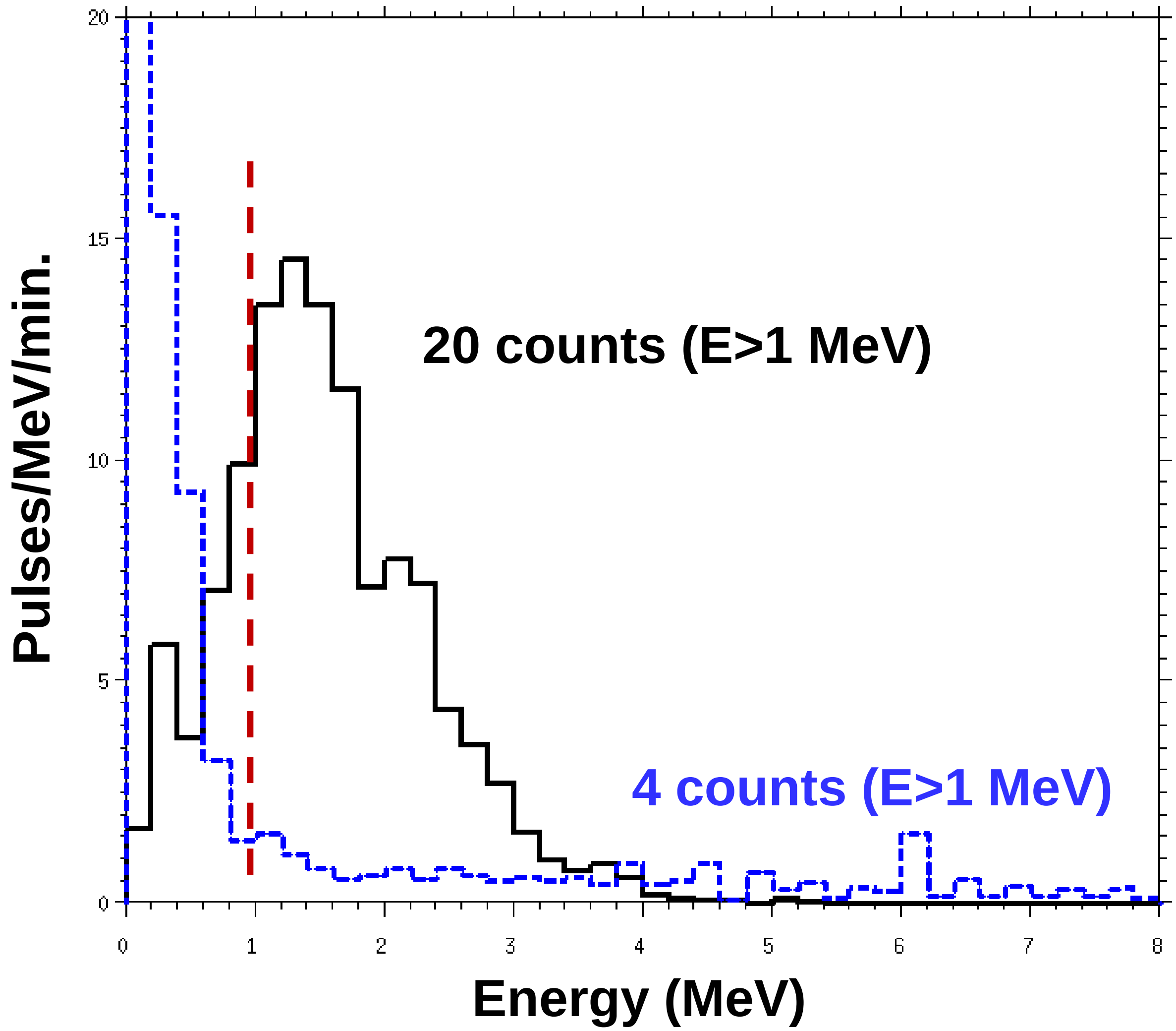
.
.
.

Tallies: ROC curve tally option – generates ROC curves from signal & noise tallies using batches of samples

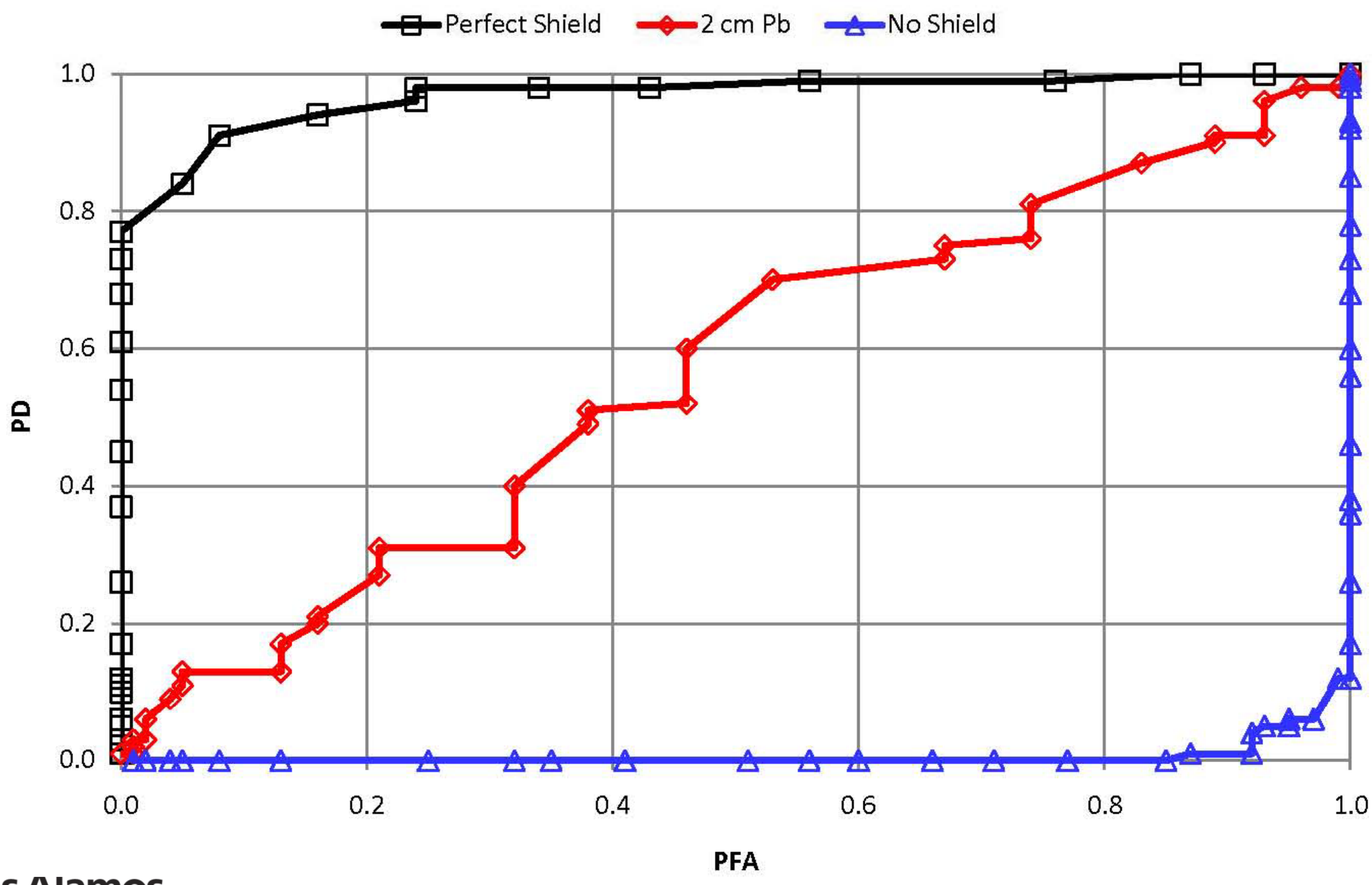


Tallies: ROC curve tally option – photon interrogation of DU with gamma background



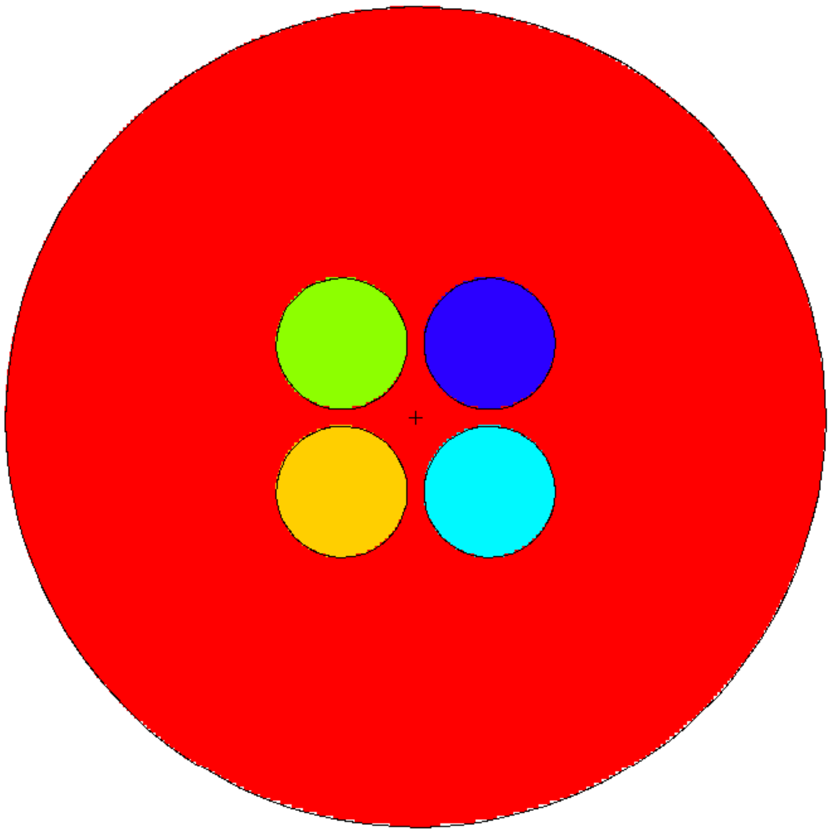


Tallies: ROC curve tally option – photon interrogation of DU with gamma background



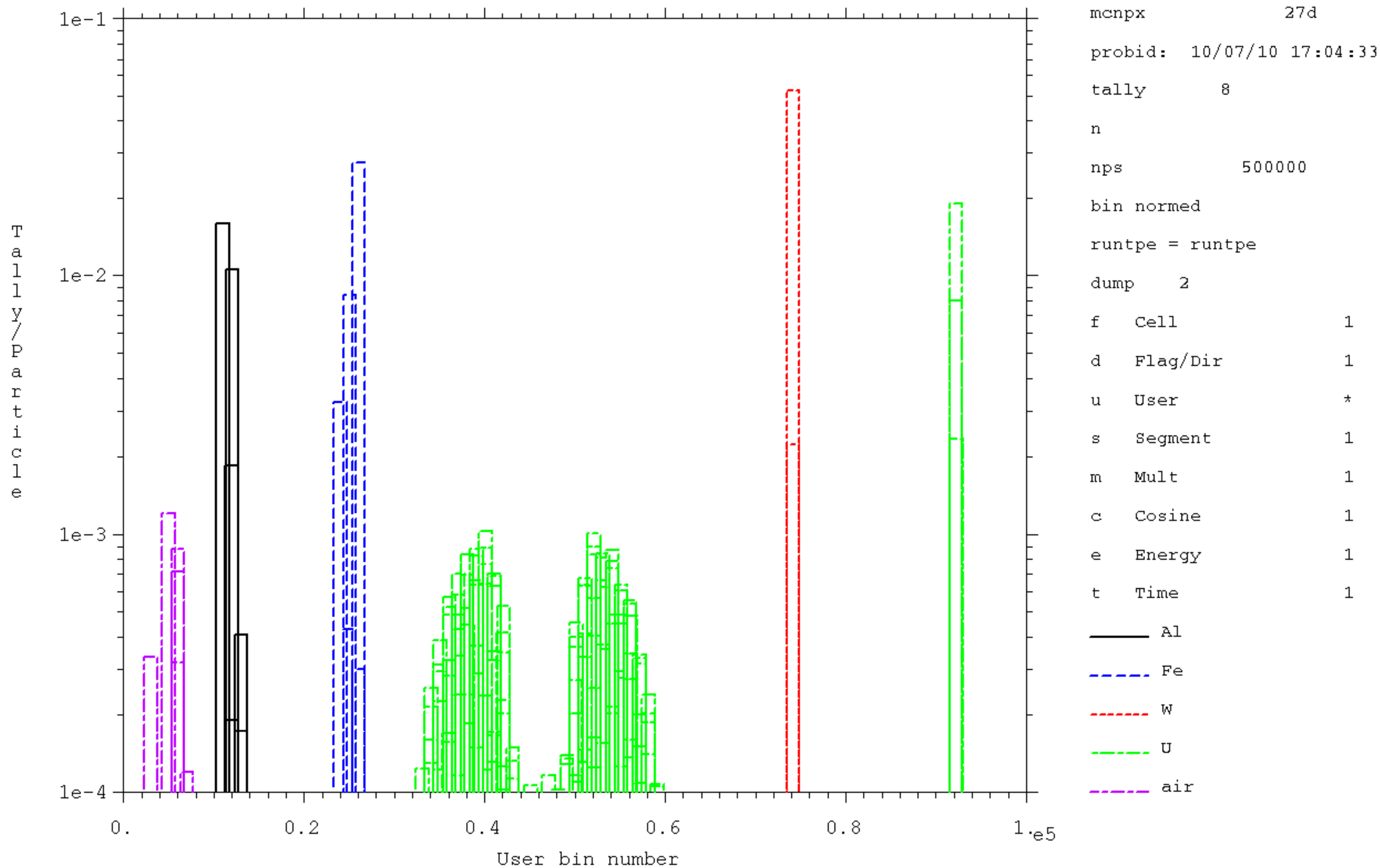
Tallies: residual tally upgrade – residuals produced by 14-MeV neutrons in various materials

```
14-MeV neutrons in 5 materials
1  1  -5     -1   imp:n=1
2  2  -5     -2   imp:n=1
3  3  -5     -3   imp:n=1
4  4  -5     -4   imp:n=1
5  5  -1e-2 -5 #1 #2 #3 #4 imp:n=1
6  0          5   imp:n=0

1  rcc  9  9 -10  0 0 20 8
2  rcc  9 -9 -10  0 0 20 8
3  rcc -9  9 -10  0 0 20 8
4  rcc -9 -9 -10  0 0 20 8
5  so 50

m1  13027  1          $ aluminum
m2  26056  1          $ iron
m3  74182  1          $ tungsten
m4  92238  1          $ uranium
m5  7014 0.8 8016 0.2  $ air
sdef
f8:n 1 2 3 4 5
ft8 res
nps 500000
prdmp 2j 1
```



14 MeV neutron source at center

Tallies: residual tally upgrade – residuals produced by 14-MeV neutrons in various materials



Tallies: triple & quadruple coincidences – extension of PHL tally option enables high-order coincidencing

- Format extended to add 3rd and 4th regions

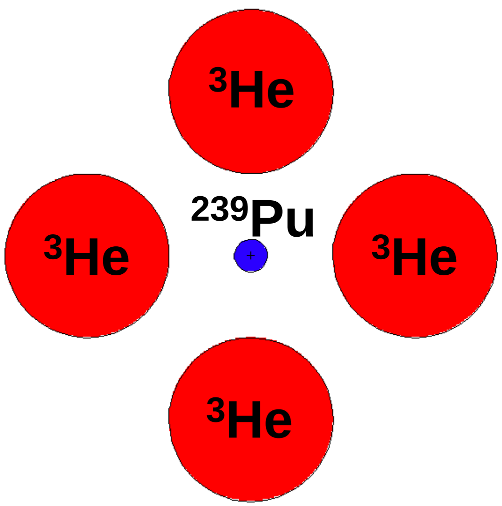
PHL	$^{1}N\ ^{1}T_1\ ^{1}F_1\ ^{1}T_2\ ^{1}F_2\ \ldots\ ^{1}T_{1N}\ ^{1}F_{1N}$	1st Region
	$[^{2}N\ ^{2}T_1\ ^{2}F_1\ ^{2}T_2\ ^{2}F_2\ \ldots\ ^{2}T_{2N}\ ^{2}F_{2N}]$	2nd Region
	$[^{3}N\ ^{3}T_1\ ^{3}F_1\ ^{3}T_2\ ^{3}F_2\ \ldots\ ^{3}T_{3N}\ ^{3}F_{3N}]$	3rd Region
	$[^{4}N\ ^{4}T_1\ ^{4}F_1\ ^{4}T_2\ ^{4}F_2\ \ldots\ ^{4}T_{4N}\ ^{4}F_{4N}]$	4th Region

- Other tally cards now allowed to specify energy channels

E8	$^{1}E_1\ ^{1}E_2\ ^{1}E_3\ ^{1}E_4\ \ldots$	1st Region
Fu8	$^{2}E_1\ ^{2}E_2\ ^{2}E_3\ ^{2}E_4\ \ldots$	2nd Region
C8	$^{3}E_1\ ^{3}E_2\ ^{3}E_3\ ^{3}E_4\ \ldots$	3rd Region
Fs8	$^{4}E_1\ ^{4}E_2\ ^{4}E_3\ ^{4}E_4\ \ldots$	4th Region

Tallies: triple & quadruple coincidences – a simple fission example with ^{3}He detectors surrounding ^{239}Pu

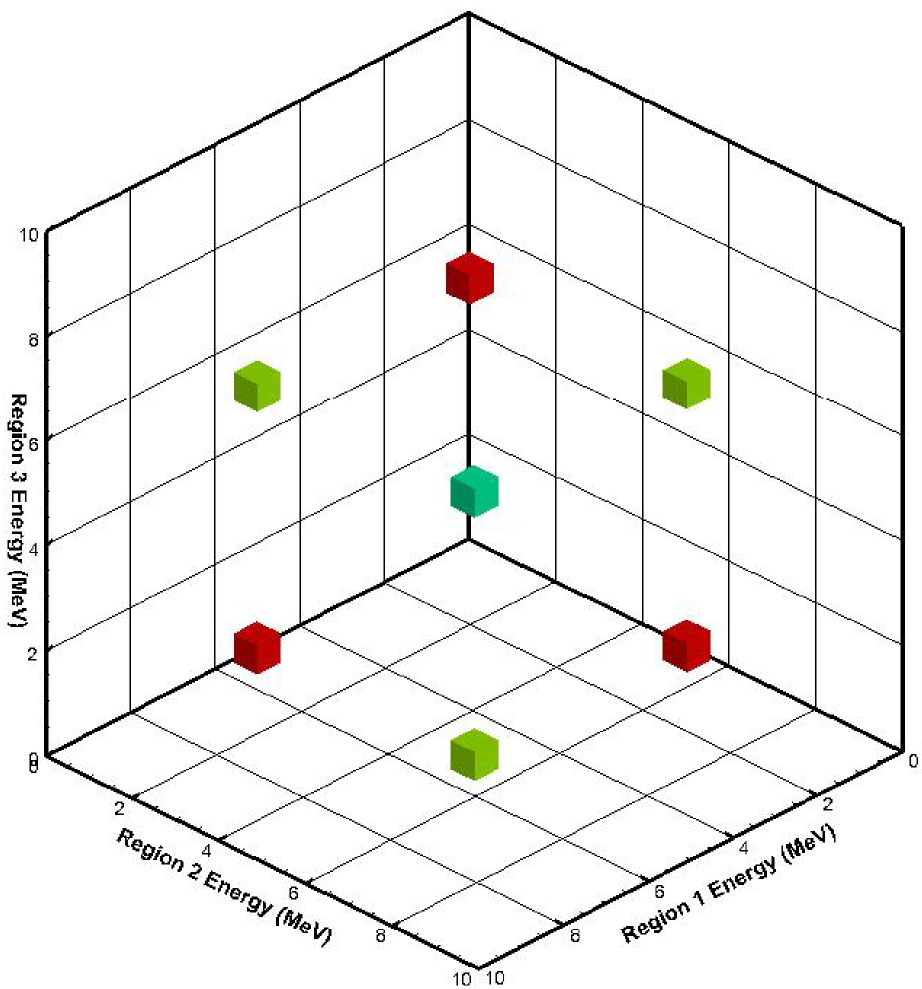
```
Thermal neutrons into Pu-239
1  1  -10.0   -1   imp:n=1
2  2  -1e-3   -2   imp:n=1
3  2  -1e-3   -3   imp:n=1
4  2  -1e-3   -4   imp:n=1
5  2  -1e-3   -5   imp:n=1
6  0           1 2 3 4 5 -6  imp:n=1
7  0                      6  imp:n=0

1  sph    0   0  0  1.0
2  rcc  -10   0 -10  0 0 20  5.0
3  rcc   10   0 -10  0 0 20  5.0
4  rcc    0 -10 -10  0 0 20  5.0
5  rcc    0  10 -10  0 0 20  5.0
6  sph    0   0  0  100.0

mode n h t s
m1   94239 1
m2    2003 1
phys:n 5j 1 2
cut:n  2j 0 0
cut:h,t,s j 0.001
sdef  par=n  erg=1e-8
f06:h  2 3 4 5
f16:t  2 3 4 5
f26:s  2 3 4 5
```



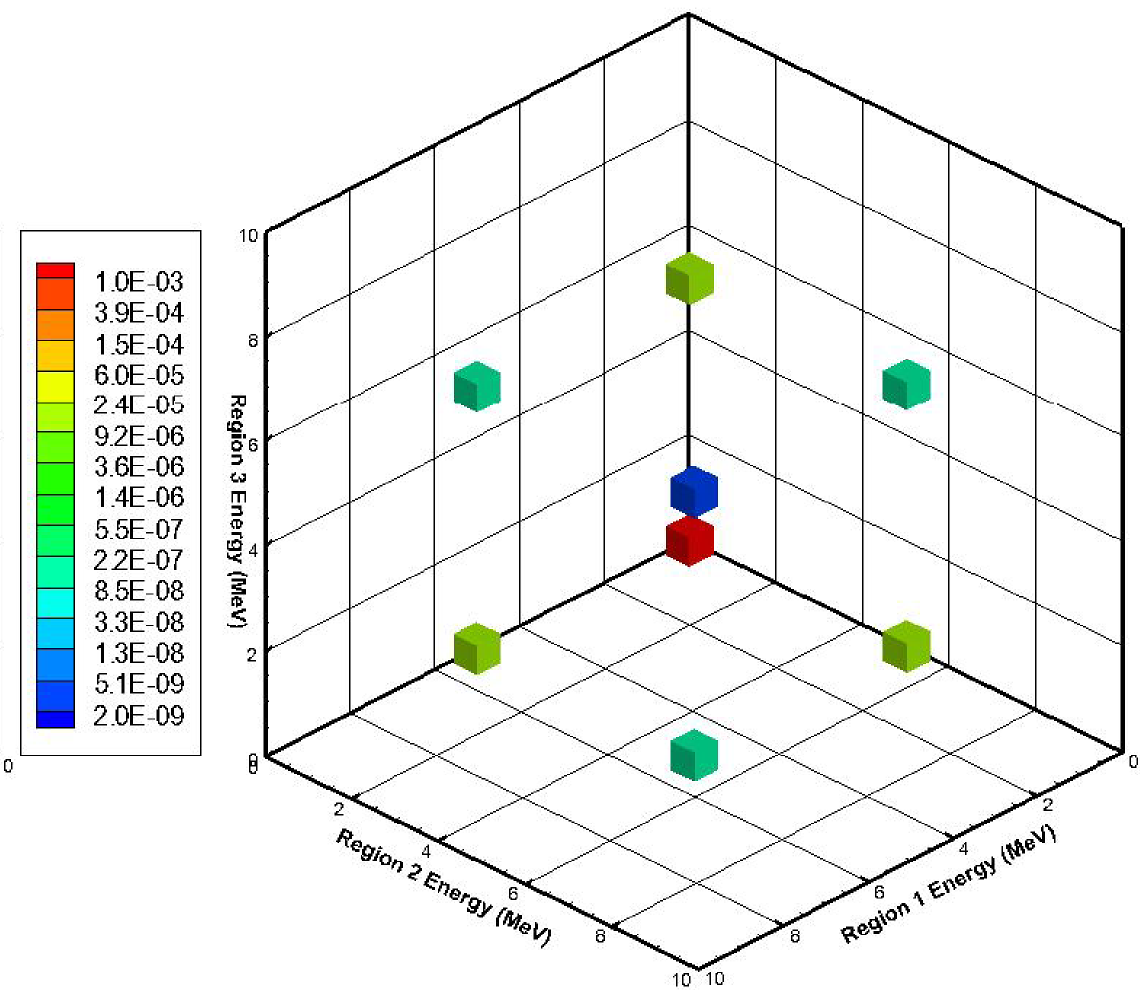

```
fc8  Integrated Pulse Spectrum
f8:h,t,s (2 3 4 5)
ft8    PHL 3 6 1 16 1 26 1
           3 6 2 16 2 26 2
           3 6 3 16 3 26 3
           3 6 4 16 4 26 4
e8  0 10 NT
fu8 0 10 NT
c8  0 10 NT
fs8 0 10 NT
fq8 s c e u
fc28  Full Pulse Spectrum
f28:h,t,s (2 3 4 5)
ft28   PHL 3 6 1 16 1 26 1
           3 6 2 16 2 26 2
           3 6 3 16 3 26 3
           3 6 4 16 4 26 4
e28  0 1 2 3 4 5 6 7 8 9 10 NT
fu28 0 1 2 3 4 5 6 7 8 9 10 NT
c28  0 1 2 3 4 5 6 7 8 9 10 NT
fs28 0 1 2 3 4 5 6 7 8 9 10 NT
fq28 s c e u
nps  10000000000
```

Tallies: triple & quadruple coincidences – a simple fission example with ^{3}He detectors surrounding ^{239}Pu

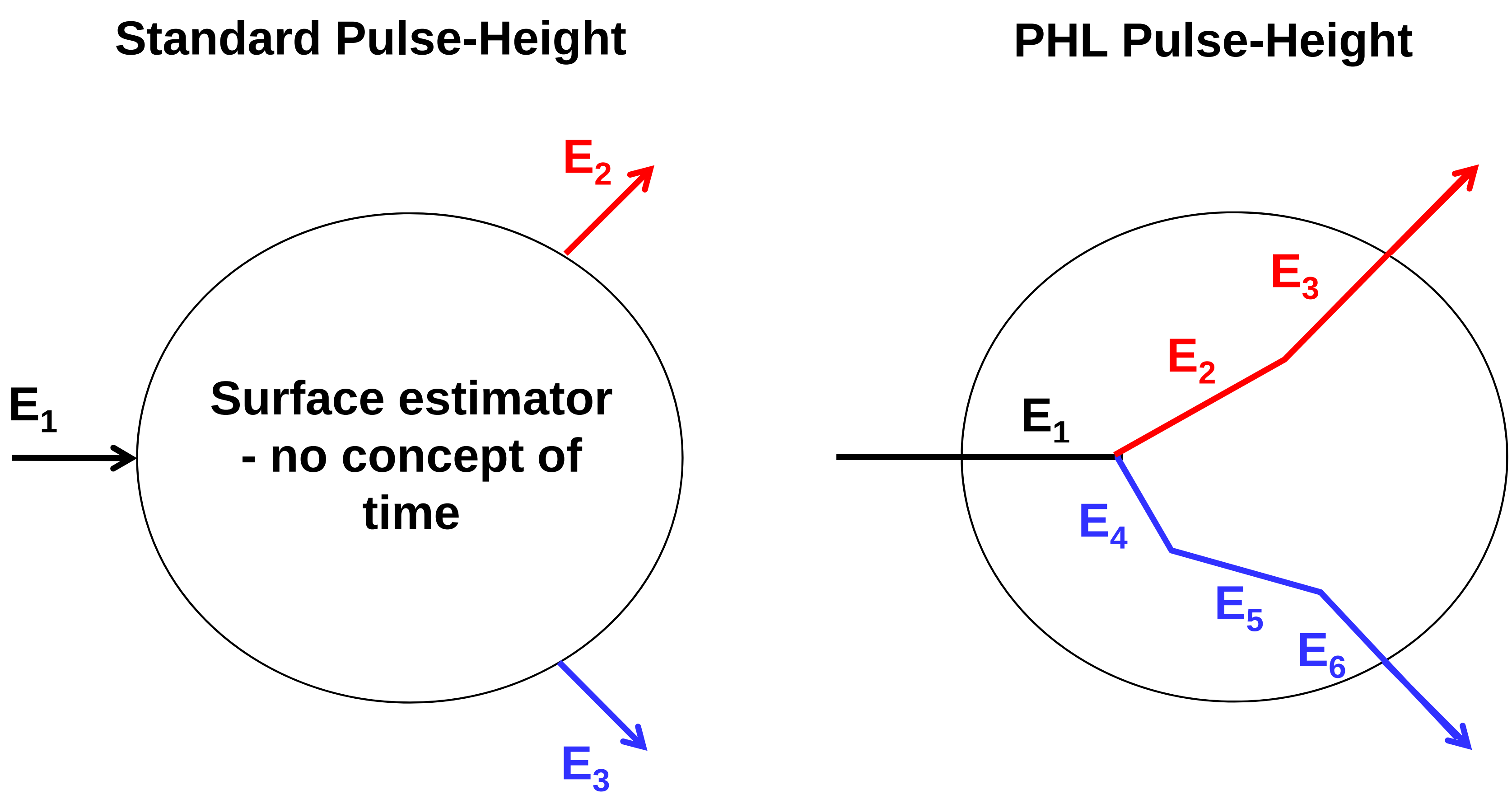
No Counts in 4th Detector



With Counts in 4th Detector



Tallies: time-dependent pulse-height tallies – extension of the PHL tally option enables pulse-shape discrimination



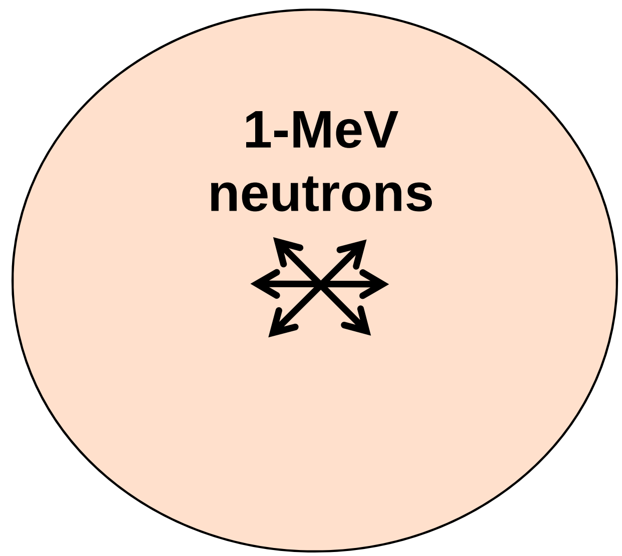
Pulse in bin $E_1 - E_2 - E_3$

Pulse in bin E_1 at T_1
Pulse in bin E_2 at T_2
etc.

Tallies: time-dependent pulse-height tallies – a simple model of a ^{3}He detector

```
1-MeV Neutrons into He-3
1  1  -1e-3   -1    imp:n=1
2  0           1 -2 imp:n=1
3  0              2 imp:n=0

1  so  100.
2  so  1000

mode n h t s
m1    2003 1
phys:n 5j 1 2
cut:h,t,s j 1e-3
sdef   par=n  erg=1
f16:h  1
f26:t  1
f36:s  1
f8:h   1
ft8    phl 1 16 1  0
e8     .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
t8     05 10 15 20 25 30 35 40 45 50 55 60
f18:t   1
ft18    phl 1 26 1  0
e18    .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
t18    05 10 15 20 25 30 35 40 45 50 55 60
f28:s   1
ft28    phl 1 36 1  0
e28    .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
t28    05 10 15 20 25 30 35 40 45 50 55 60
f38:h,t,s   1
ft38     phl 3 16 1 26 1 36 1  0
e38      .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
t38      05 10 15 20 25 30 35 40 45 50 55 60
nps  100000000
print
```

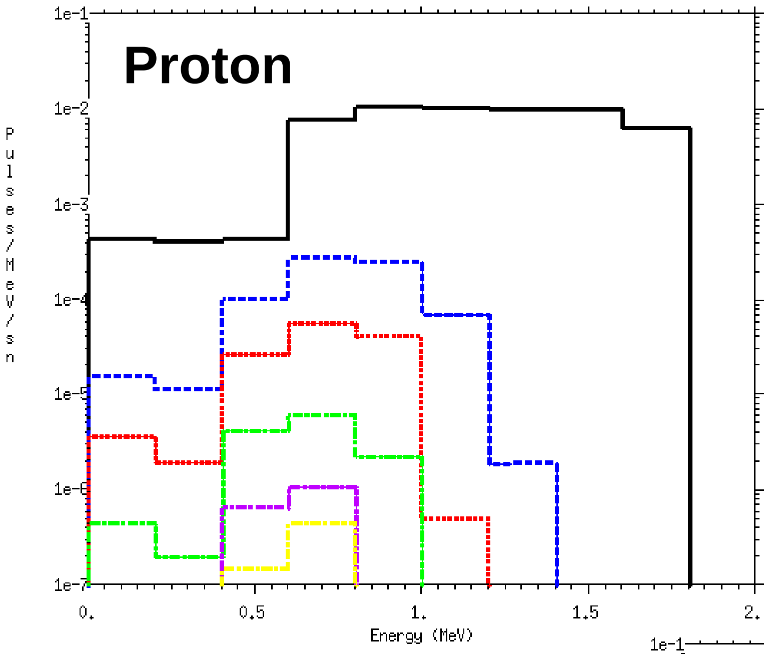
1-m Sphere of ^{3}He

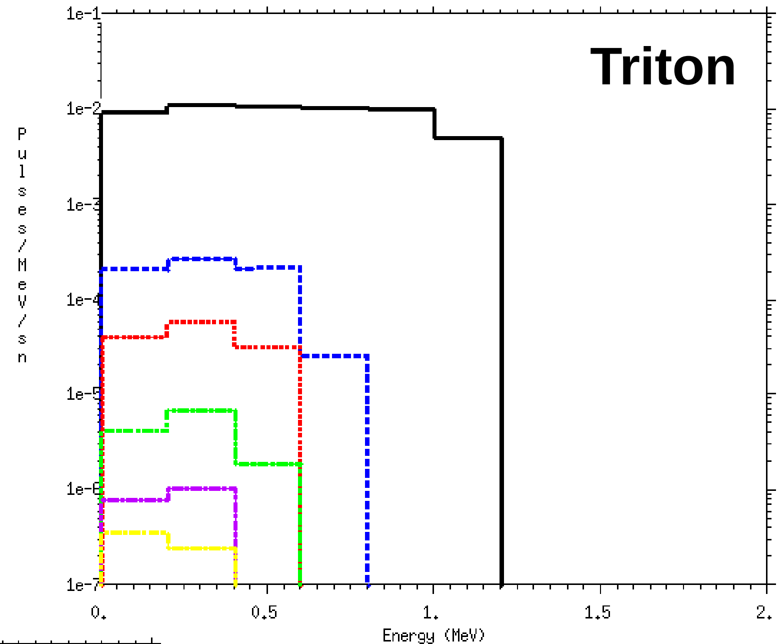


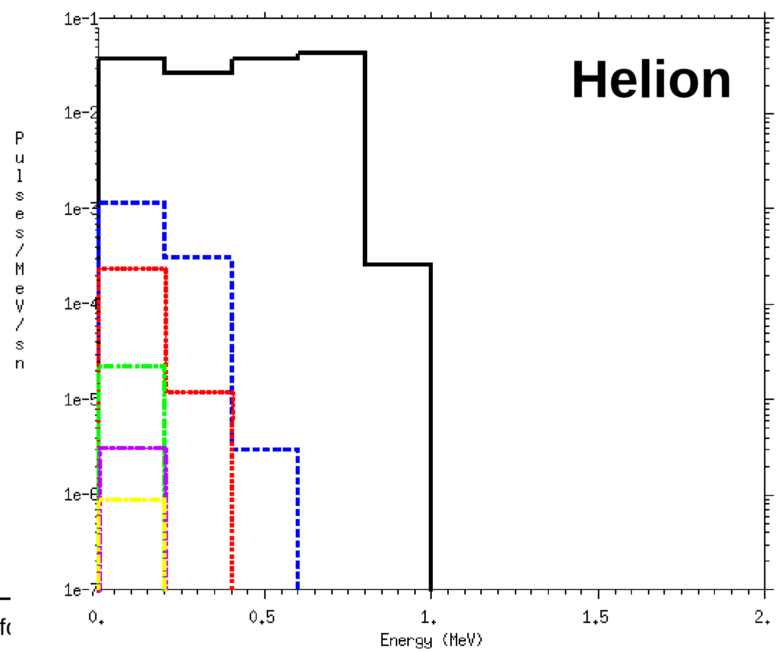
^{3}He + n -> p + t

^{3}He + n -> ^{3}He^{+} + n'

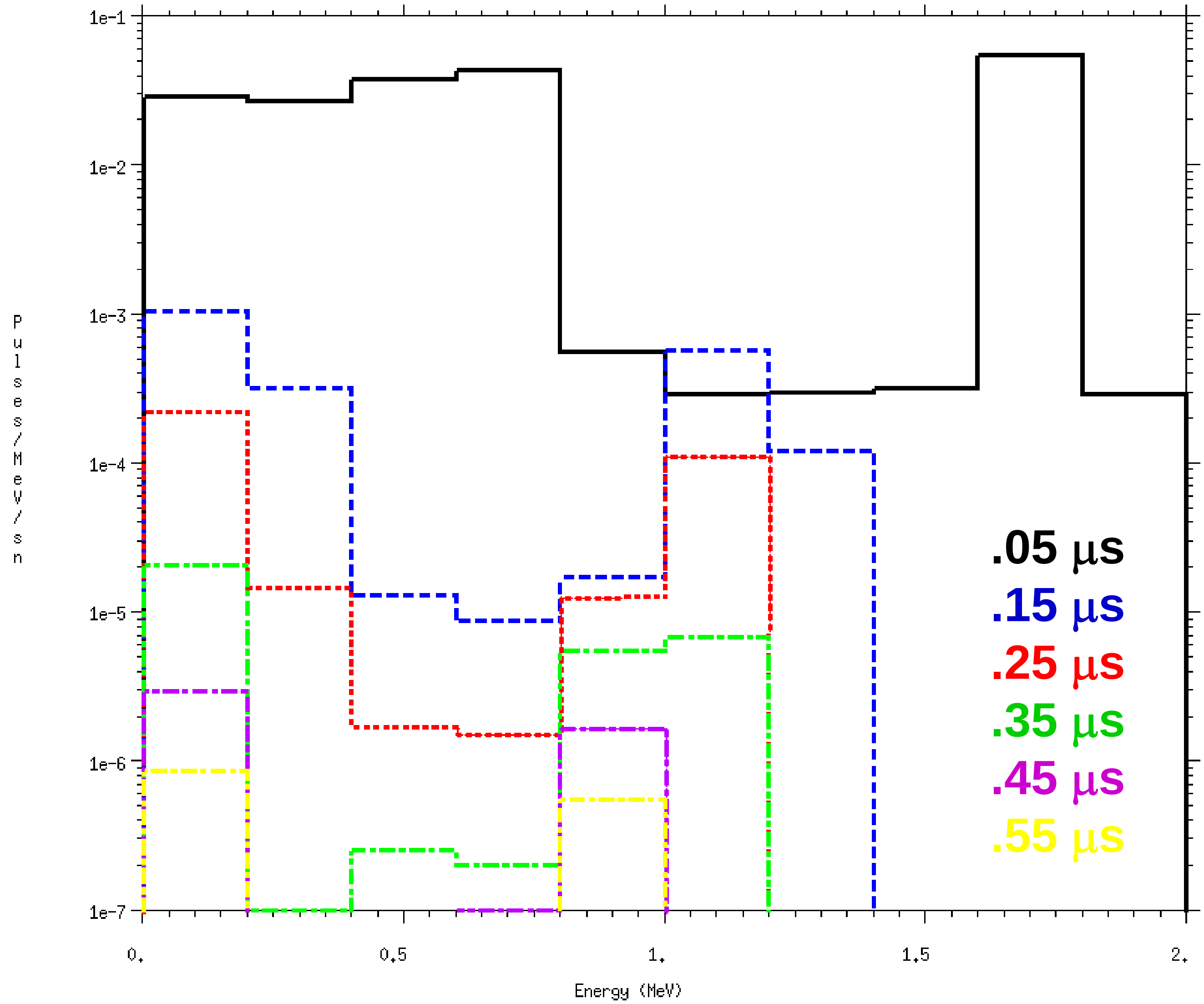
Tallies: time-dependent pulse-height tallies – particle-dependent & time-dependent pulse spectra







Tallies: time-dependent pulse-height tallies – combined time-dependent pulse spectra



MCNP6 Enhancements of Delayed-Particle Production

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IEEE NSS/MIC

Anaheim, CA, October 29 - November 3, 2012

Outline

- Recent DNDO features being implemented in MCNP6
- Delayed neutron enhancement
- Delayed gamma enhancement
- Delayed beta enhancement
- Conclusions

Recent DNDO features being implemented in MCNP6

- Cosmic source option (SDEF card)
- Background source option (SDEF card)
- Delayed beta physics option (ACT card)
- PHT trigger option (FT card)
- Built-in photon detector response functions (FT card)
- CGM correlated secondary particle production (PHYS:n card)
- Compton-image tally option (FT card)
- Fixed-source eigenvalue solution (KCODE card)
- Mesh tallies with time bins (ERGSH card)
- First-fission tally option (FT card)

Task 1: Background Activation (McKinney, Kawano)

- **Objective**

  Develop capability for MCNPX to automate the creation of delayed signatures emitted from the decay of radioactive:

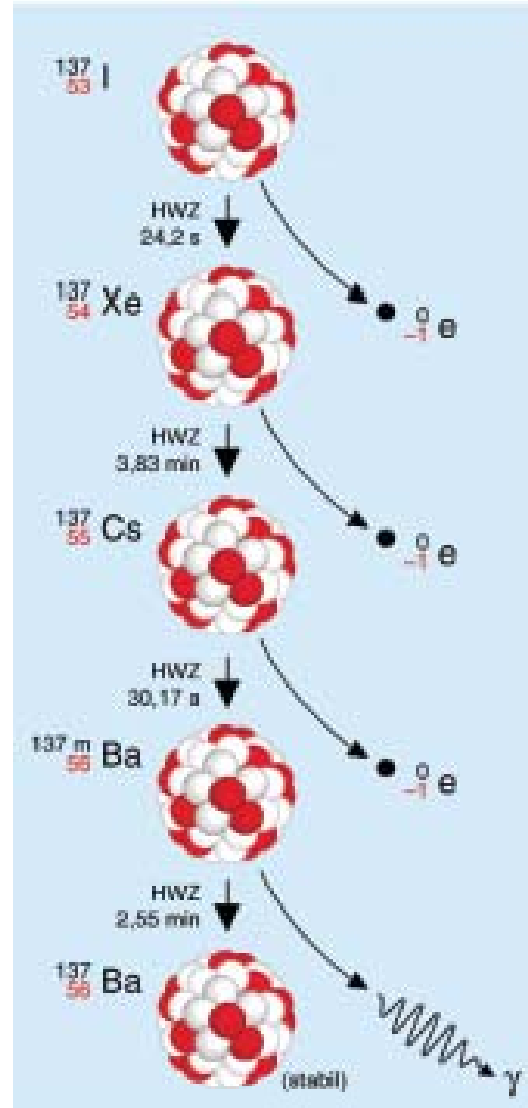
  - Fission products created by neutron-induced fission or photofission;
  - Residual nuclides created by non-fission transmutation.

- **Significance**
  - Radioactive decay frequently results in the emission of gammas and neutrons at times appreciably later than the initiating event
  - The distribution of fission products vary with the fissioning isotope and the particle inducing the fission
  - The delayed-particle emissions occur with intensities and at energies that are unique to each radionuclide

Decay Chains and Emission Sampling

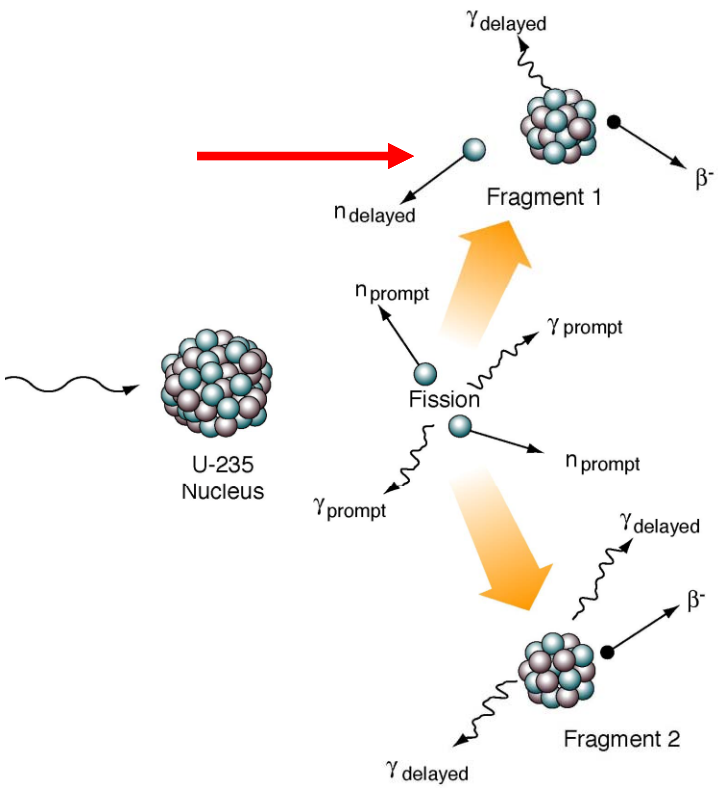
Not only are the fission-products and residual nuclides radioactive sources, but so too are their decay products. Each contributes to the delayed signature. Thus, a fission event may have hundreds or thousands of lines contributing to its signature.

CINDER90 has been integrated into MCNPX to calculate the radioactive decay-chain nuclide densities as a function of time. The nuclide densities, decay constants, and particle (neutron, gamma) emission probabilities are used to calculate distributions that are sampled for particle emission energy and delay time (direction is sampled isotropically).

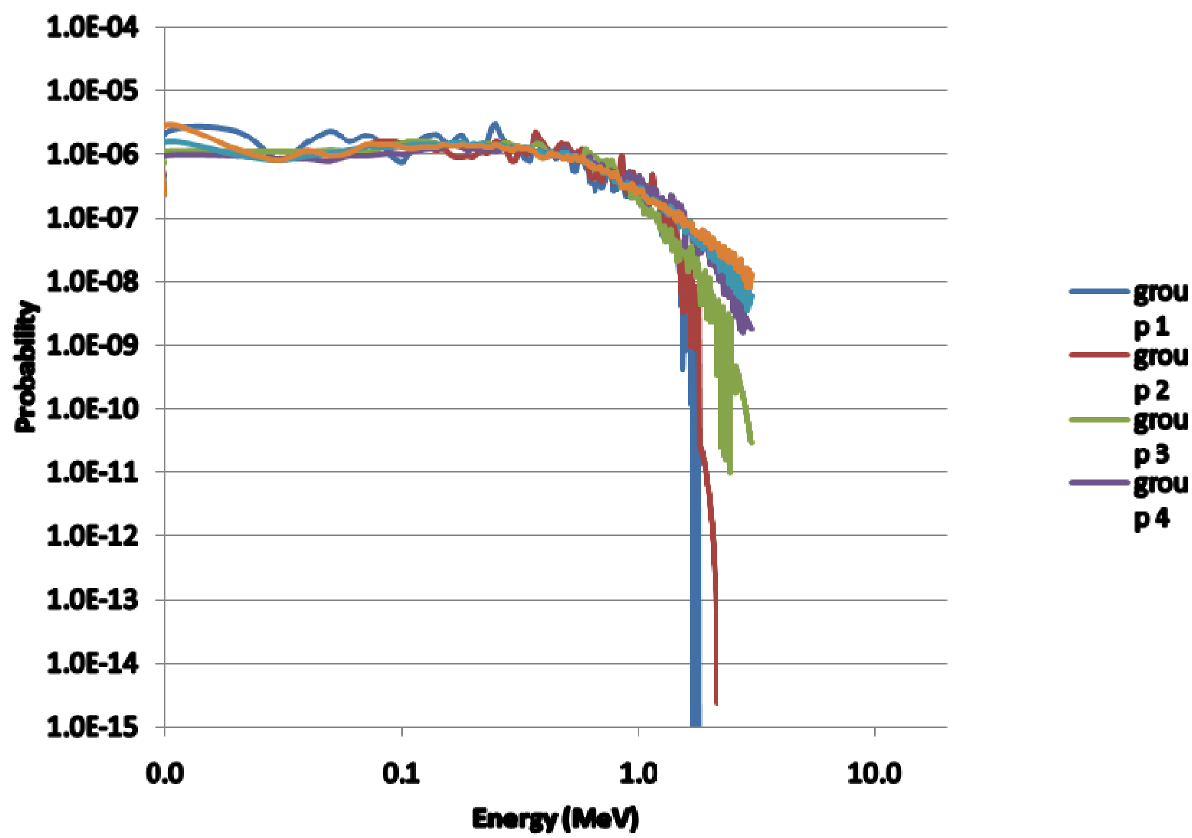


The delayed neutron (DN) treatment included only 6 time groups & ACE data existed for a small set of actinides

The fission process

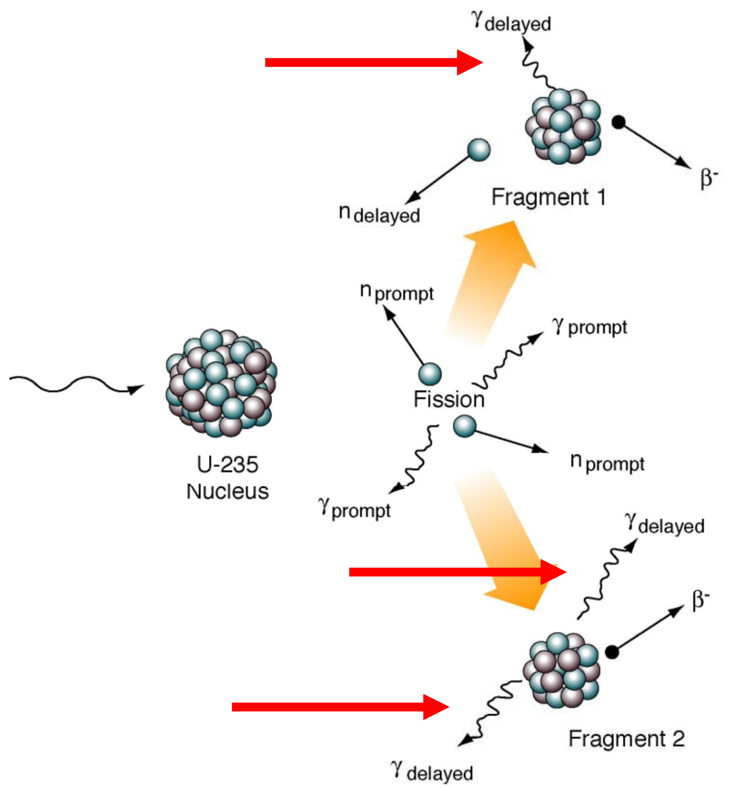


ENDF/B-VI DN spectra for ^{235}U

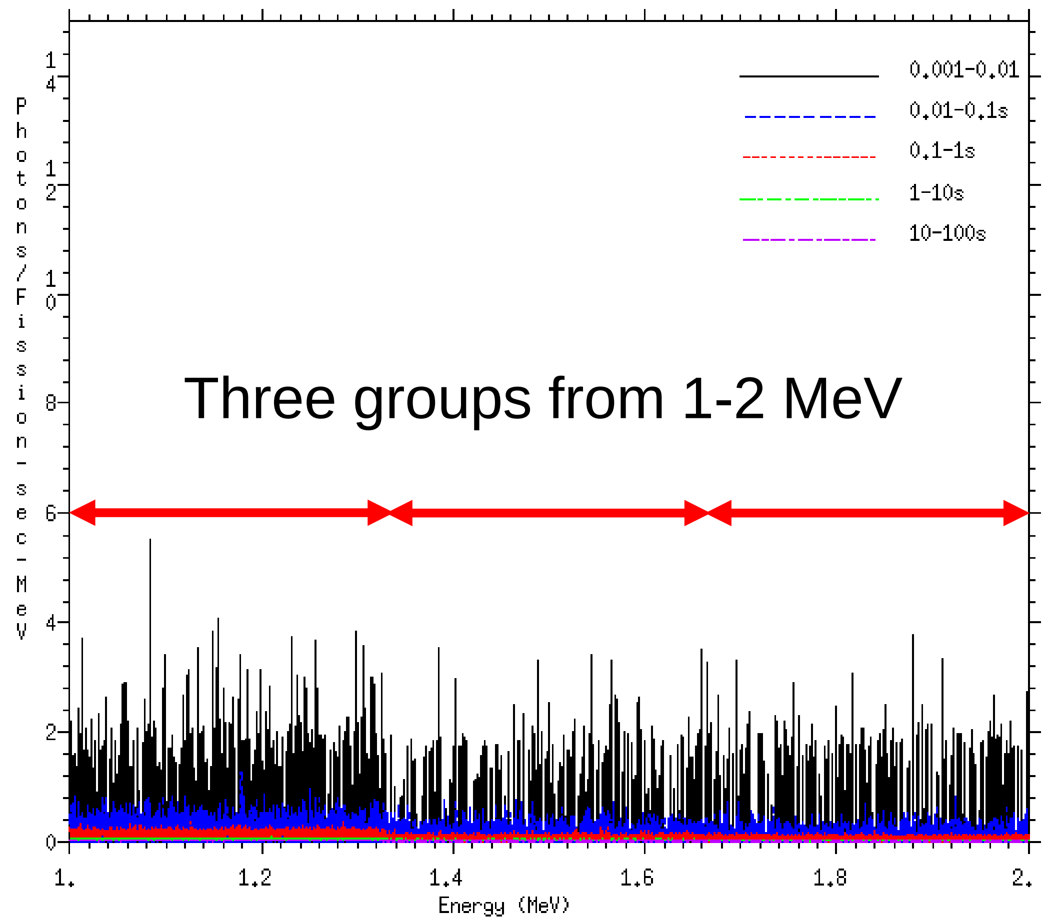


The multi-group treatment for delayed gammas (DG) was unreleased & it prohibited spectroscopic analysis

The fission process

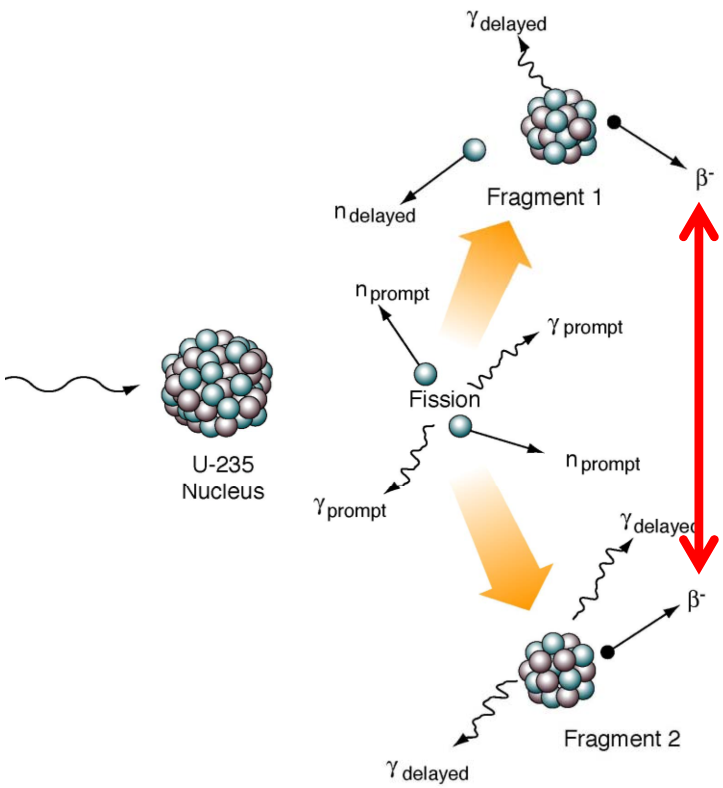


25-group DG spectrum from neutron-induced fission of ^{235}U

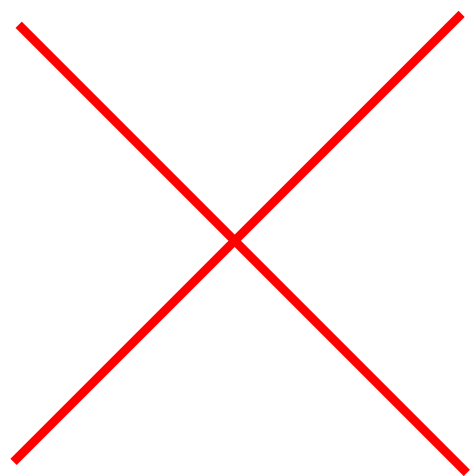


There was no delayed beta (DB) treatment included in MCNPX

The fission process



No DB treatment



DN energy integration algorithm was improved – new treatment includes the entire decay chain

Previously, the DN energy sampling algorithm used only the spectrum of the precursor. With this upgrade, the spectra from all DN emitters within a decay chain are combined and used for sampling DN emission. This upgrade produces a small effect, since it is rare to have multiple DN emitters within a single decay chain.

```
1000        750         100          0          0 1171 279 1201 0 0
 0.0000E+00 1.0000E+04 2.0000E+04 3.0000E+04 4.0000E+04 5.0000E+04
 6.0000E+04 7.0000E+04 8.0000E+04 9.0000E+04 1.0000E+05 1.1000E+05
                                ...
 9.9000E+06 9.9100E+06 9.9200E+06 9.9300E+06 9.9400E+06 9.9500E+06
 9.9600E+06 9.9700E+06 9.9800E+06 9.9900E+06 1.0000E+07
 0.0000e+00 1.0000e+04 2.0000e+04 3.0000e+04 4.0000e+04 5.0000e+04
 6.0000e+04 7.0000e+04 8.0000e+04 9.0000e+04 1.0000e+05 1.1000e+05
                                ...
 7.4400e+06 7.4500e+06 7.4600e+06 7.4700e+06 7.4800e+06 7.4900e+06
 7.5000e+06
 0.0000E+00 1.0000E+05 2.0000E+05 3.0000E+05 4.0000E+05 5.0000E+05
 6.0000E+05 7.0000E+05 8.0000E+05 9.0000E+05 1.0000E+06 1.1000E+06
                                ...
 9.0000E+06 9.1000E+06 9.2000E+06 9.3000E+06 9.4000E+06 9.5000E+06
 9.6000E+06 9.7000E+06 9.8000E+06 9.9000E+06 1.0000E+07
                                ...
 9030 0.00000 0.00000   0   0 1.00000 0.00000   0   0
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 6.8687E-01 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 2.0202E-01 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
                                ...
```

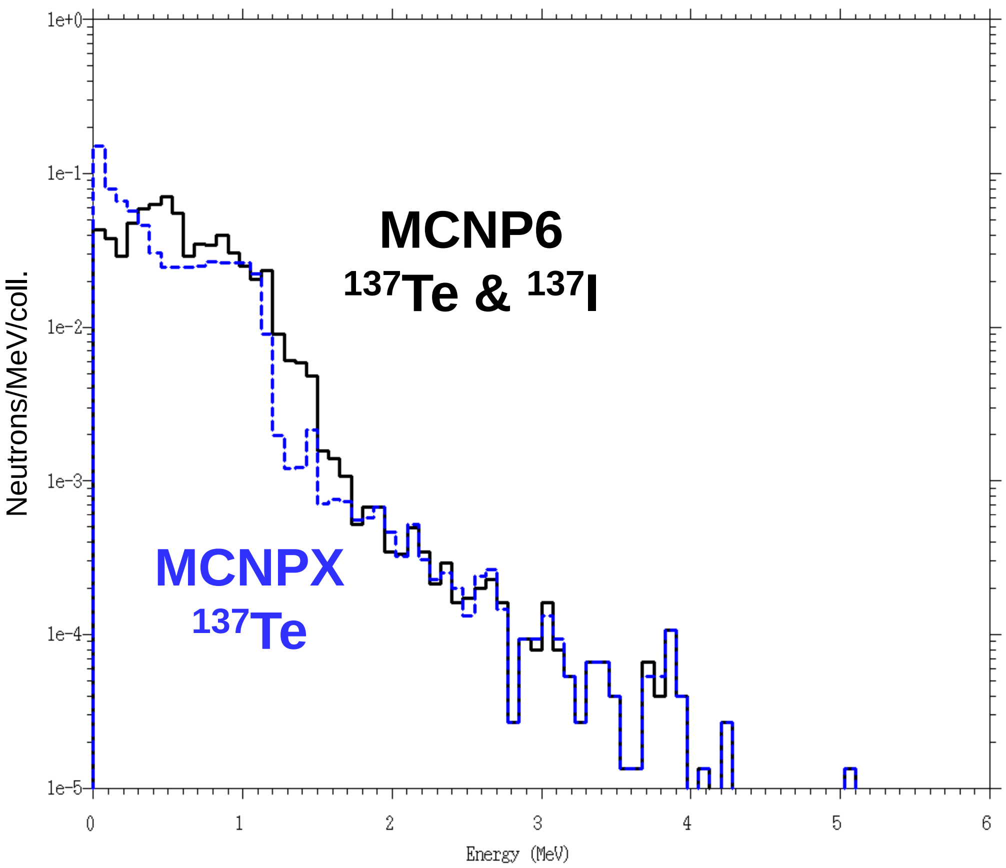
DN energy integration algorithm was improved – 30-MeV neutron activation of ^{137}Te with decay of ^{137}I ($T_{1/2}$=24s)

```
30-MeV neutrons into Te-137
1  1  -1.0    -1  imp:n=1
2  0           1  imp:n=0

1  so  1.0

mode n
m1   52137 1
sdef par=n  erg=30
ACT  NONFISS=n DN=model
lca  7j -2
f1:n  1
t1    100 1e37
e1    1e-3 199i 10
f11:n 1
t11   0.001e8 199log 1000e8
print
nps  100000
```

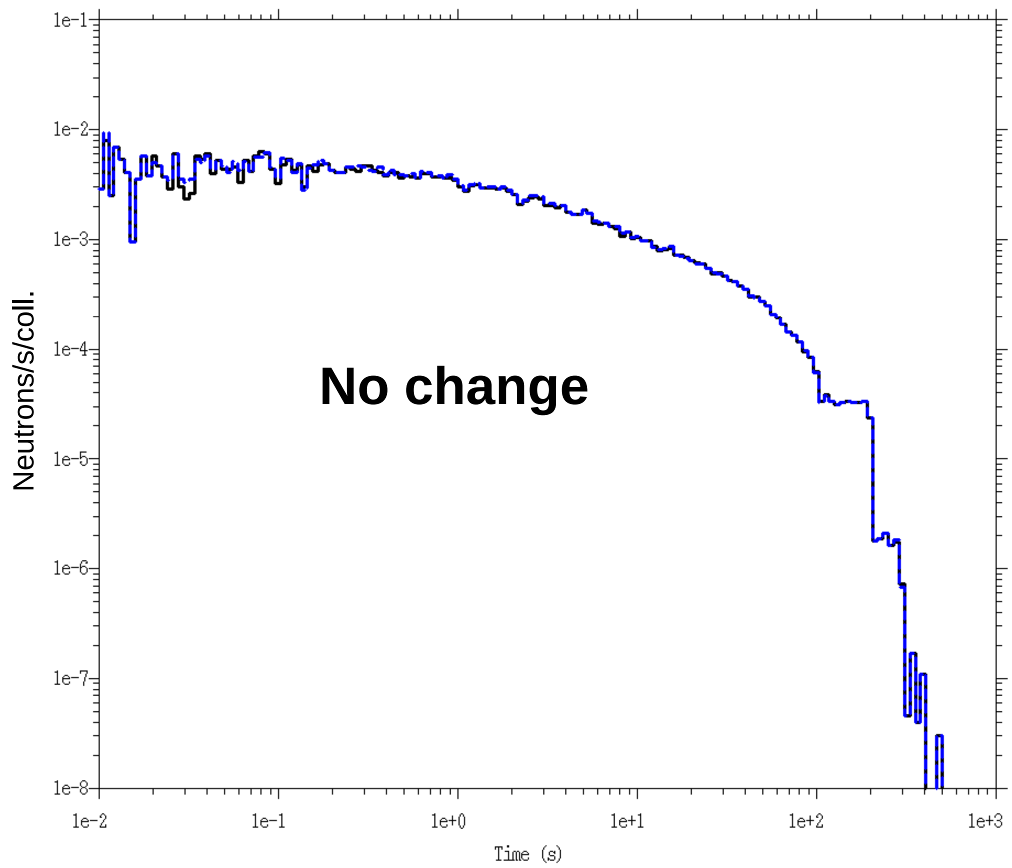
Same input file for MCNPX 2.7.0 or MCNP6 6.3.X

DN energy integration algorithm was improved – 30-MeV neutron activation of ^{137}Te with decay of ^{137}I ($T_{1/2}$=24s)

Energy Spectrum



Time Spectrum



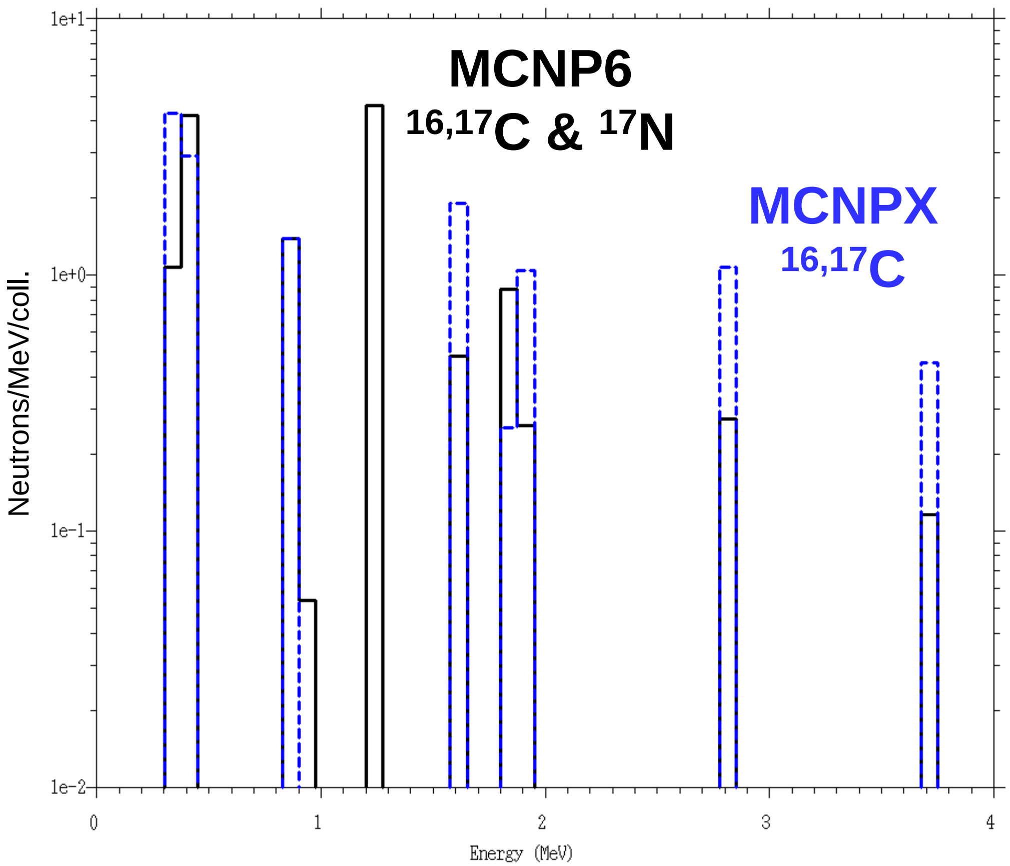
DN energy integration algorithm was improved – 1-MeV neutron activation of ^{17}C with decay of ^{16}C & ^{17}N ($T_{1/2}$=4s)

```
1-MeV neutrons into C-17
1  1  -1.0    -1  imp:n=1
2  0           1  imp:n=0

1  so  1.0

mode n
m1   6017 1
sdef par=n  erg=1
ACT  NONFISS=n DN=model
lca  7j -2
f1:n  1
t1    100 1e37
e1    1e-3 199i 10
f11:n 1
t11   0.001e8 199log 1000e8
print
nps  100000
```

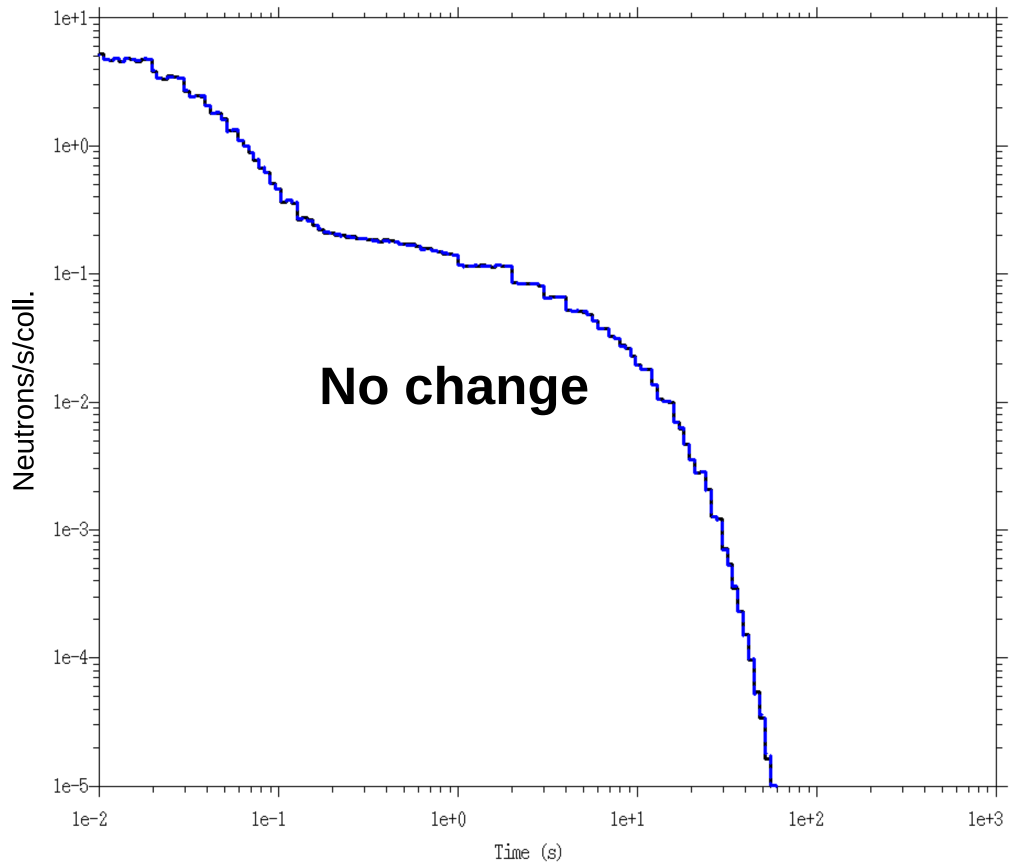
Same input file for MCNPX 2.7.0 or MCNP6 6.3.X

DN energy integration algorithm was improved – 1-MeV neutron activation of ^{17}C with decay of ^{16}C & ^{17}N ($T_{1/2}$=4s)

Energy Spectrum



Time Spectrum



DG bin-wise data & algorithms were improved – higher fidelity data incorporated into Release 2 of delayed library

Previously, the ~20-year-old DG library consisted of ENDF/B-V,VI data placed in a 25-bin format. The latest ENDF/ B-VII data has been placed into a 1000-bin format for 1171 nuclides within the new delayed library (shown in blue). Results will be compared to next-generation DG data recently produced by CGM. The bin structure can now be easily modified and updated within this file.

```
1000        750        100          0          0 1171 279 1201 0 0
 0.0000E+00 1.0000E+04 2.0000E+04 3.0000E+04 4.0000E+04 5.0000E+04
 6.0000E+04 7.0000E+04 8.0000E+04 9.0000E+04 1.0000E+05 1.1000E+05
                                 ...
 9.9000E+06 9.9100E+06 9.9200E+06 9.9300E+06 9.9400E+06 9.9500E+06
 9.9600E+06 9.9700E+06 9.9800E+06 9.9900E+06 1.0000E+07
 0.0000e+00 1.0000e+04 2.0000e+04 3.0000e+04 4.0000e+04 5.0000e+04
 6.0000e+04 7.0000e+04 8.0000e+04 9.0000e+04 1.0000e+05 1.1000e+05
                                 ...
 7.4400e+06 7.4500e+06 7.4600e+06 7.4700e+06 7.4800e+06 7.4900e+06
 7.5000e+06
 0.0000E+00 1.0000E+05 2.0000E+05 3.0000E+05 4.0000E+05 5.0000E+05
 6.0000E+05 7.0000E+05 8.0000E+05 9.0000E+05 1.0000E+06 1.1000E+06
                                 ...
 9.0000E+06 9.1000E+06 9.2000E+06 9.3000E+06 9.4000E+06 9.5000E+06
 9.6000E+06 9.7000E+06 9.8000E+06 9.9000E+06 1.0000E+07
7040 1.00000 0.00000    0    0 0.00000 0.00000    0    0 0.00000 0.00000    0    0
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 1.0440E-01
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
                                 ...
```

DG bin-wise data & algorithms were improved – DG production from thermal fission of ^{235}U

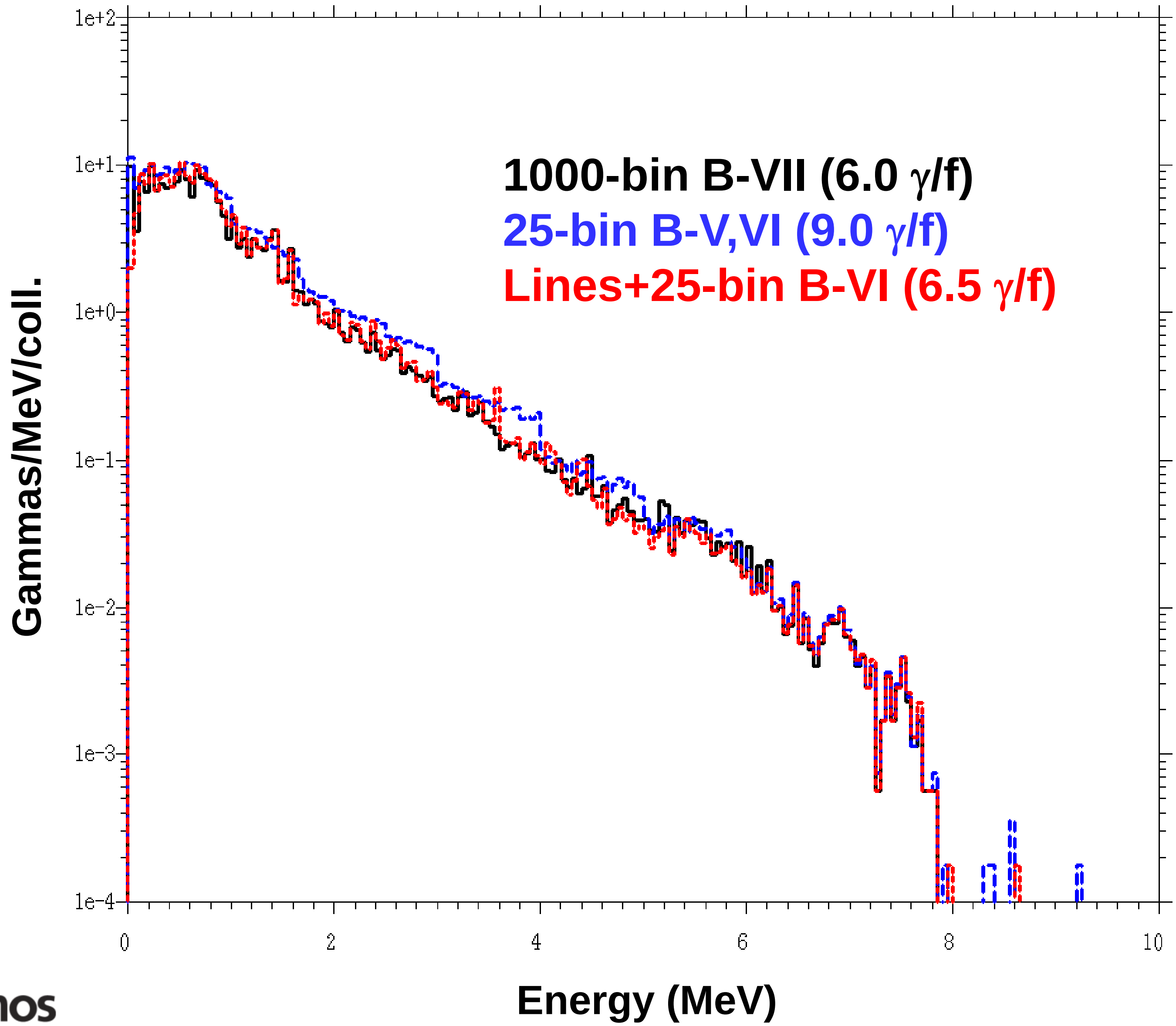
```
Thermal fission of U-235
1  1  -1.0    -1  imp:n=1
2  0           1  imp:n=0

1  so  1.0

mode n p e
m1   92235 1
sdef par=n  erg=1e-6
ACT  FISSION=n,p,e DN=model
     DG=mg    $ Cases 1 & 2
c    DG=lines $ Case 3
lca  7j -2
f11:p 1
t11   100 1e37
e11   1e-3 199i 10
print
nps  100000
```

Case 1 (1000-bin ENDF/B-VII)
- **Use MCNP6 6.3.X**
- **Release 2 of delay_library.dat**

Case 2 (25-bin ENDF/B-V,VI)
- **Use MCNPX 2.7.0**
- **Release 1 of delay_library.dat**

Case 3 (line data + 25-bin)
- **Use MCNPX 2.7.0**
- **Release 1 of delay_library.dat**

DG bin-wise data & algorithms were improved – DG production from thermal fission of ^{235}U



DB data & sampling algorithms have been incorporated – includes a 100-bin structure for 1201 nuclides

DB data has been extracted from ENDF/B-VII files for 1201 nuclides and binned into a 100-bin energy structure (0-10 MeV). This data has been incorporated into the **delay_library.dat** file (shown in green). Bench-marking of this data is underway.

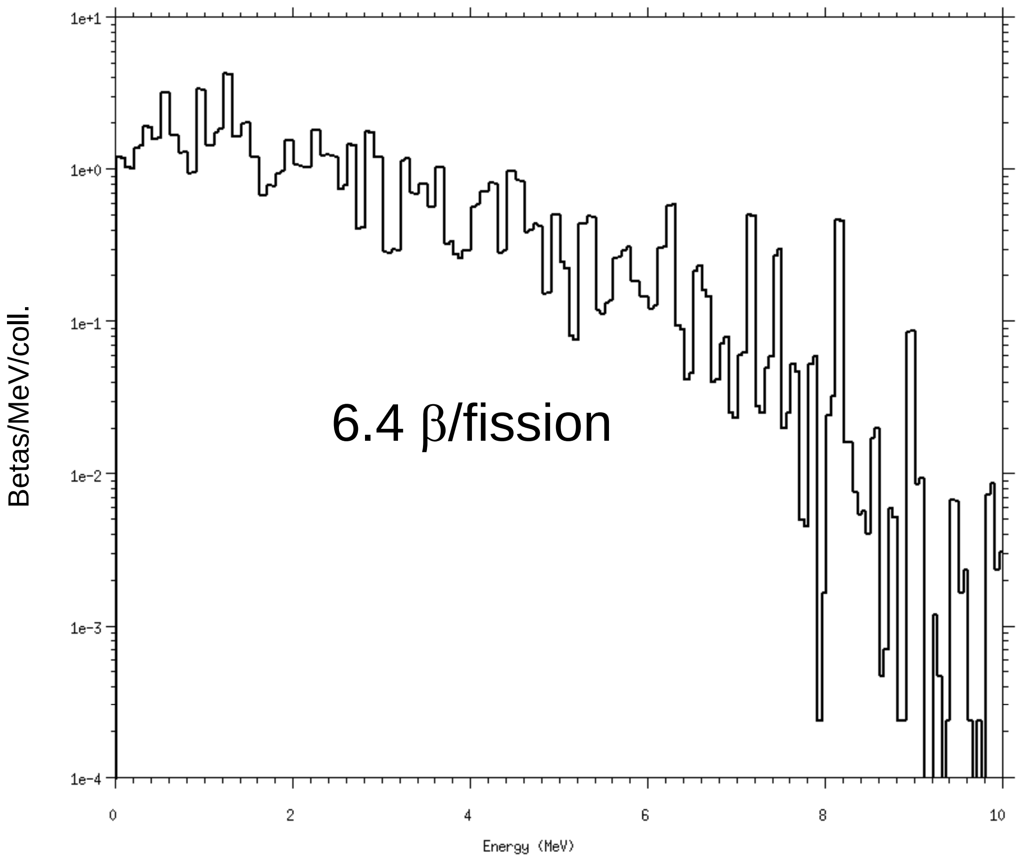
```
1000        750         100           0           0 1171 279 1201 0 0
 0.0000E+00 1.0000E+04 2.0000E+04 3.0000E+04 4.0000E+04 5.0000E+04
 6.0000E+04 7.0000E+04 8.0000E+04 9.0000E+04 1.0000E+05 1.1000E+05
                                ...
 9.9000E+06 9.9100E+06 9.9200E+06 9.9300E+06 9.9400E+06 9.9500E+06
 9.9600E+06 9.9700E+06 9.9800E+06 9.9900E+06 1.0000E+07
 0.0000e+00 1.0000e+04 2.0000e+04 3.0000e+04 4.0000e+04 5.0000e+04
 6.0000e+04 7.0000e+04 8.0000e+04 9.0000e+04 1.0000e+05 1.1000e+05
                                ...
 7.4400e+06 7.4500e+06 7.4600e+06 7.4700e+06 7.4800e+06 7.4900e+06
 7.5000e+06
 0.0000E+00 1.0000E+05 2.0000E+05 3.0000E+05 4.0000E+05 5.0000E+05
 6.0000E+05 7.0000E+05 8.0000E+05 9.0000E+05 1.0000E+06 1.1000E+06
                                ...
 9.0000E+06 9.1000E+06 9.2000E+06 9.3000E+06 9.4000E+06 9.5000E+06
 9.6000E+06 9.7000E+06 9.8000E+06 9.9000E+06 1.0000E+07
                                ...
 3010 0.00000 0.00000   0   0 0.00000 0.00000   0   0 1.00000 0.00000   0   0
 1.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 10040 0.00000 0.00000   0   0 0.00000 0.00000   0   0 1.00000 0.00000   0   0
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 1.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
                                ...
```

DB data & sampling algorithms have been incorporated – thermal fission of ^{235}U

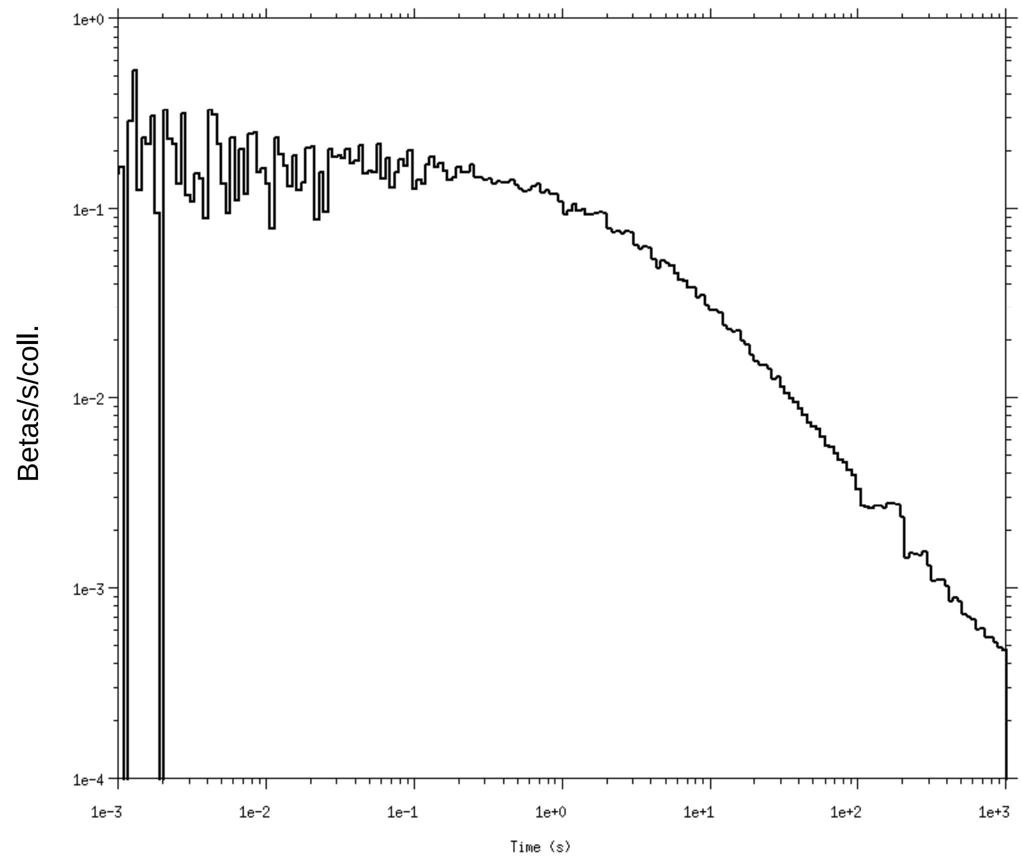
```
Thermal fission of U-235
1  1  -1.0    -1  imp:n=1
2  0           1  imp:n=0

1  so  1.0

mode n p e
m1   92235 1
sdef par=n  erg=1e-6
ACT  FISSION=n,p,e DN=model DG=mg
lca  7j -2
f21:e 1
t21   100 1e37
e21   1e-3 199i 10
f31:e 1
t31   .001e8 199log 1000e8
print
nps  100000
```

DB data & sampling algorithms have been incorporated – thermal fission of ^{235}U

Energy Spectrum



Time Spectrum

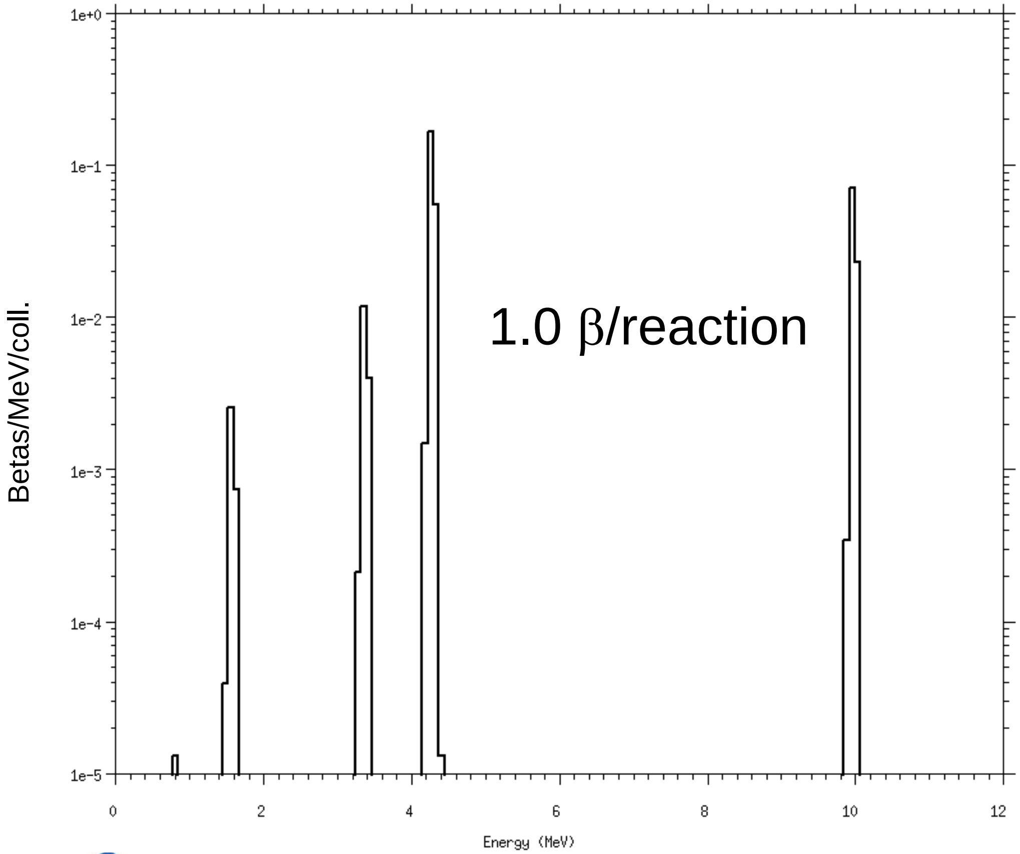


DB data & sampling algorithms have been incorporated – 12-MeV neutron activation of ^{16}O with decay of ^{16}N ($T_{1/2}$=7s)

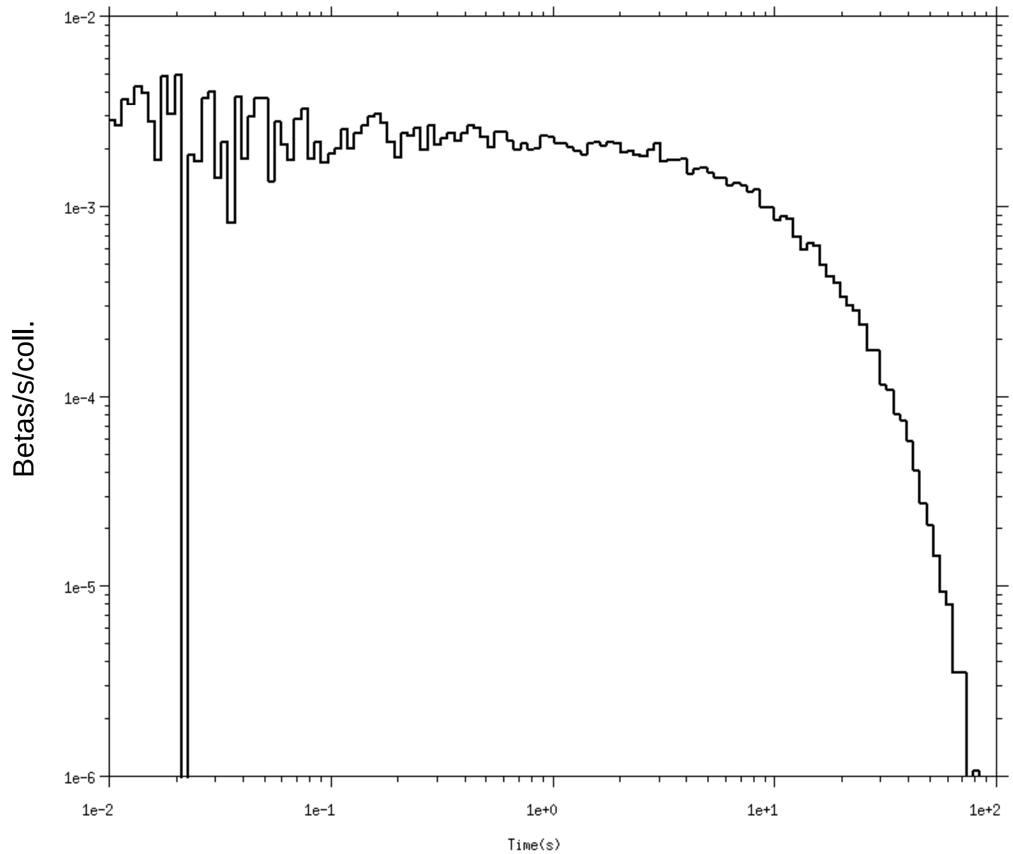
```
12-MeV neutrons into O-16
1  1  -1.0    -1  imp:n=1
2  0           1  imp:n=0

1  so  1.0

mode n p e
m1   8016 1
cut:n 2j 0 0 $ analog capture
sdef par=n  erg=12
ACT  FISSION=none NONFISS=n,p,e DN=model DG=mg
lca  7j -2
f21:e 1
t21   100 1e37
e21   1e-3 199i 15
f31:e 1
t31   .001e8 199log 1000e8
print
nps  1000000
```

DB data & sampling algorithms have been incorporated – 12-MeV neutron activation of ^{16}O with decay of ^{16}N ($T_{1/2}$=7s)

Energy Spectrum



Time Spectrum

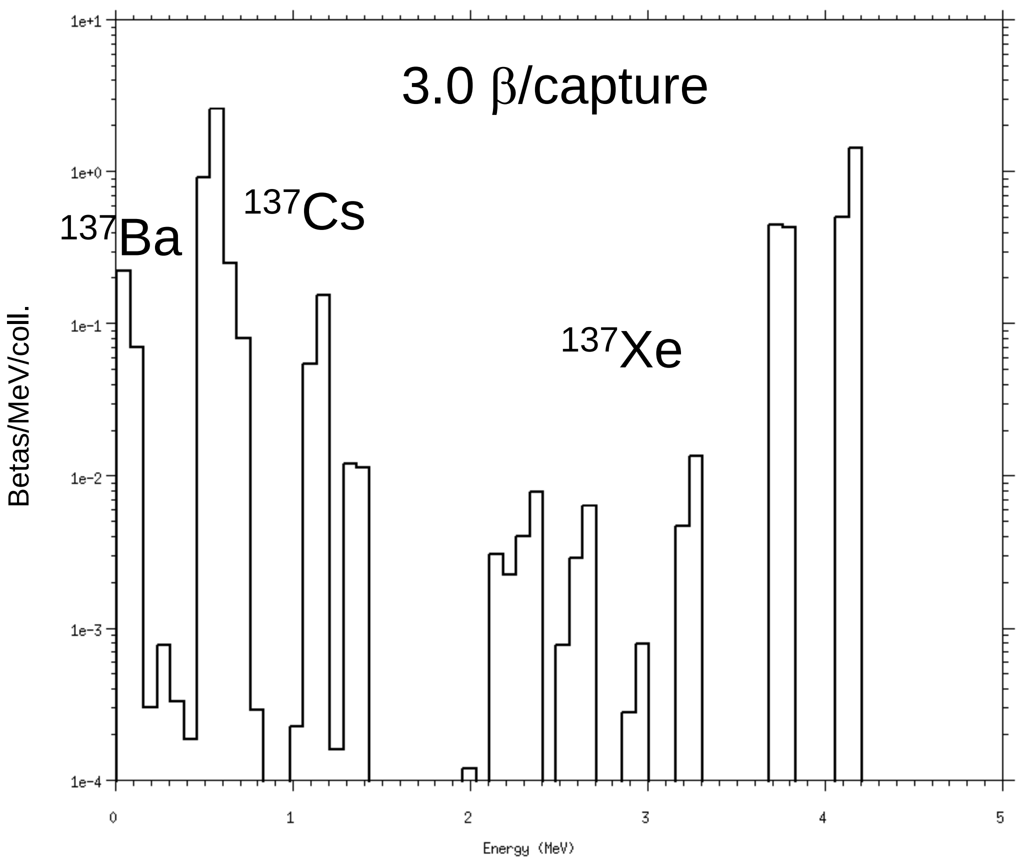


DB data & sampling algorithms have been incorporated – neutron activation of ^{136}Xe with decay of ^{137}Xe,^{137}Cs,^{137}Ba

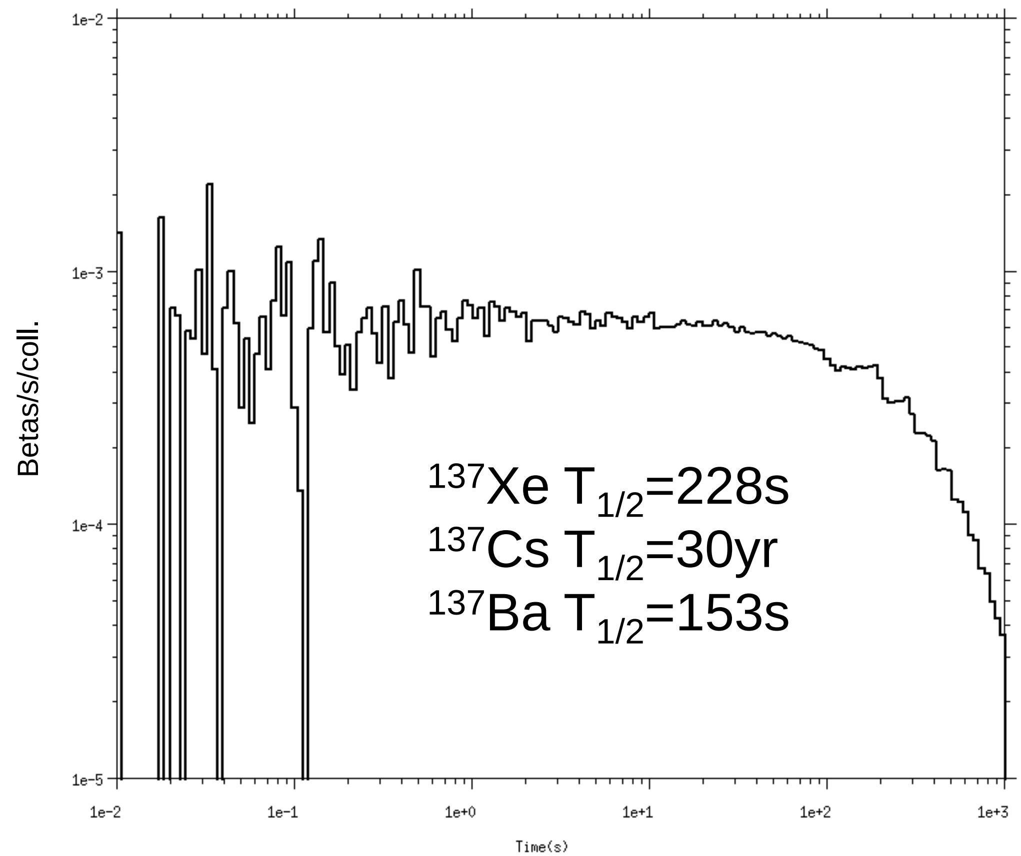
```
Thermal neutrons into Xe-136
1  1  -1.0    -1  imp:n=1
2  0           1  imp:n=0

1  so  1.0

mode n p e
m1   54136 1
cut:n 2j 0 0 $ analog capture
sdef par=n  erg=1.1e-10
ACT  FISSION=none NONFISS=n,p,e DN=model DG=mg
lca  7j -2
f21:e 1
t21   100 1e37
e21   1e-3 199i 15
f31:e 1
t31:e 0.001e8 199log 1000e8
print
nps  1000000
```

DB data & sampling algorithms have been incorporated – neutron activation of ^{136}Xe with decay of ^{137}Xe,^{137}Cs,^{137}Ba

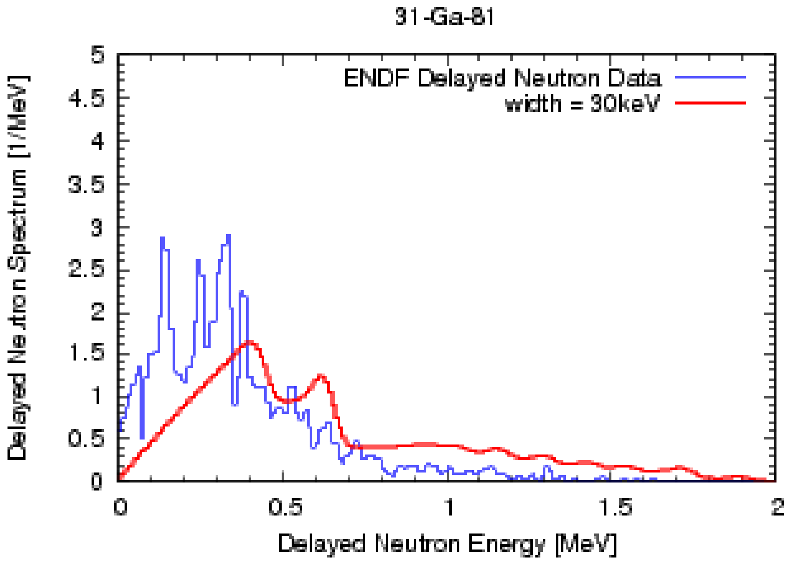
Energy Spectrum

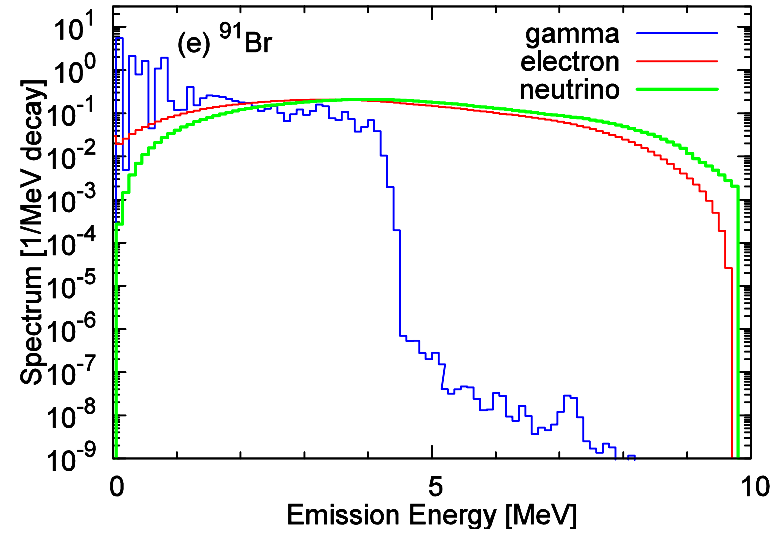


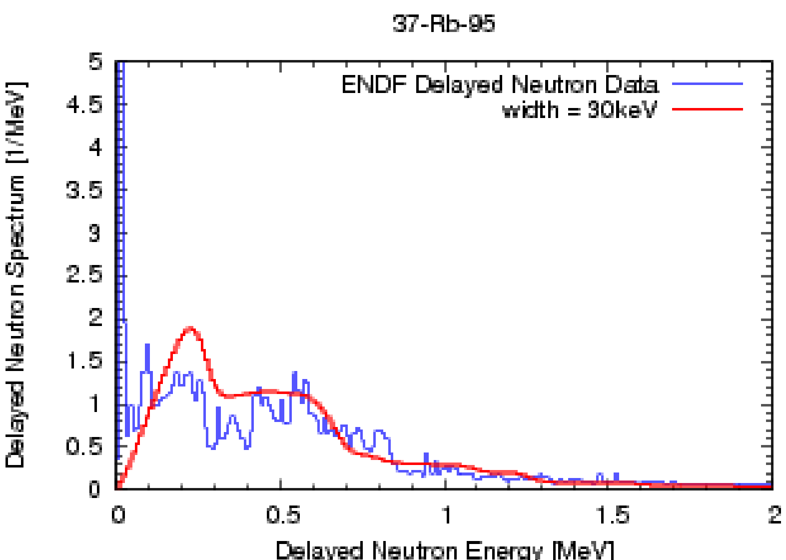
Time Spectrum

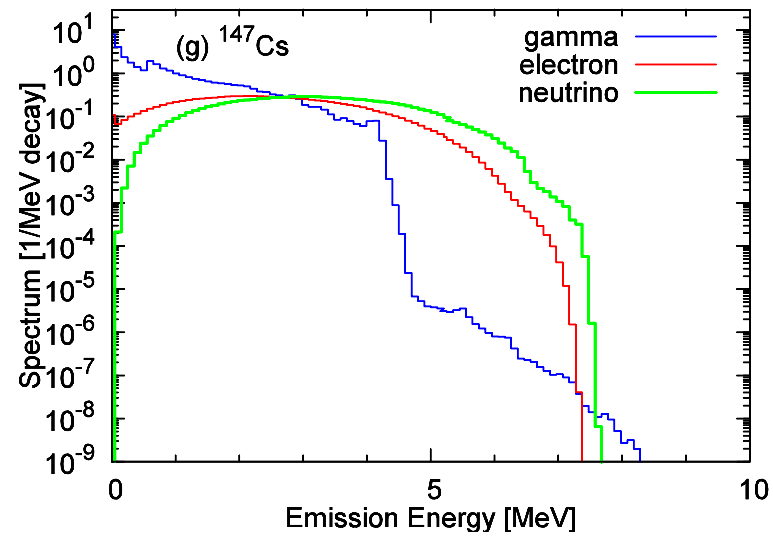


CGM 3.0 code generated delayed data for 1412 nuclides – data will be incorporated into Release 3 of delayed library









Conclusions

- MCNP6 provides DN, DG, DB for nearly all interactions (except photonuclear & proton non-fission library interactions)
- Release 2 of delay_library.dat will likely be included in Beta 3 of MCNP6 (~12/2012)
- Release 3 of delay_library.dat should be available by first public version of MCNP6 (~6/2013)
- Hope to add spontaneous beta sources (SDEF PAR=sb)
- Hope to add delayed alpha data & algorithms (ACT FISSION=a NONFISS=a)