MCNPX – New Features Demonstrated

G. W. McKinney
J. W. Durkee, J. S. Hendricks, M. R. James, D. B. Pelowitz, L. S. Waters
Los Alamos National Laboratory
Los Alamos, NM

F. X. Gallmeier
Oak Ridge National Laboratory
Oak Ridge, TN

International Workshop on Monte Carlo Codes, Teddington, UK
March 26-27, 2007

Contributors

Code Development Team

Joe W. Durkee, Harry W. Egdorf, Franz Gallmeier, John S. Hendricks, Gregg W. McKinney, Teresa L. Roberts, Laurie S. Waters, Joshua P. Finch

Library Development Team

Mark B. Chadwick, Stephanie C. Frankle, Gerald M. Hale, Robert C. Little, Robert MacFarlane, Morgan C. White, Phillip G. Young

Physics Development Team

David G. Madland, Stepan Mashnik, Richard E. Prael, Arnold J. Sierk, Jean-Christophe David, Alfredo Ferrari

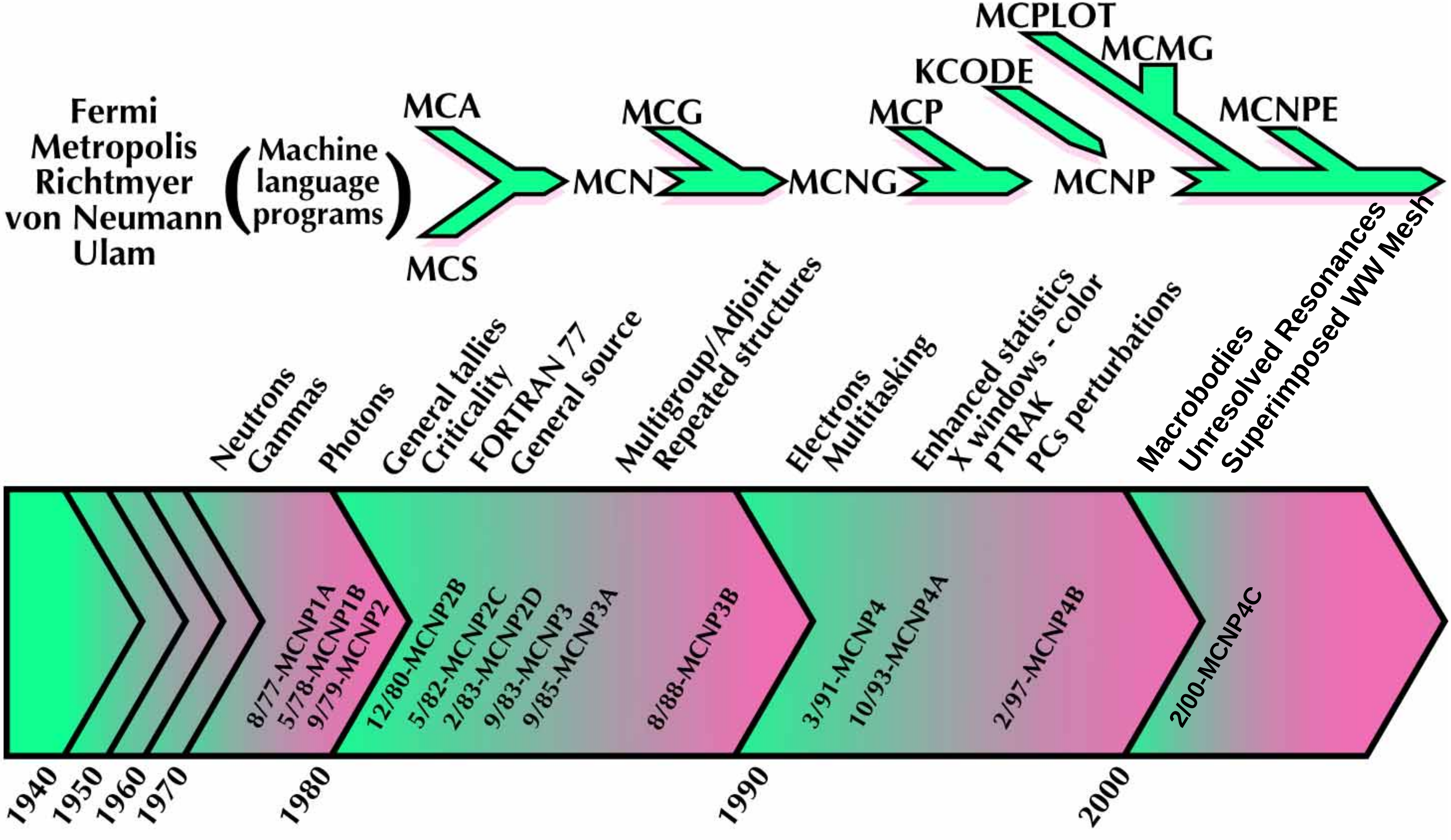
Outline

- **Overview**
- **Development History**
- **User Base**
- **New 2.5.0 Features**
- **New 2.6.x Features**
- **Future Development**

Overview

- **Monte Carlo radiation transport code**
  - Extends MCNP 4C to virtually all particles and energies
  - 34 particle types (n,p,e, 5 Leptons, 11 Baryons, 11 Mesons, 4 LI)
  - Continuous energy (roughly 0-100 GeV)
  - Data libraries below ~ 150 MeV (n,p,e,h) and 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 PVM or MPI)

HISTORY OF MCNP DEVELOPMENT



Fermi
Metropolis
Richtmyer
von Neumann
Ulam

(Machine
language
programs)

MCA

MCS

MCN

MCG

MCNG

MCP

KCODE

MCPLOT

MCMG

MCNP

MCNPE

Neutrons
Gammas

Photons

General tallies
Criticality
FORTRAN 77
General source

Multigroup/Adjoint
Repeated structures

Electrons
Multitasking

Enhanced statistics
X windows - color
PTRAK
PCs perturbations

Macrobodies
Unresolved Resonances
Superimposed WW Mesh

8/77-MCNP1A
5/78-MCNP1B
9/79-MCNP2

12/80-MCNP2B
5/82-MCNP2C
2/83-MCNP2D
9/83-MCNP3
9/85-MCNP3A

8/88-MCNP3B

3/91-MCNP4
10/93-MCNP4A

2/97-MCNP4B

2/00-MCNP4C

1940
1950
1960
1970
1980
1990
2000

Development History

- **MCNP & LAHET Merger Project 1995**
- **Version 2.1.5 November 14, 1999**
  - HISTP/HTAPE3X, Mesh & radiography tallies, CEM
- **Version 2.3.0 April 27, 2002**
  - Proton libraries
- **Version 2.4.0 August 1, 2002**
  - Update to MCNP 4C, Fortran 90, Windows PC support
- **Version 2.5.0 March 21, 2005**
  - Twenty-eight features

User Base

- **Over 2000 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://rsicc.ornl.gov
  - Limited access to MCNPX web site
    - http://mcnpx.lanl.gov (some documentation)
- **Over 1500 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	13
Detectors, experiments, Threat Reduction	39	12
ATW, ADS, Energy Amplifiers	37	11
Fuel cycles, beginning to end, including storage	32	10
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
Materials studies (IFMIF)	6	2
Radioactive Ion Beams	5	2
Irradiation Facilities	4	1
Neutrino Targets	4	1
Light Sources, electron machines	3	1

New 2.5.0 Features

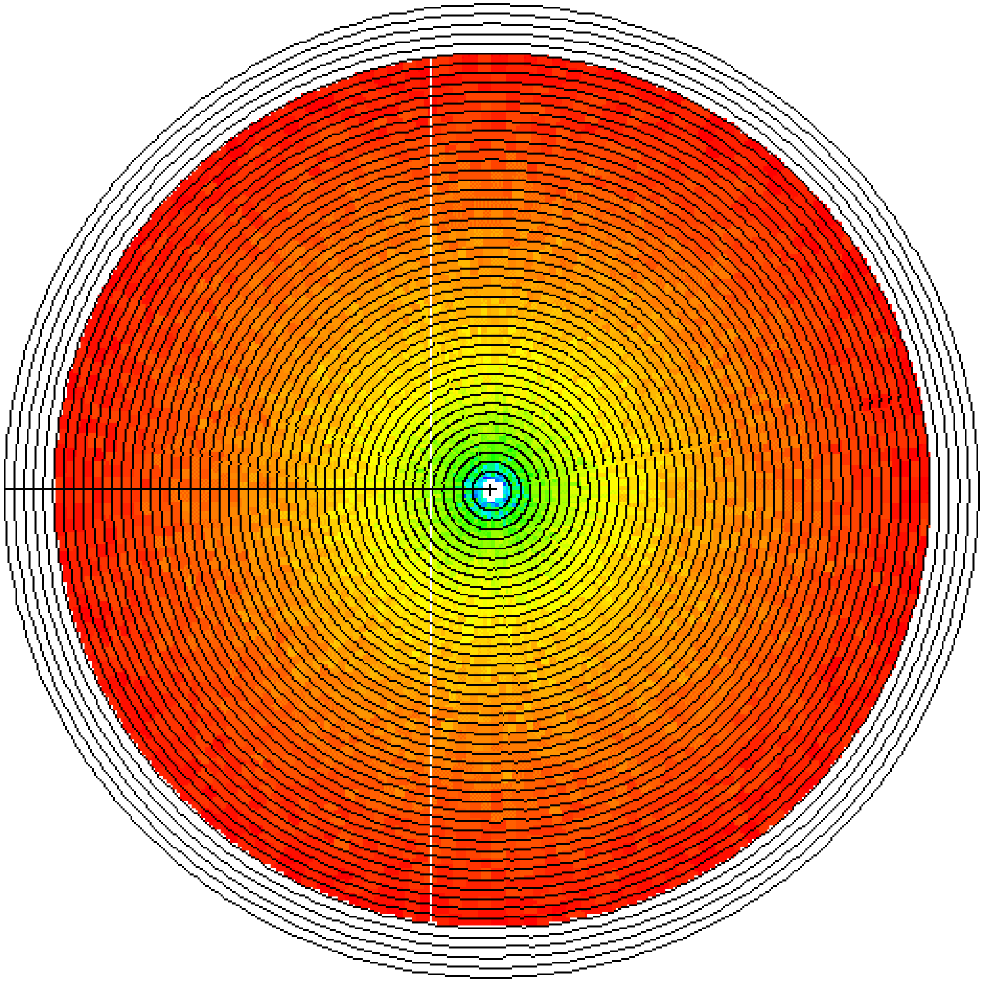
- **User-interface enhancements (15)**
  - 5 new source options
  - 4 new tally options
  - 3 new graphics options
  - 3 other miscellaneous improvements
- **Physics enhancements (9)**
  - 4 new model physics features
  - 2 new neutron physics features
  - 3 new photon physics features
- **Infrastructure enhancements (4)**

User-Interface Enhancements

- **Five new source options**
  - Positron sources
  - Spontaneous fission sources
  - Multiple source particles
  - Default VEC for cylindrical sources
  - Extension of the TR keyword

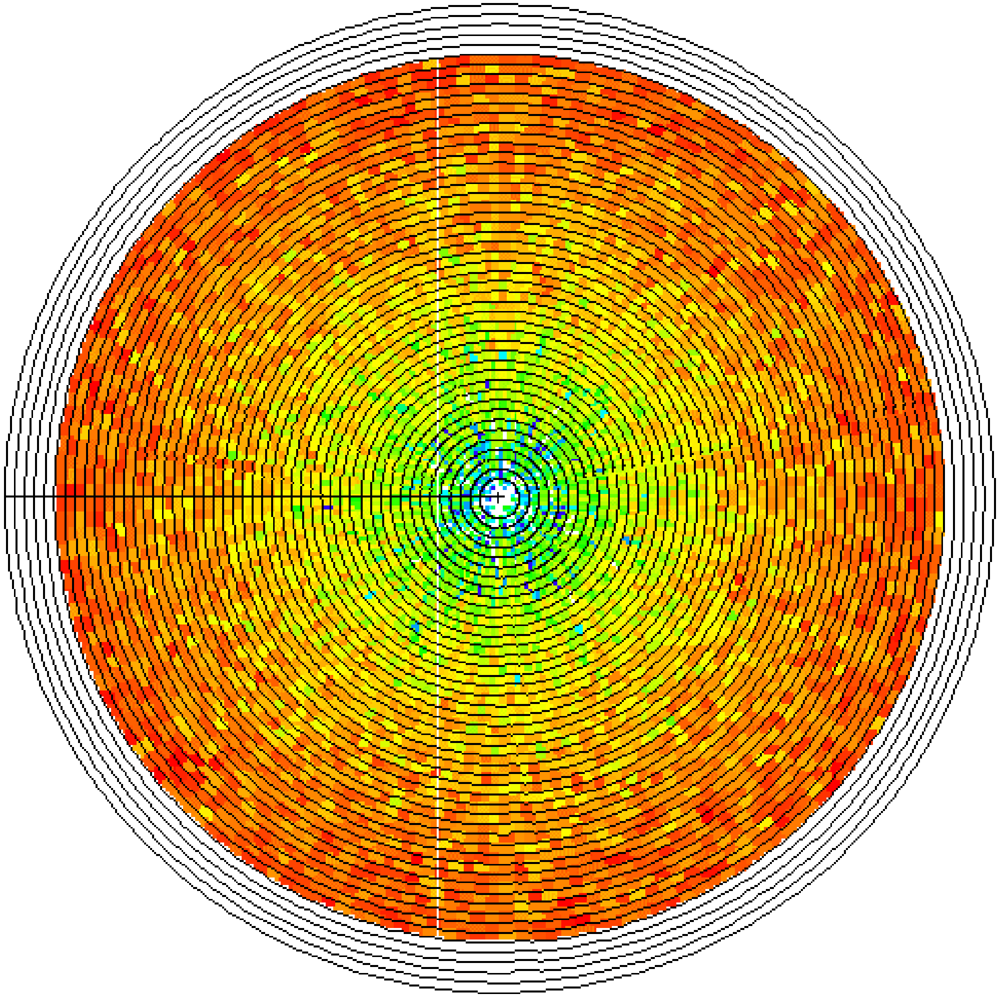
Positron Sources

```
1.0 MeV Positron Source on a Disk
1   0     -1    imp:n=1
2   0      1    imp:n=0

1 SPH 0 0 0 100

mode e
sdef  par=-e erg=1.0
      pos=0 0 0 rad=d1 axs=0 0 1 ext=0
si1   0 90
sp1   -21 1
nps  1000000
tmesh
 cmesh2   e
 cora2   2 48i 100
 corb2  -1 1
 corc2   2 178i 360
endmd
print
```



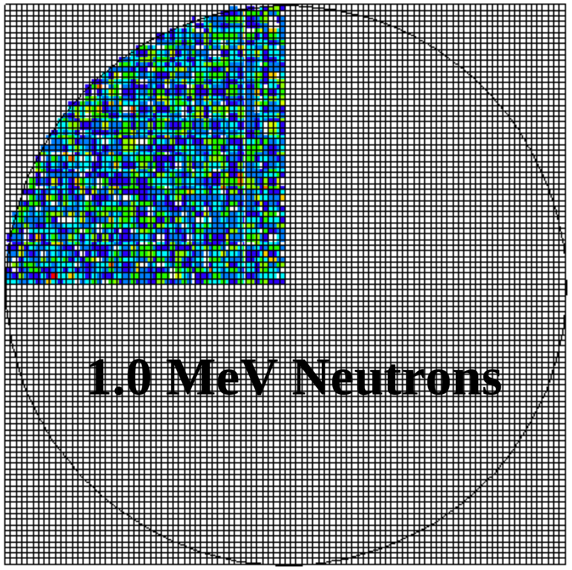
Spontaneous Fission Sources

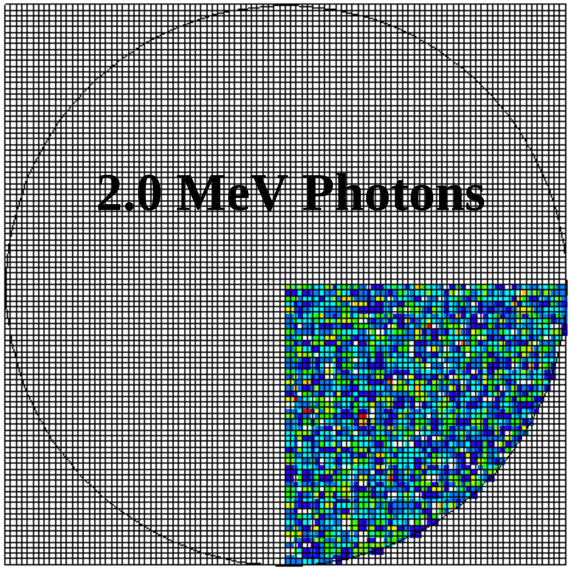
```
Pu-239 Spontaneous Fission Source in H2O
1  1 -1.0   -1    imp:n=1
2  0         1    imp:n=0

1 SPH 0 0 0 100

sdef  par=sf
      pos=0 0 0 rad=d1 axs=0 0 1 ext=0
si1   0 90
sp1   -21 1
m1    1001 2 8016 1 94239 1.e-4
nps  100000
tmesh
 cmesh2  n
 cora2   2 48i 100
 corb2  -1 1
 corc2   2 178i 360
endmd
print
```



Multiple Source Particles / TR Extension

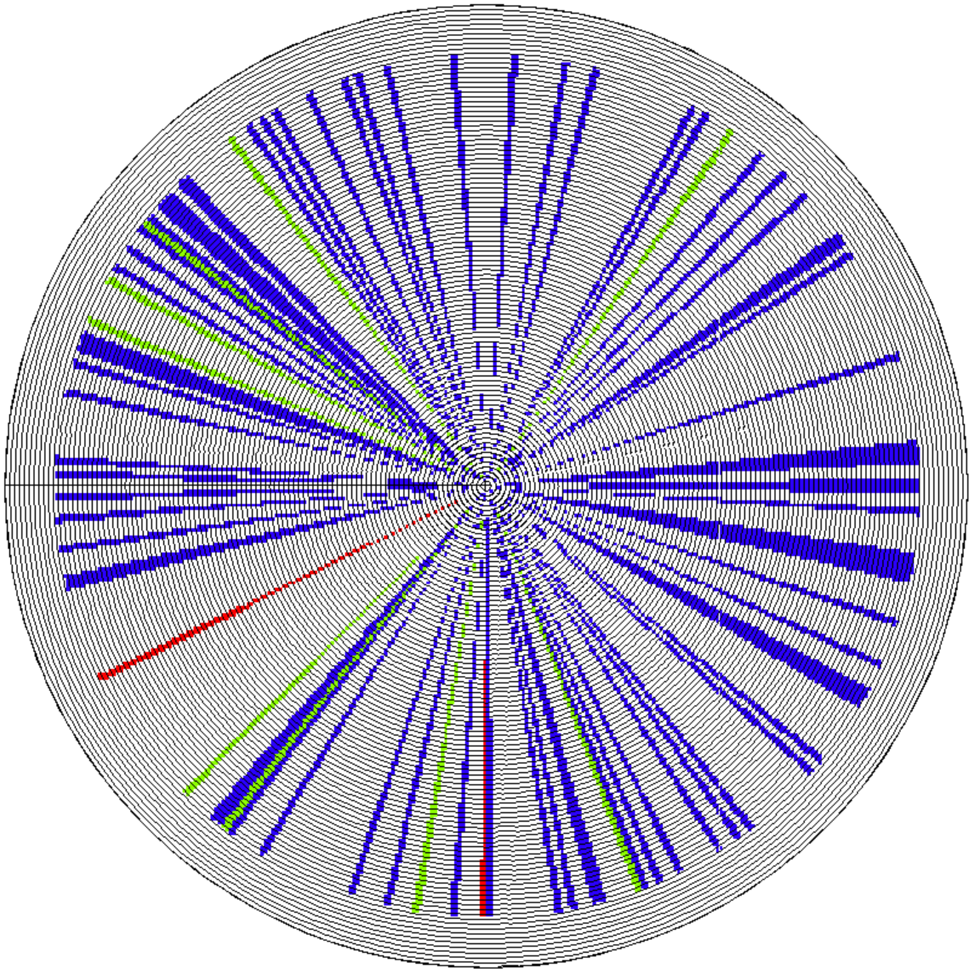
```
Distribution for PAR and TR Keywords
1  0    -1    imp:n=1
2  0     1    imp:n=0

1 SPH 0 0 0 100

mode n p
sdef  par=d1 erg=fpar=d2 tr=fpar=d3
      x=d4 y=d5 z=0 cell=1
si1   L n   p
sp1     1   1
ds2   L 1.0 2.0
ds3   L 1   2
si4   -50 50
sp4     0  1
si5   -50 50
sp5     0  1
tr1   -50  50 0
tr2    50 -50 0
nps  10000
tmesh
 rmesh2  n p
 cora2  -100 99i 100
 corb2  -100 99i 100
 corc2  -1 1
endmd
```





Default VEC for Cylindrical Sources

```
Cylindrical Source with Default VEC
1   0     -1 2   imp:n=1
2   0     -2:1   imp:n=0

1 SPH 0 0 0 100
2 SPH 0 0 0 1

sdef pos=0 0 0 rad=90 axs=0 0 1 ext=0
     dir=1 nrm=-1
nps  100
tmesh
 cmesh1:n traks
 cora1 1 98i 100
 corb1 -1 1
 corc1 1 358i 360
endmd
```



User-Interface Enhancements

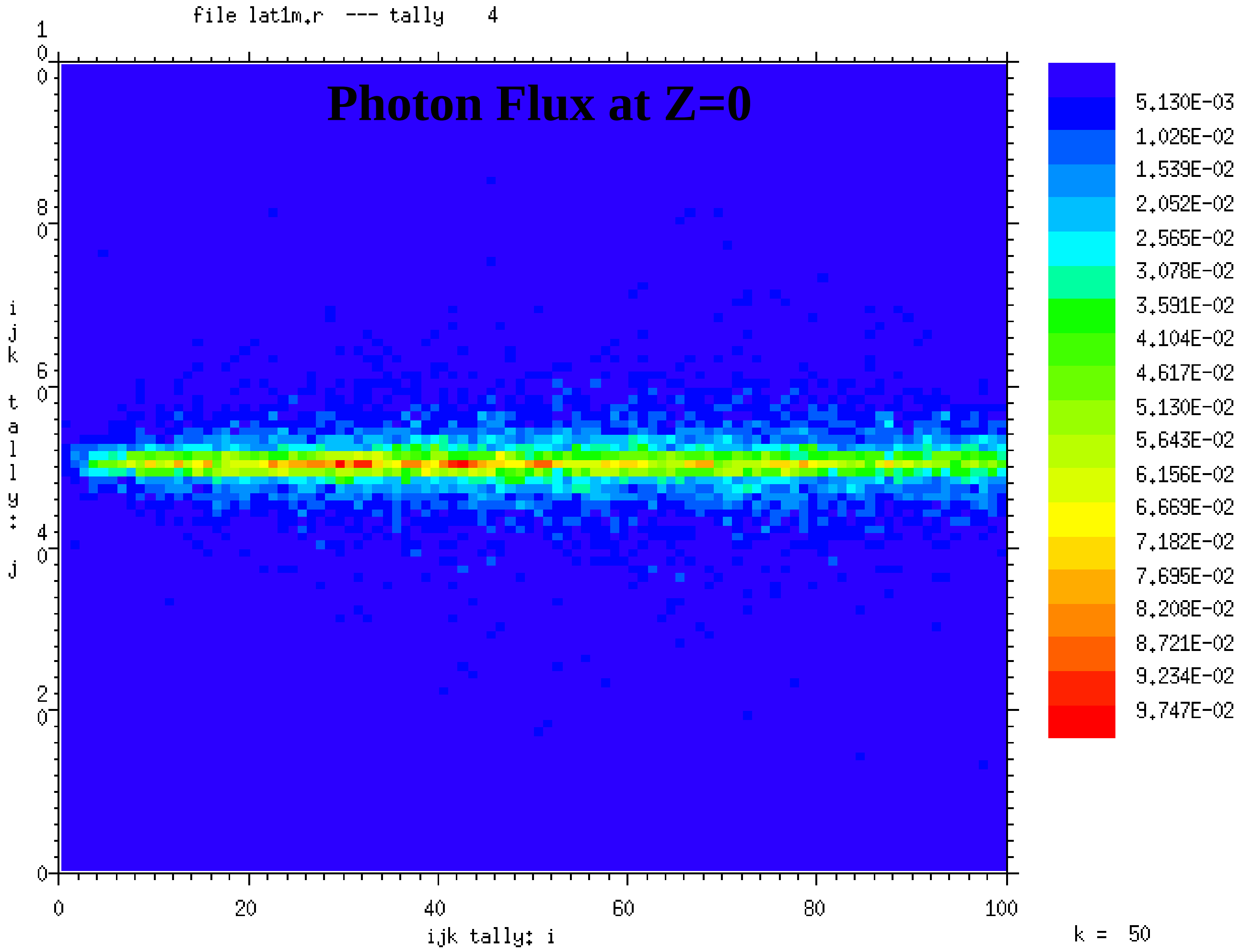
- **Four new tally options**
  - Lattice tally speedup
  - Anticoincidence pulse-height tally
  - Coincidence capture pulse-height tally
  - Residual nuclei pulse-height tally

Lattice Tally Speedup

```
5 MeV Photons into a 100x100x100 Water Phantom
1 1 -1.0 -1 u=1 imp:p=1
2 1 -1.0  1 u=1 imp:p=1
3 0      -2 u=2 fill=1 imp:p=1
4 0      -3 u=3 imp:p=1
     lat=1 fill=-50:49 -50:49 -50:49 2 999999R
5 0      -4 fill=3 imp:p=1
6 0       4        imp:p=0

1 sph 0 0 0 .05
2 sph 0 0 0 10
3 rpp -.1 .1 -.1 .1 -.1 .1
4 rpp -10.099 9.899 -10.099 9.899 -10.099 9.899

mode   p
m1     1000 2 8000 1
sdef   erg=5 pos=-10.098 0 0 vec=1 0 0 dir=1
nps    100000
f4:p (1<3<4[-50:49 -50:49 -50:49]<5)
sd4  1
fm4  1.0
de4  1e-11 100
df4  1     1
talnp
```

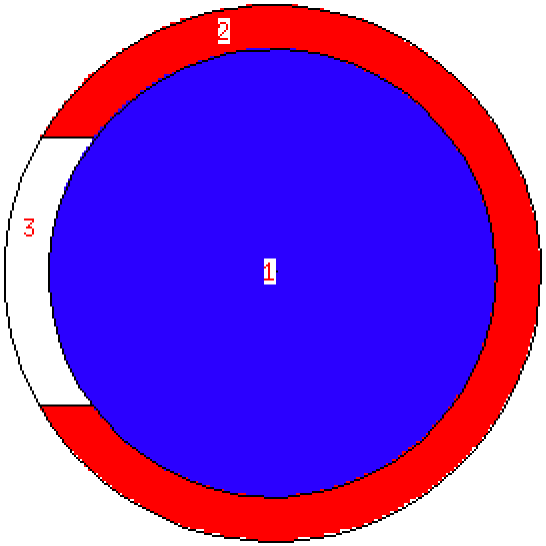
	Startup Time (m)	Tracking Time (part./m)	Speedup
MCNPX 2.5.0	.02	23,300	17,260
MCNPX 2.4.0	230	1.35	1
MCNP5 1.20	226	1.47	~1
MCNP5 1.30	220	Crashed	--

Lattice Tally Speedup



Anticoincidence Pulse-Height Tally

```
Anticoincidence PHT 1 MeV Photons => Plastic/BGO
1 1 -7.130 -1       imp:p=1
2 2 -1.032  1 -2  3 imp:p=1
3 0         1 -2 -3 imp:p=1
4 0         2       imp:p=0

1 SPH 0 0 0 5.0
2 SPH 0 0 0 6.0
3 RCC -7 0 0 4 0 0 3.0

mode p e
sdef sur=2 nrm=-1 par=p erg=1.0
nps  100000
m1   83000 -0.671 32000 -0.175 8000 -0.154
m2   6000 -0.9153 1000 -0.0847
f26:e  2                   $ Plastic energy dep.
ft26   GEB 0 0.1098 0
sd26   1
f36:e  1                   $ BGO energy dep.
ft36   GEB 0 0.1098 0
sd36   1
f18:e  1                   $ Plastic/BGO PHT
e18    0. 1.0
fu18   0. 99i 1.0
ft18   phl 1 26 1 1 36 1
fq18   u e
```



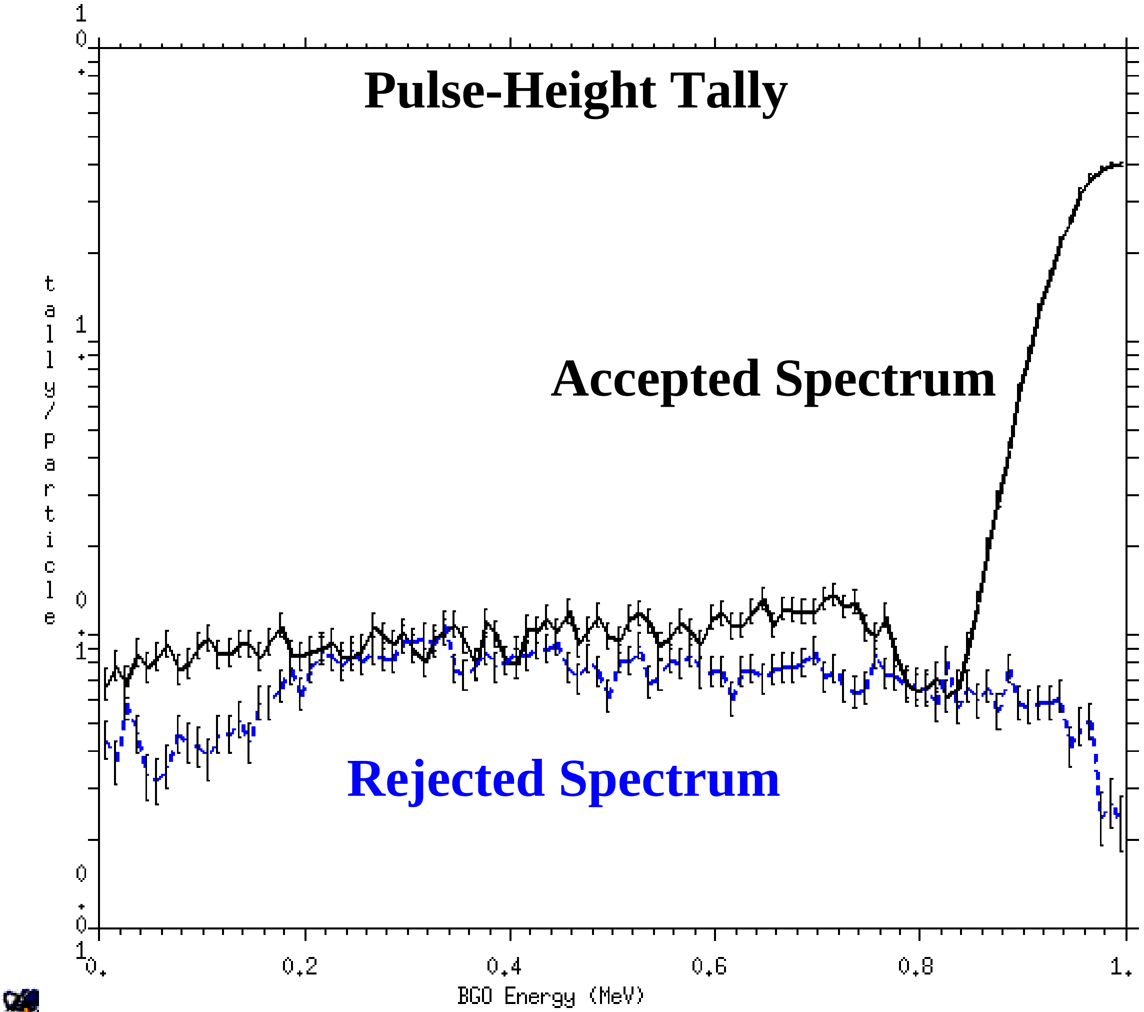
Anticoincidence Pulse-Height Tally

```
1tally  18        nps =   100000
+                                    ACS/BGO Pulse Height Response - all particles
           tally type 8    pulse height distribution.                   units   number
           particle(s): photon      electron
           this tally is modified by   ft  phl

 cell  1
       energy:       0.0000E+00           1.0000E+00             total
    user bin
    0.0000E+00   1.30000E-04 0.2773   8.84300E-02 0.0102   8.85600E-02 0.0101
    1.0000E-02   6.80000E-04 0.1212   4.40000E-04 0.1507   1.12000E-03 0.0944
    2.0000E-02   7.90000E-04 0.1125   3.70000E-04 0.1644   1.16000E-03 0.0928
    3.0000E-02   6.90000E-04 0.1203   5.90000E-04 0.1302   1.28000E-03 0.0883
    4.0000E-02   8.70000E-04 0.1072   4.60000E-04 0.1474   1.33000E-03 0.0867
    5.0000E-02   7.80000E-04 0.1132   3.30000E-04 0.1740   1.11000E-03 0.0949
    6.0000E-02   8.40000E-04 0.1091   3.20000E-04 0.1767   1.16000E-03 0.0928
    7.0000E-02   9.30000E-04 0.1036   3.60000E-04 0.1666   1.29000E-03 0.0880
    8.0000E-02   7.60000E-04 0.1147   4.60000E-04 0.1474   1.22000E-03 0.0905
    9.0000E-02   8.00000E-04 0.1118   4.30000E-04 0.1525   1.23000E-03 0.0901
    1.0000E-01   9.20000E-04 0.1042   4.20000E-04 0.1543   1.34000E-03 0.0863
    1.1000E-01   9.80000E-04 0.1010   3.80000E-04 0.1622   1.36000E-03 0.0857
    1.2000E-01   8.60000E-04 0.1078   4.60000E-04 0.1474   1.32000E-03 0.0870
    1.3000E-01   8.70000E-04 0.1072   4.60000E-04 0.1474   1.33000E-03 0.0867
    1.4000E-01   9.30000E-04 0.1036   5.20000E-04 0.1386   1.45000E-03 0.0830
    1.5000E-01   9.30000E-04 0.1036   4.30000E-04 0.1525   1.36000E-03 0.0857
    1.6000E-01   8.40000E-04 0.1091   5.90000E-04 0.1302   1.43000E-03 0.0836
    1.7000E-01   9.50000E-04 0.1025   5.90000E-04 0.1302   1.54000E-03 0.0805
    1.8000E-01   1.08000E-03 0.0962   6.70000E-04 0.1221   1.75000E-03 0.0755
    .
    .
    .
```

Plastic

BGO

Anticoincidence Pulse-Height Tally



Coincidence Capture Pulse-Height Tally

```
Coincidence Capture Tally Pu-239 in H2O/B-10
1  1 -1.0   -1    imp:n=1
2  2 -1.0    1 -2 imp:n=1
3  0         2    imp:n=0

1 SPH 0 0 0 10
2 SPH 0 0 0 20

sdef  par=sf pos=0 0 0 rad=d1
si1   0 10
sp1   -21 2
m1    1001 2 8016 1 94239 1.e-4
m2    5010 1
nps   100000
f8:n  2
ft8   CAP -8 -8 5010
t8    1e2 1e5 1e8           $ 1us, 1ms, 1s
print
```

Coincidence Capture Pulse-Height Tally

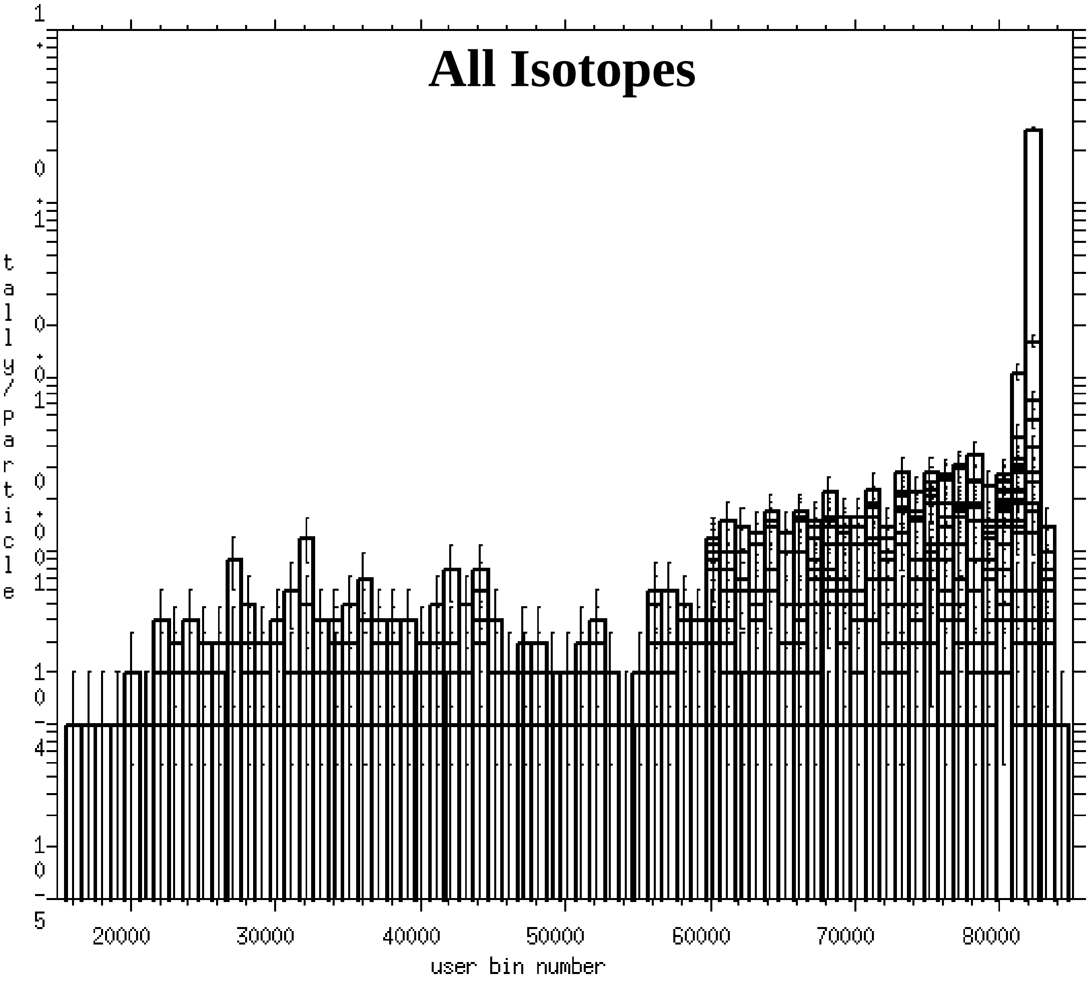
```
1 neutron captures, moments and multiplicity distributions.   tally   8                                   print table 118

 weight normalization by source fission neutrons =          215705

 cell:     2

 time bin: 1.0000E+02

 neutron captures on 10b

                             captures         captures          multiplicity fractions
                 histories  by number        by weight         by number        by weight       error

 captures =  0       38079          0      0.00000E+00      3.80790E-01      1.76533E-01       0.0040
 captures =  1       39130      39130      1.81405E-01      3.91300E-01      1.81405E-01       0.0039
 captures =  2       17769      35538      1.64753E-01      1.77690E-01      8.23764E-02       0.0068
 captures =  3        4429      13287      6.15980E-02      4.42900E-02      2.05327E-02       0.0147
 captures =  4         555       2220      1.02918E-02      5.55000E-03      2.57296E-03       0.0423
 captures =  5          38        190      8.80833E-04      3.80000E-04      1.76167E-04       0.1622

    total           100000      90365      4.18929E-01      1.00000E+00      4.63596E-01       0.0031

      factorial moments               by number               by weight

             10b                 9.03650E-01 0.0031      4.18929E-01 0.0031
        10b(10b-1)/2!            3.47660E-01 0.0076      1.61174E-01 0.0076
     10b(10b-1)(10b-2)/3!        7.02900E-02 0.0183      3.25862E-02 0.0183
  10b(10b-1) .... (10b-3)/4!     7.45000E-03 0.0520      3.45379E-03 0.0520
  10b(10b-1) .... (10b-4)/5!     3.80000E-04 0.1622      1.76167E-04 0.1622
```

Coincidence Capture Pulse-Height Tally

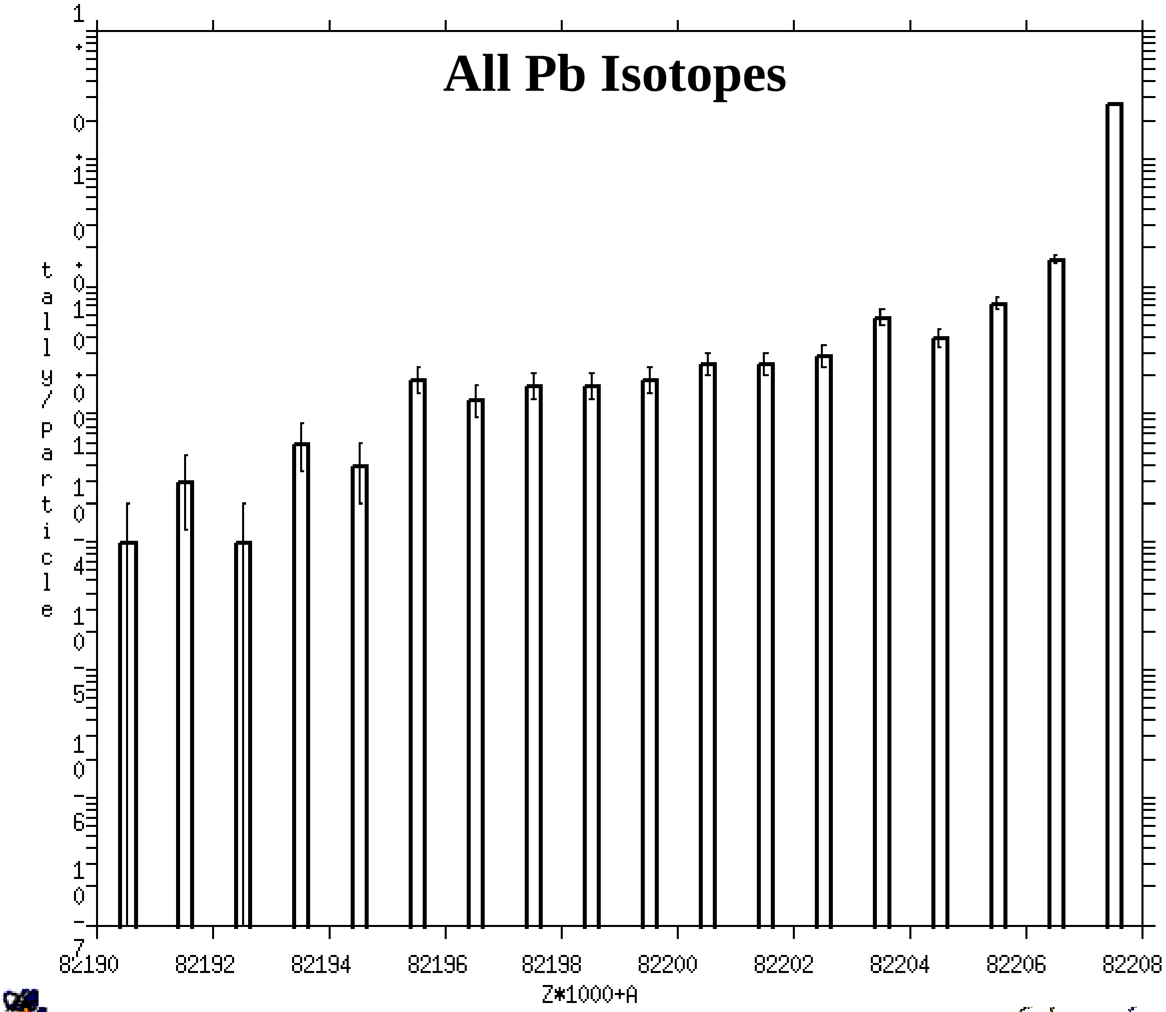
```
cell:     2

time bin: 1.0000E+05

neutron captures on 10b

                           captures         captures          multiplicity fractions
               histories  by number        by weight        by number        by weight       error

captures =  0      64457          0      0.00000E+00      6.44570E-01      2.98820E-01      0.0023
captures =  1      27555      27555      1.27744E-01      2.75550E-01      1.27744E-01      0.0051
captures =  2       6212      12424      5.75972E-02      6.21200E-02      2.87986E-02      0.0123
captures =  3       1263       3789      1.75657E-02      1.26300E-02      5.85522E-03      0.0280
captures =  4        362       1448      6.71287E-03      3.62000E-03      1.67822E-03      0.0525
captures =  5         86        430      1.99346E-03      8.60000E-04      3.98693E-04      0.1078
captures =  6         46        276      1.27953E-03      4.60000E-04      2.13254E-04      0.1474
captures =  7         12         84      3.89421E-04      1.20000E-04      5.56315E-05      0.2887
captures >  7          7         58      2.68886E-04      7.00000E-05      3.24517E-05      0.3780

   total          100000      46064      2.13551E-01      1.00000E+00      4.63596E-01      0.0050

     factorial moments              by number               by weight

            10b                4.60640E-01 0.0050      2.13551E-01 0.0050
       10b(10b-1)/2!           1.41880E-01 0.0172      6.57750E-02 0.0172
    10b(10b-1)(10b-2)/3!       5.36700E-02 0.0533      2.48812E-02 0.0533
 10b(10b-1) .... (10b-3)/4!    2.53200E-02 0.1255      1.17383E-02 0.1255
 10b(10b-1) .... (10b-4)/5!    1.20200E-02 0.2487      5.57243E-03 0.2487
 10b(10b-1) .... (10b-5)/6!    5.08000E-03 0.4377      2.35507E-03 0.4377
 10b(10b-1) .... (10b-6)/7!    1.80000E-03 0.6758      8.34473E-04 0.6758
 10b(10b-1) .... (10b-7)/8!    5.10000E-04 0.8837      2.36434E-04 0.8837
```

Residual Nuclei Pulse-Height Tally

```
Residuals for 1.2 GeV Protons => Pb
1 1 -11. -1 imp:h 1
2 0       1 imp:h 0

1 so .01

mode h n
sdef par h erg=1200
     vec 0 0 1 dir 1
m1 82208 1
phys:h 1300 j 0
phys:n 1300 3j 0
nps 10000
f8:h 1
ft8  RES 1 99
lca  7j -2 0
```



Residual Nuclei Pulse-Height Tally

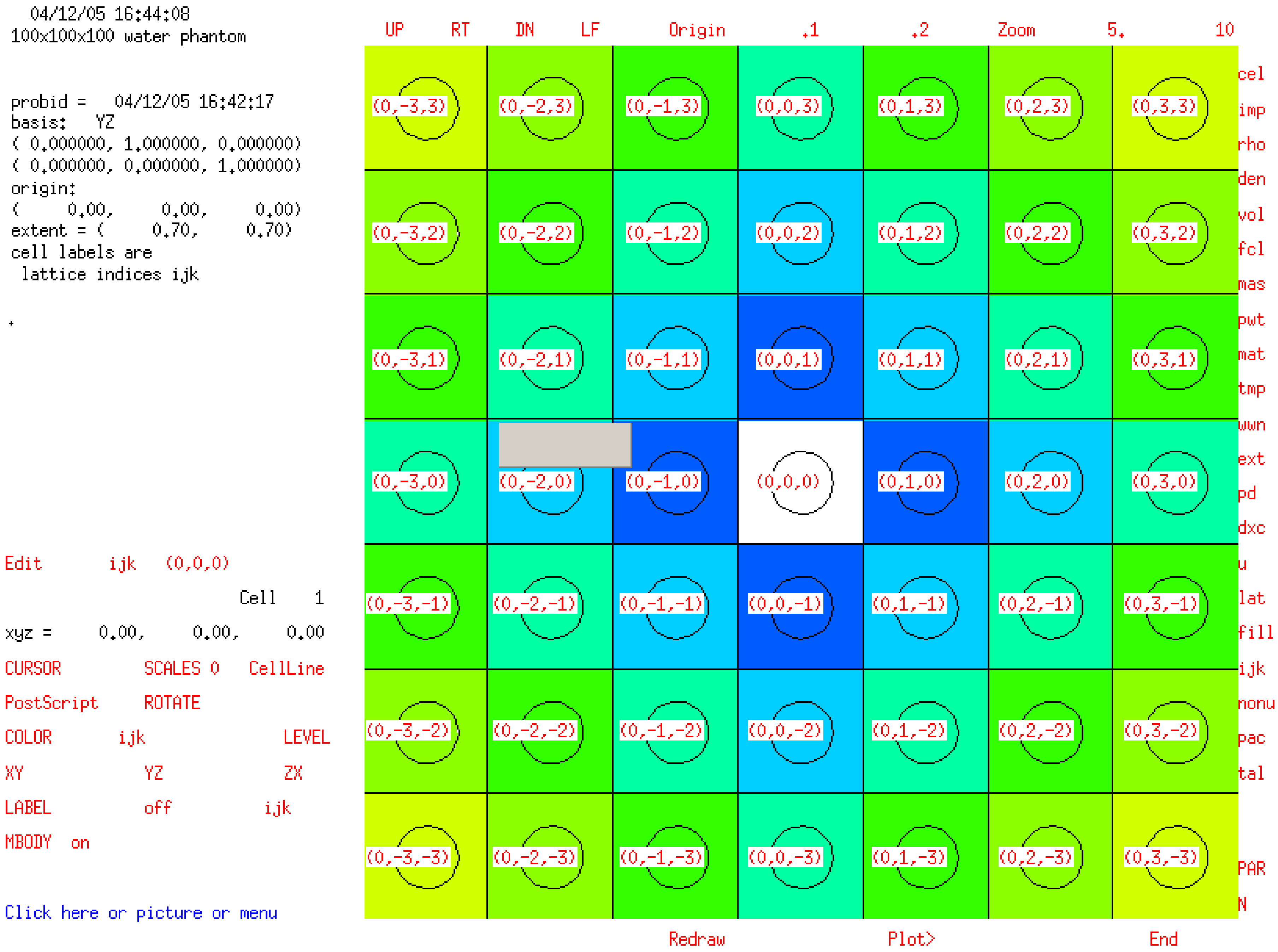


User-Interface Enhancements – 2.5.0

- **Three new graphics options**
  - Lattice index labeling
  - WWG superimposed mesh plots
  - Color contour and mesh tally plots

Lattice Index Labeling

```
5 MeV Photons => 100x100x100 Water Phantom
1 1 -1.0 -1 u=1 imp:p=1
2 1 -1.0  1 u=1 imp:p=1
3 0       -2 u=2 fill=1 imp:p=1
4 0       -3 u=3 imp:p=1
     lat=1 fill=-50:49 -50:49 -50:49 2 999999R
5 0       -4 fill=3 imp:p=1
6 0        4        imp:p=0

1 sph 0 0 0 .05
2 sph 0 0 0 10
3 rpp -.1 .1 -.1 .1 -.1 .1
4 rpp -10.099 9.899 -10.099 9.899 -10.099 9.899

mode   p
m1     1000 2 8000 1
sdef   erg=5 pos=-10.098 0 0 vec=1 0 0 dir=1
nps    100000
f4:p (1<3<4[-50:49 -50:49 -50:49]<5)
sd4  1
fm4  1.0
de4  1e-11 100
df4  1     1
talnp
```



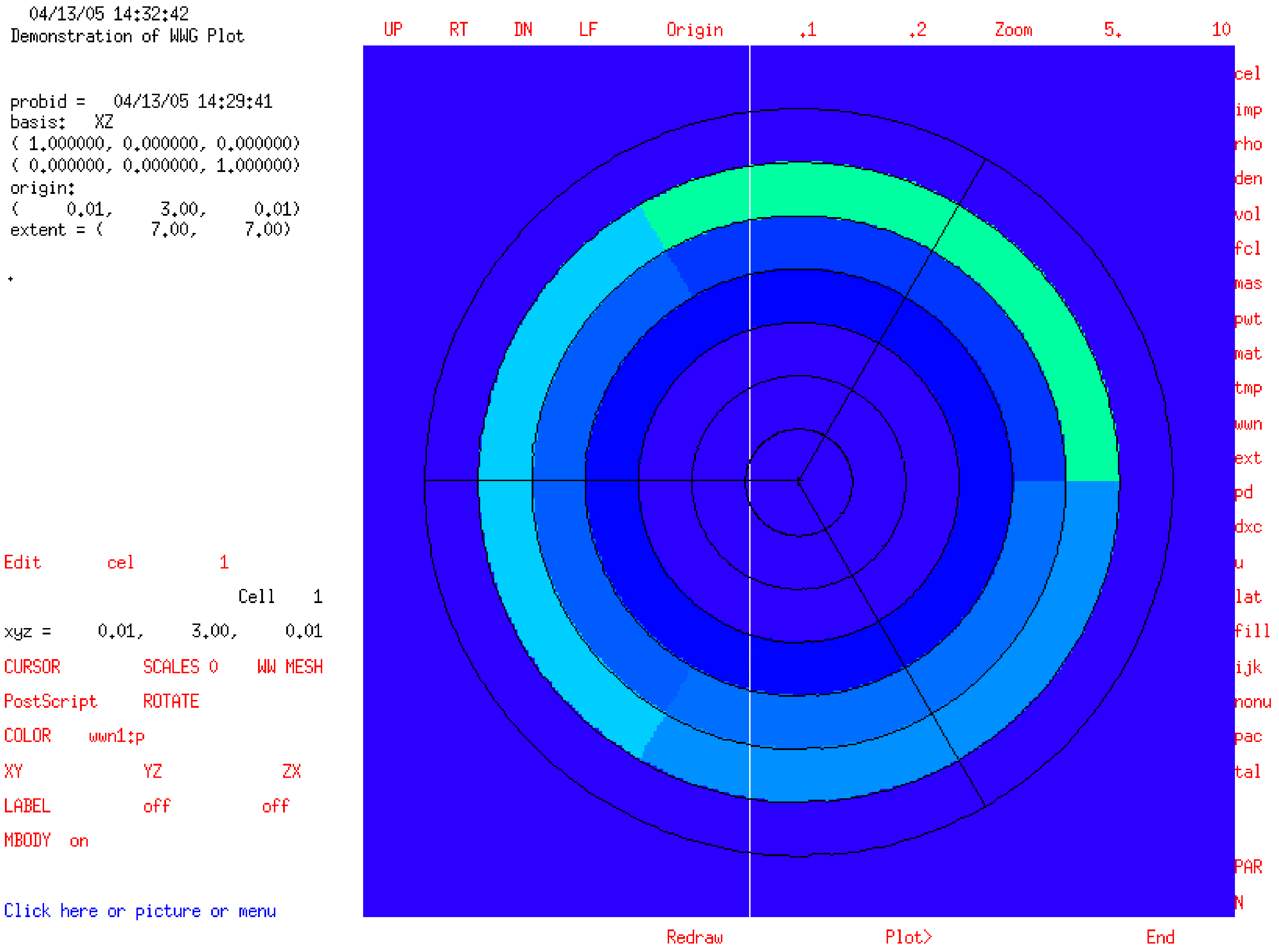
```
  04/12/05 16:44:08
100x100x100 water phantom

probid =   04/12/05 16:42:17
basis:   YZ
( 0.000000, 1.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
(      0.00,      0.00,      0.00)
extent = (      0.70,      0.70)
cell labels are
 lattice indices ijk
```

```
Edit        ijk    (0,0,0)

                         Cell    1

xyz =      0.00,      0.00,      0.00
```

WWG Superimposed Mesh Plots

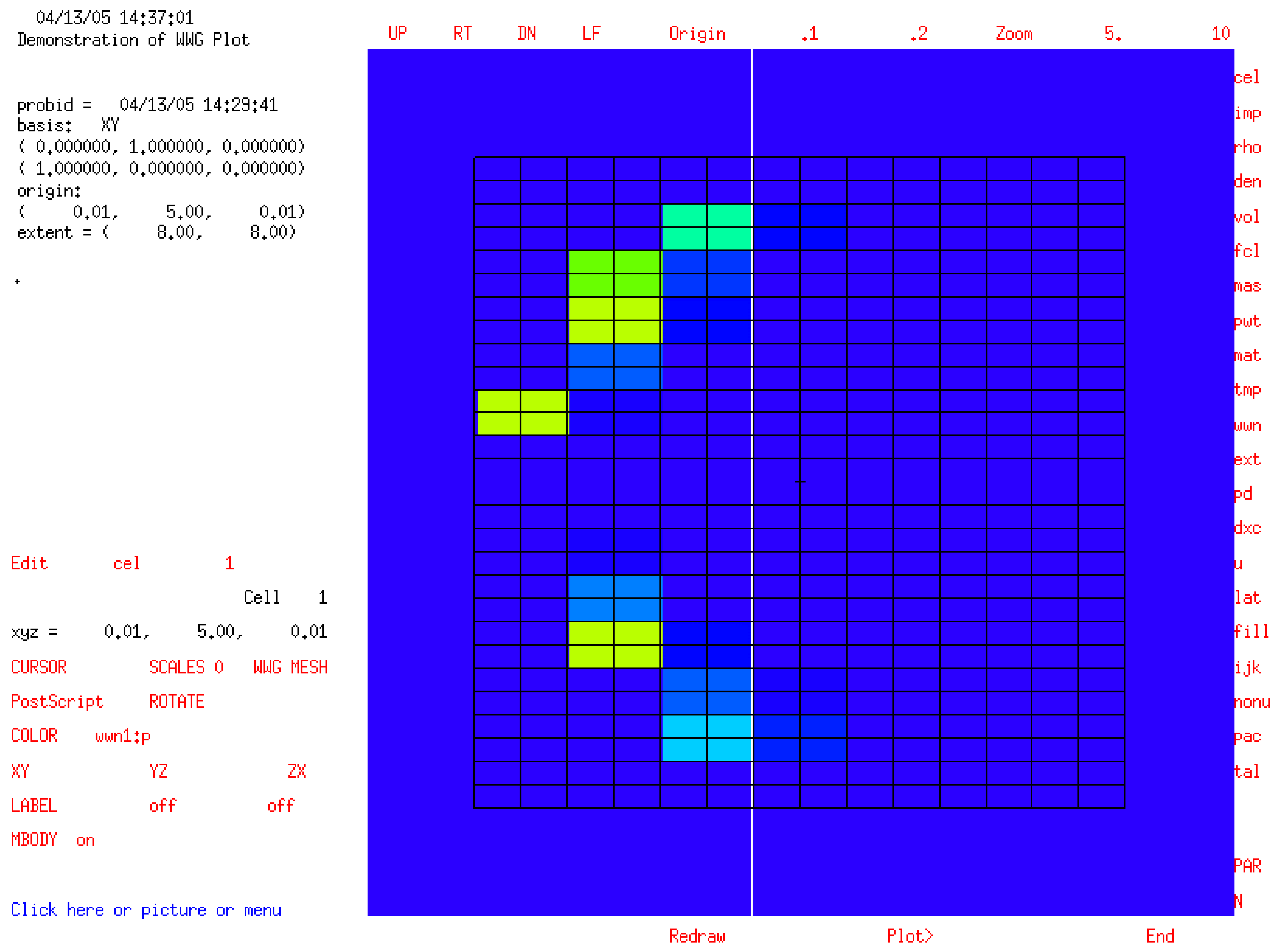
```
Cylindrical WW Mesh-3 MeV Photons => H2O
1 1 1.0    -1  imp:p 1
2 0         1  imp:p 0

1 rcc 0 0 0  0 10 0  5

mode p
sdef sur=1.3 vec=0 1 0 dir=1 erg=3
m1 1001 2 8016 1
nps 1000000
f1:p 1.2
wwg 1 0
mesh geom=cyl origin=0 -1 0 ref=0 .1 0
     axs=0 1 0 vec=1 0 0
     imesh 6   iints 7
     jmesh 12  jints 7
     kmesh 1   kints 3
```

```
Cylindrical WW Mesh-3 MeV Photons => H2O
1 1 1.0    -1  imp:p 1
2 0         1  imp:p 0

1 rcc 0 0 0  0 10 0  5

mode p
sdef sur=1.3 vec=0 1 0 dir=1 erg=3
m1 1001 2 8016 1
nps 1000000
f1:p 1.2
wwg 1 0
mesh geom=cyl origin=0 -1 0 ref=0 .1 0
     axs=0 1 0 vec=1 0 0
     imesh 6   iints 14
     jmesh 12  jints 14
     kmesh 1   kints 6
wwp:p 4j -1
```



```
   04/13/05 14:32:42
 Demonstration of WWG Plot

 probid =   04/13/05 14:29:41
 basis:   XZ
 ( 1.000000, 0.000000, 0.000000)
 ( 0.000000, 0.000000, 1.000000)
 origin:
 (      0.01,      3.00,      0.01)
 extent = (      7.00,      7.00)

                              Cell    1

xyz =     0.01,      3.00,      0.01
```

```
Edit         cel          1
CURSOR           SCALES 0      WW MESH
COLOR    wwn1:p
LABEL            off            off
MBODY   on
```



```
  04/13/05 14:37:01
 Demonstration of WWG Plot

 probid =   04/13/05 14:29:41
 basis:   XY
 ( 0.000000, 1.000000, 0.000000)
 ( 1.000000, 0.000000, 0.000000)
 origin:
 (      0.01,      5.00,      0.01)
 extent = (      8.00,      8.00)

 .
```

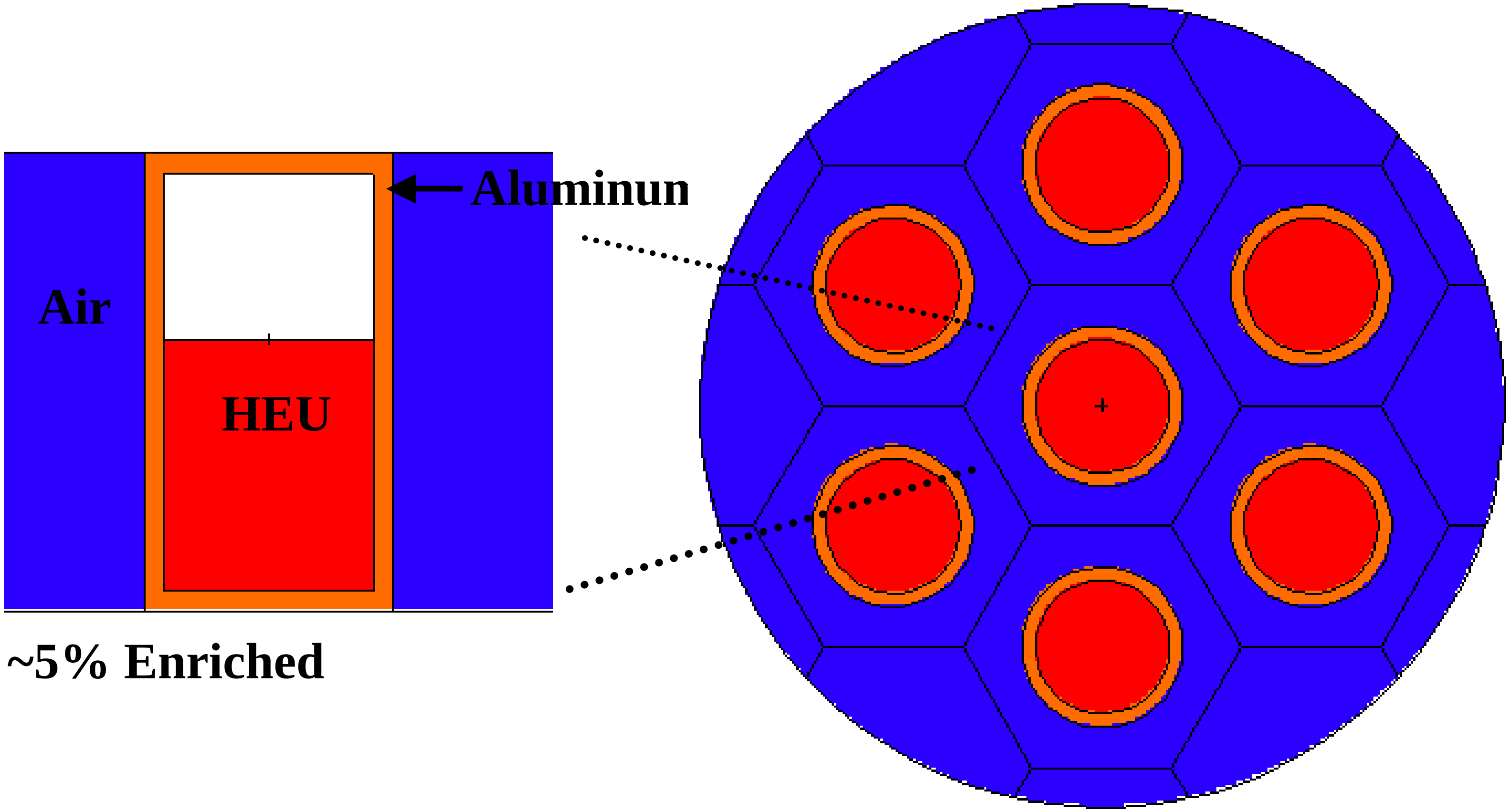
```
Edit        cel          1

                              Cell    1

xyz =      0.01,      5.00,      0.01
```

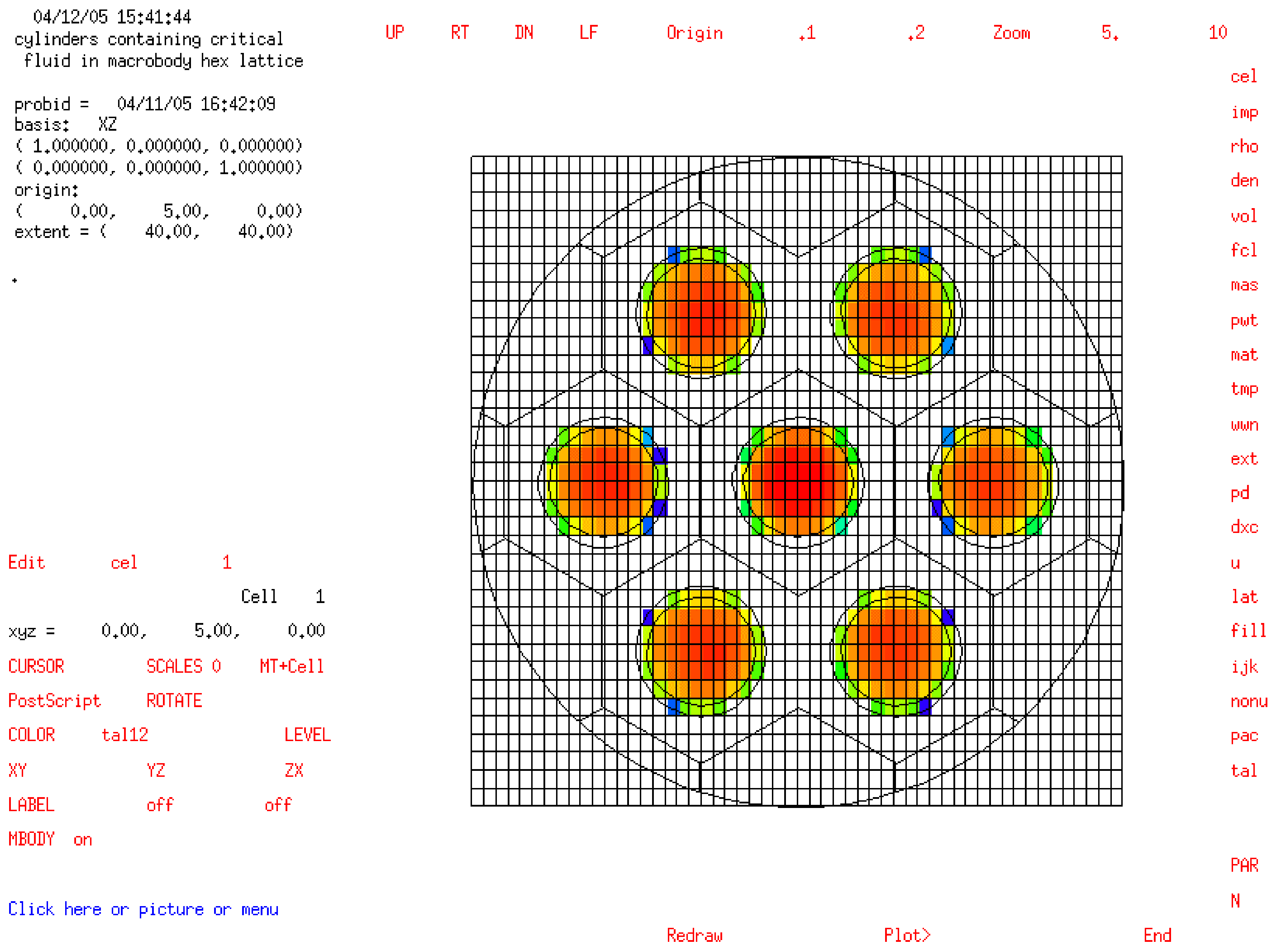
```
CURSOR          SCALES 0    WWG MESH
PostScript      ROTATE
COLOR     wwn1:p
XY              YZ              ZX
LABEL           off          off
MBODY   on

Click here or picture or menu
```

Color Contour and Mesh Tally Plots

```
HEU Cans in a Hex Lattice
1 1 -8.4      -1      u=1    imp:n=1
2 0           -2      u=1    imp:n=1
3 2 -2.7      -3 1 2  u=1    imp:n=1
4  3 -.001     3      u=1    imp:n=1
10 3 -.001    -6 lat=2 u=2   imp:n=1 fill=-2:2 -2:2 0:0
     2 2 2 2 2 2 2 1 1 2 2 1 1 1 2 2 1 1 2 2 2 2 2 2 2
11 0          -8             imp:n=1 fill=2
50 0           8             imp:n=0

1 rcc 0  0 0  0 12 0  5
2 rcc 0 12 0  0 8  0  5
3 rcc 0 -1 0  0 22 0  6
6 rhp 0 -1 0  0 22 0  9 0 0
8 rcc 0 -1 0  0 22 0  30

m1   1001 5.7058e-2 8016 3.2929e-2 92238 2.0909e-3  92235 1.0889e-4
m2   13027 1
m3   7014 .8 8016 .2
kcode 10000 1 10 40
ksrc 0 6 0   18 6 0   -18 6 0   9 6 15   -9 6 15   9 6 -15   -9 6 -15
tmesh
 rmesh12
 cora12  -30. 53i 30.
 corb12  0. 12.
 corc12  -30. 35i 30.
endmd
```

Color Contour and Mesh Tally Plots





```
  04/12/05 15:41:44
cylinders containing critical
 fluid in macrobody hex lattice

probid =   04/11/05 16:42:09
basis:   XZ
( 1.000000, 0.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
(     0.00,     5.00,     0.00)
extent = (    40.00,    40.00)
```

```
Edit        cel          1

                        Cell    1

xyz =       0.00,       5.00,       0.00
```

```
CURSOR        SCALES 0     MT+Cell
PostScript    ROTATE
COLOR     tal12               LEVEL
XY            YZ             ZX
LABEL         off          off
MBODY   on
```

Click here or picture or menu

User-Interface Enhancements – 2.5.0

- **Three other miscellaneous improvements**
  - READ card
  - HISTP card extension
  - DXTRAN/Detector underflow control

User-Interface Enhancements

```
HEU Cans in a Hex Lattice
READ FILE=cells NOECHO

READ FILE=surfaces

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
kcode 10000 1 10 40
ksrc  0 6 0   18 6 0   -18 6 0   9 6 15
     -9 6 15   9 6 -15   -9 6 -15
tmesh
 rmesh12
 cora12  -30. 53i 30.
 corb12  0. 12.
 corc12  -30. 35i 30.
endmd
```

File “cells”

```
1 1 -8.4      -1      u=1    imp:n=1
2 0           -2      u=1    imp:n=1
3 2 -2.7      -3 1 2  u=1    imp:n=1
4  3 -.001     3      u=1    imp:n=1
10 3 -.001    -6 lat=2 u=2   imp:n=1
     fill=-2:2 -2:2 0:0
          2 2 2 2 2
          2 2 1 1 2
          2 1 1 1 2
          2 1 1 2 2
          2 2 2 2 2
11 0          -8             imp:n=1 fill=2
50 0           8             imp:n=0
```

File “surfaces”

```
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
```

Physics Enhancements

- **Four model physics improvements**
  - Mix & match of libraries and models
  - CEM upgrade to 2K
  - INCL 4/ABLA physics models
  - Secondary-particle production

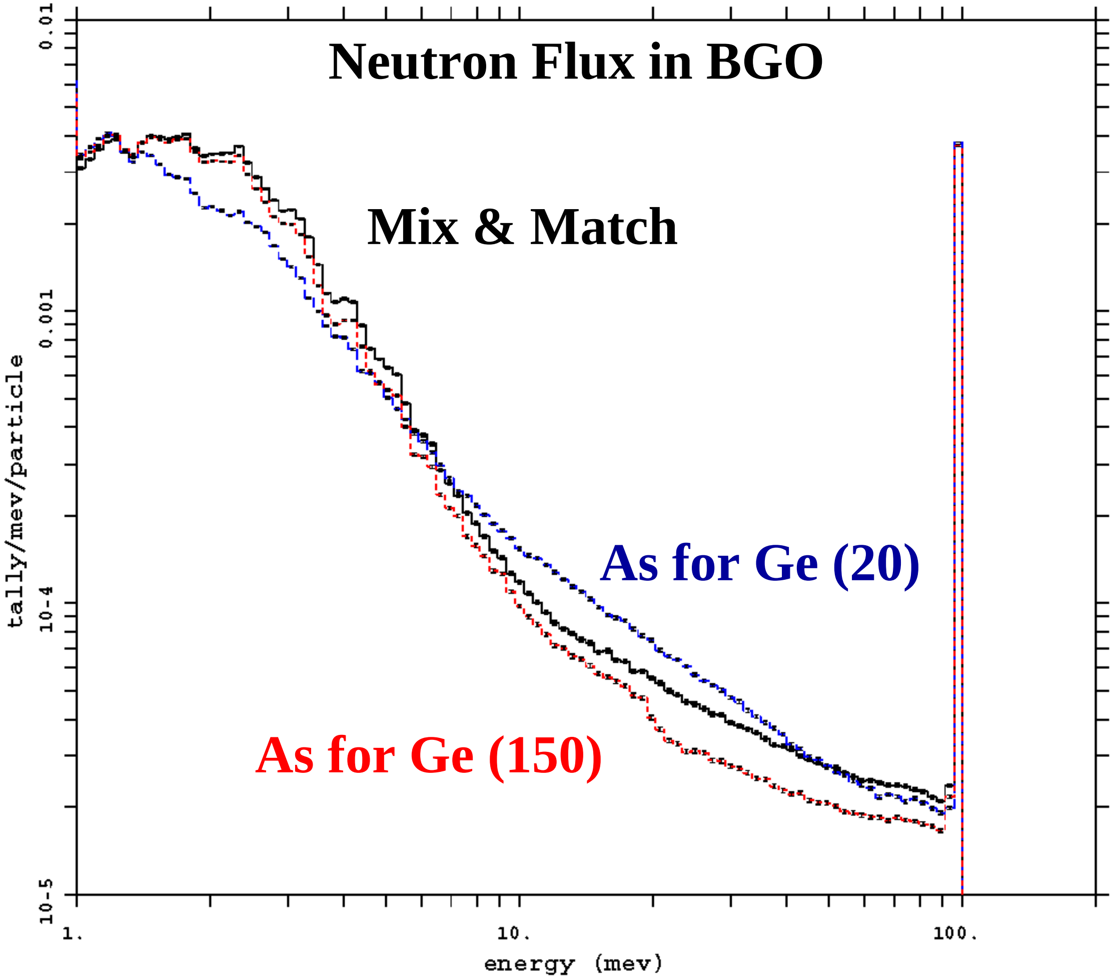
Mix & Match of Libraries and Models

- **Mix and Match**
  - 5th entry on PHYS:N (3rd on PHYS:H) is superseded.
    - Code will choose cutoff based on individual library's upper energy.
  - MX card allows the user to substitute isotopes or specify model physics based on individual M card entries.
    - Isotope substitution can be done for nuclides where no table data is available.
    - No neutron data table exists for Ge. As-75 could be used where the material cards call for Ge (see example).
  - Available for neutrons, protons, and photons (photonuclear) only.

Mix & Match of Libraries and Models

```
Mix & Match for 100 MeV Neutrons => BGO Crystal
1 1 -7.130 -1 imp:n=1
2 0         1 imp:n=0

1 RCC 0 0 0 0 0 8.433 3.932

sdef sur=1.3 vec=0 0 1 dir=1 erg=100
nps 1000
m1     83209.24c 0.2105 8016.24c 0.6316 32000 0.1579
phys:n 101 3j -1
c    mx1:n     j                j            33075
c    phys:n 101 3j 20 $ Models above 20 MeV
c    mx1:n     j                j            33075
c    phys:n 101 3j 150 $ Models above 150 MeV
mode n p
f4:n 1
e0 1 100log 100
f21:p 1.2

m1     1002 1    1003 1    6012 1    20040 1
mx1:n  j         model     6000      20000
mx1:h  model     1001      j         j
mx1:p  6012      0         j         j
```

Mix & Match of Libraries and Models



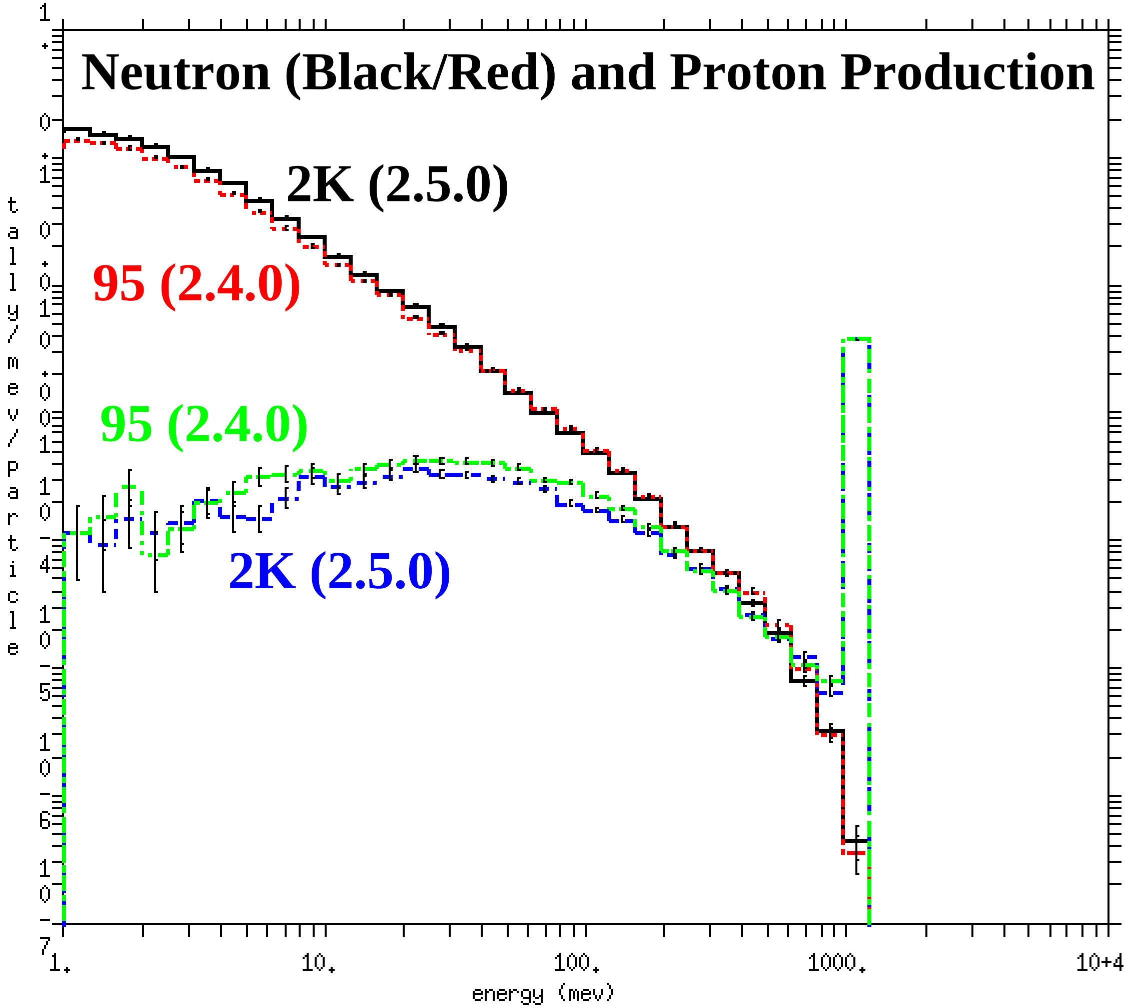
CEM Upgrade to 2K (from 95)

- **CEM 2k**
  - Improvements in elementary cross sections, nuclear masses and pairing energies.
  - Algorithm improvements decrease time required for some problems by a factor of 6.
  - Utilizes measurements from the GSI experiments on isotope production.

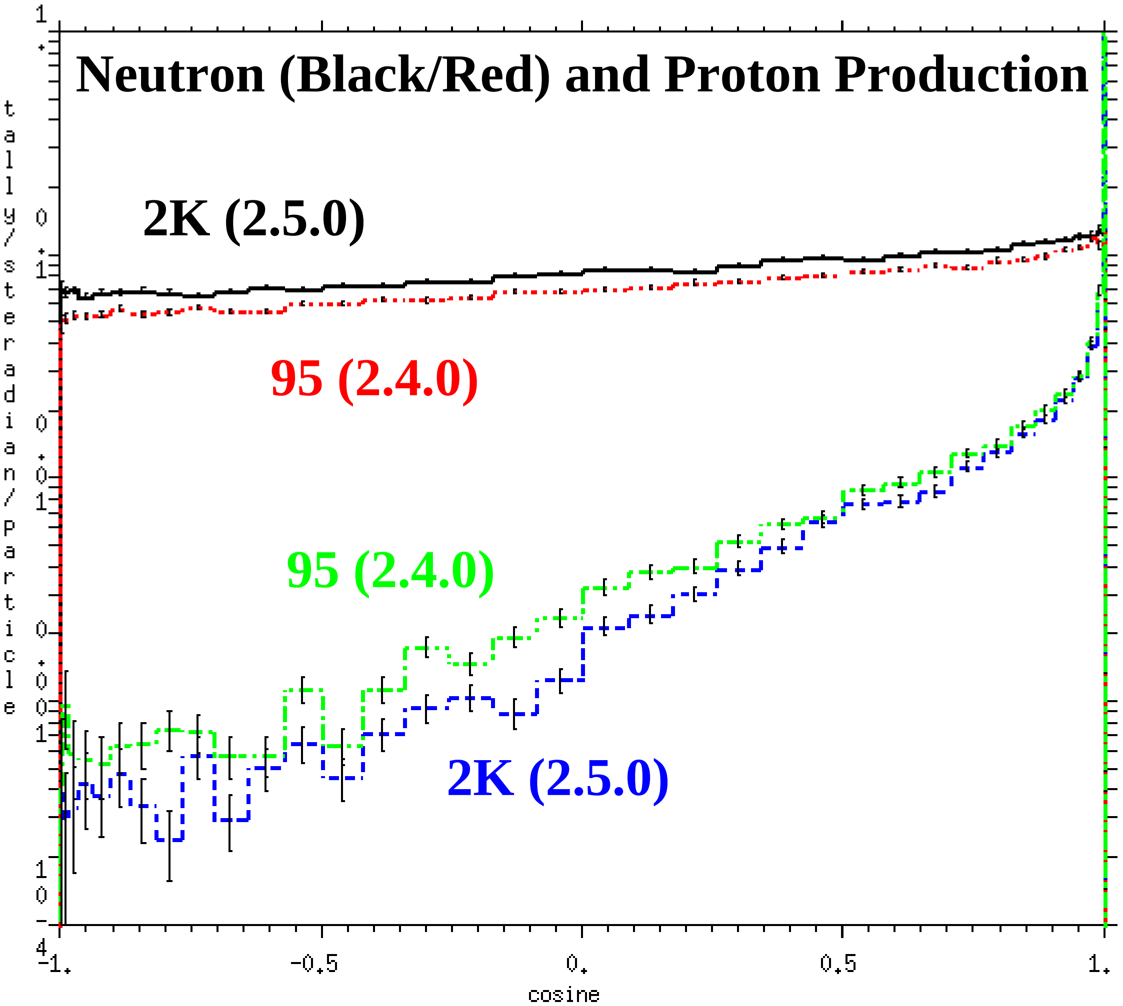
CEM Upgrade to 2K (from 95)

```
CEM for 1.2 GeV Protons => Pb
1 1 -11. -1 imp:h 1
2 0       1 imp:h 0

1 so 1.0

mode h n
sdef par h erg=1200 vec 1 0 0 dir 1
m1 82208 1
phys:h 1300 j 1
phys:n 1300 3j 1
nps 100000
lca    8j 1
f1:n   1
ft1    frv 1 0 0
*c1    175 34i 0
f11:n  1
e11    1. 30log 1200.
f21:h  1
ft21   frv 1 0 0
*c21   175 34i 0
f31:h  1
e31    1. 30log 1200.
```

CEM Upgrade (version 95 to 2K)



CEM Upgrade (version 95 to 2K)



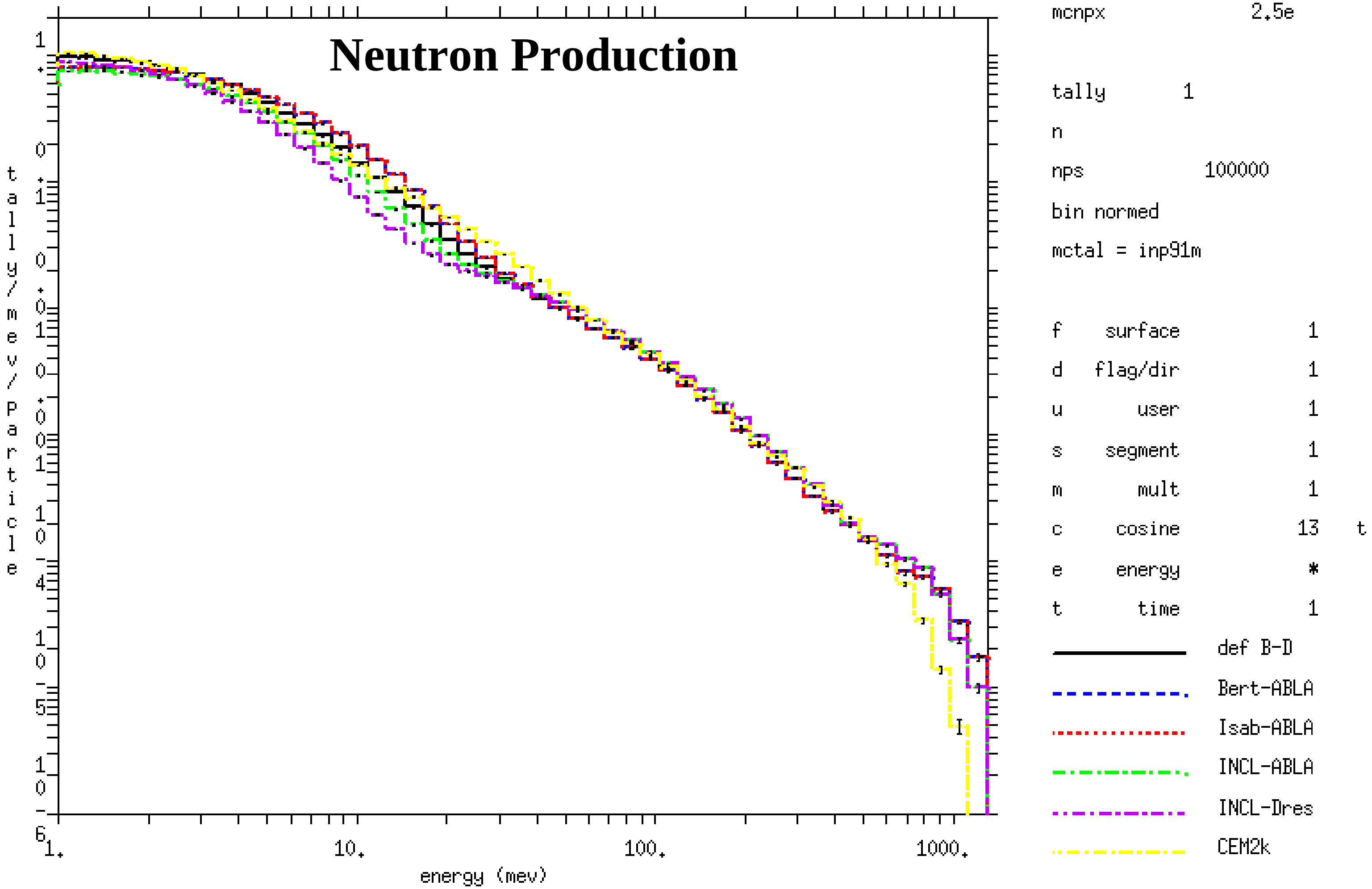
INCL 4/ABLA Physics Models

- **INCL 4/ABLA is a combined intranuclear cascade/evaporation model.**
  - User can specify combinations of existing models and INCL 4/ABLA (see example).
  - Implemented by agreement with CEA
  - Primarily useful in the 200 MeV – 2 GeV range.
  - Somewhat slower than Bertini and CEM2K.

INCL 4/ABLA Physics Models

```
Various Physics Models for 1.2 GeV Protons => Pb
1 1 -11. -1 imp:h 1
2 0       1 imp:h 0

1 so .01

mode h n
sdef par h erg=1200 vec 0 0 1 dir 1
m1 82208 1
phys:h 1300 j 0
phys:n 1300 3j 0
nps 100000
f1:n  1
ft1   frv 0 0 1
*c1   167.5 9i 17.5 0 T
e1    1 50log 1300
LCA   7j -2 0     $ Bertini/Dresner

LCA   7j -2 0     $ Bertini/ABLA
LEA   6J  2
LCA   2j  2 4j -2 $ ISABEL/Dresner
LCB   4j  1300
LCA   2j  2 4j -2 $ ISABEL/ABLA
LCB   4j  1300
LEA   6J  2
LCA   7j -2 2     $ INCL4/ABLA
LEA   6j  2
LCA   7j -2 2     $ INCL4/Dresner
LCA   7j -2 1     $ CEM2K
```

Secondary-Particle Production



Physics Enhancements - 2.5.0

- **Two neutron physics improvements**
  - Fission multiplicity
  - S(α,β) secondary-energy smoothing

Fission Multiplicity

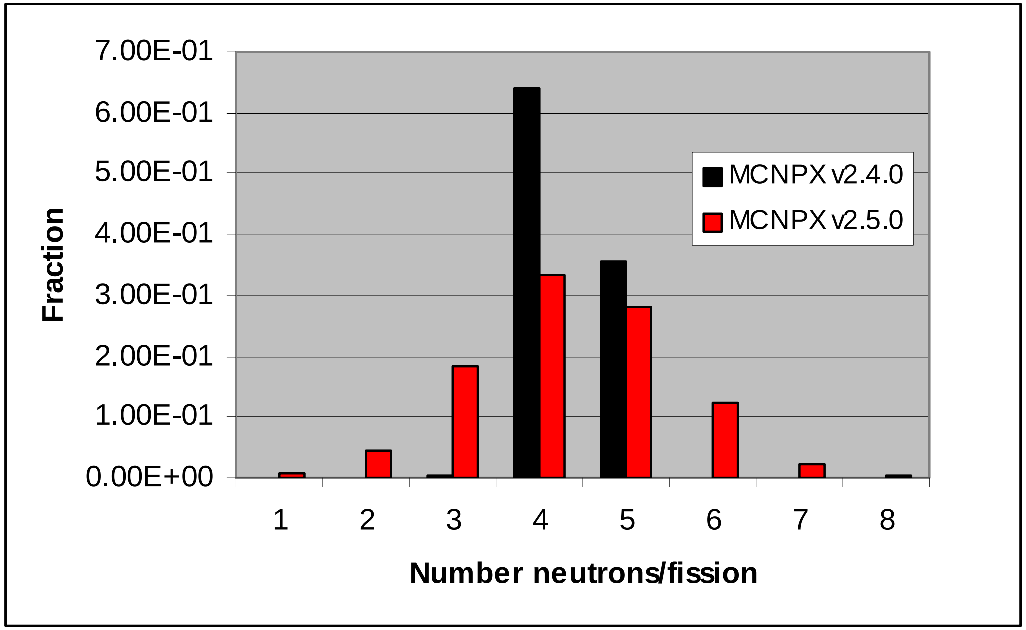
- **Implements more precise distribution of neutrons per fission event.**
  - Previous method used linear sampling between the two integers that bracket ν.
  - New method implements a sampling based on specific nuclei data or a Gaussian sampling on user-specified value.
  - Controlled by 6th entry on PHYS:N card.
  - Specifically will improve sampling for coincidence neutron populations.

Fission Multiplicity

```
U-235 Fission Multiplicity in H2O
1  1 -1.0   -1    imp:n=1
2  0         1    imp:n=0

1 SPH 0 0 0 0.1

sdef
m1    1001 2 8016 1 92235 1.e-1
c phys:n 5j 0
phys:n 5j -1
print
nps  5000000
```

Fission Multiplicity

14 MeV Neutrons on U-235



Physics Enhancements – 2.5.0

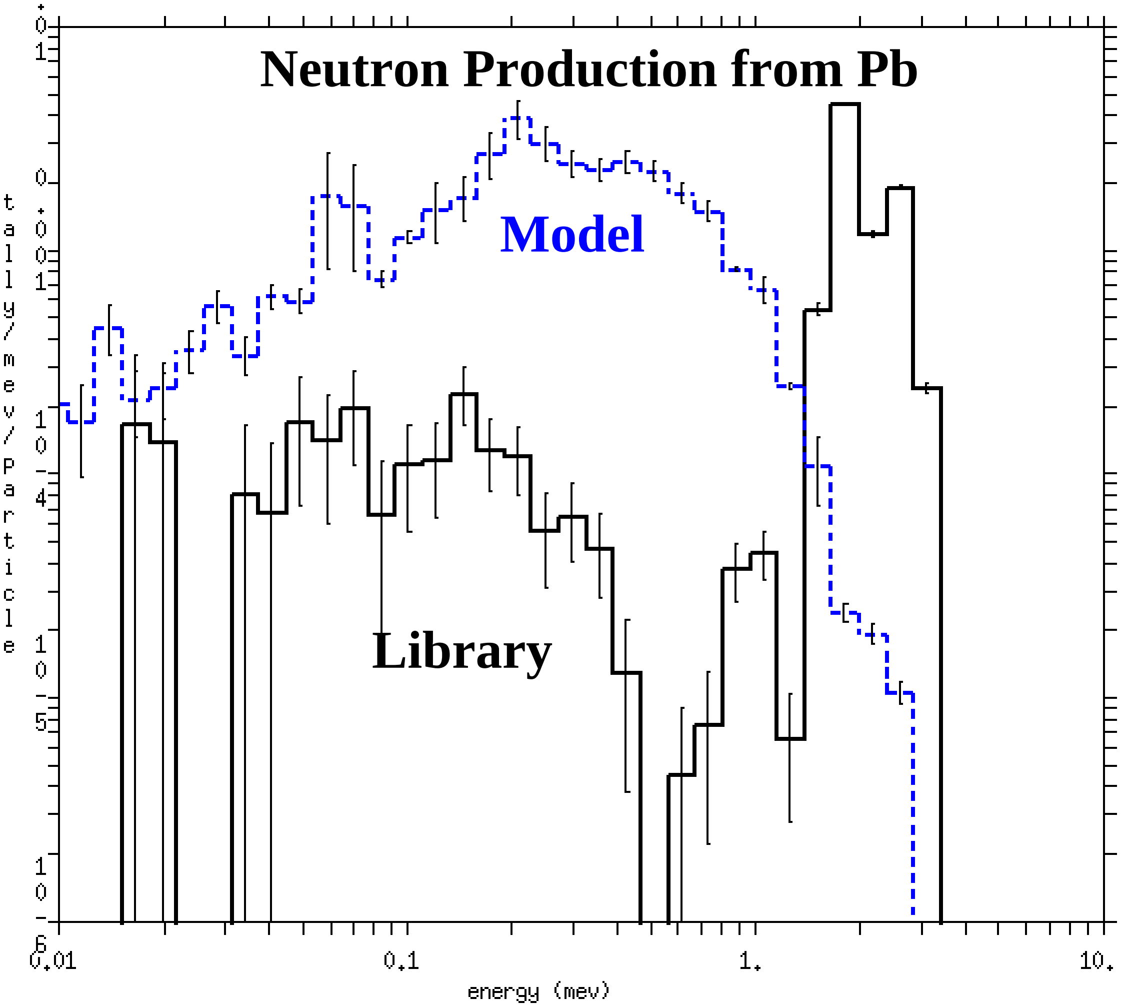
- **Three photon physics improvements**
  - Photonuclear physics model
  - Photon Doppler broadening
  - Variance reduction with pulse-height tallies

Photonuclear Physics Model

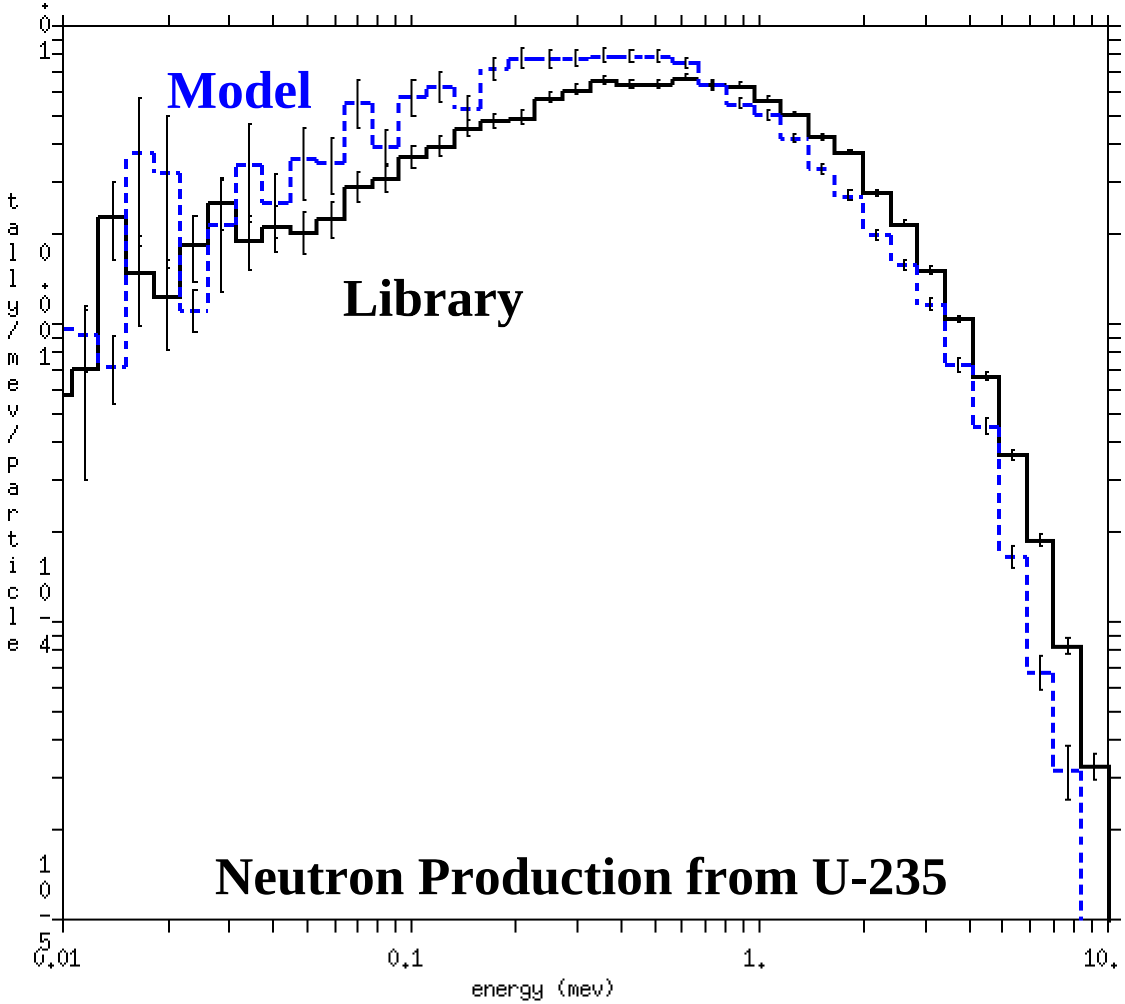
```
Photonuclear 10 MeV Photons => Pb
1  1 -7.86   -1    imp:n=1
2  0          1    imp:n=0

1 SPH 0 0 0 2

mode   n p
sdef   par=p erg=10.0
phys:p 3j 1
m1     82208 1
c    mx1:p  model
nps    1000000
f1:n   1
e1     1e-3 50log 10.
```

```
Photonuclear 10 MeV Photons => U-235
1  1 -7.86   -1    imp:n=1
2  0          1    imp:n=0

1 SPH 0 0 0 2

mode   n p
sdef   par=p erg=10.0
phys:p 3j 1
m1     92235 1
xs1 92235.27u 233.024994 bofod01u 0 1 54868 2946 0 0 0.0
c    mx1:p  model
nps    1000000
f1:n   1
e1     1e-3 50log 10.
```

Photonuclear Physics Model

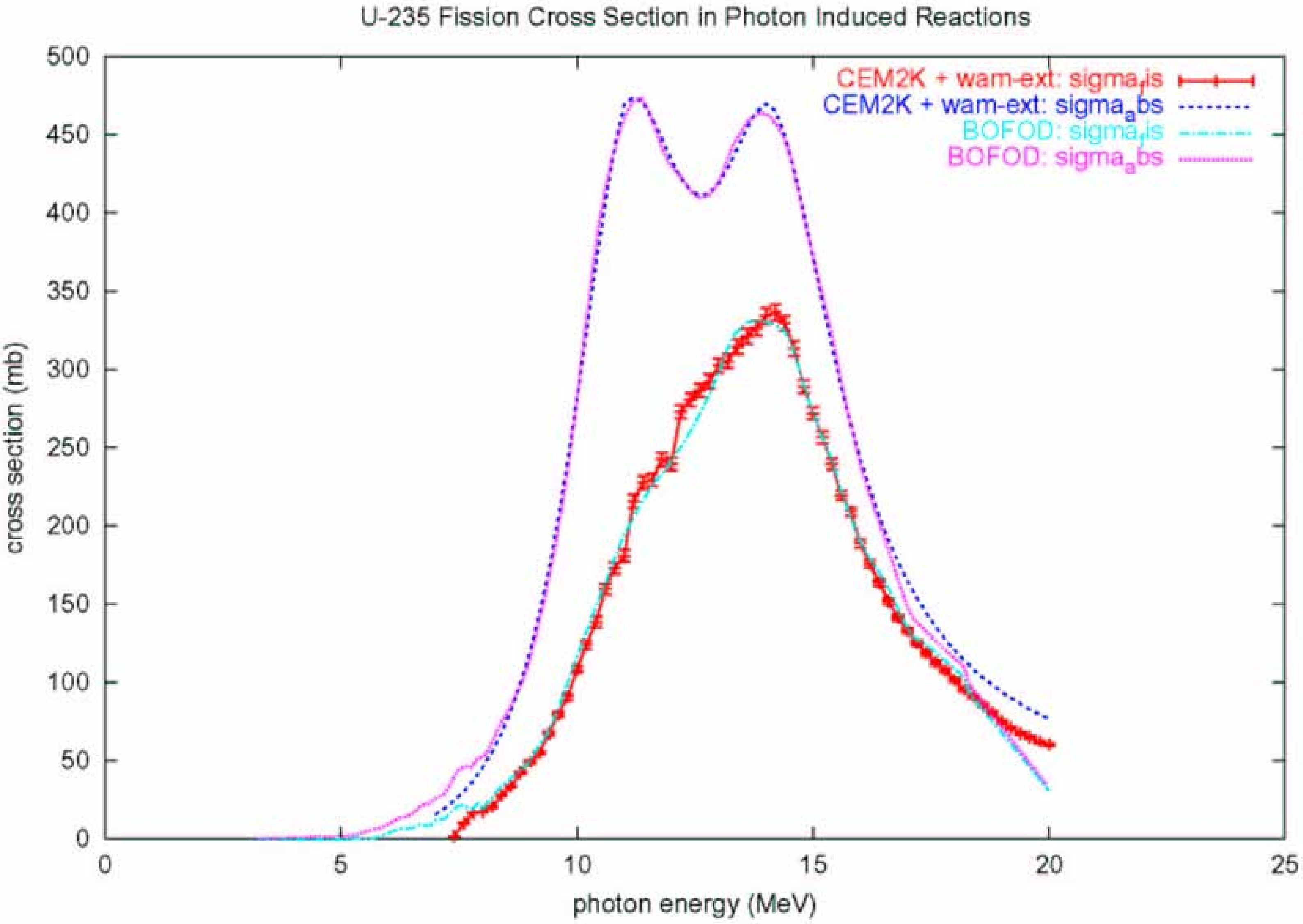


Photonuclear Physics Model



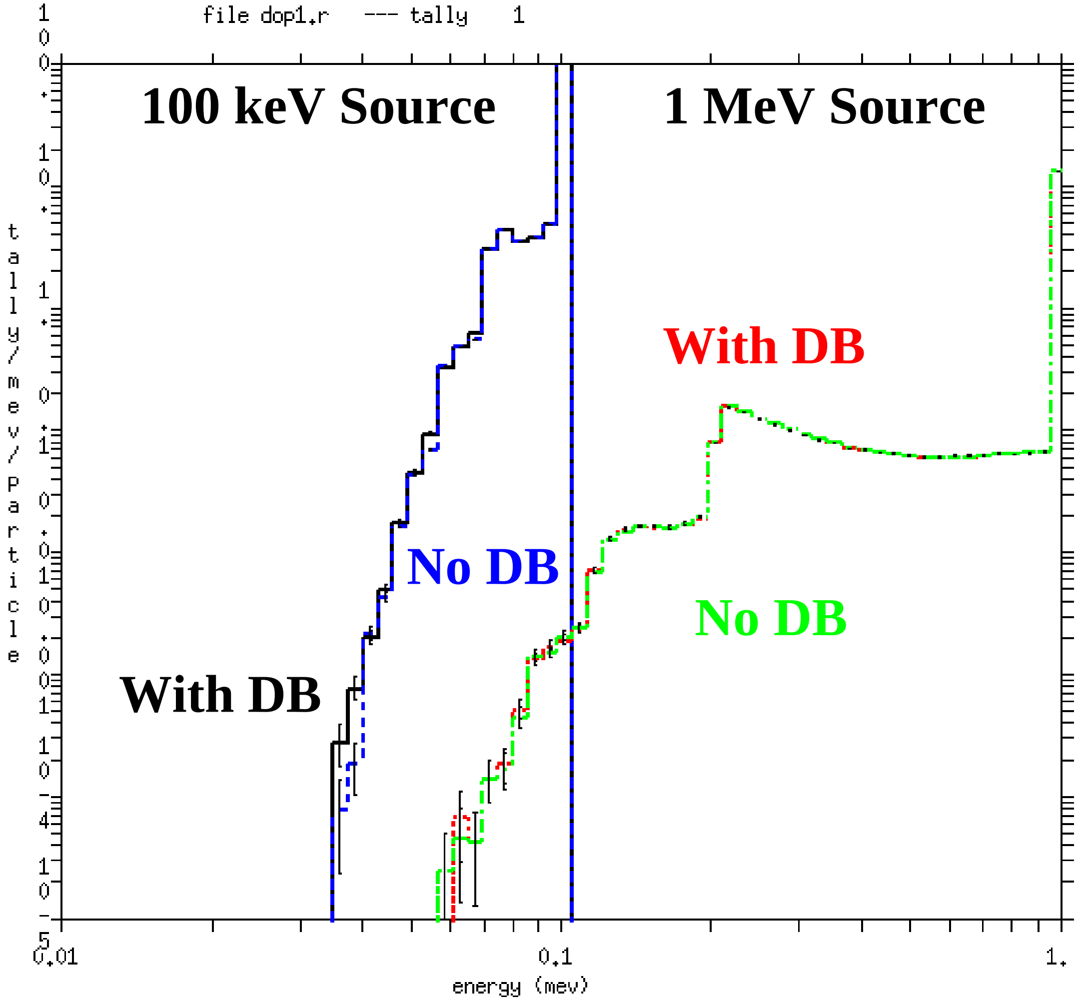
Photonuclear Capabilities

- Libraries available for some nuclides
  - H, C, O, Al, Si, Ca, Fe, Cu, Ta, W, Pb
  - Feature implemented in 2000
- Models available for all nuclides
  - Provided with the CEM2K INC package (April 2003)
  - Actinide GDR parameters recently improved
- User can control use of libraries vs models
  - Default is to use libraries, otherwise models
  - Biasing available to enhance secondary production


U-235 Fission Cross Section in Photon Induced Reactions
CEM2K + wam-ext: sigma$_{f}$is
CEM2K + wam-ext: sigma$_{a}$bs
BOFOD: sigma$_{f}$is
BOFOD: sigma$_{a}$bs
cross section (mb)
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
photon energy (MeV)

Photon Doppler Broadening

```
DB for 100 keV Photons => C
1  1 -1.00   -1    imp:p=1
2  0          1    imp:p=0

1 SPH 0 0 0 1

mode    p
sdef    par=p erg=0.1
        vec=1 0 0 dir=1
phys:p j 1 1 j 0
m1      6000 1
nps     10000000
f1:p    1
e1      1e-2 99log 1
```



Variance Reduction with Pulse-Height Tallies

- **Pulse-Height tally Variance Reduction has been a goal in Monte-Carlo codes for many years.**
  - Implemented in MCNPX v2.5.0 and can result in dramatic speed improvements.
  - Deconvolves the particle “trees” to get correct PHT.
  - Not all variance reduction techniques supported.
  - Unsupported VRTs result in a fatal error.

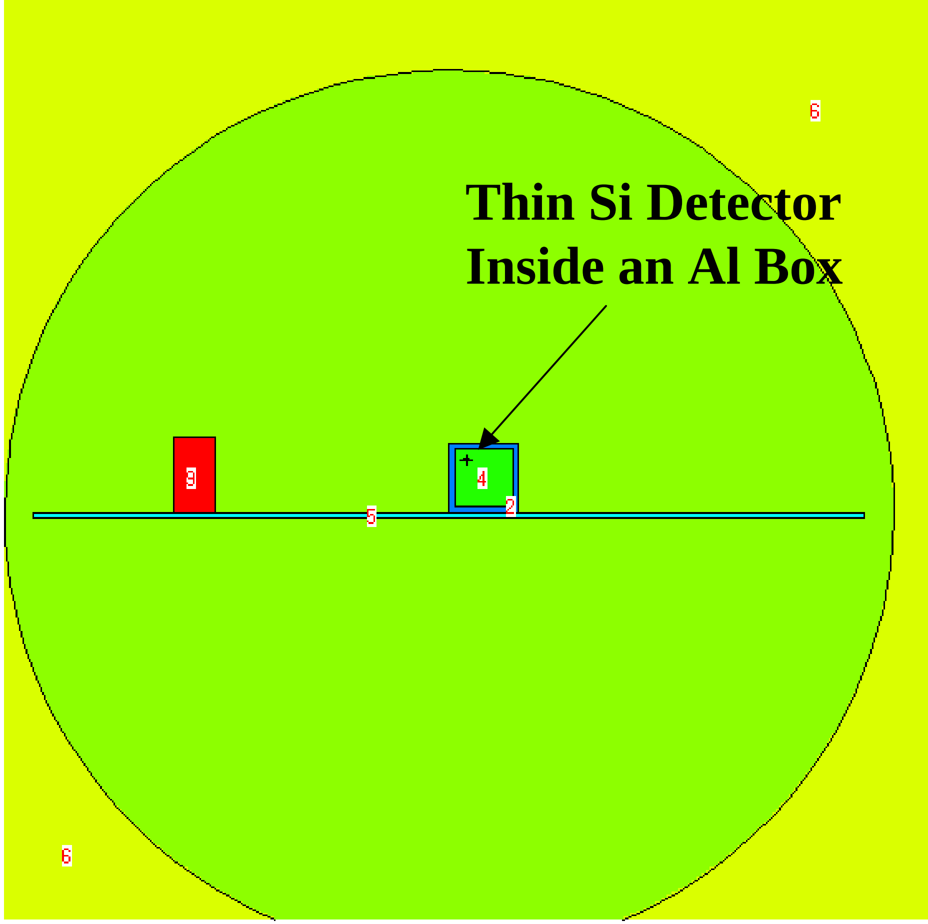
Variance Reduction with Pulse-Height Tallies

```
VRT with PHT 1 MeV Photons Incident
1 2 -2.33 -1     imp:p,e 1
2 1 -2.7  -2 5   imp:p,e 1
3 1 -2.7 -3      imp:p,e 1
4 1 -1.35 -5 20  imp:p,e 1
5 0 2 3 -4 6 7 8 imp:p,e 1
6 0 4            imp:p,e 0
7 1 -2.7 -6      imp:p,e 1
8 1 -2.7 -7      imp:p,e 1
9 1 -2.7 -8      imp:p,e 1
20 1 -1.35 -20 21 imp:p,e 1
21 1 -1.35 -21 1  imp:p,e 1

1 rcc 3 3 9 0 0 0.25 0.4
2 box 0 0 0 12 0 0 0 12 0 0 0 12
5 box 1 1 1 10.0 0 0 0 10.0 0 0 0 10.0
3 rcc 0 0 -1 0 0 1.0 72.0
4 sph 0 0 0 77.0
6 rcc -9 44 0 0 0 16 5
7 rcc 30 30 0 0 0 12 10
8 rcc 9 -44 0 0 0 13 7
20 sph 3 3 9.1 1.8
21 sph 3 3 9.1  .9
```

```
wwp:p 100 4 4
wwn1:p .0002 .002 .02 .001 .02 -1
       .02 .02 .02 .0005 .0002
fcl:p -1 0 7r -1 -1
mode p e
m1 13027 1 $ (2.7 g/cc) Al
m2 14028 1 $ Si (detector element, 2.33 g/cc)
sdef erg=1 pos=0 0 21 par=p rad=d1 ext=0
     axs=0 0 1 vec=0 0 -1 dir=1
si1 0 72.0
sp1 -21 1
phys:p
phys:e 7j 0
f8:p 1
e8   0 1.e-5 .001 2i .007 .01 .015 .02
     7i .1 19i 1.1
nps  100000000
```

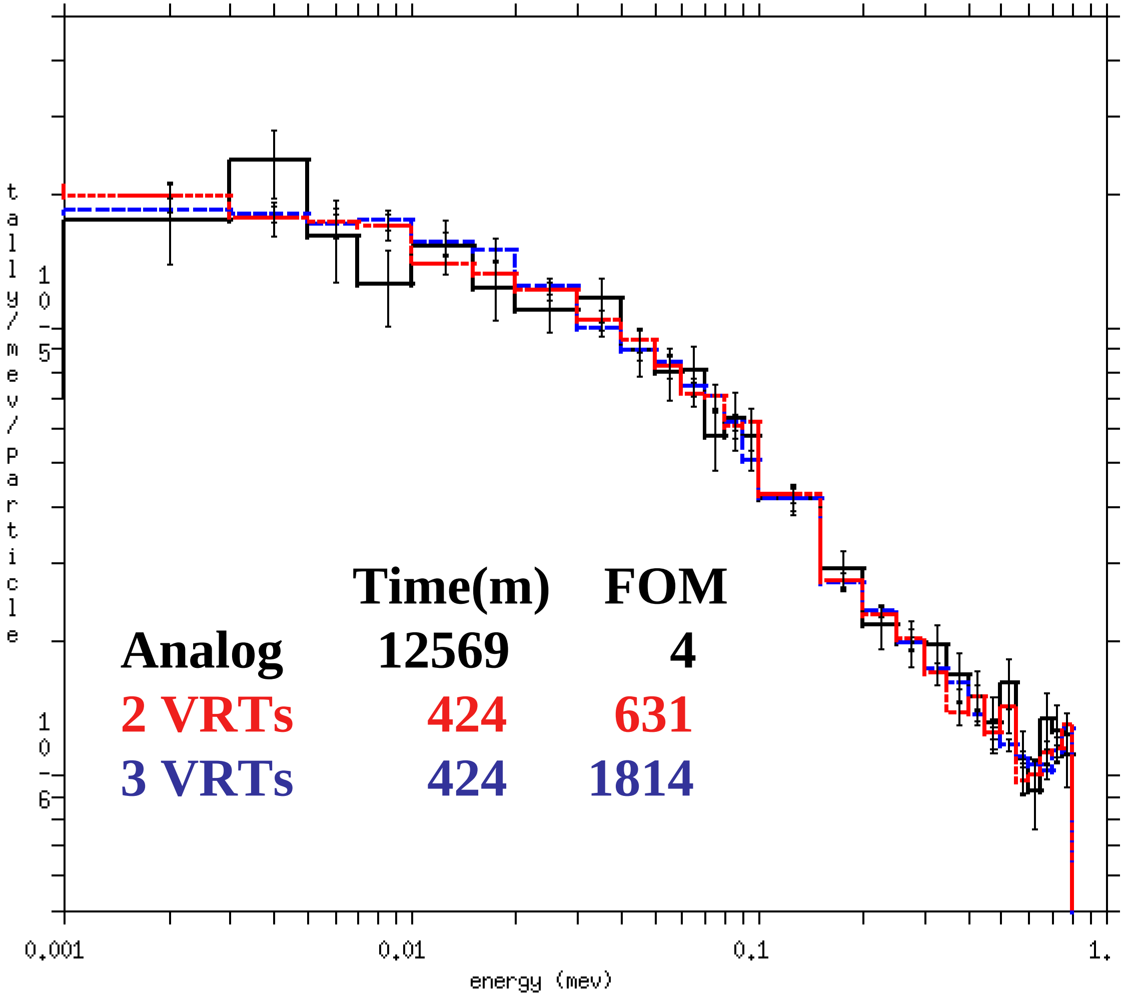
Variance Reduction with Pulse-Height Tallies

1 MeV Photons Incident From Above



Thin Si Detector Inside an Al Box

Variance Reduction with Pulse-Height Tallies

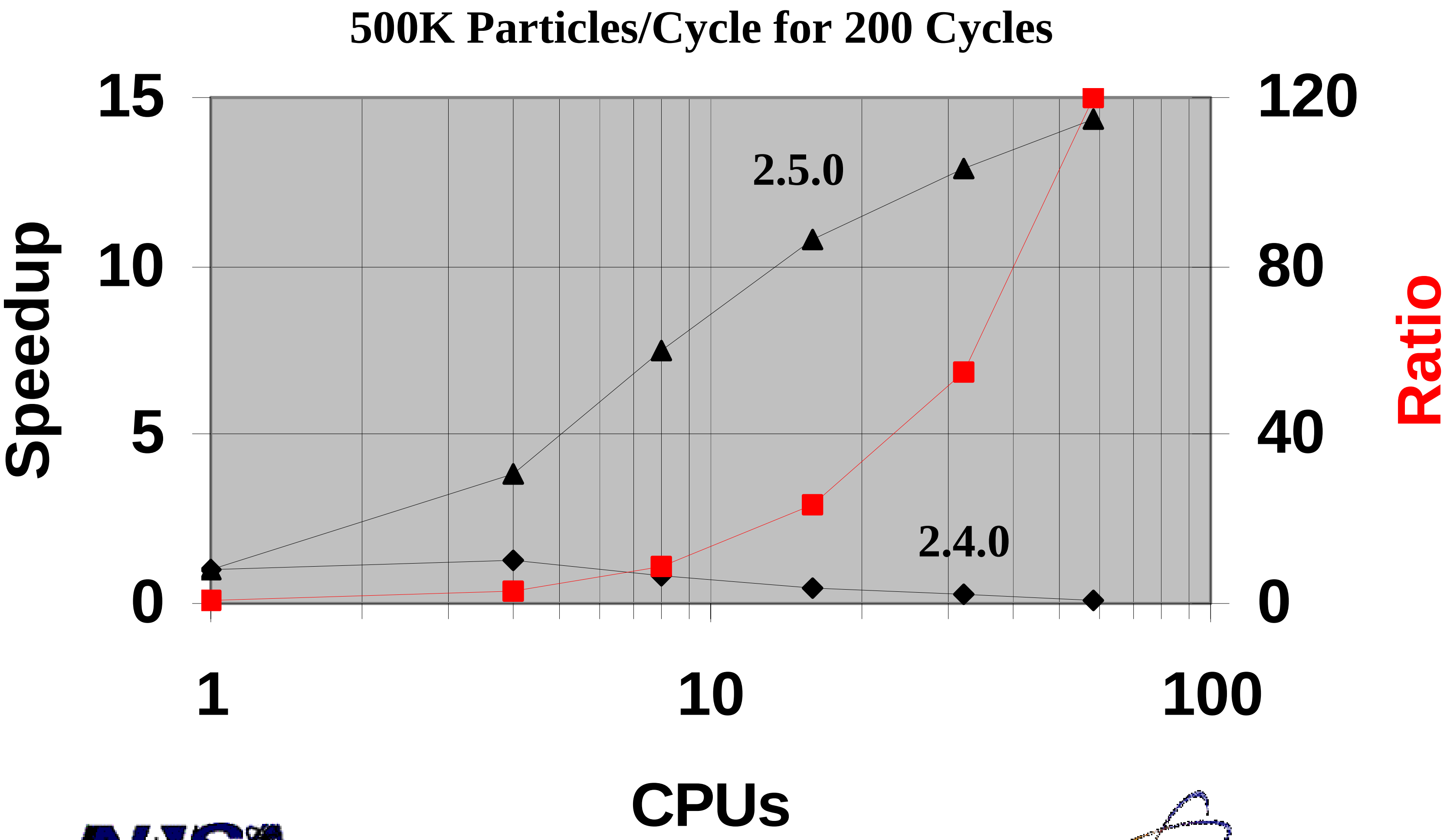


	Time(m)	FOM
Analog	**12569**	**4**
2 VRTs	**424**	**631**
3 VRTs	**424**	**1814**

Infrastructure Enhancements – 2.5.0

- **8-byte integers**
  - Users can now run billions of particles
  - Often required for parallel calculations
  - Runs about 20% slower on most systems
- **Support for new compilers**
  - Mac OS X with IBM compiler
  - Windows PC and Linux with Intel compiler
- **Parallel processing with MPI**
  - PVM option is still available
- **MPI speedup for criticality problems**
  - Eliminates collection of fission source after each cycle

Godiva Run on a Linux Cluster

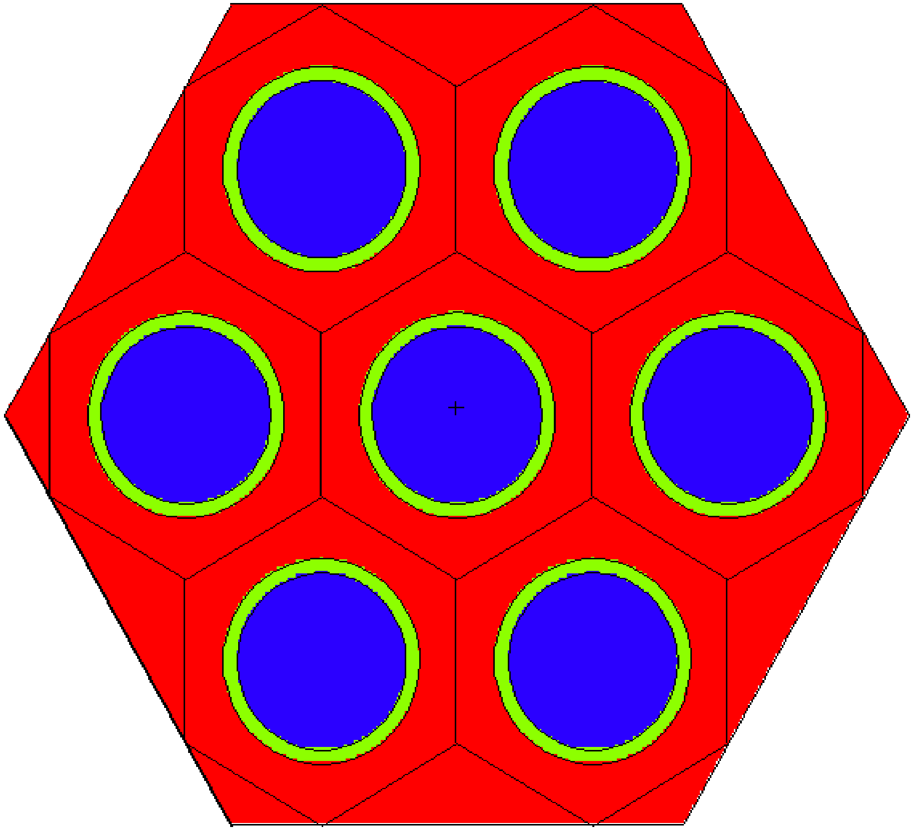


New Features - MCNPX Version 2.6.A

- **BURN card - transmutation using Cinder90**
  - **M. Fensin's paper in session Best of RPSD**
- **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**

BURN Card

```
Burn 7 fuel pins surrounded by H2O in a hex lattice
1  1  -8.3    -1      u=1 imp:n=1   vol=192.287       $ Fuel
2  8  -6.5    1 -2     u=1 imp:n=1                    $ Clad
3  9  -0.7      2      u=1 imp:n=1                    $ Water
100 9  -1.8    -3  u=8 lat=2 imp:n=1 fill=-2:2 -2:2 0
                      8 8 8 8 8
                       8 8 1 1 8
                        8 1 1 1 8
                         8 1 1 8 8
                          8 8 8 8 8
101  0                -4          imp:n=1 fill=8
102  9  -1.8    4 -5              imp:n=1
103  0                 5          imp:n=0

1 rcc 0  0 0  0 0 365  0.4095
2 rcc 0 0 -1  0 0 367  0.4750
3 rhp 0 0 -1  0 0 367  0.6565 0  0
4 rhp 0 0 -1  0 0 367  0 1.895  0
*5 rhp 0 0 -1.1  0 0 367.2  0 1.896 0

BURN  TIME=50,500
      MAT=1
      POWER=0.066956
      PFRAC=1.0,1.0
      OMIT=1,6,6014,7016,8018,9018,90234,91232
      BOPT=1.0, 4
m1    8016.60c   2.0  92235.60c  0.01  92238.60c  0.9
m8    40000.60c  1.0
m9     1001.60c  2.0  8016.60c  1.0
mt9   lwtr.01t
kcode 100 1.0 10 50
ksrc  0 0 150 1.313 0 150 -1.313 0 150 0.6565 1.137 150
      0.6565 -1.137 150 -0.6565 1.137 150 -0.6565 -1.137 150
```



```
1burnup summary table by material                                                     print table 210

 nuclides with atom fractions below 1.000E-10 for a material are zeroed and deleted from print tables after t=0

 neutronics and burnup data

 step  duration     time       power     keff       flux     ave. nu    ave. q     burnup
         (days)     (days)      (MW)                                              (GWd/MTU)
   0  0.000E+00  0.000E+00  6.696E-02  0.99763  3.641E+14    2.449    200.981  0.000E+00
   1  5.000E+01  5.000E+01  6.696E-02  1.00012  3.701E+14    2.554    203.154  2.383E+00
   2  5.000E+02  5.500E+02  6.696E-02  0.85037  4.638E+14    2.869    209.385  2.621E+01
…
 actinide inventory for sum of materials at end of step  2, time 5.500E+02 (days), power 6.696E-02 (MW)

  no. zaid     mass      activity   sp. act.  atom den.   atom fr.   mass fr.
               (gm)        (Ci)     (Ci/gm)    (a/b-cm)
   1  92234  3.465E-04  2.154E-06  6.217E-03  4.636E-09  2.577E-07  2.533E-07
   2  92235  3.935E-01  8.506E-07  2.161E-06  5.244E-06  2.914E-04  2.877E-04
   3  92236  1.789E+00  1.157E-04  6.467E-05  2.374E-05  1.319E-03  1.308E-03
   4  92237  7.849E-03  6.405E+02  8.160E+04  1.037E-07  5.763E-06  5.739E-06
   5  92238  1.355E+03  4.553E-04  3.361E-07  1.782E-02  9.905E-01  9.904E-01
   6  92239  1.539E-03  5.158E+04  3.351E+07  2.016E-08  1.121E-06  1.125E-06
…
  14  94242  1.117E+00  4.418E-03  3.954E-03  1.446E-05  8.034E-04  8.169E-04
     totals  1.368E+03  1.041E+05  7.610E+01  1.799E-02  1.000E+00  1.000E+00
…
 nonactinide inventory for sum of materials at end of step  2, time 5.500E+02 (days), power 6.696E-02 (MW)

  no. zaid     mass      activity   sp. act.  atom den.   atom fr.   mass fr.
               (gm)        (Ci)     (Ci/gm)    (a/b-cm)
   1   6012  2.336E-06  0.000E+00  0.000E+00  6.096E-10  1.638E-08  1.186E-08
   2   6013  1.057E-02  0.000E+00  0.000E+00  2.545E-06  6.839E-05  5.366E-05
   3   8016  1.891E+02  0.000E+00  0.000E+00  3.702E-02  9.946E-01  9.599E-01
   4   8017  1.405E-02  0.000E+00  0.000E+00  2.588E-06  6.954E-05  7.132E-05
…
  16  60145  3.469E-01  1.426E-14  4.112E-14  7.497E-06  2.014E-04  1.761E-03
     totals  1.970E+02  8.830E+01  4.483E-01  3.722E-02  1.000E+00  1.000E+00
```

Long File Names

```
E:\MCNPX\scratch>.\mcnpx inp=test_long_names.txt na=test_long_names.
 mcnpx    ver=26bc1 ld=Sat Jul 01 08:00:00 MST 2006   11/12/06 20:08:04
…
dynamic storage =         0 words,          0 bytes.      cp0 =  0.00
 run terminated when        10 particle histories were done.
 dump    2 on file test_long_names.r   nps =          10  coll =              0
                              ctm =      0.00     nrn =             40
 mcrun  is done

E:\MCNPX\scratch>dir

Directory of E:\MCNPX\scratch

11/12/2006  08:08 PM    <DIR>          .
11/12/2006  08:08 PM    <DIR>          ..
09/11/2006  03:23 PM         6,574,080 mcnpx.exe
11/12/2006  08:08 PM            22,513 test_long_names.d
11/12/2006  08:08 PM            25,510 test_long_names.o
11/12/2006  08:08 PM           401,342 test_long_names.r
08/04/2006  01:21 PM               481 test_long_names.txt
               5 File(s)      7,023,926 bytes
               2 Dir(s)  31,759,495,168 bytes free
```

STOP Card

```
14 MeV neutrons in water - test STOP card
c    cell cards
1     1  -1.  -1 IMP:N=1
2     0        1 IMP:N=0

1     so 30.0

m1     1001.60c 2. 8016.60c 1.
mt1    hh2o.20t
xs1   hh2o.20t 0.998623 ct00 0 1 1 1237501 0 0 2.530E-08
sdef  erg=14.1
e0    1.00000E-11 625log 1.44544E+01
vol     1.
f44:n   1
f141:n  1
STOP    F44 .01 NPS 10000 CTME 10.0
```

OUTPUT FILE

```
1tally fluctuation charts

                       tally   44                                tally  141
       nps      mean     error   vov  slope    fom      mean     error   vov  slope    fom
      1000   5.6661E+01 0.0144 0.0031 10.0  489705   3.7459E-01 0.0354 0.0003  0.0   81225
      2000   5.6824E+01 0.0103 0.0016 10.0  468574   3.7000E-01 0.0254 0.0002 10.0   77294
      3000   5.7028E+01 0.0083 0.0010 10.0  477186   3.6737E-01 0.0209 0.0001 10.0   75590

 ********************************************************************************************
 dump no.    2 on file stop.r     nps =        3000   coll =         599417     ctm =    0.03
```

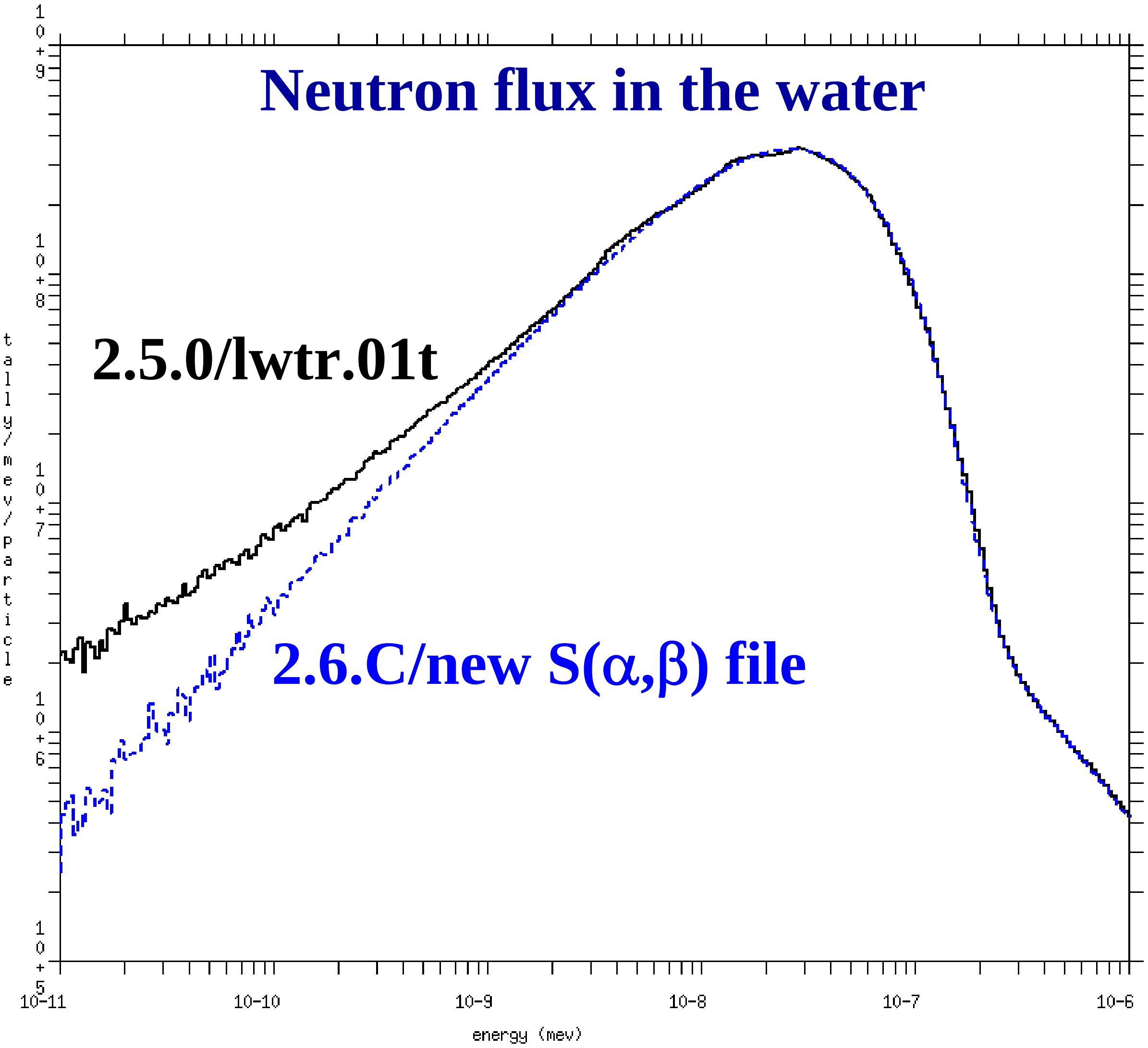
S(α,β) Secondary-Energy Smoothing

- **Improvement in S(α,β) algorithm in code**
  - User interface is unchanged but underlying secondary energy treatment is improved.
  - The structure in the S(α,β) data is often in discrete energies resulting in non-physical spikes in the thermal neutron spectrum.
  - New algorithm smooths over non-physical structure in data to provide smoother and better low-energy neutron spectra.

S(α,β) Secondary-Energy Smoothing

```
S(alpha,beta) Smoothing for HEU Cans in a Hex Lattice
1 1 -8.4      -1      u=1    imp:n=1
2 0           -2      u=1    imp:n=1
3 2 -2.7      -3 1 2  u=1    imp:n=1
4  3 -.001     3      u=1    imp:n=1
10 3 -.001    -6 lat=2 u=2   imp:n=1 fill=-2:2 -2:2 0:0
     2 2 2 2 2 2 2 1 1 2 2 1 1 1 2 2 1 1 2 2 2 2 2 2 2
11 0          -8             imp:n=1 fill=2
50 0           8             imp:n=0

1 rcc 0  0 0  0 12 0  5
2 rcc 0 12 0  0 8  0  5
3 rcc 0 -1 0  0 22 0  6
6 rhp 0 -1 0  0 22 0  9 0 0
8 rcc 0 -1 0  0 22 0  30

m1   1001 5.7058e-2   8016 3.2929e-2
     92238 2.0909e-3  92235 1.0889e-4
mt1  lwtr.01t
m2   13027 1
m3   7014 .8 8016 .2
kcode 10000 1 10 40
ksrc 0 6 0   18 6 0   -18 6 0   9 6 15   -9 6 15   9 6 -15   -9 6 -15
f4:n (1<(10[-2:2 -2:2 0:0])<11)
sd4  1
e4   1e-11 50log 1e-6
```

New S(α,β) Treatment

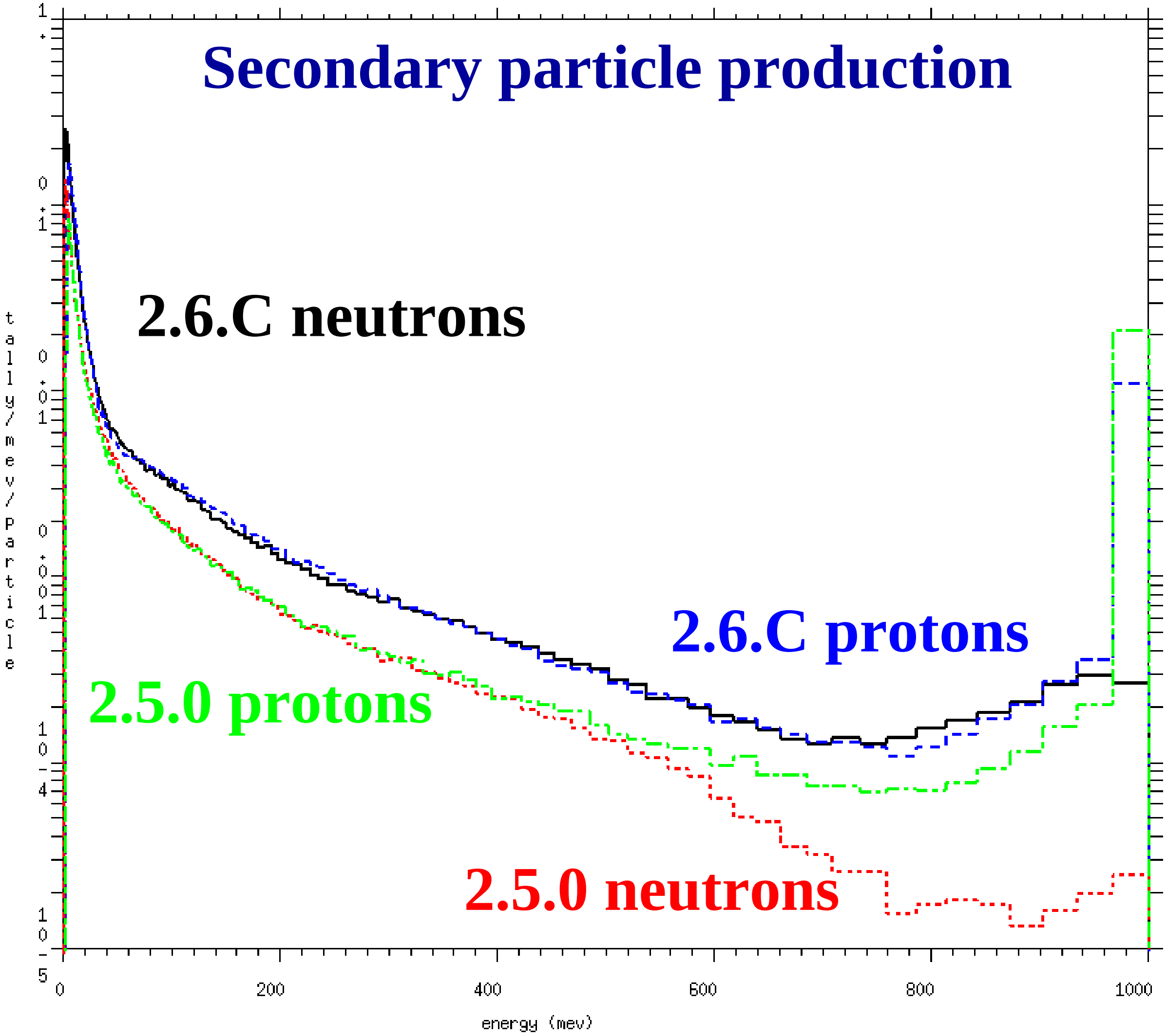


New Features – Version 2.6.B

- **Transmutation improvements**
  - **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**

CEM Upgrade

```
1 GeV protons into Fe-56
1     1  -7.86 -1 IMP:N=1
2     0          1 IMP:N=0

1     so 1.0

mode  n h
m1    26056.24c 1.
nps   200000
sdef  erg=1000 par=h
PHYS:N 1001.0
LCA   7j -2 1 $ Use CEM
e0    1 199log 1000
c0    0 1
f1:n  1
f11:h 1
prdmp 2j 1
```



Secondary particle production

CEM Upgrade

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

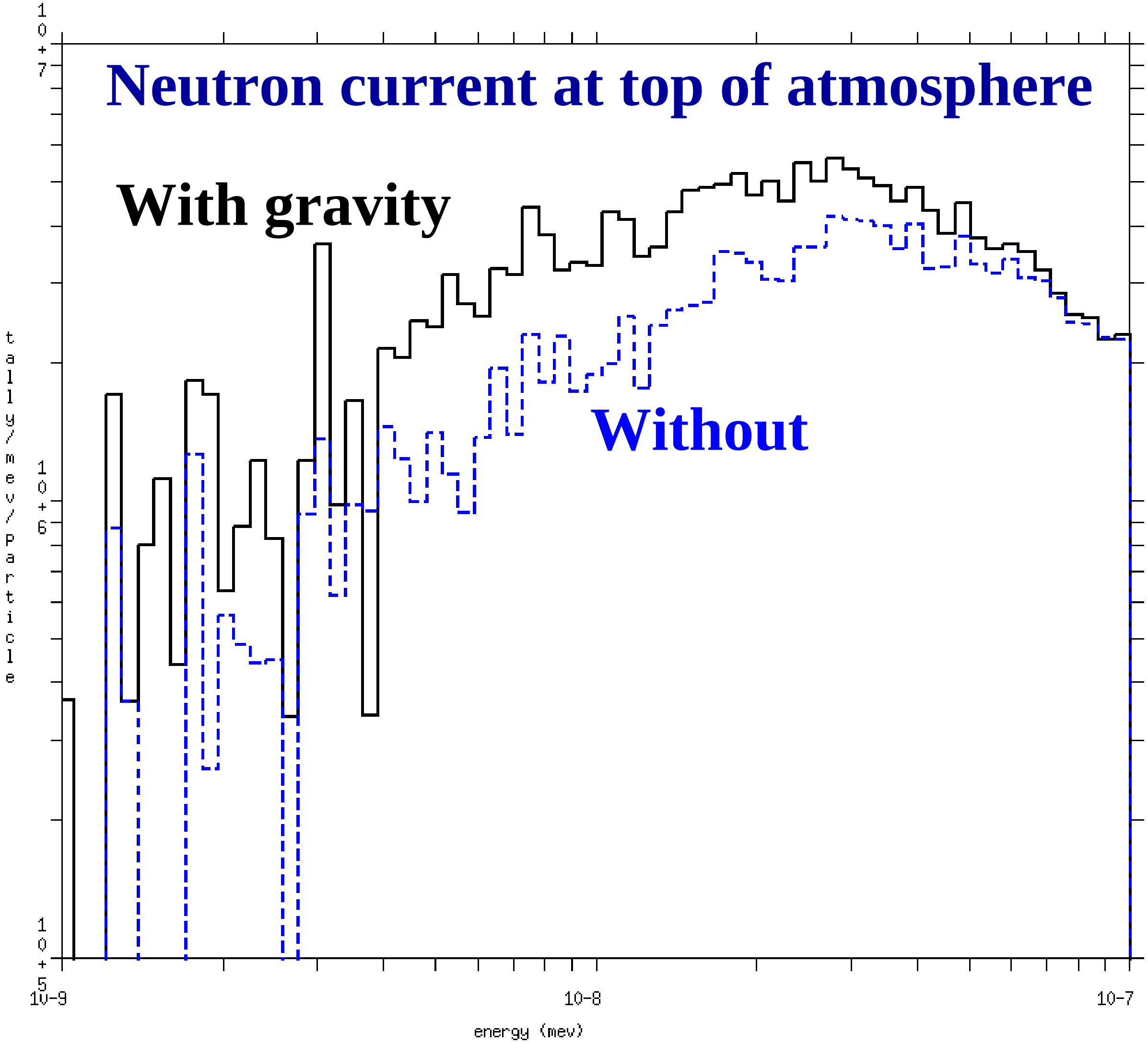
Mean-squared deviation factors between model predictions and experimental data measured at ITEP.

FIELD Card

```
5 GeV protons into Martian soil with 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
print
phys:n 5010 j j j 20
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.
f11:p 1
ft11  tag 1
e21   1e-10 99log 1e-7
f21:n 105
```

Undocumented Feature

FIELD Card


Neutron current at top of atmosphere
With gravity
Without
10+7
10+6
10+5
tally/mev/particle
10-9
10-8
10-7
energy (mev)

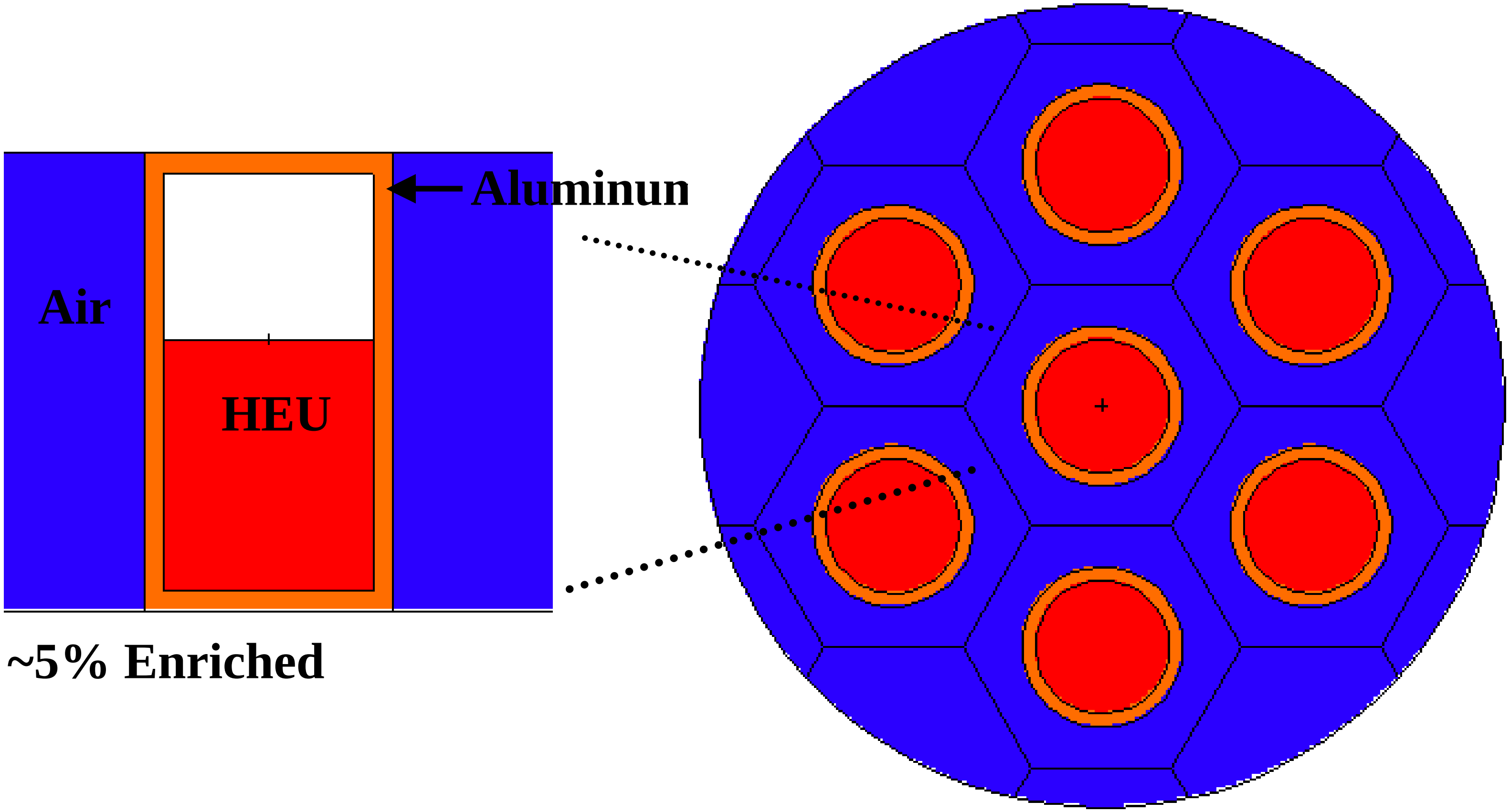
New Features – Version 2.6.C

- **Eigenfunction convergence improvement**
- **Transmutation improvements**
  - **Support for continue-runs**
  - **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**

Eigenfunction Convergence

- ADS / LANL ADS reactor application
- Before - eigenfunction exhibits false convergence within fissile regions
  - Fission source produced by power iteration method
  - Can have a significant effect on burnup and shielding results
  - Can only be overcome by running more particles/cycle
- Now - fission source distribution is biased to minimize false convergence
  - Fission matrix is tabulated and split into symmetric/asymmetric parts
  - Asymmetric component is dampened to minimize statistical variations
  - Biasing parameters are derived and used in the next cycle
  - Increases eigenfunction convergence by factors of 10-100

7-Can HEU Test Problem

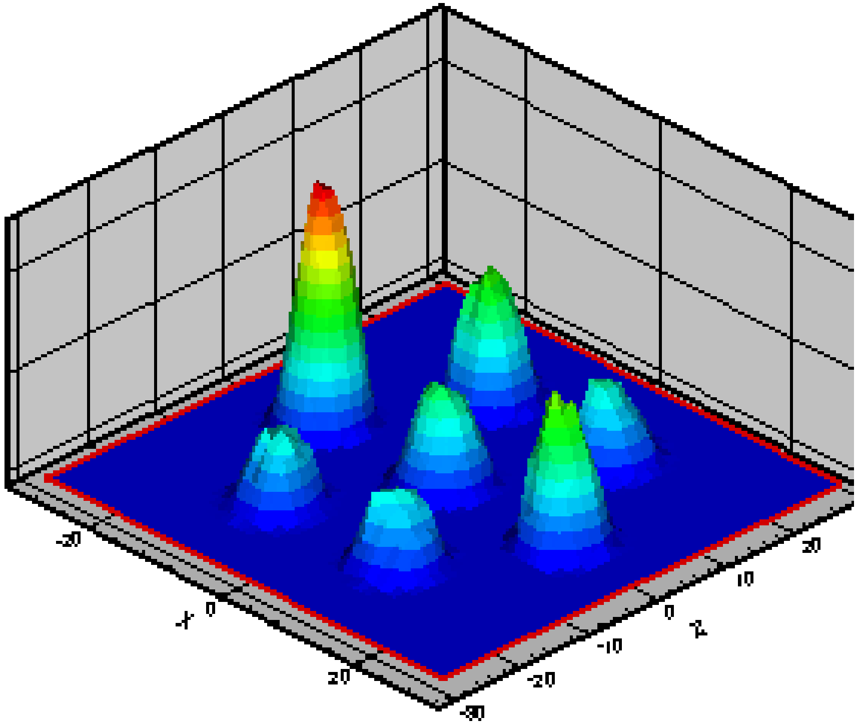


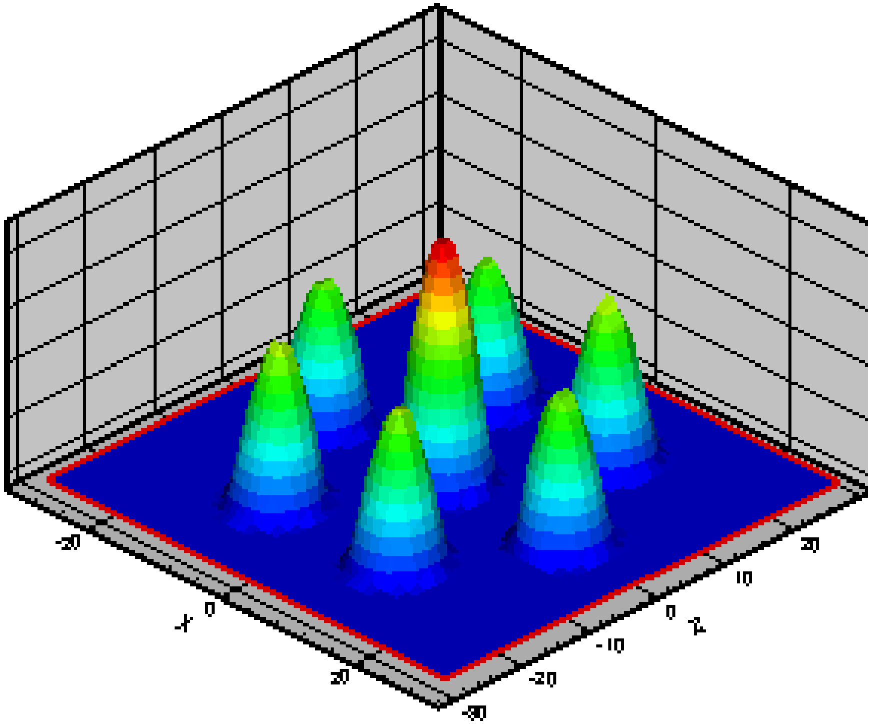
~5% Enriched

Eigenfunction from the Standard Method

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

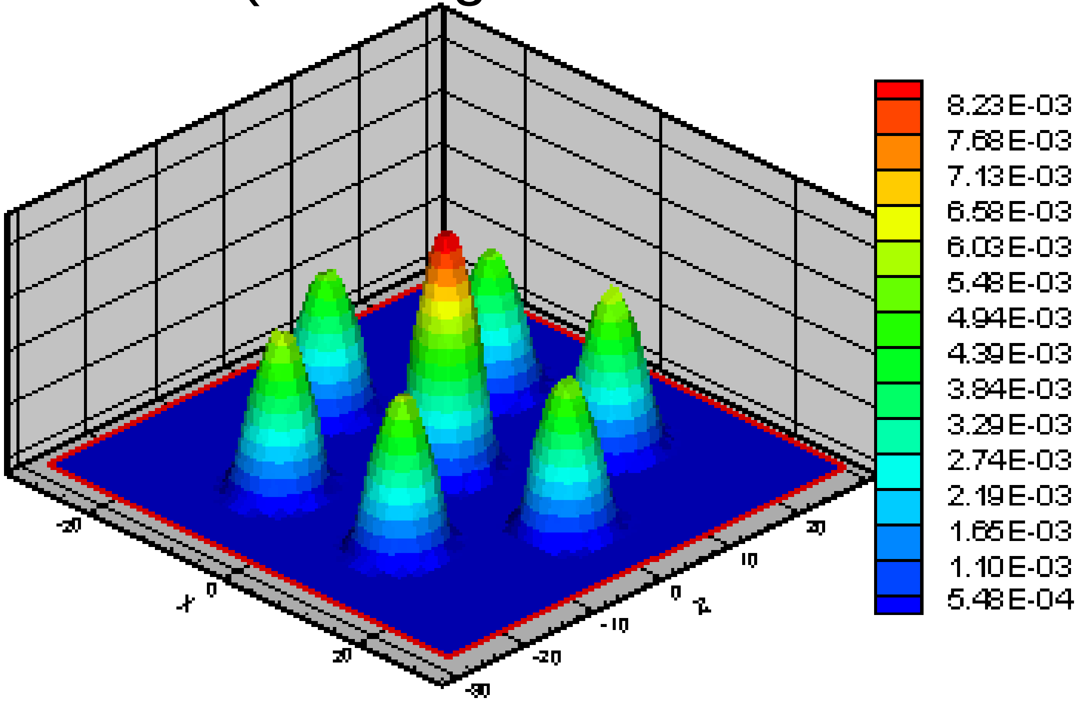
- 100,000 particles/cycle
- 100 active cycles (30 settle)
- ~10% flux tilt





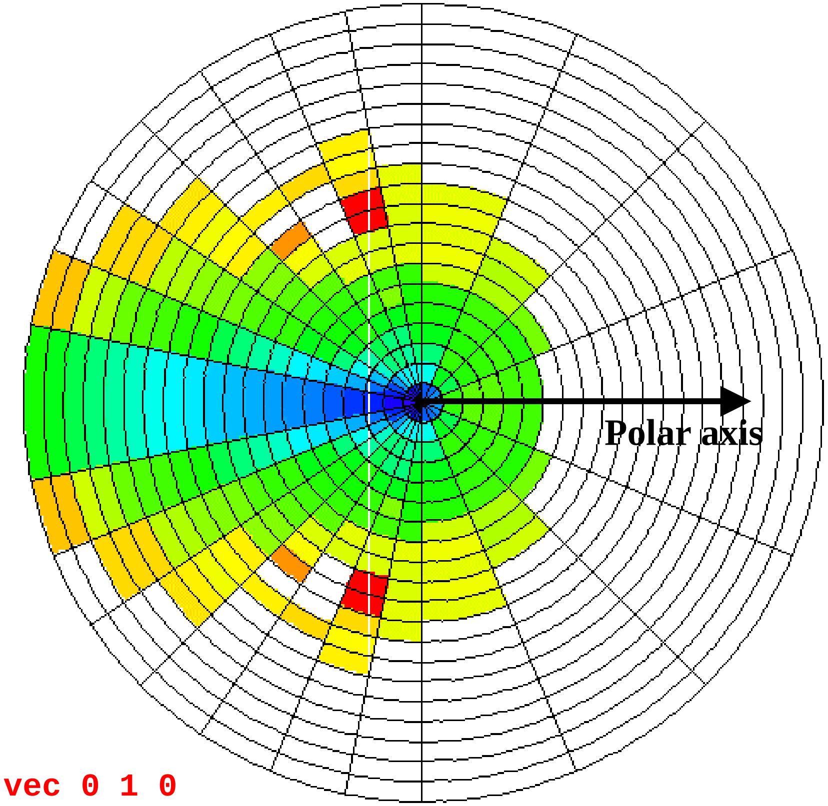
Eigenfunction from the New Method

- 1,000 particles/cycle
- 100 active cycles (30 settle)
- ~10% flux tilt (converges ~100 faster than SM)



Spherical Weight Windows

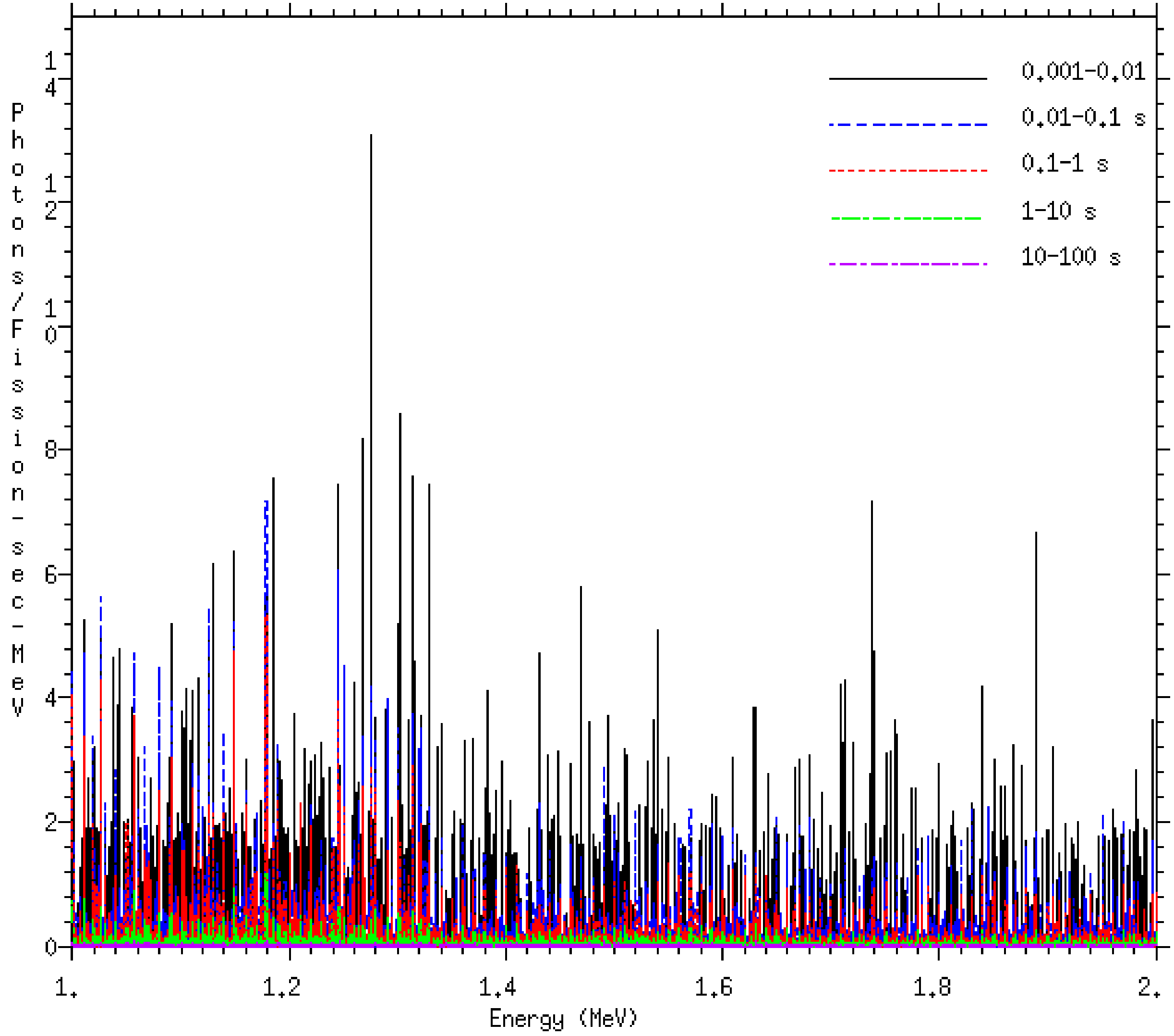
```
Disk of 10 MeV photons into 95cm H2O surrounding 3cm HEU
1  1  -19.0   -1    imp:p=1
2  2  -1.0    +1 -2 imp:p=1
3  0          +2 -3 imp:p=1
4  0             -3 imp:p=0

1 sph 0 0 0  3
2 sph 0 0 0  100
3 sph 0 0 0  200

mode p
sdef erg=10 pos -105 0 0 rad=d1 axs=1 0 0 ext=0
     vec=1 0 0 dir=d2
si1  0 10
sp1  -21 1
si2  0 1
sp2  0 1
m1   92235 .5 92238 .5
m2   1001 2 8016 1
nps 100000
f4:p 1
wwg 4 0
mesh geom rpt origin=0 0 0 ref=-99 1 1 axs 1 0 0 vec 0 1 0
     imesh  101.   iints  20
     jmesh  .25 .5 jints  4 8
     kmesh   1     kints  1
c    wwp:p  4j -1    $ Add this card to use WW
```



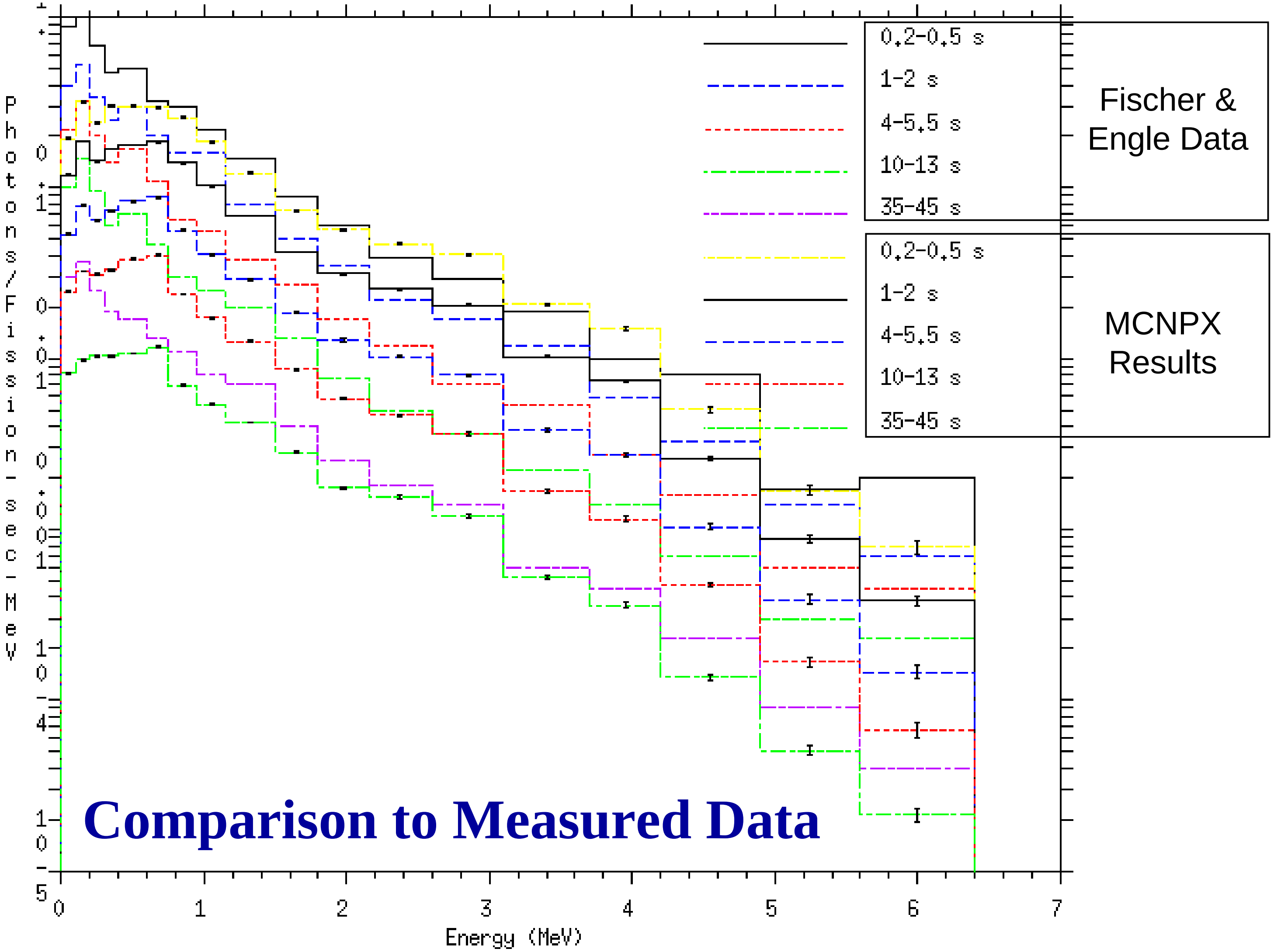
Delayed Neutrons and Gammas

```
Delayed gammas from Watt fission in U-235
1      1 -18.9   -1 IMP:N=1
2      0          1 IMP:N=0

1      so 0.01975

mode   n p
m1     92235.60c 1.
nps    20000000
sdef   erg=d1 par=n
sp1    -3
phys:p 5j -1
e0     0. 1024i 10.0
t0     .001e8 .01e8 .1e8 1e8 10e8 100e8
f1:p   1
```

Delayed Neutrons and Gammas



Delayed Neutrons and Gammas



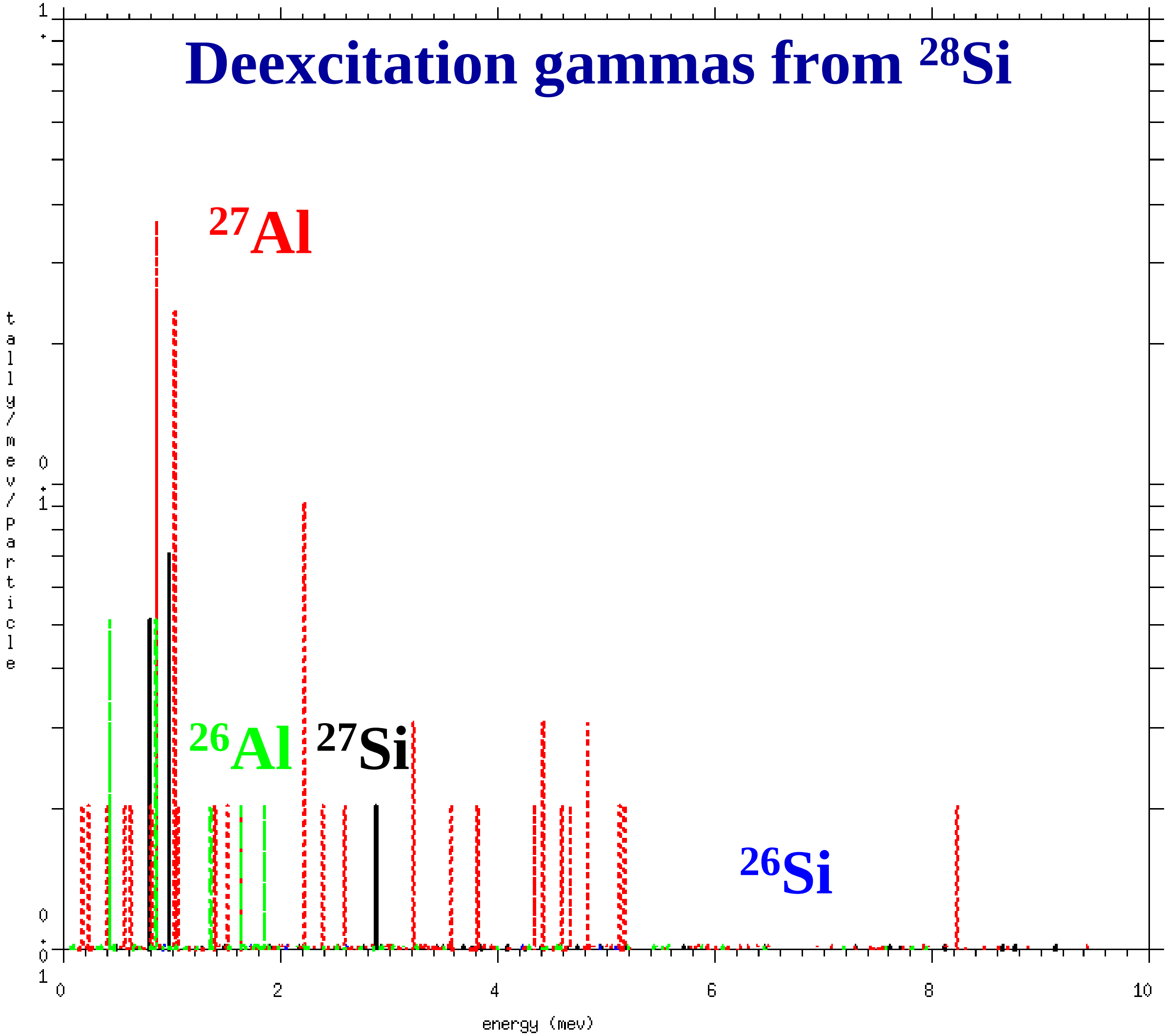
Comparison to Measured Data

Photon Tally Tagging

```
5 GeV protons into Martian soil with photon tagging
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
print
phys:n 5010 j j j 20
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.
f11:p 1
ft11  tag 1
e21   1e-10 99log 1e-7
f21:n 105
```

Undocumented Feature

Photon Tally Tagging

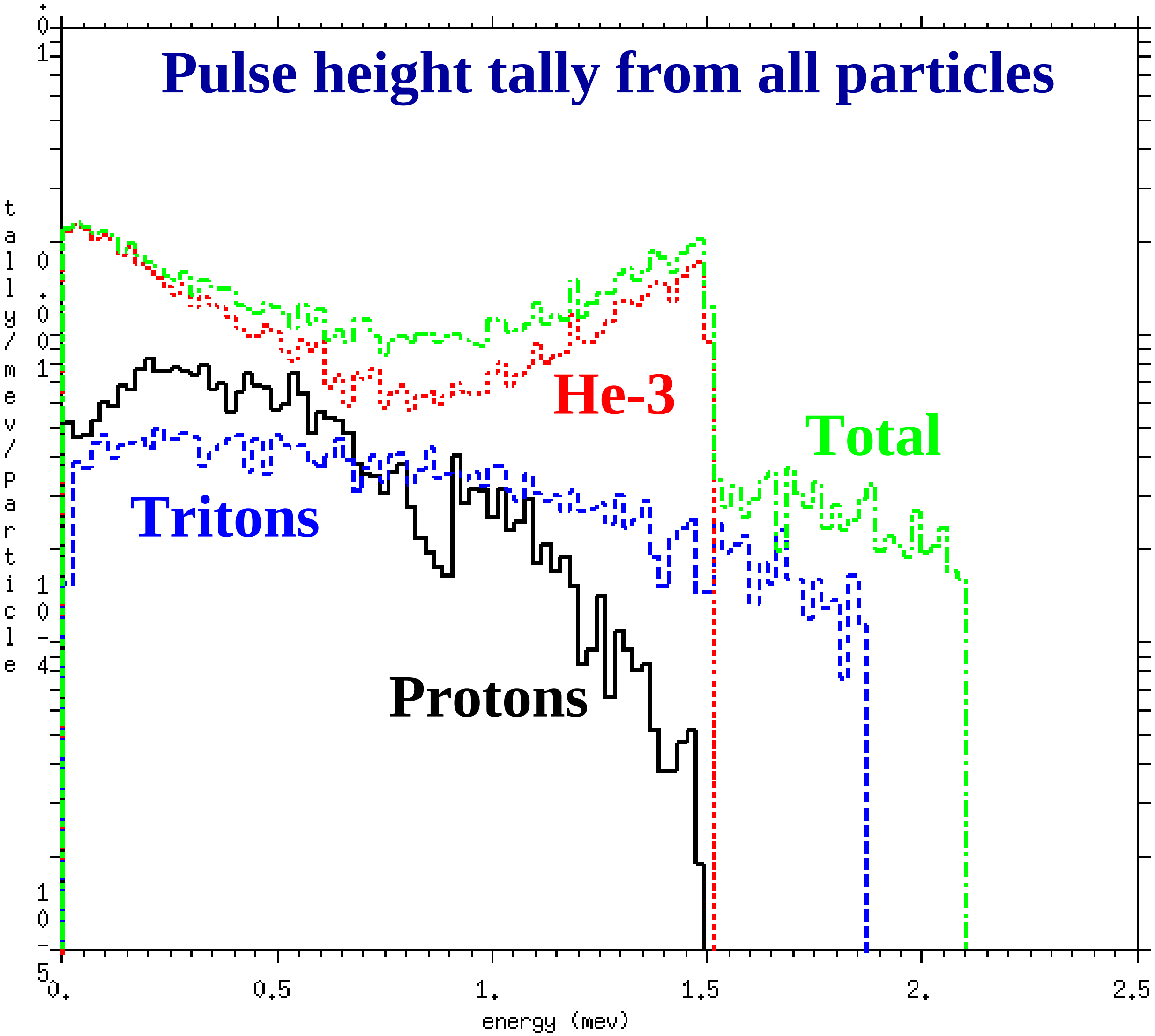


Models for Library Interactions

```
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
```

Models for Library Interactions



Future of MCNPX

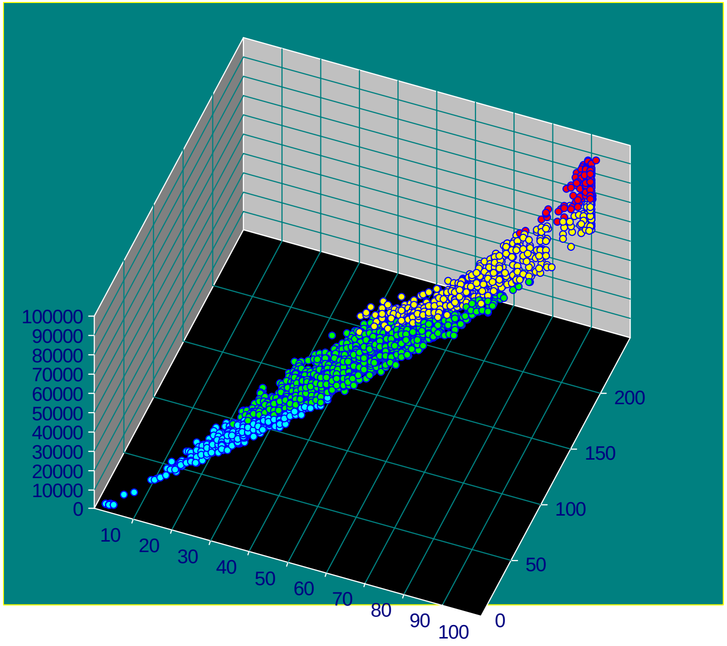
- **Possible public release of 2.6.0 (Summer 2007)**
- **Version 2.6.D/2.7.A (April 2007)**
  - **Transmutation improvements**
  - **Energy and time weight windows**
  - **Radioactive source option**
  - **Photofission and delayed neutron improvements**
- **MCNPX and MCNP merger**
  - **Hope to preserve all features of both codes**
  - **Preliminary version by Summer 2007**
  - **Public release perhaps by 2008**

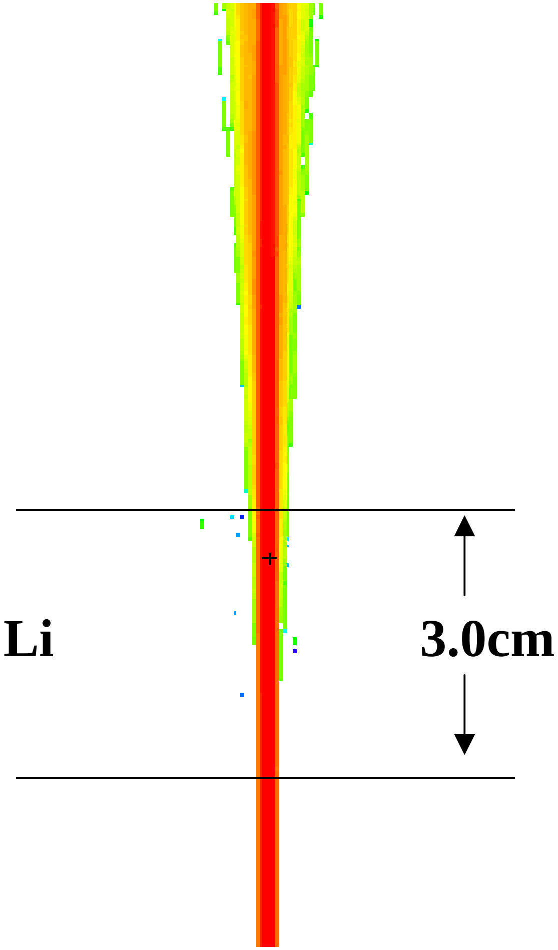
Future Development

- **Heavy-ion tracking and LAQGSM physics model (2.6.?)**
- **Magnetic fields**
- **CAD interface (with spline-surface tracking)**
- **Variance reduction techniques extended to models**
- **Improve point detectors/DXTRAN for models**
- **Extend electron data to 100 GeV**

Heavy Ion Transport

- Example: U-238 at 400 GeV/nucleon traveling through a Li jet.





Existing Burnup Capabilities

- **Numerous "scripts" written to link MC codes to depletion codes**
  - MOCUP (MCNP/ORIGEN2, INEL, 1995)
  - MC-REBUS (MCNP/REBUS, ANL, 1998)
  - OCTOPUS (MCNP/FISPACT, ECN NRG Netherlands, 1998)
  - MCB (MCNP/Custom, RIT Sweden, 1999)
  - MonteBurns2 (MCNP/ORIGEN2 or CINDER90, LANL, 1999)
  - MCWO (MCNP/ORIGEN2, INEEL, 2000)
  - BURNCAL (MCNP/Custom, SNL, 2002)
  - MCODE (MCNP/ORIGEN2, MIT, 2002)
- **Disadvantages of a "link" approach**
  - Several input files to create and understand
  - Numerous input/output files to manage
  - Approximations to convert data from one format/code to another

MCNPX/CINDER90 Interface

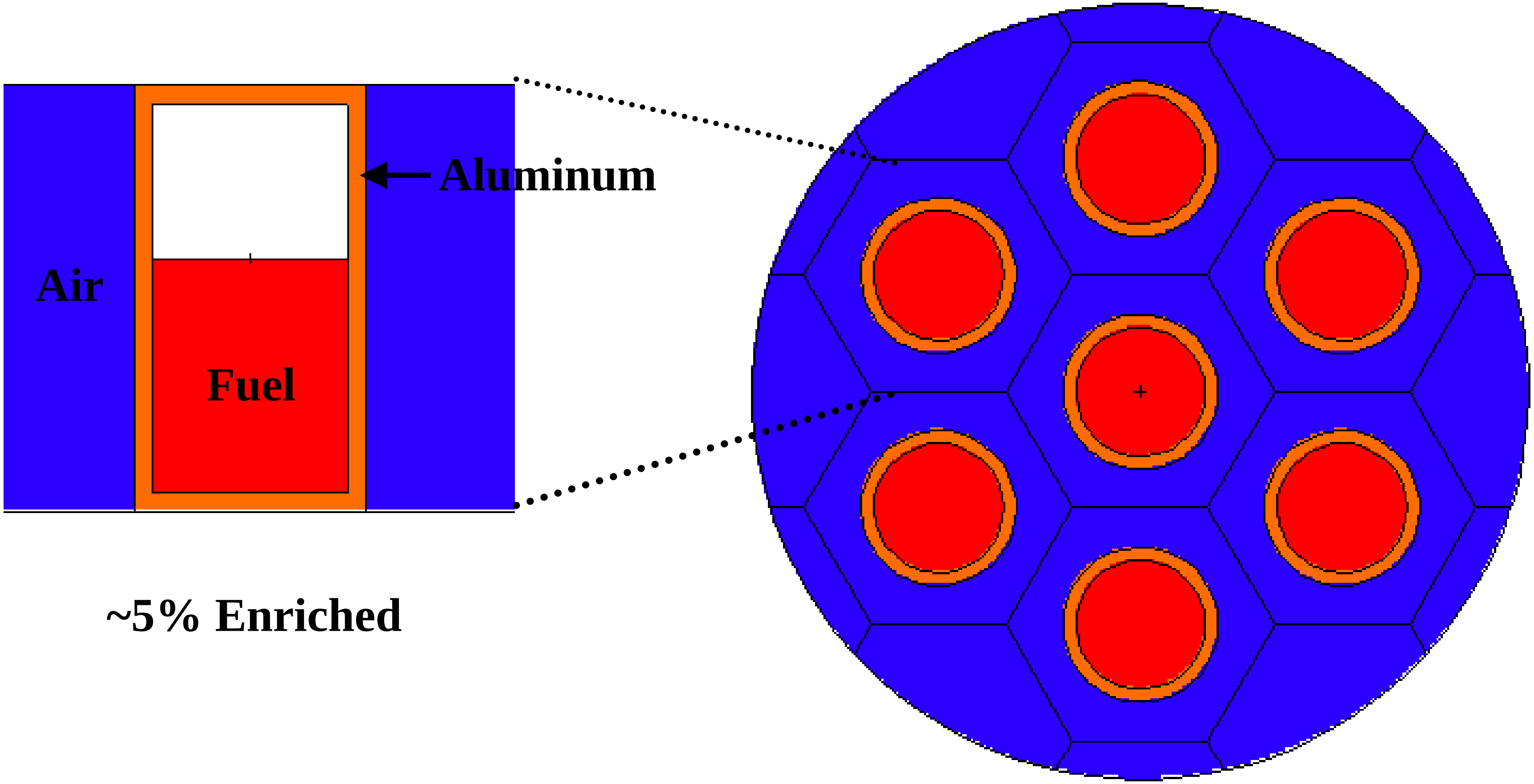
- **MCNPX provides to CINDER90**
  - 63-group fluxes in each material to be burned
  - Isotopic atom densities and material volumes
  - Absorption and fission reaction rates for each nuclide
  - Average k_{eff} and fission ν, and fission Q
  - Power level and burn time
- **CINDER90 provides to MCNPX**
  - Updated isotopic atom densities
  - Burnup quantities
- **User interface (BURN card)**
  - BURN card without any entries defaults to 1 MW power for 1 day
  - User can specify burn materials, power level, burn times, etc.
  - Histories run per burn time are taken from NPS or KCODE card

BURN Card

```
BURN   POWER=2.0   TIME=15,30,30   MAT=3,4
        OMIT=3,3,8017,92234,94239,4,1,92234
```

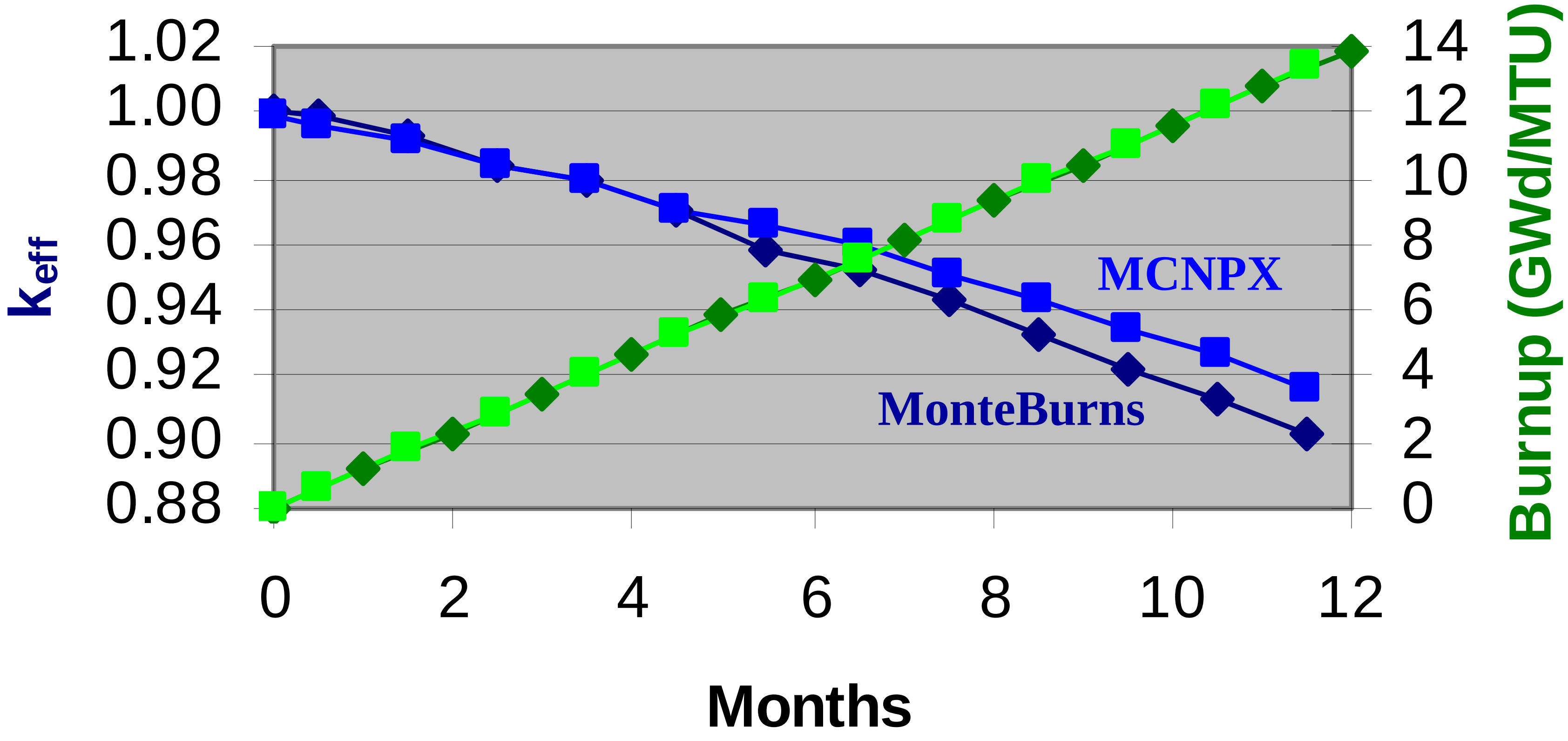
Specifies a power level of 2 MW for a duration of 75 days (steps of 15, 30, and 30 days). Materials 3 and 4 are included in the burn with isotopes ^{17}O, ^{234}U, and ^{239}Pu excluded from material 3 and isotope ^{234}U excluded from material 4. Nuclides with an atom fraction less than 1e-10 are also excluded. To force the inclusion of a nuclide, simply list that nuclide on the appropriate material card with an insignificant atom fraction.

7-Can HEU Test Problem

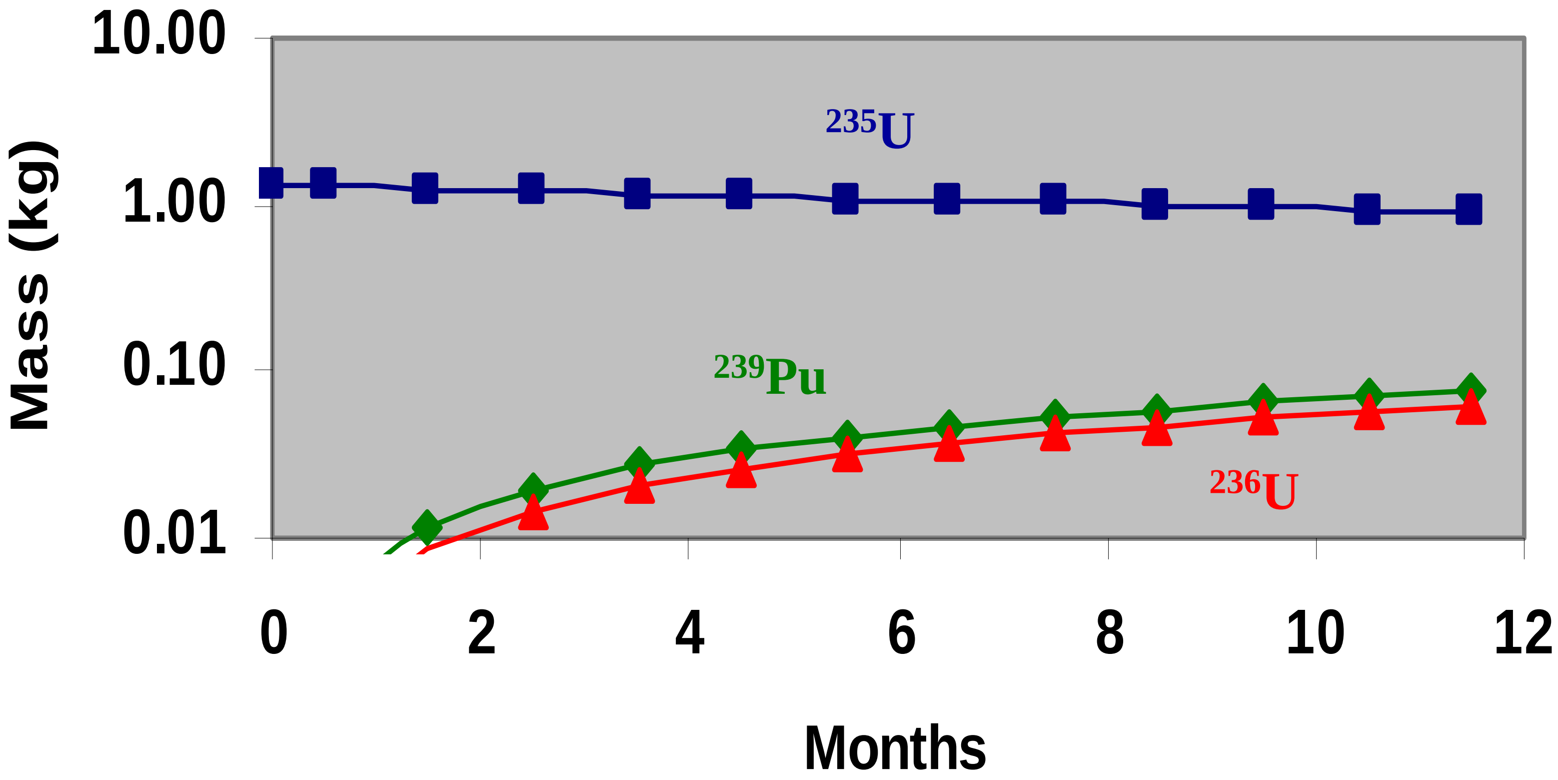


~5% Enriched

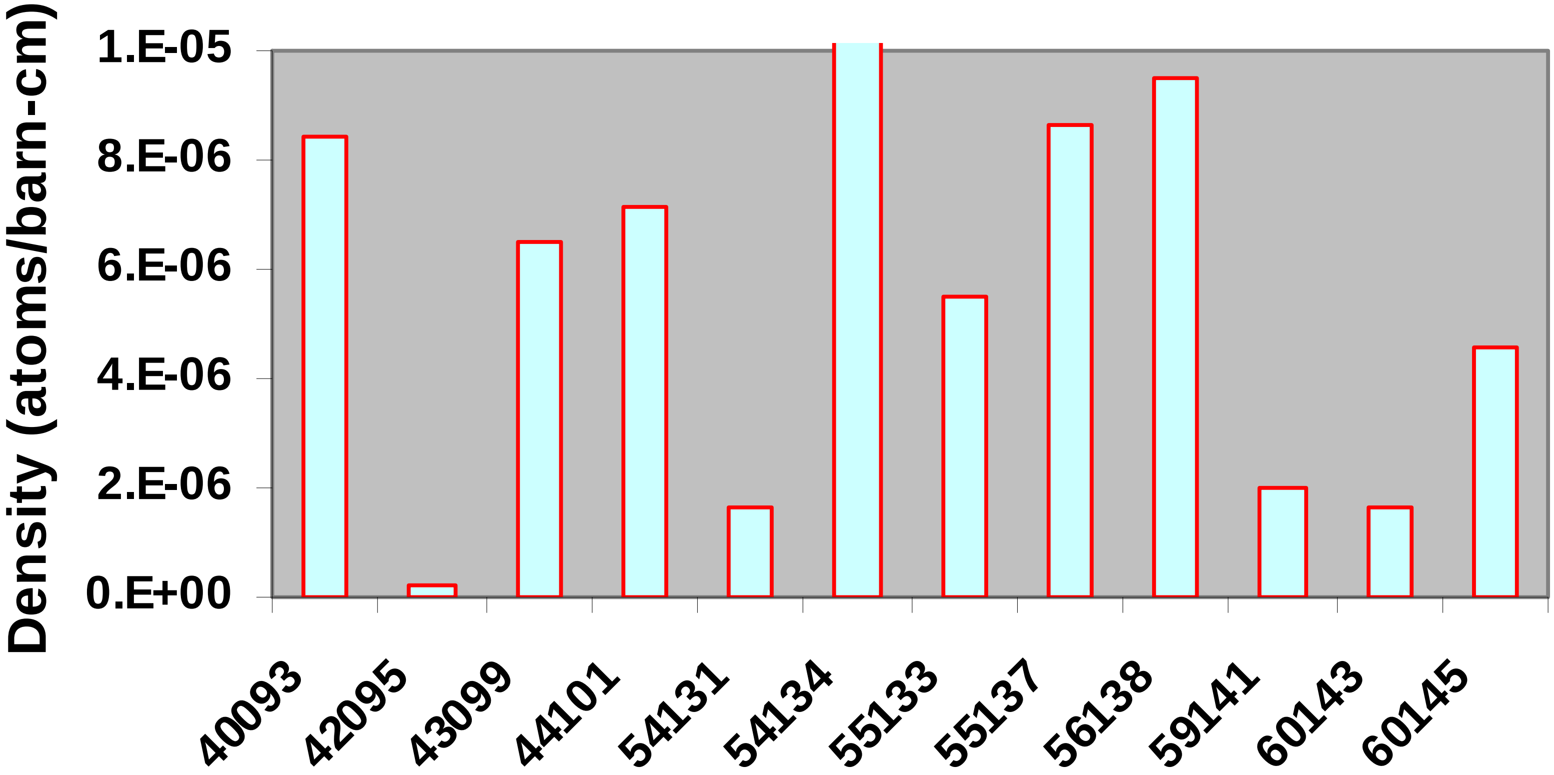
Comparison to MonteBurns



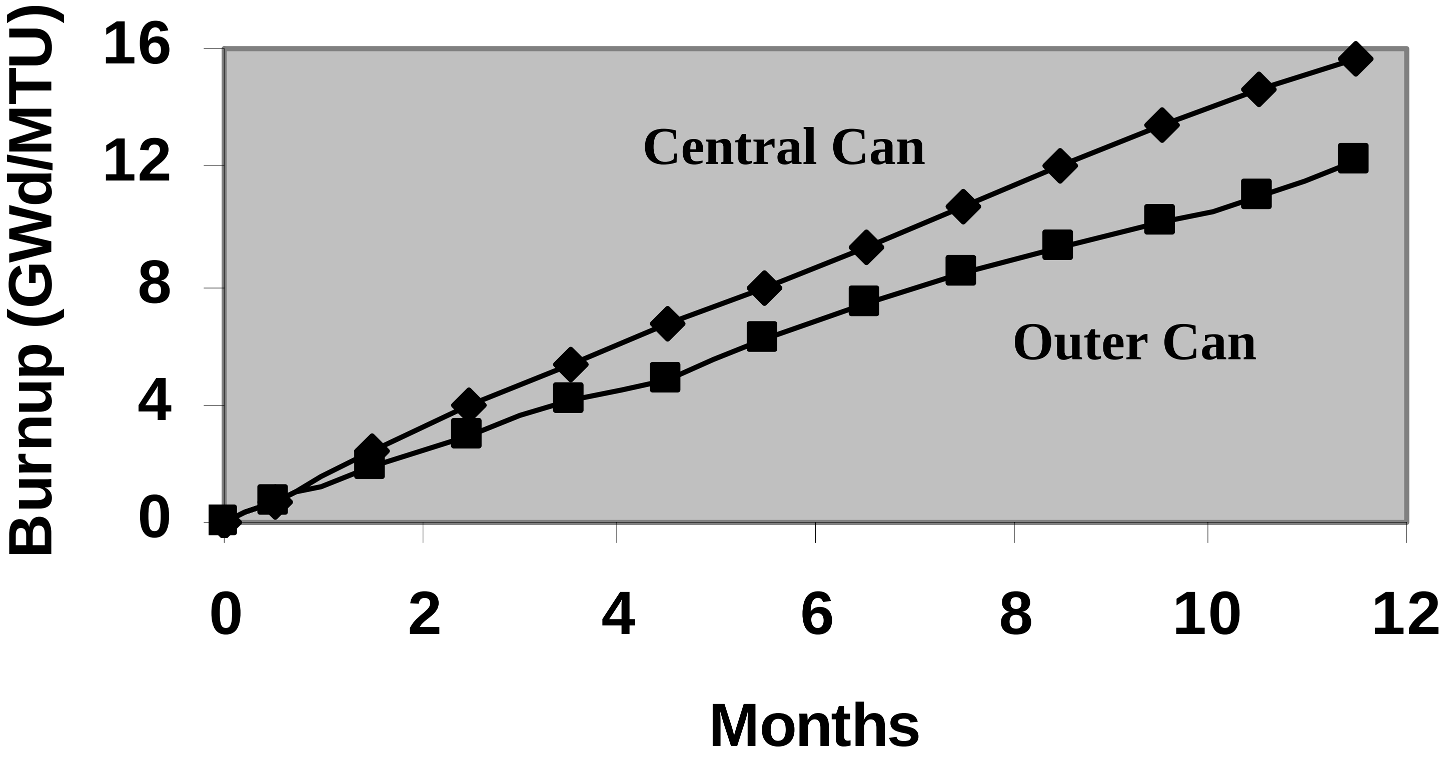
Actinide Inventories



Fission Product Inventories



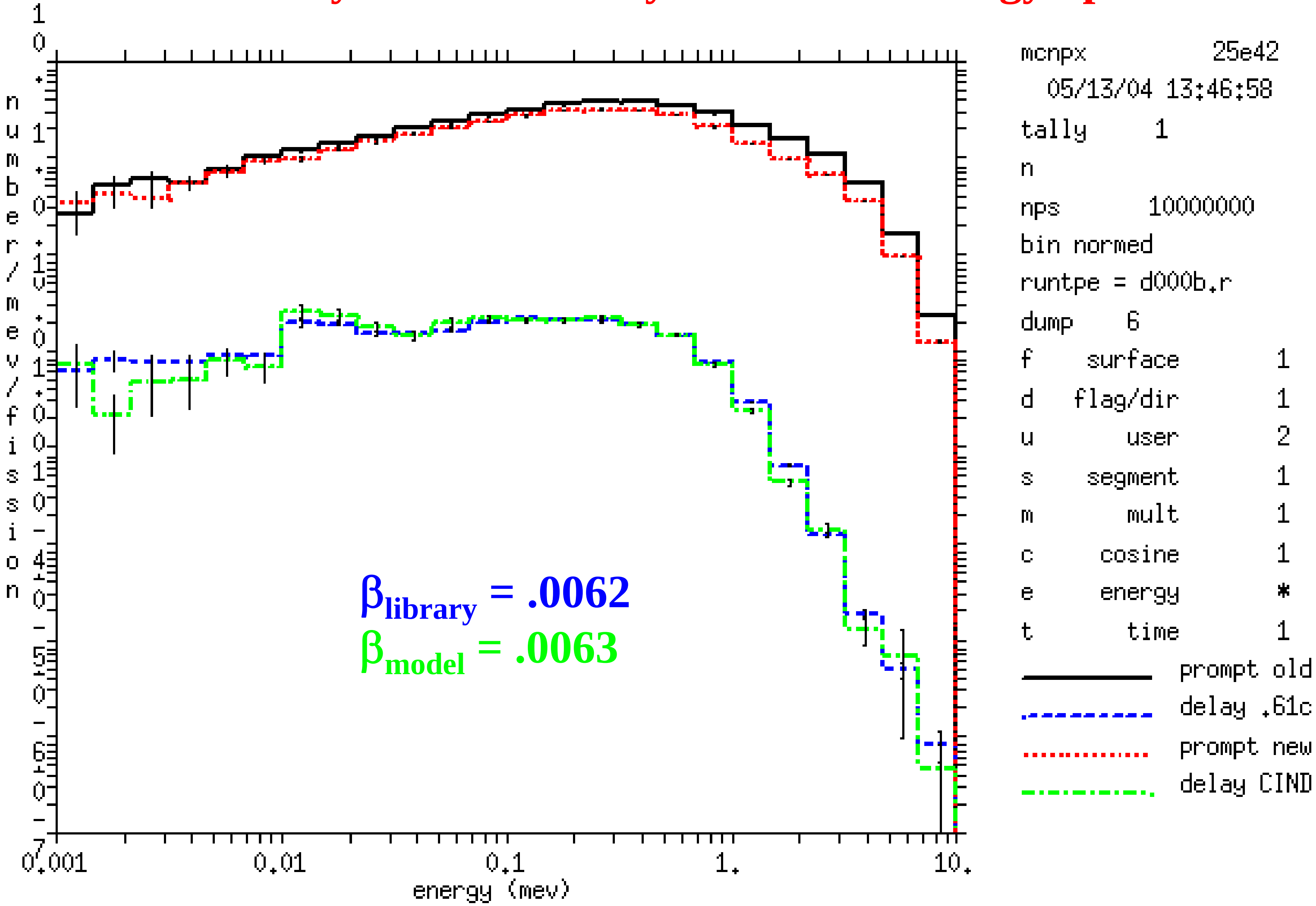
Can Burnup


Burnup (GWd/MTU)
16
12
8
4
0
0
2
4
6
8
10
12
Months
Central Can
Outer Can

Delayed Neutron/Gamma Capability

- Delayed treatment for model and library interactions
  - All events for model interactions
  - Fission events for library interactions
- Delayed distributions provided by CINDER90
  - Uses residual nuclides from model interactions
  - Samples fission products for library fission events
  - Includes virtually all possible decay chains
  - Provides energy distributions in groups (300 n, 25 g)
  - Provides time distributions (continuous => 70 bins)
- Biasing available to enhance delayed production

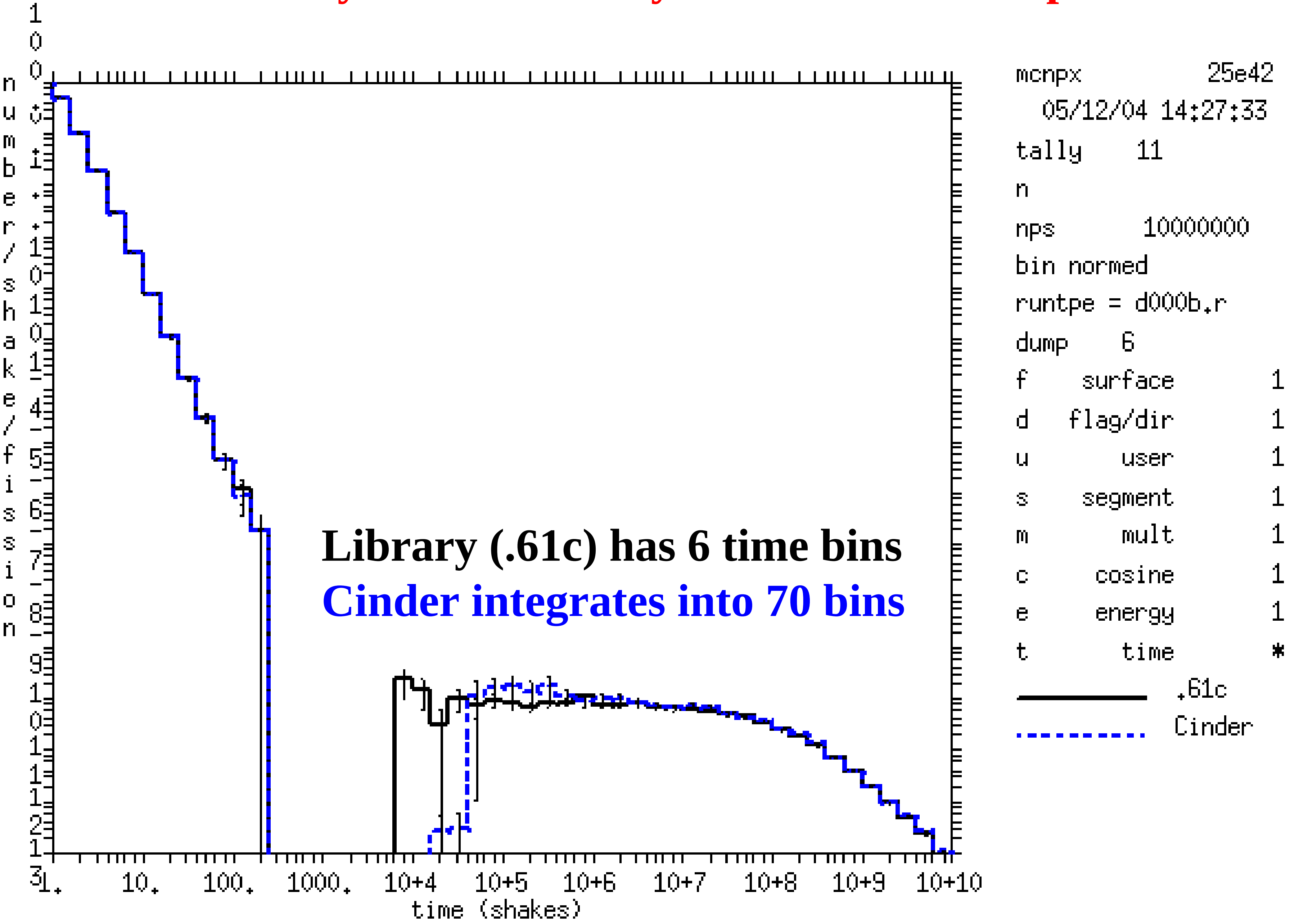
^{235}U Library vs Model Delayed Neutron Energy Spectra



$\beta_{library} = .0062$

$\beta_{model} = .0063$

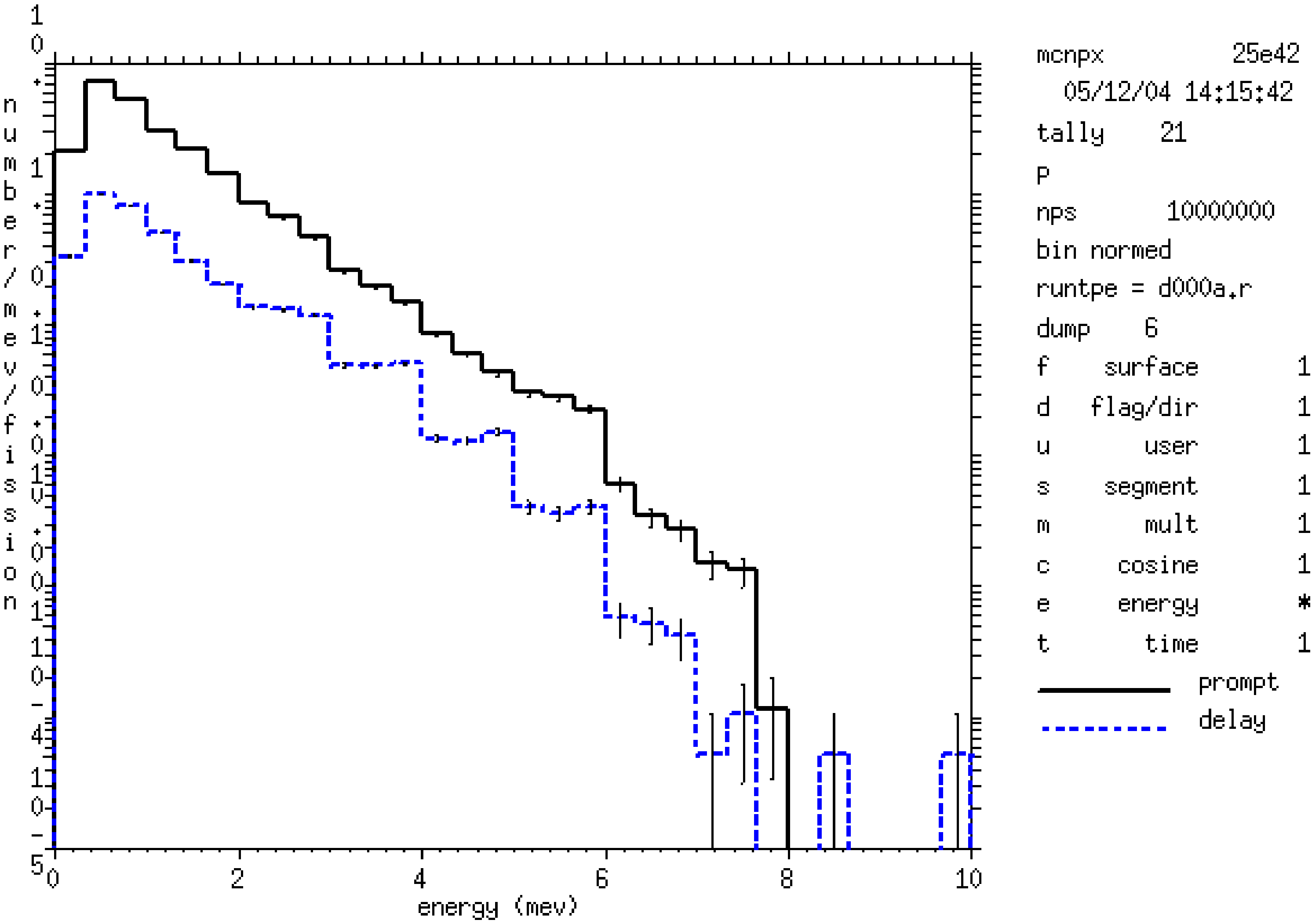
^{235}U Library vs Model Delayed Neutron Time Spectra



Library (.61c) has 6 time bins

Cinder integrates into 70 bins

^{235}U Delayed Gamma Production per Fission



^{235}U Delayed Gamma Production per Fission