MCNPX 2.5.0

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Outline

- **Overview**
- **New 2.5.0 Features**
- **Heavy Ion Transport**
- **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)

Accelerator Application

- **MCNPX is well-suited for high-energy accelerator modeling**
  - Large beta-test team and user community.
  - Many years of experience in accelerator community, esp. at LANSCE facility.
  - Multiple physics models provide a wide variety of options.
    - Bertini, CEM,INCL4, ISABEL, FLUKA.
  - Calculates values of interest such as fluxes, shielding, detector response, radioisotope inventories, cross sections, etc.
  - Active development program.

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

New 2.5.0 Features (28)

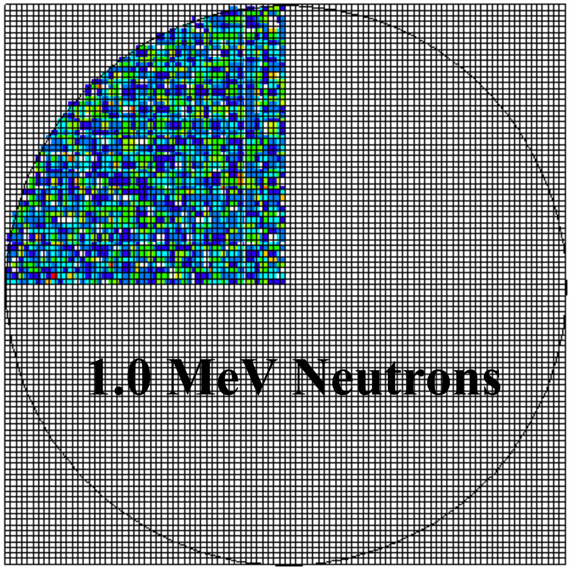
- **User-interface enhancements (15)**
  - 5 new source options
  - 4 new tally options
  - 3 new graphics options
  - 3 other miscellaneous improvements
- **Physics enhancements (9)**
  - 4 new model physics features
  - 2 new neutron physics features
  - 3 new photon physics features
- **Infrastructure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

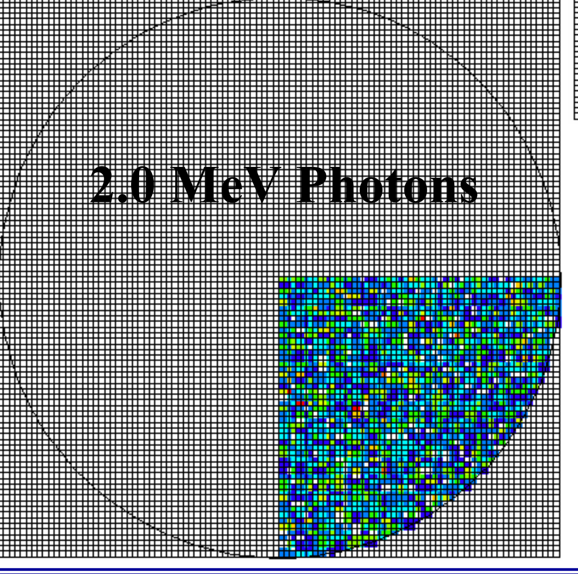
User-Interface Enhancements

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

Multiple Source Particles / TR Extension

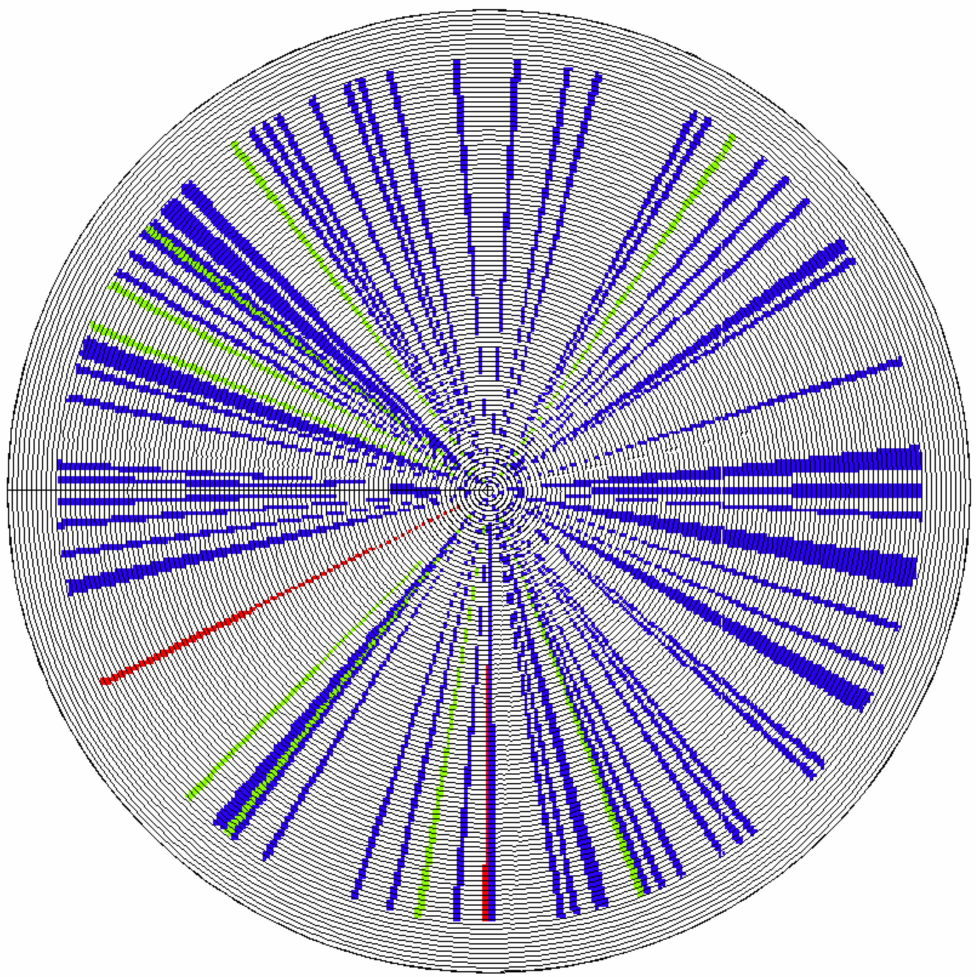
```
Distribution for PAR and TR Keywords
1   0     -1     imp:n=1
2   0      1     imp:n=0

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
```

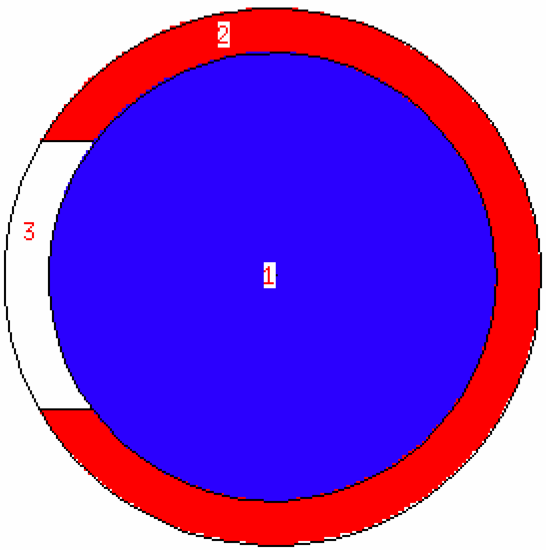


User-Interface Enhancements

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

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
```



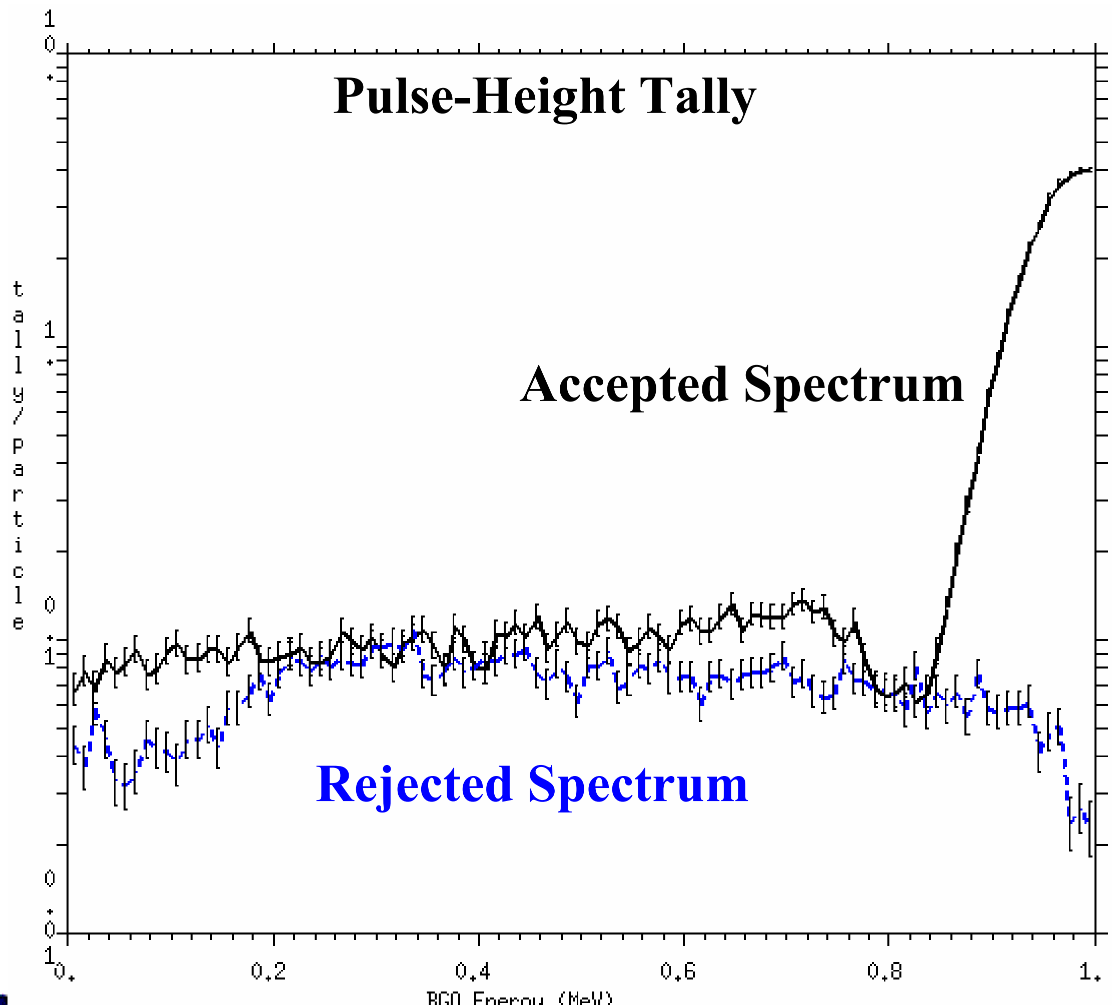
Anticoincidence Pulse-Height Tally

```
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**

B G O ↓

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

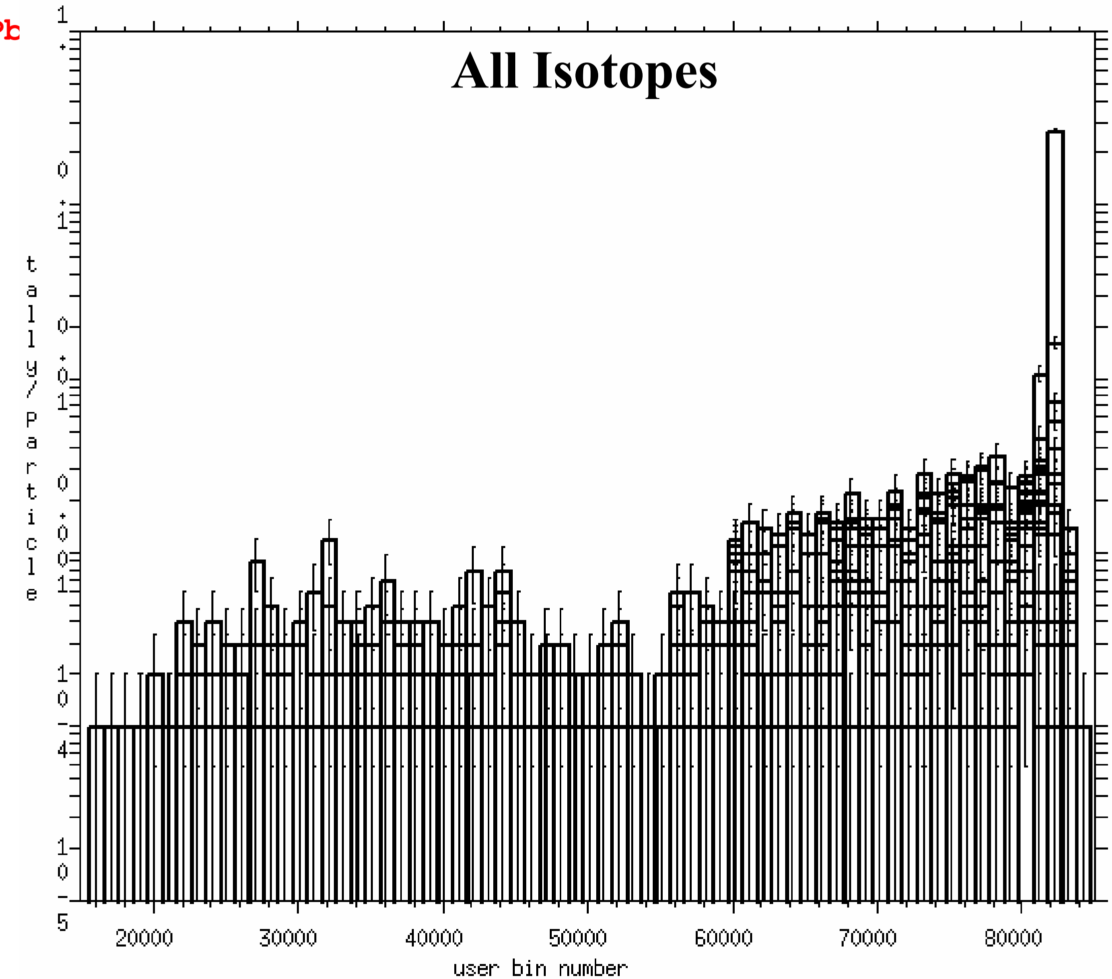
neutron captures on 10b

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

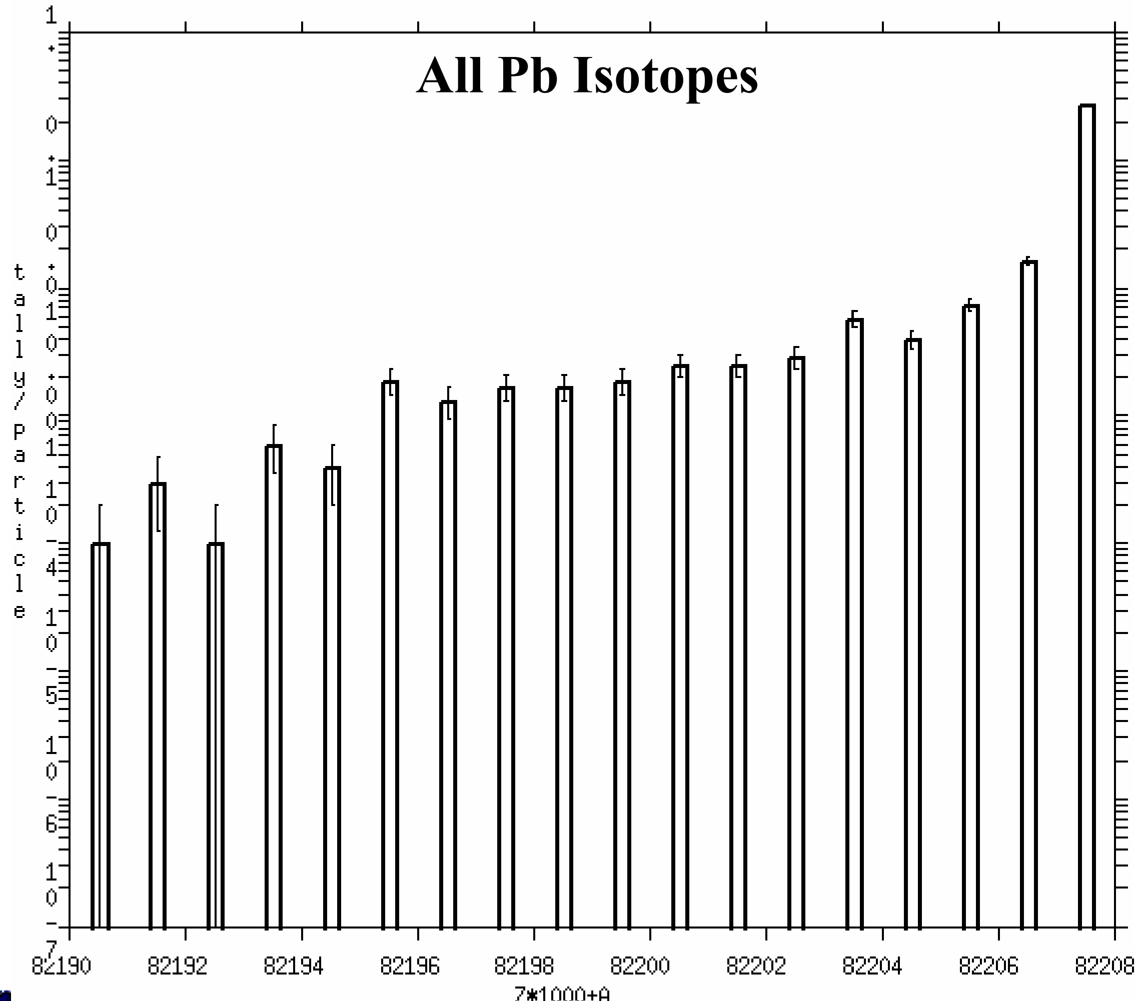
factorial moments	by number		by weight	
10b	4.60640E-01	0.0050	2.13551E-01	0.0050
10b(10b-1)/2!	1.41880E-01	0.0172	6.57750E-02	0.0172
10b(10b-1)(10b-2)/3!	5.36700E-02	0.0533	2.48812E-02	0.0533
10b(10b-1) .... (10b-3)/4!	2.53200E-02	0.1255	1.17383E-02	0.1255
10b(10b-1) .... (10b-4)/5!	1.20200E-02	0.2487	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



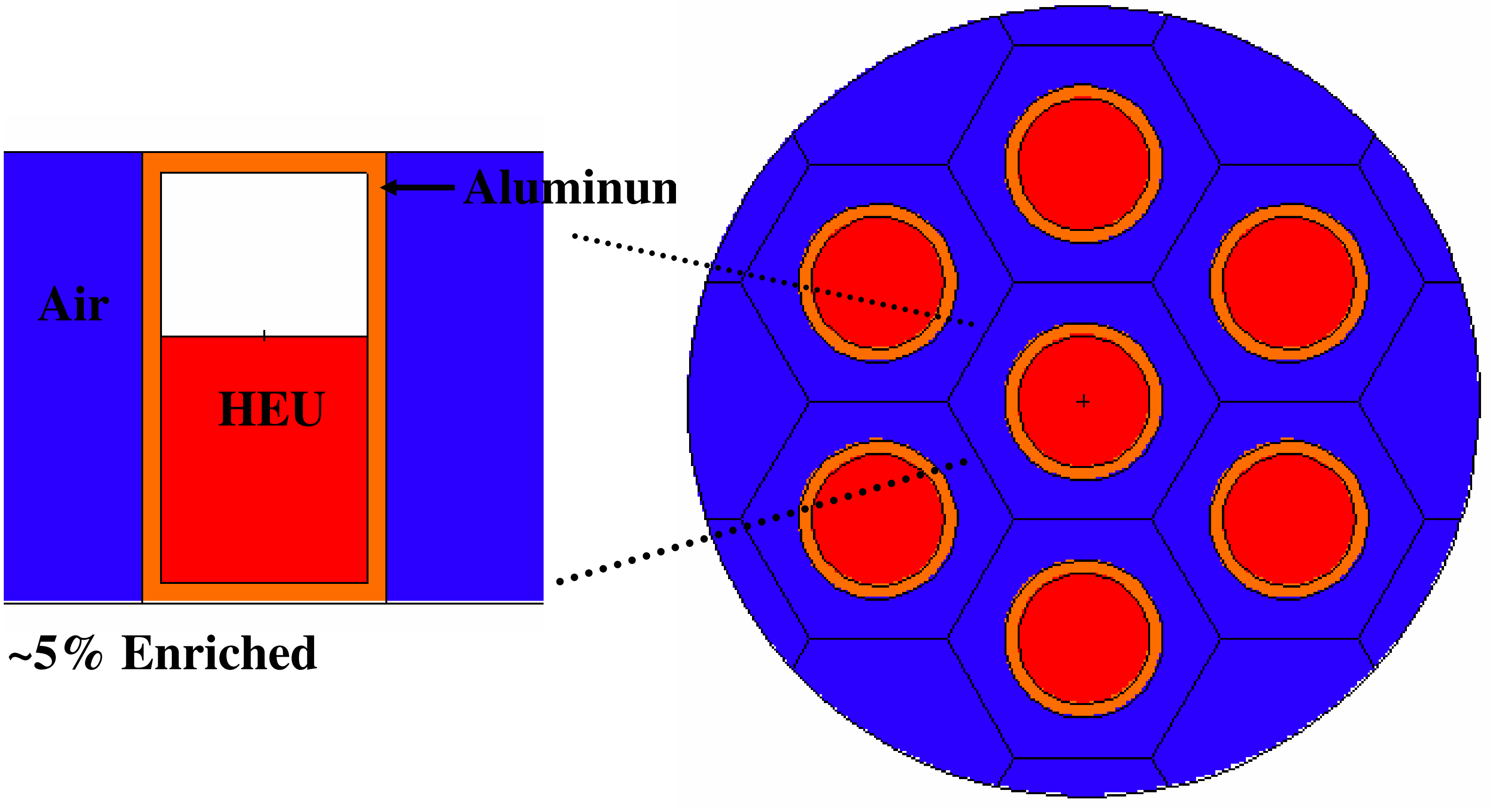
User-Interface Enhancements

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

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

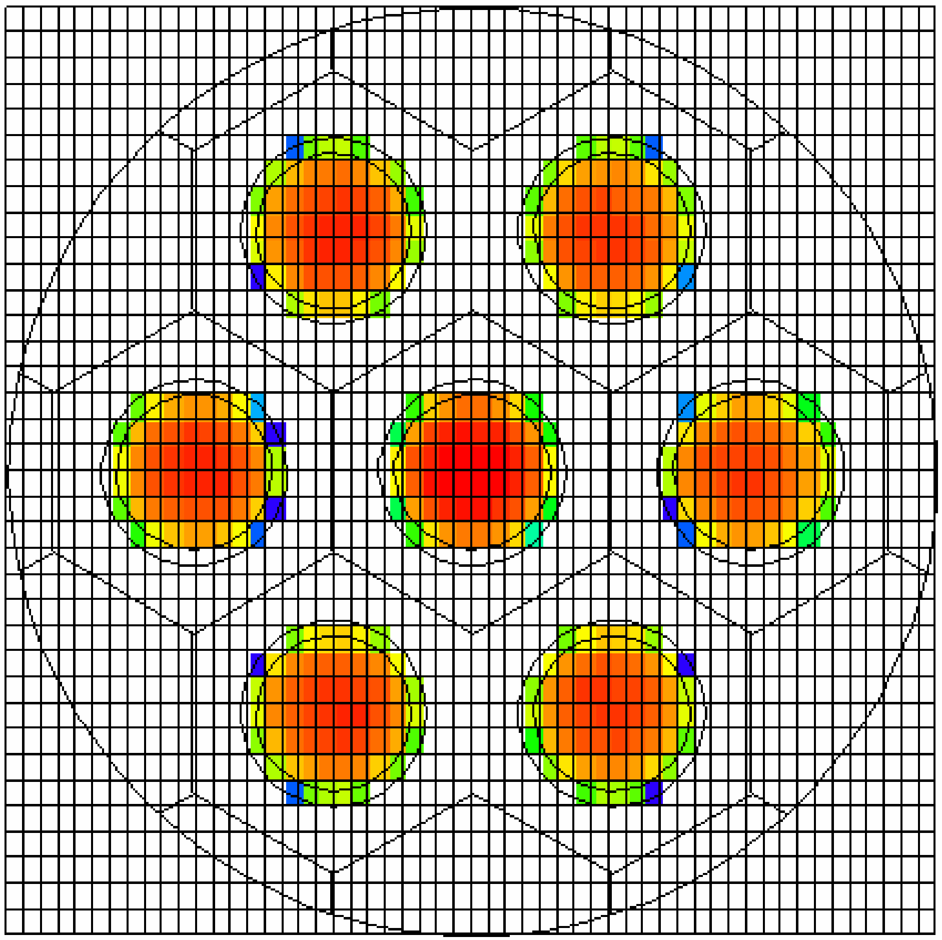


~5% Enriched

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)

UP RT DN LF Origin .1 .2 Zoom 5. 10



cel imp rho den vol fcl mas pwt mat tmp wwn ext pd dxc u lat fill ijk nonu pac tal

PAR N

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

Redraw Plot> End

User-Interface Enhancements

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

Physics Enhancements

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

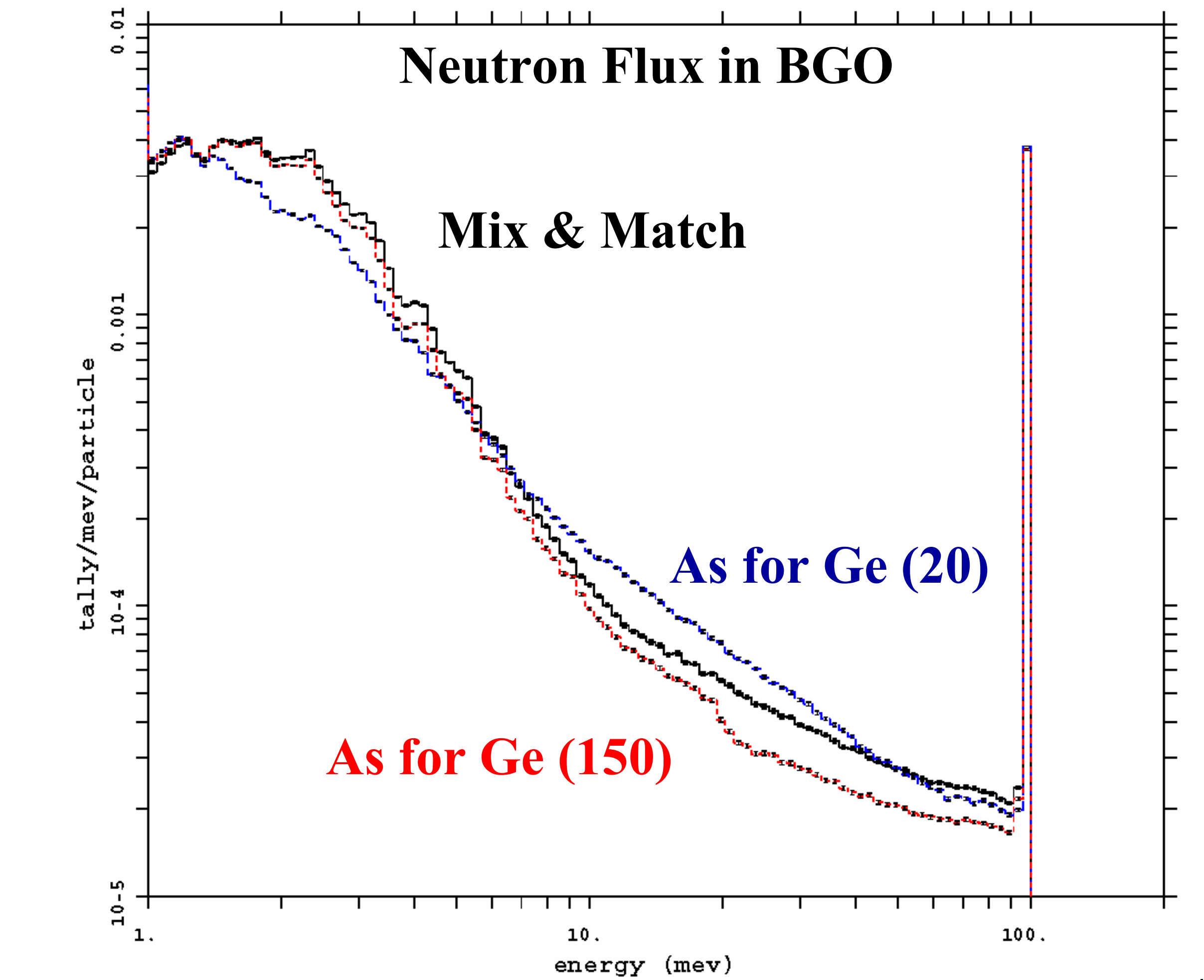
Mix & Match of Libraries and Models

- **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



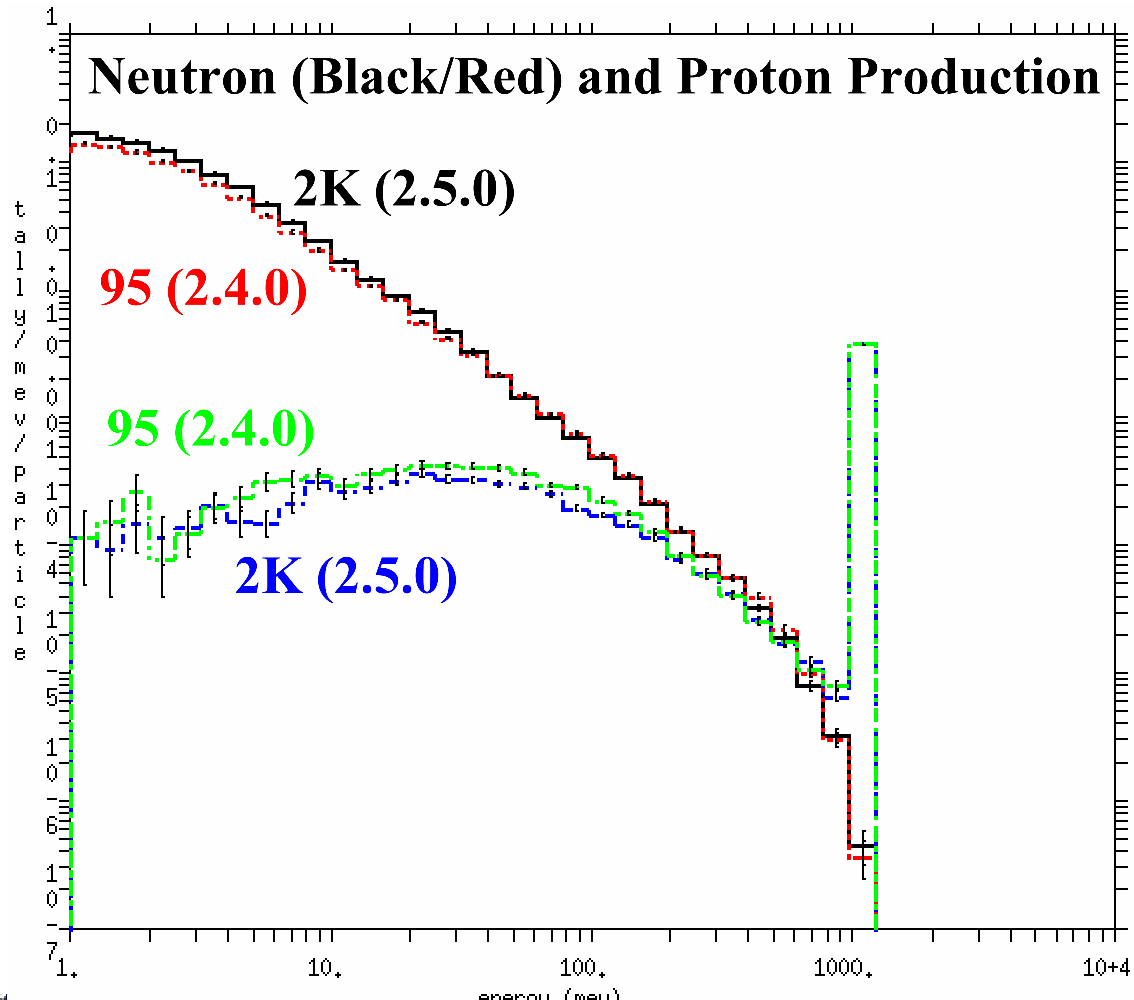
CEM Upgrade to 2K (from 95)

- **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.

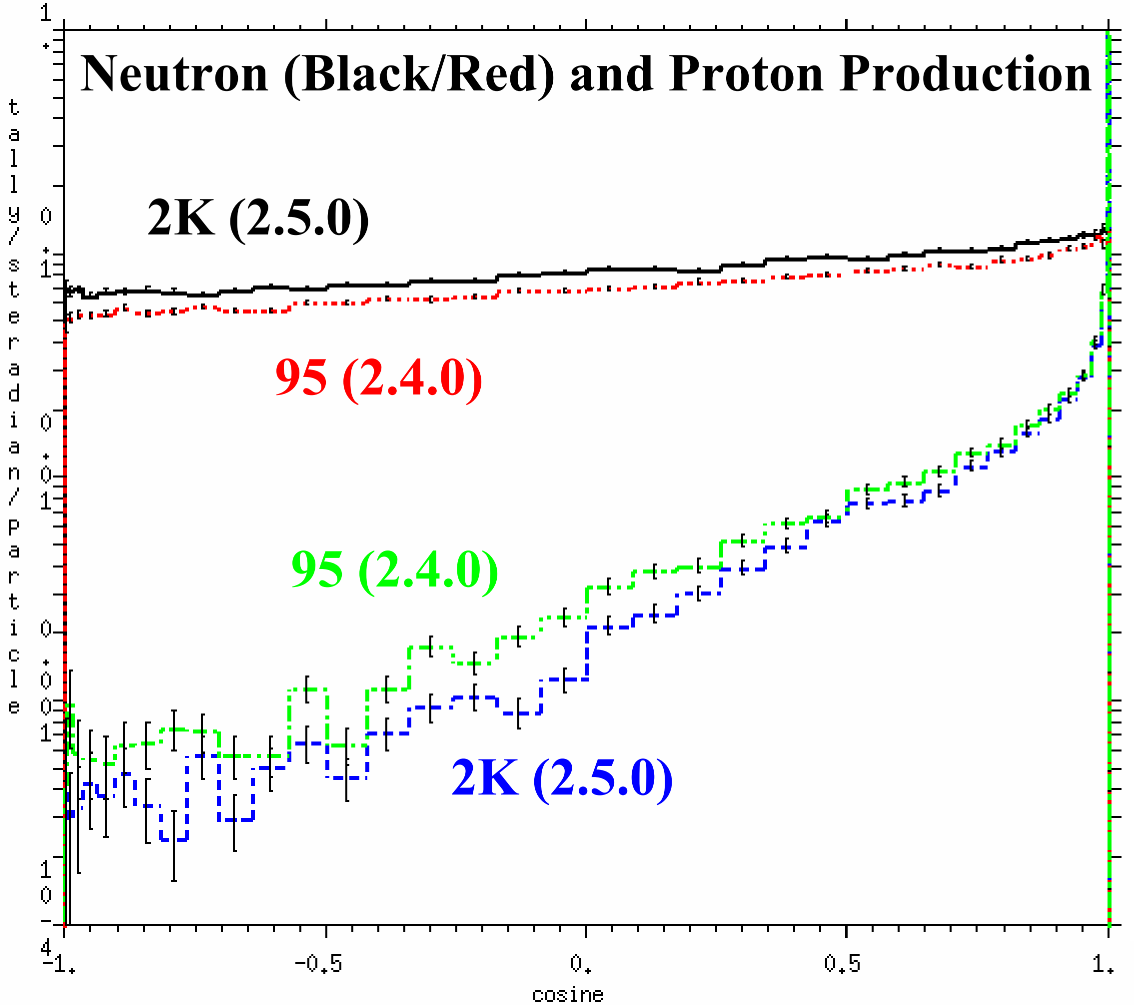
CEM Upgrade to 2K (from 95)

```
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)



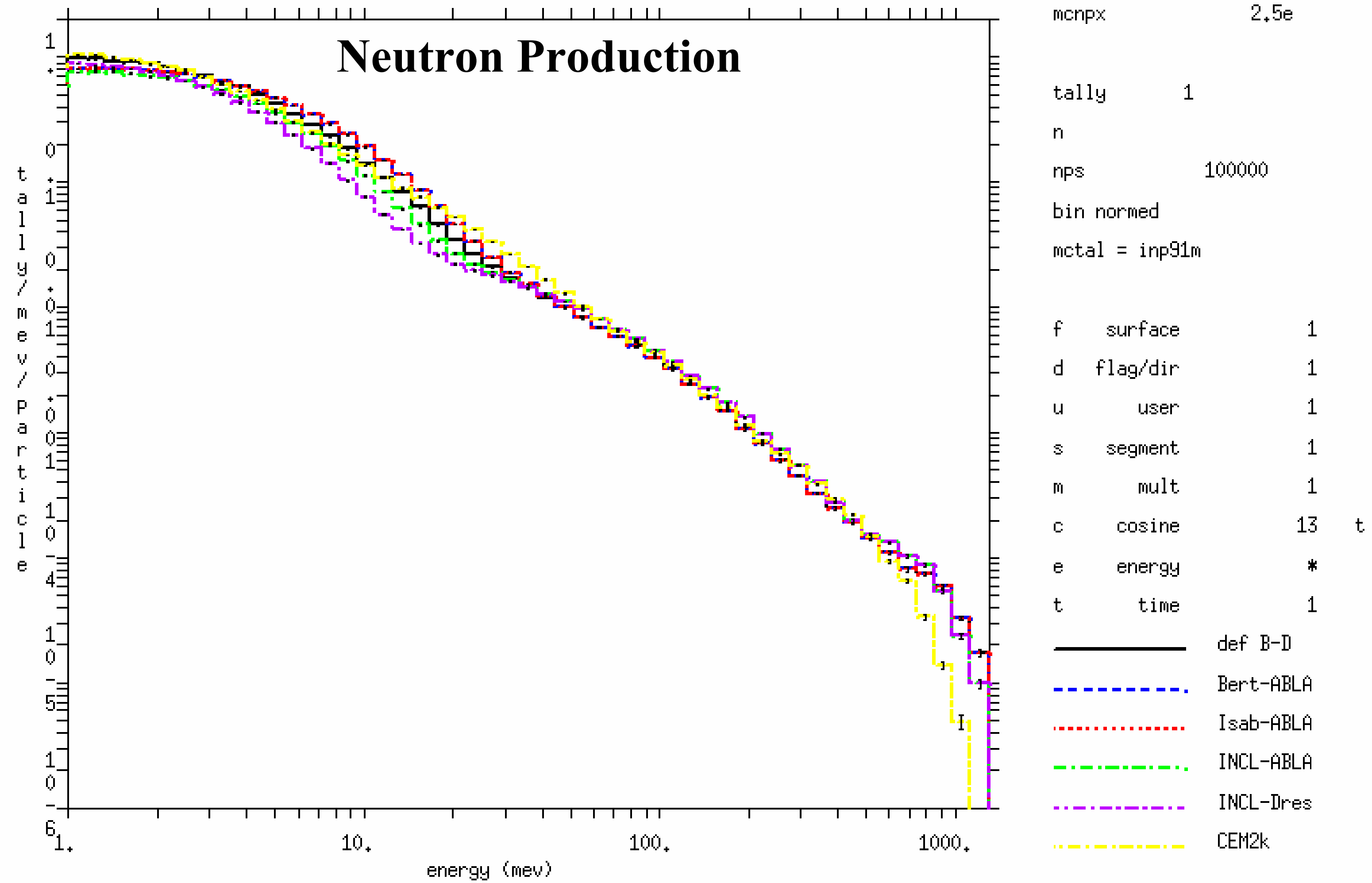
INCL 4/ABLA Physics Models

- **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

- **Two neutron physics improvements**
  - Fission multiplicity
  - $S(\alpha,\beta)$ secondary-energy smoothing

$S(\alpha,\beta)$ Secondary-Energy Smoothing

- **Improvement in $S(\alpha,\beta)$ algorithm in code**
  - User interface is unchanged but underlying secondary energy treatment is improved.
  - The structure in the $S(\alpha,\beta)$ 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.

Physics Enhancements

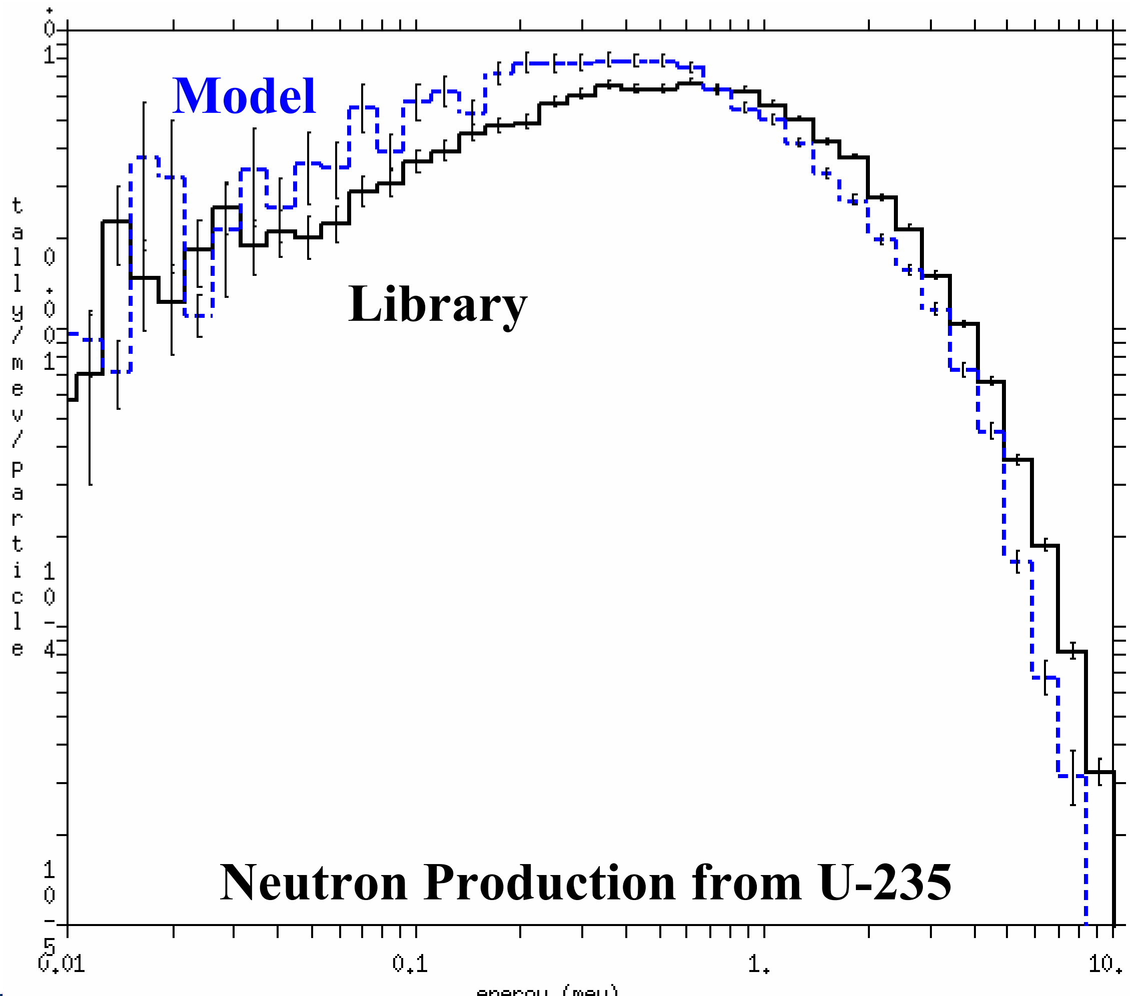
- **Three photon physics improvements**
  - Photon Doppler broadening
  - Photonuclear physics model
  - Variance reduction with pulse-height tallies

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



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.

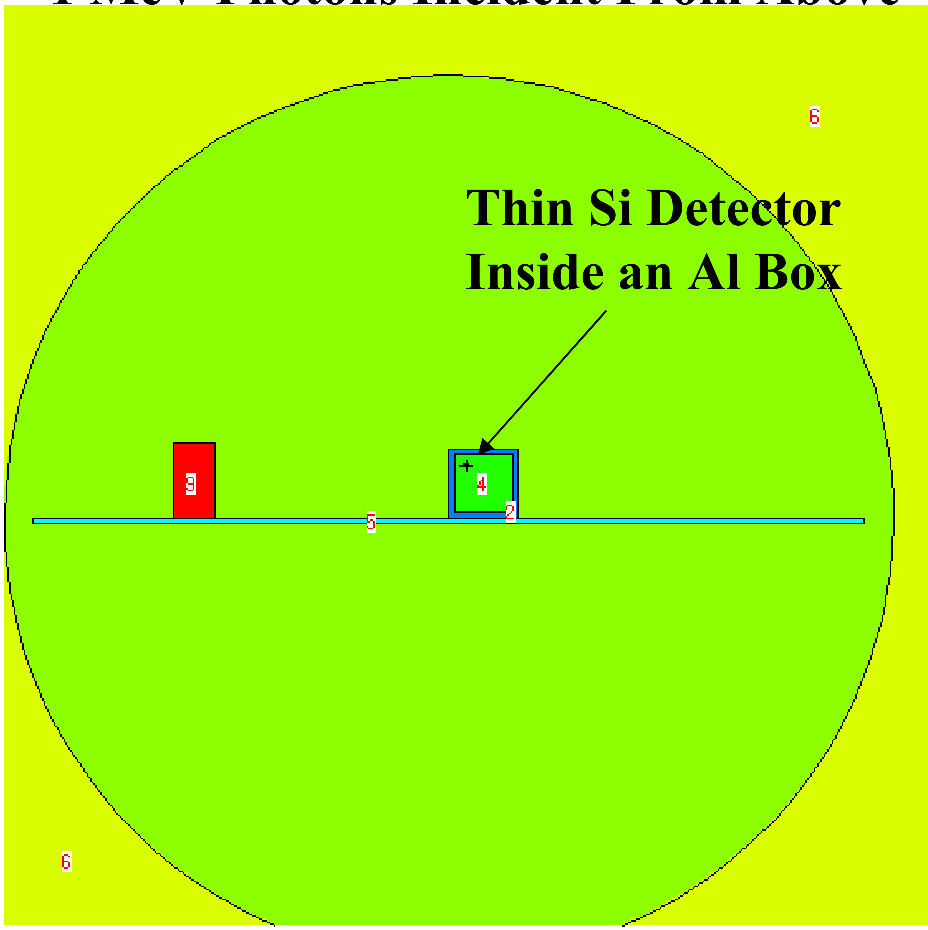
Variance Reduction with Pulse-Height Tallies

```
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
```

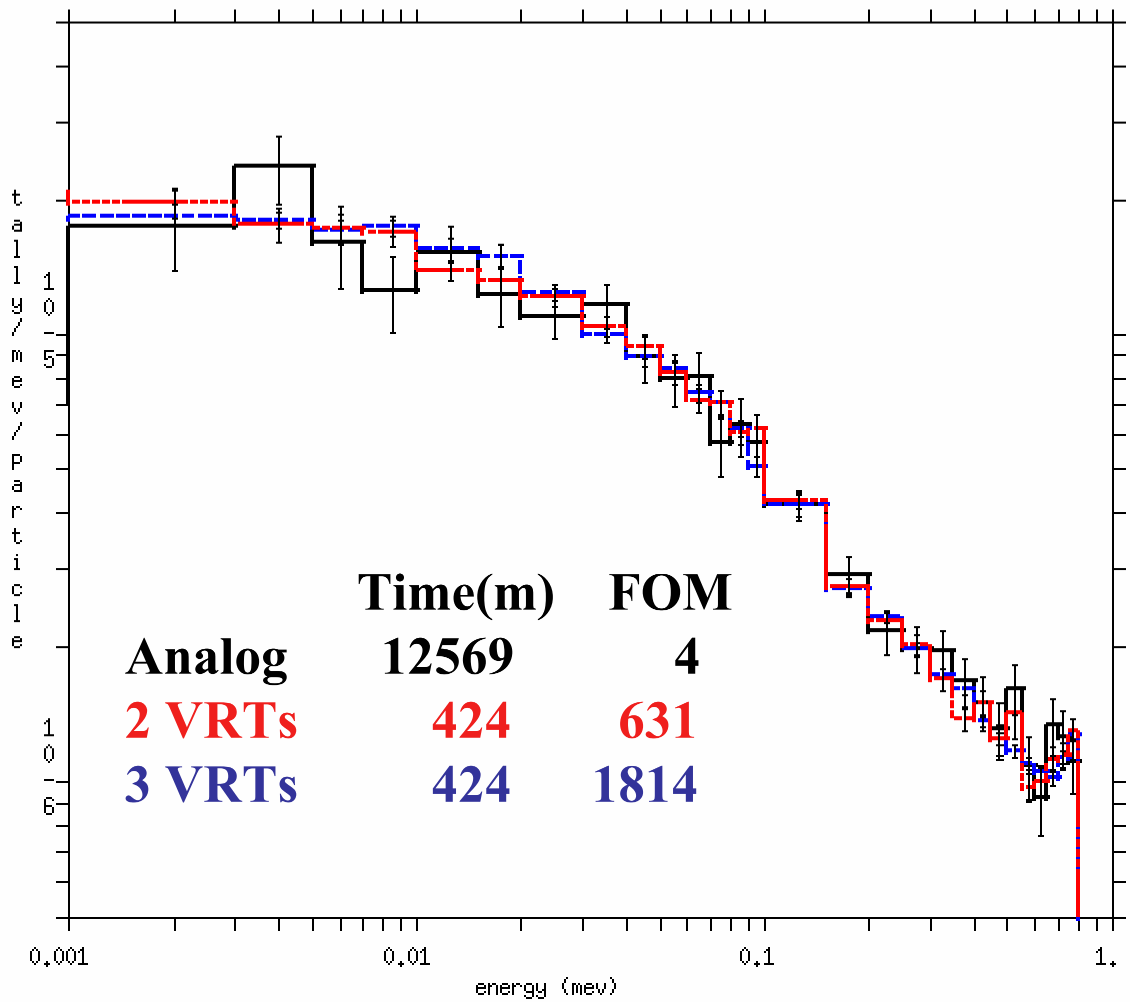
```
wwp:p 100 4 4
wwn1:p .0002 .002 .02 .001 .02 -1
       .02 .02 .02 .0005 .0002
fcl:p -1 0 7r -1 -1
mode p e
m1 13027 1 $ (2.7 g/cc) Al
m2 14028 1 $ Si (detector element, 2.33 g/cc)
sdef erg=1 pos=0 0 21 par=p rad=d1 ext=0
     axs=0 0 1 vec=0 0 -1 dir=1
si1 0 72.0
sp1 -21 1
phys:p
phys:e 7j 0
f8:p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



Variance Reduction with Pulse-Height Tallies



Infrastructure Enhancements

- **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

Future Development

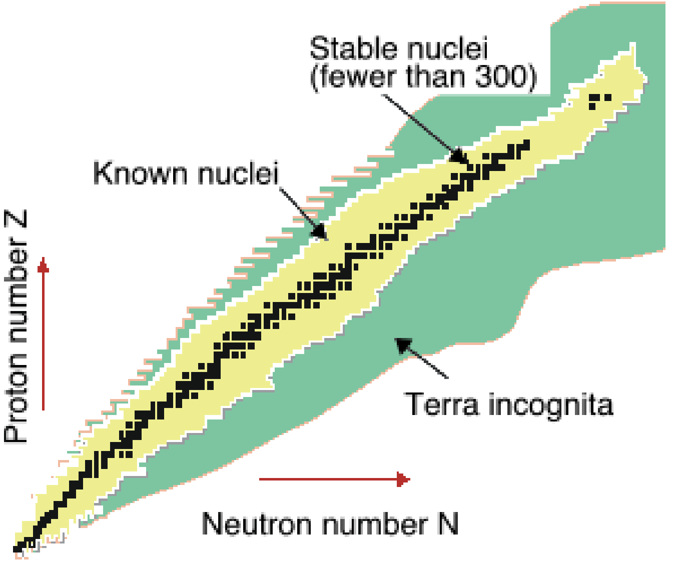
- **Eigenfunction convergence (2.6.A)**
- **Transmutation (2.6.A)**
- **Heavy-ion tracking and interaction physics (2.6.B)**
- **Delayed neutron and gamma models (2.6.B)**
- **Magnetic fields (2.6.C)**
- **CEM upgrade to version 03 (2.6.C)**
- **CAD interface (with spline-surface tracking)**
- **Variance reduction techniques extended to models**
- **Improve point detectors/DXTRAN for models**
- **Extend electron data to 100 GeV**

MCNPX HI Tracking

- A patch now exists for Version 2.5.0 that will enable tracking of HIs.
  - "Heavy ions" cover most isotopic nuclei, except for those that already exist in the code (deuteron, triton, He-3, and He-4).
  - The "#" sign is used for all HIs, regardless of ZAID.
- The default HI is Pb-208.
  - Using "#" on the sdef card will start a Pb-208.
  - Other ions can be started by specifying the ZAID as the particle type on the sdef card (e.g., sdef par = 6012 for a C-12).
- Flux tallies can be used for HIs, although the default behavior tallies all HIs together. Separate bins for HI identity can be created with an FU card.

MCNPX HI Tracking – cont.

- The code initializes cross sections from a list of all potential trackable isotopes (He-5 through Fm-259).
  - 2205 isotopes total



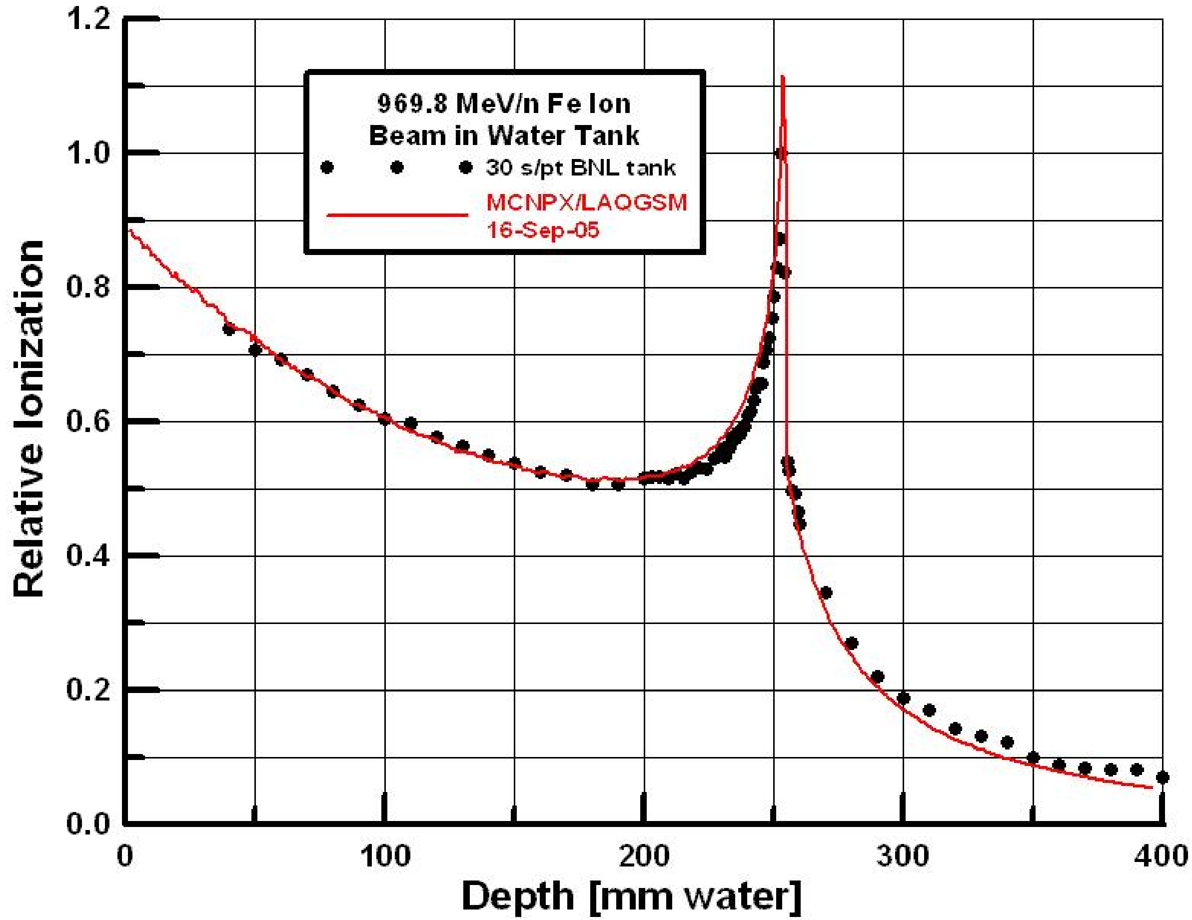
- All secondaries produced in the <u>model physics</u> region are banked.
  - This includes the residual nuclides array.
  - The table physics region does not produce residuals.
- Residual nuclei outside of the table are automatically put into the "below" array (no transport, energy is deposited locally).

LAQGSM

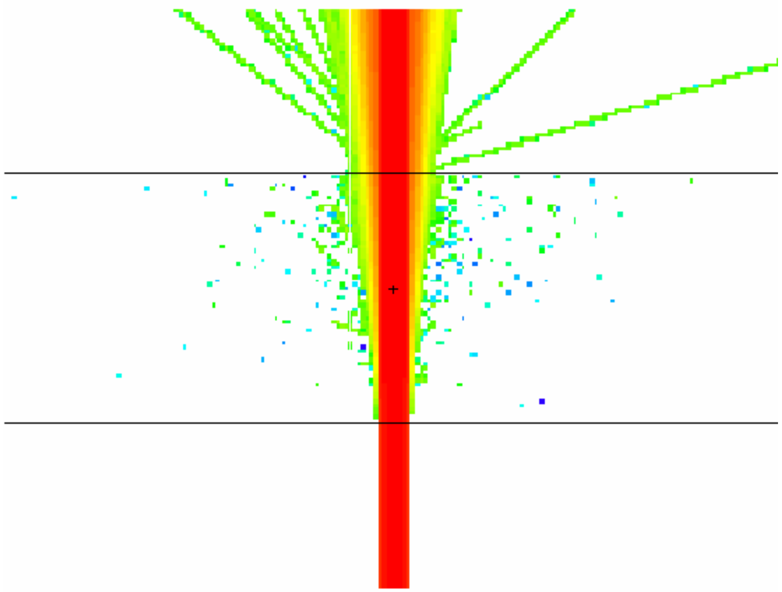
- LAQGSM - Los Alamos Quark-Gluon String Model
  - The LAQGSM model promises to be an improvement on the ISABEL model.
  - LAQGSM has been implemented as a physics option in MCNPX.
  - It can calculate $A_1 + A_2$, pions, and nucleon interactions (photonuclear reactions expected in the next version).
  - Upper-energy limit of ~1 TeV/nucleon (could also replace FLUKA for many (most?) high-energy applications).

Energy Deposition Benchmark

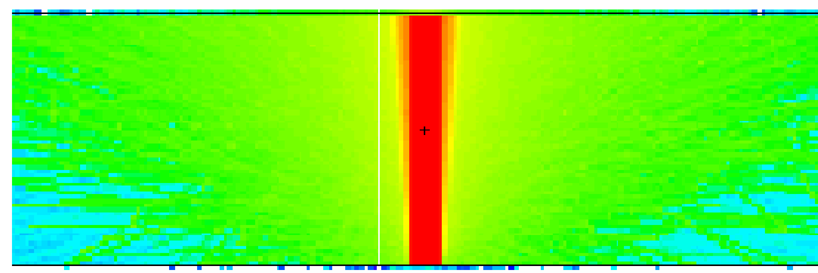
- Fe-56 at 54 GeV energy deposited in H_2O.
- MCNPX calculation is normalized to leading edge of curve.



U-238 on Li-6—Mesh Tallies



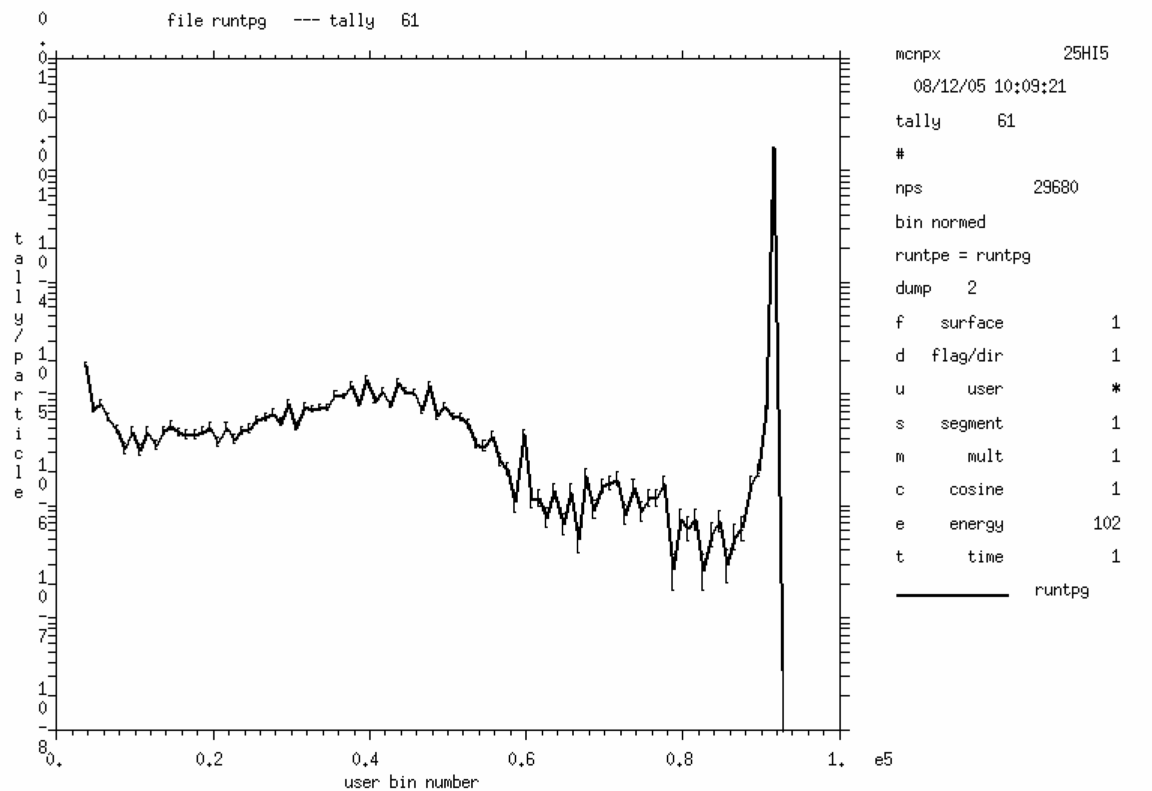
Heavy Ion Flux



Energy Deposition

U-238 Incident on Li-6—Residuals

- Example problems.
  - U-238 on Li-6 at 400 MeV/nucleon.
- 2-mm cylindrical beam directed on 3-cm-diam cylinder.
- Tallied n, h, alpha, He-3, d, t, and HIs on surface of cylinder.
- HIs divided into 92 user bins (one for each element).



Status of Heavy Ion Tracking

- HI tracking is now possible with an experimental version of MCNPX.
- A new physics model, LAQGSM, has been implemented that benefits not just the HI transport, but also the high-energy physics for many particles.
- Results must be checked against data and good benchmark problems.

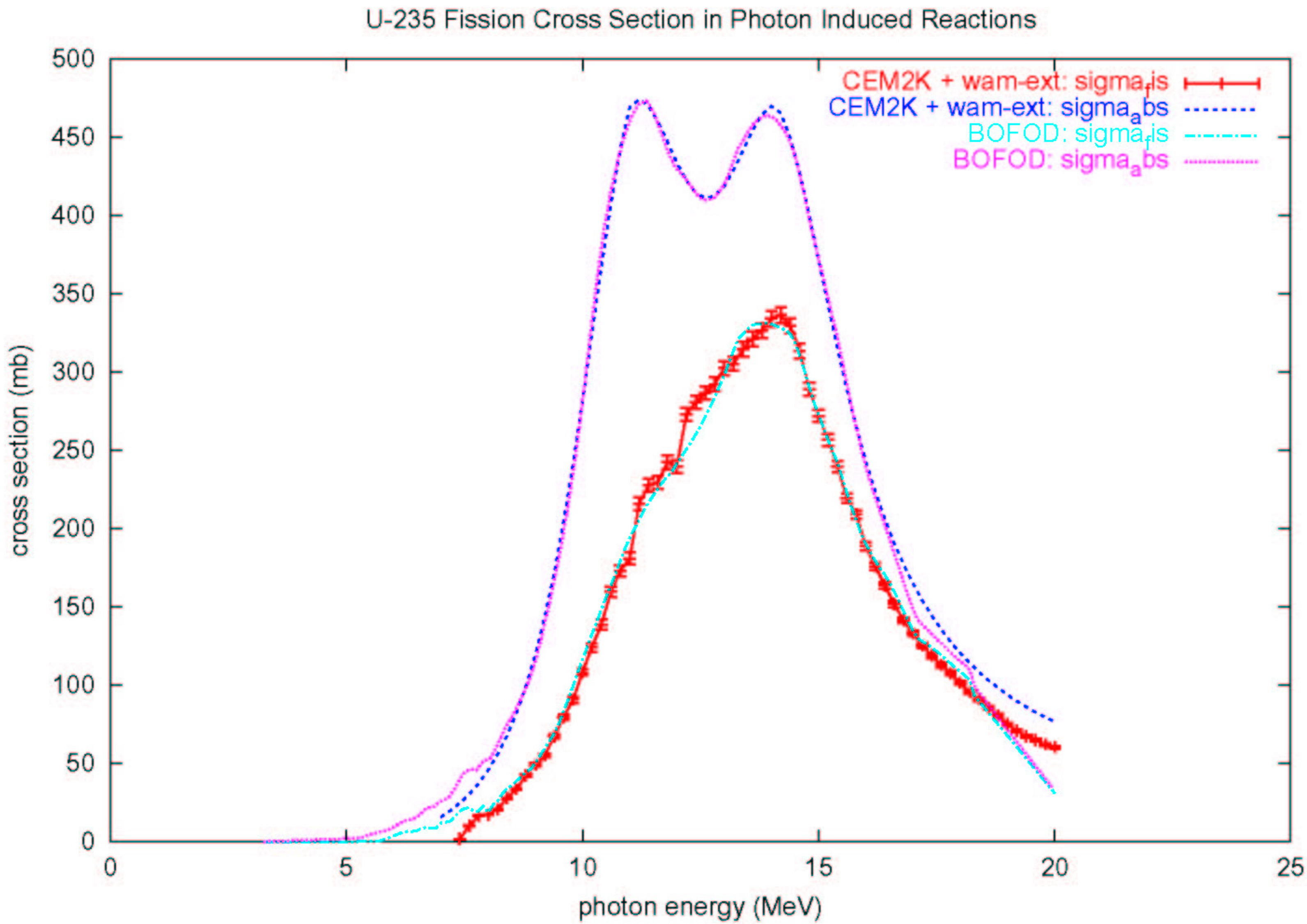
- Future work will be focused on completing a full-featured implementation.

Summary – MCNPX 2.5.0

- **MCNPX is an excellent tool for understanding issues surrounding the design and operation of accelerator sources.**
- **Built upon well-established codes in the community.**
- **Continues active development of new options and features.**

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

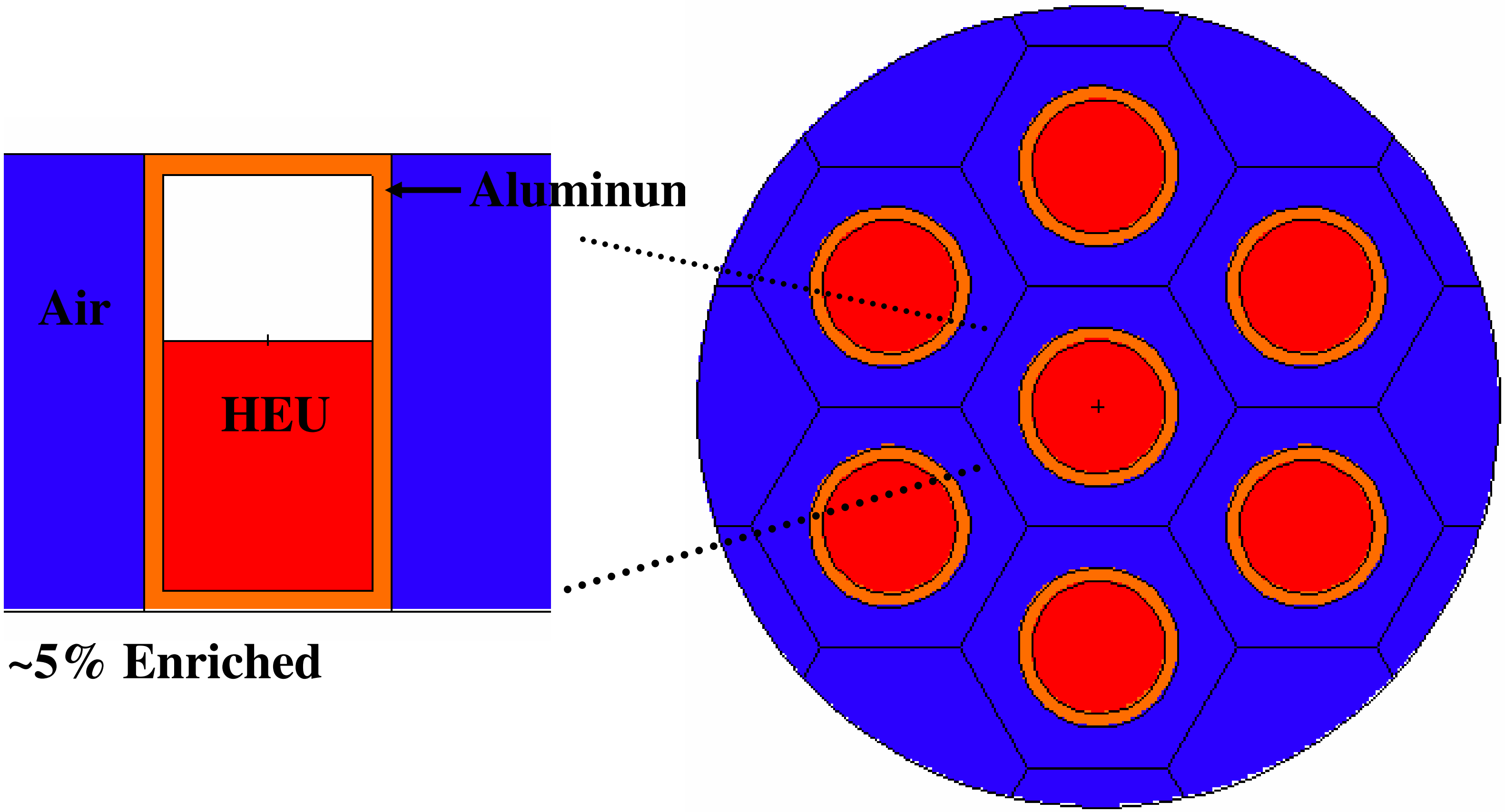


U-235 Fission Cross Section in Photon Induced Reactions
CEM2K + wam-ext: sigma_fis
CEM2K + wam-ext: sigma_abs
BOFOD: sigma_fis
BOFOD: sigma_abs
cross section (mb)
photon energy (MeV)
0
50
100
150
200
250
300
350
400
450
500
0
5
10
15
20
25

Eigenfunction Convergence

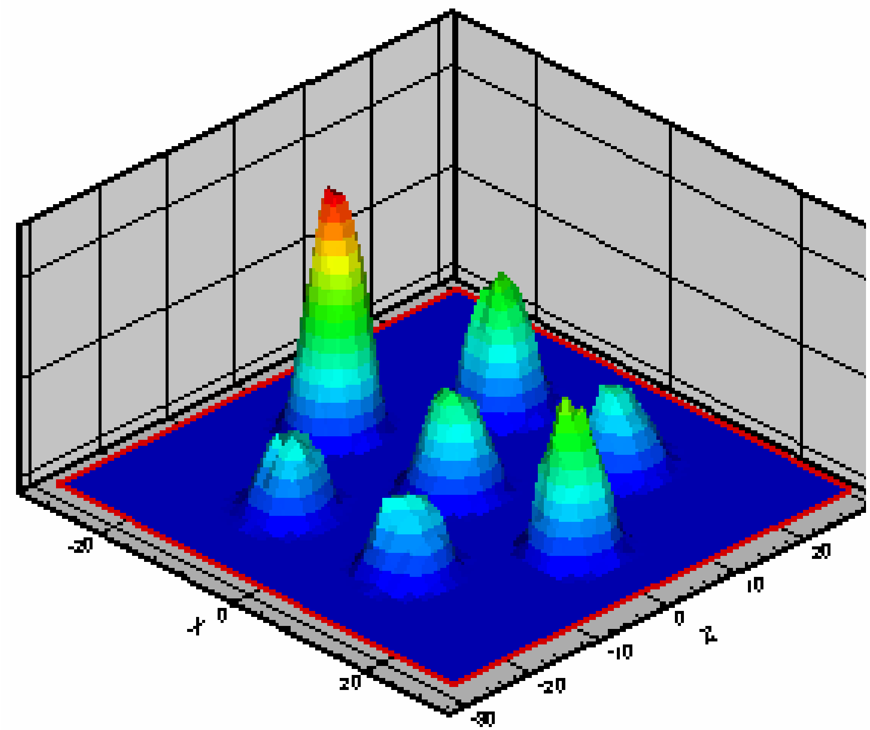
- ADS / LANL ADS reactor application
- Before - eigenfunction exhibits false convergence within fissile regions
  - Fission source produced by power iteration method
  - Can have a significant effect on burnup and shielding results
  - Can only be overcome by running more particles/cycle
- Now - fission 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

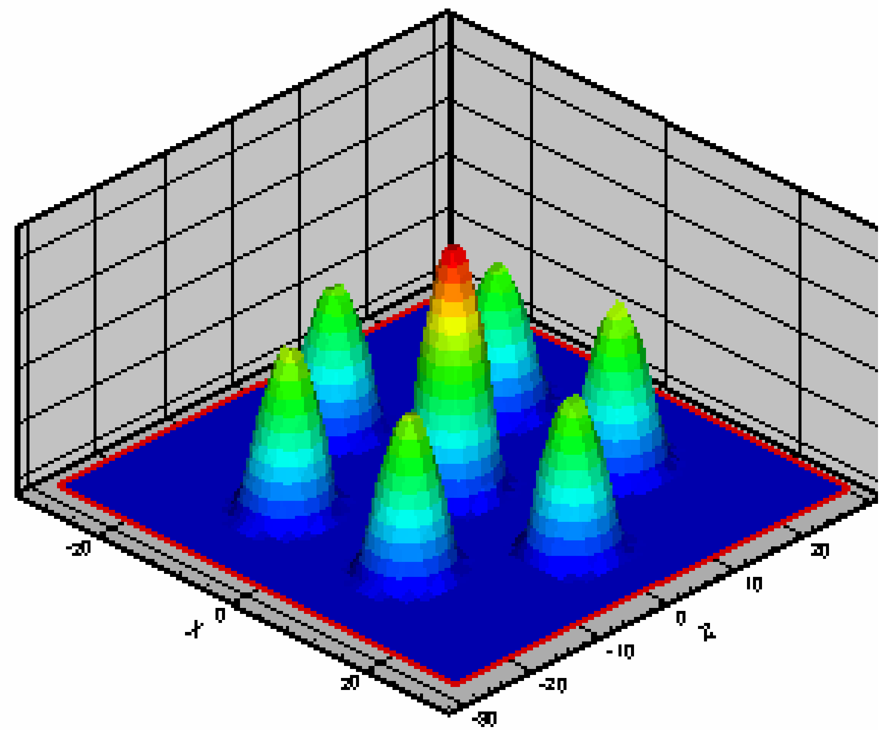


Eigenfunction from the Standard Method

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

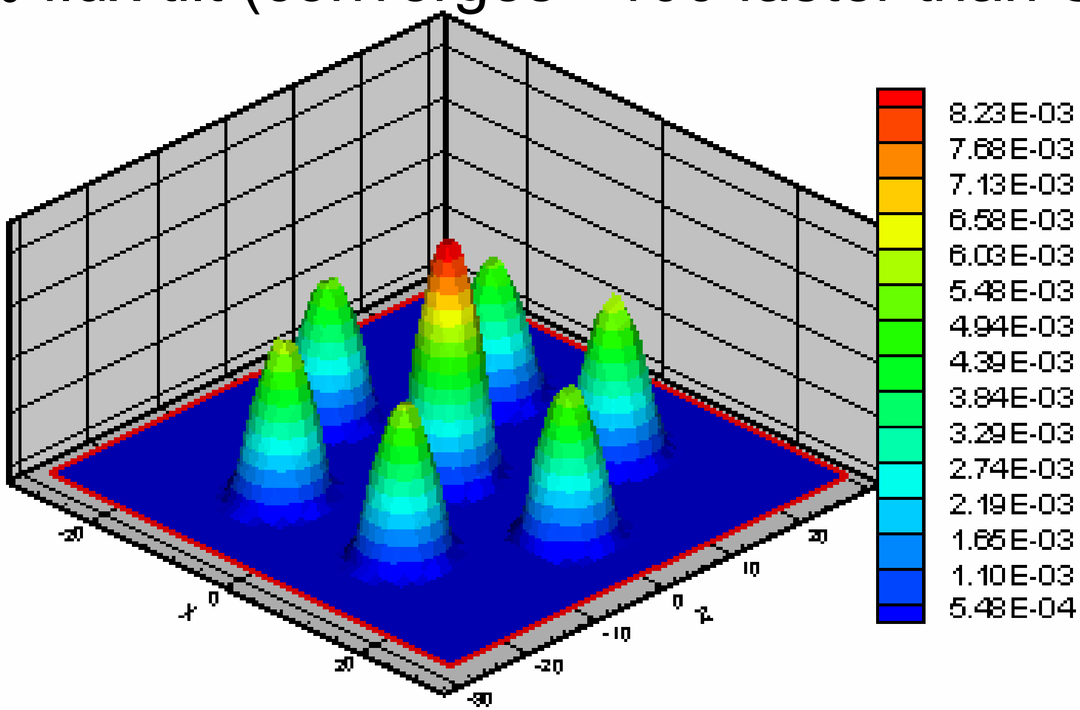


- 100,000 particles/cycle
- 100 active cycles (30 settle)
- ~10% flux tilt



Eigenfunction from the New Method

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



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

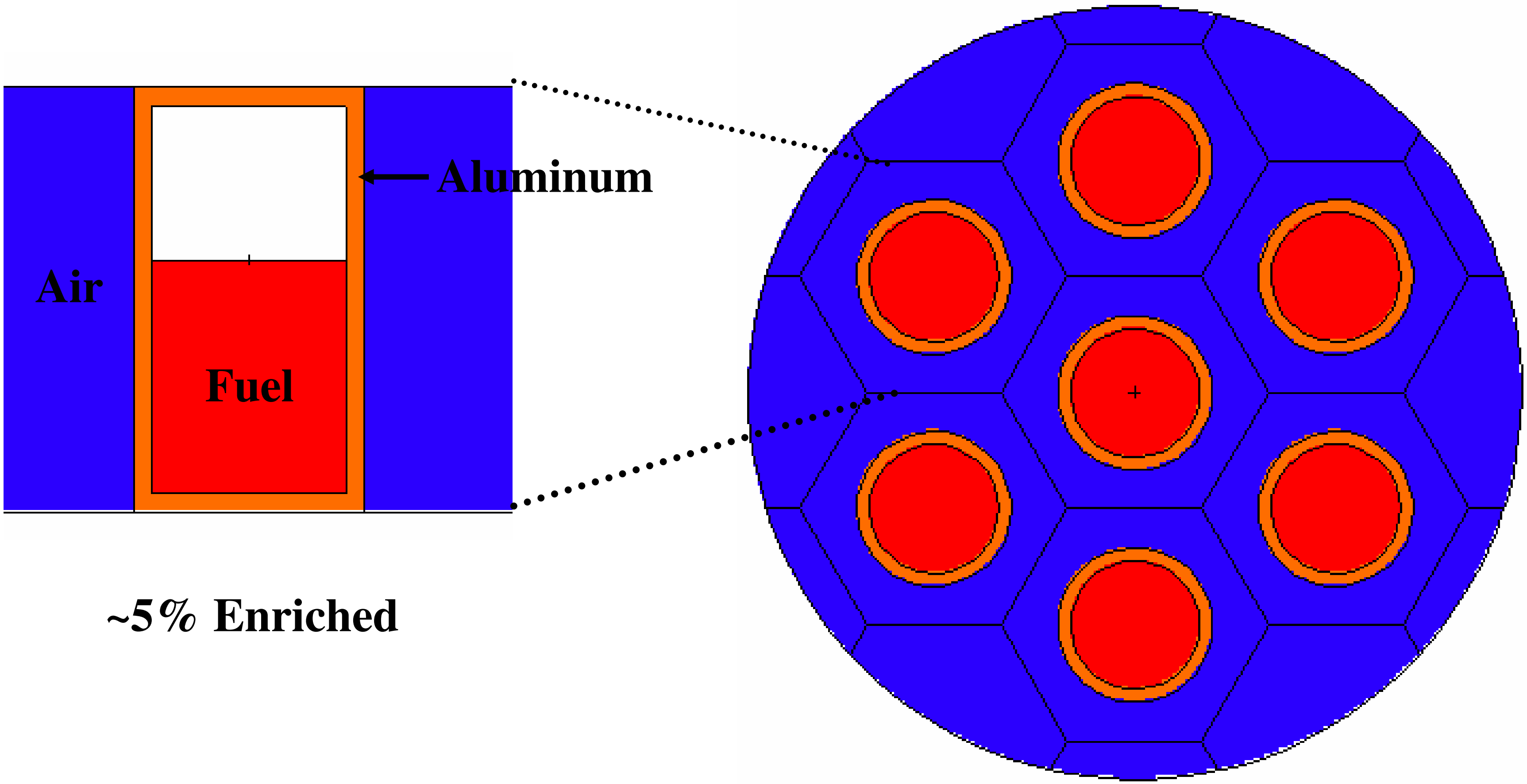
- **MCNPX provides to CINDER90**
  - 63-group fluxes in each material to be burned
  - Isotopic atom densities and material volumes
  - Absorption and fission reaction rates for each nuclide
  - Average k_{eff} and fission ν, and fission Q
  - Power level and burn time
- **CINDER90 provides to MCNPX**
  - 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
```

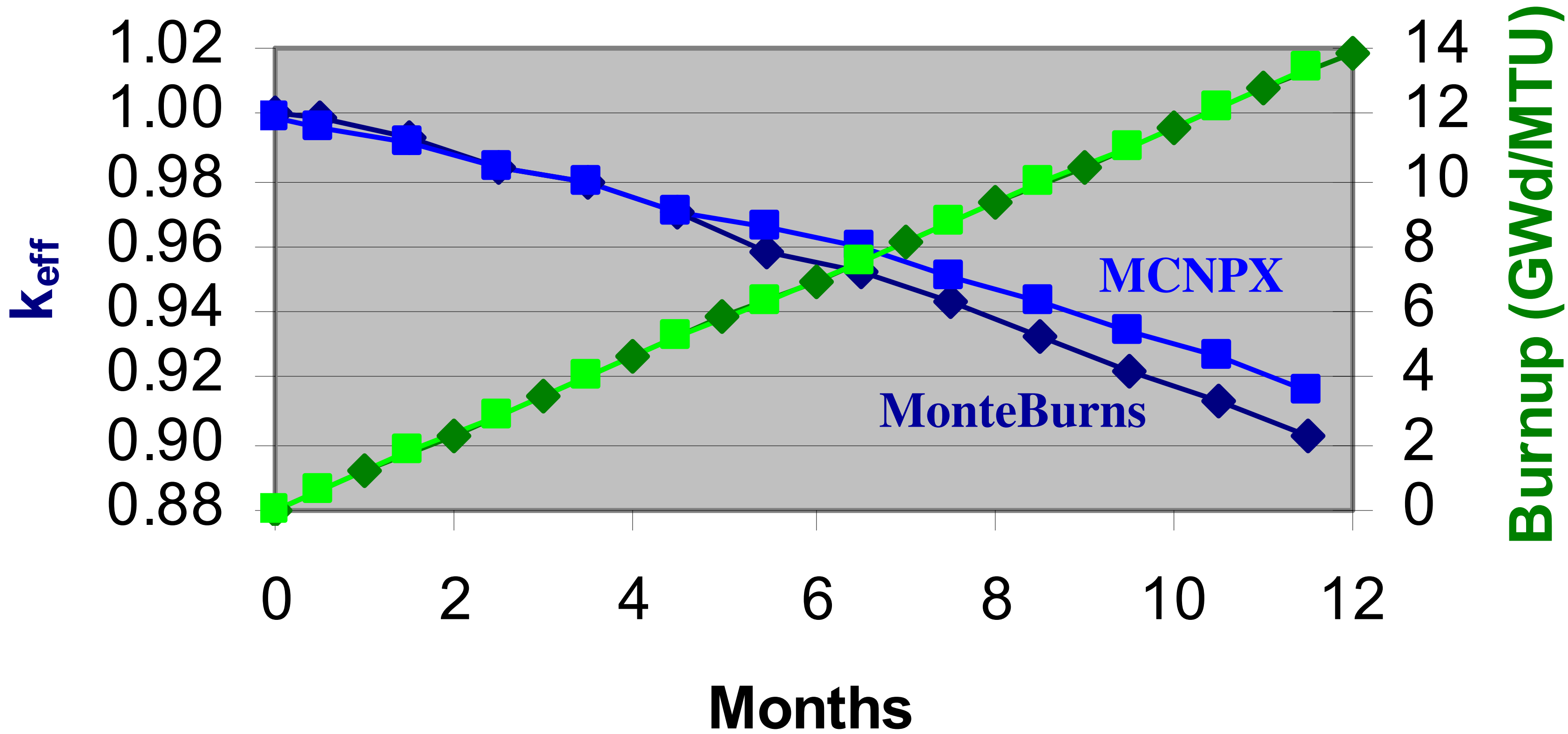
Specifies a power level of 2 MW for a duration of 75 days (steps of 15, 30, and 30 days). Materials 3 and 4 are included in the burn with isotopes ^{17}O, ^{234}U, and ^{239}Pu excluded from material 3 and isotope ^{234}U excluded from material 4. Nuclides with an atom fraction less than 1e-10 are also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

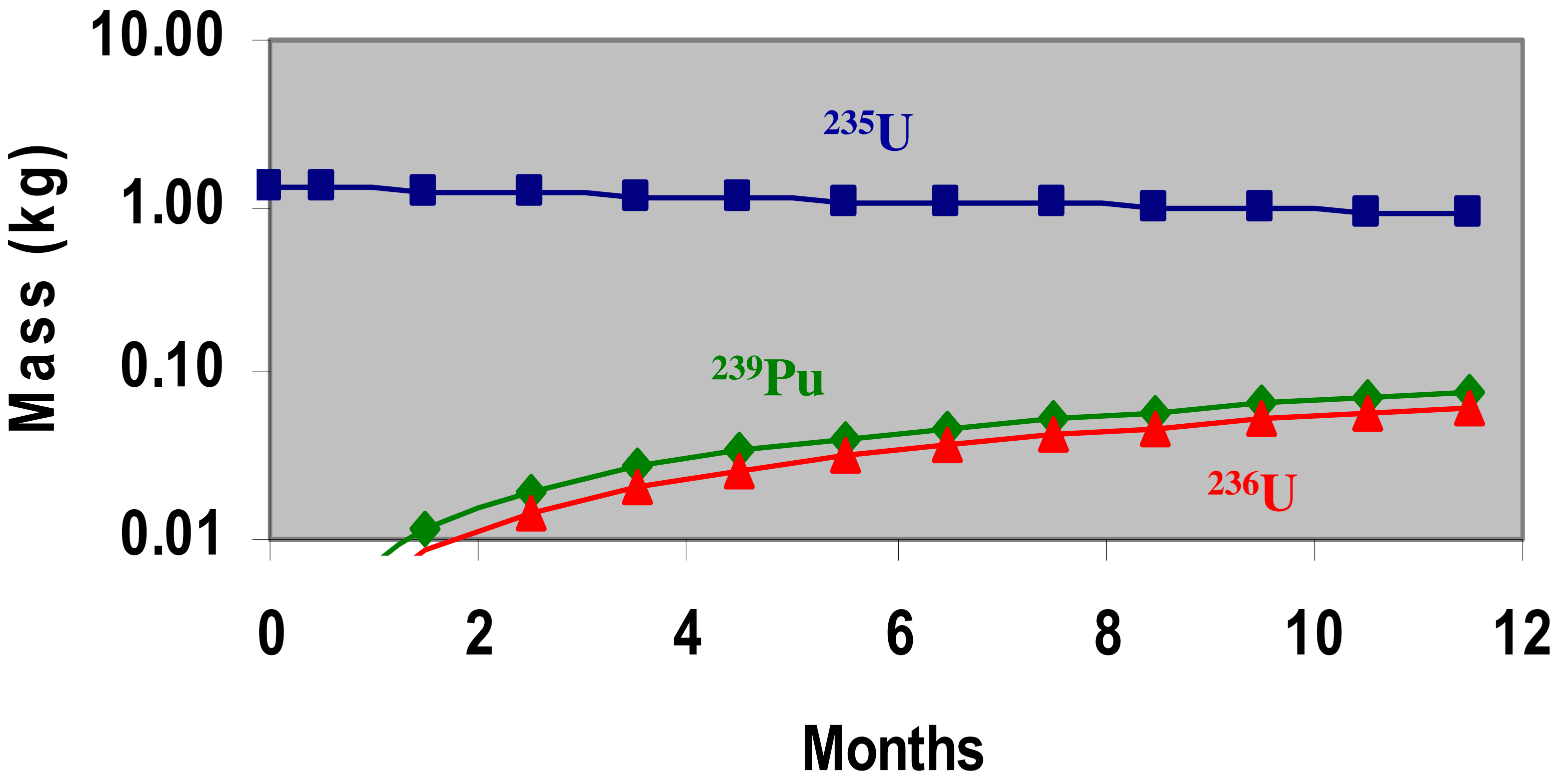


~5% Enriched

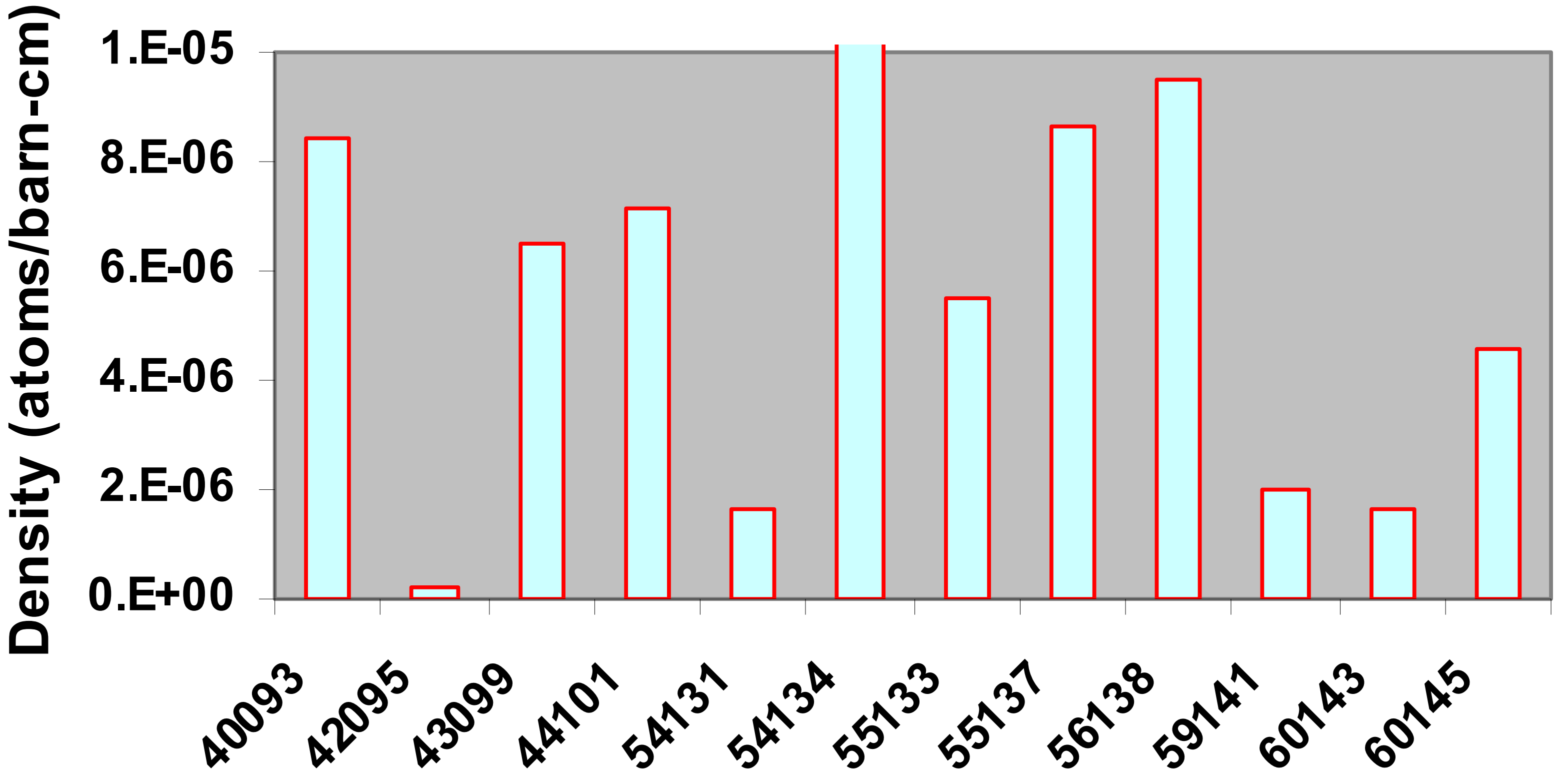
Comparison to MonteBurns



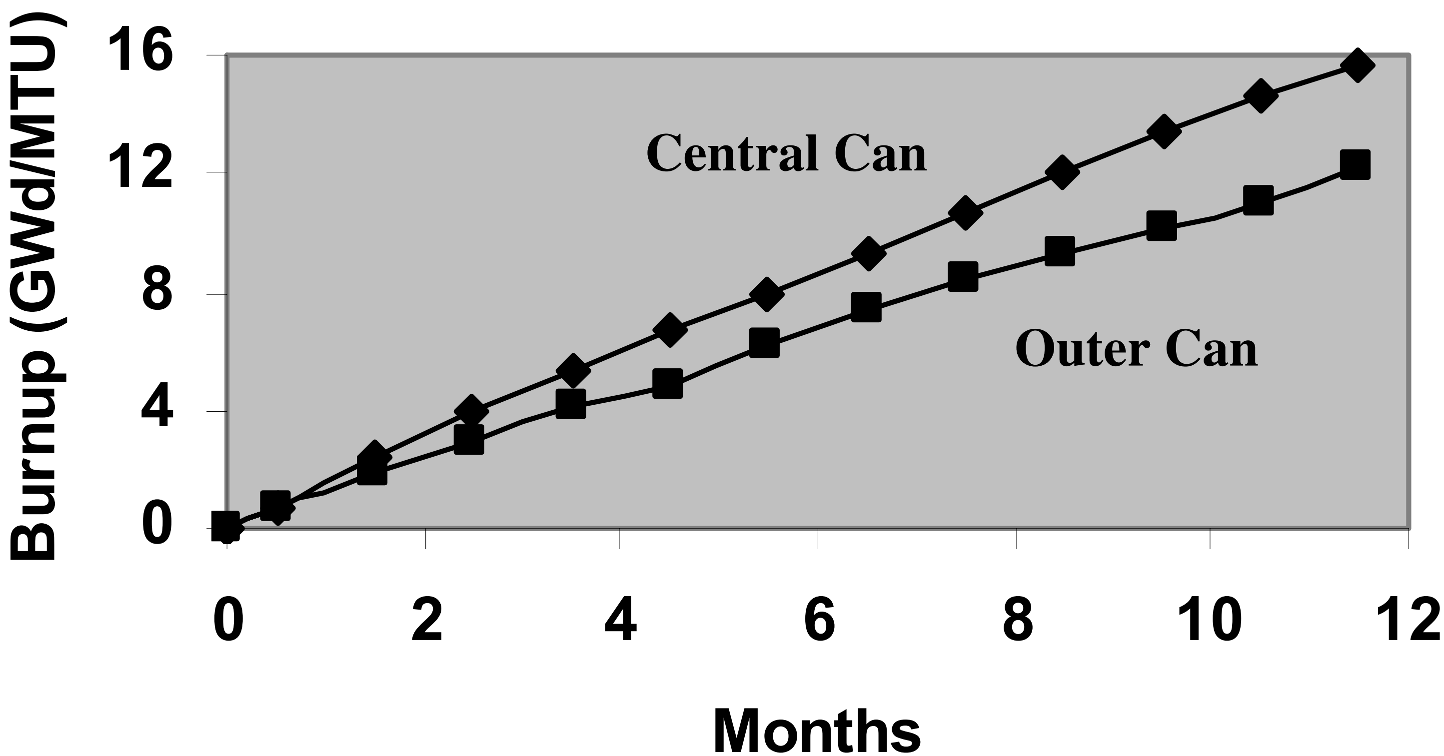
Actinide Inventories



Fission Product Inventories



Can Burnup

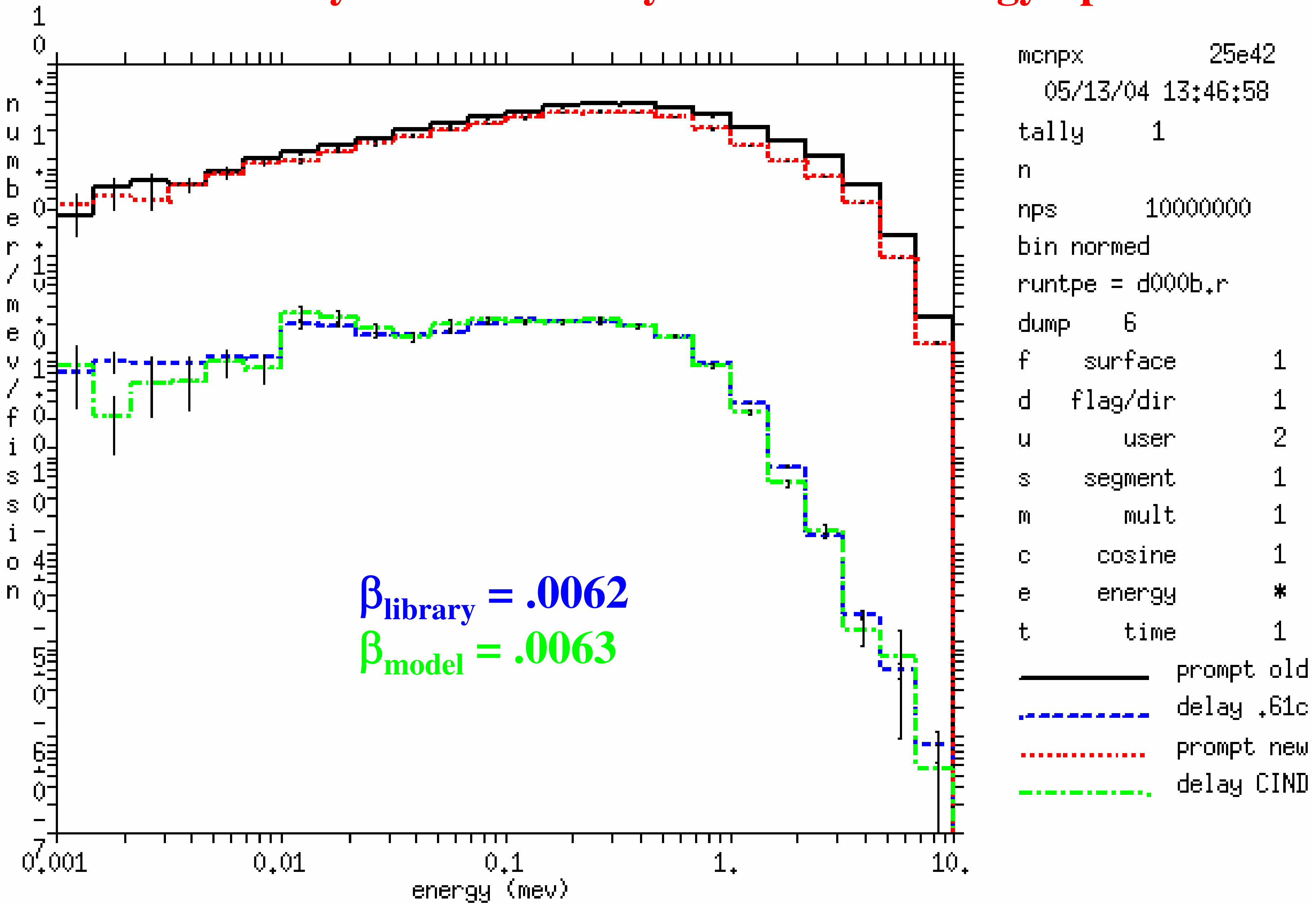


Burnup (GWd/MTU)
16
12
8
4
0
Central Can
Outer Can
0
2
4
6
8
10
12
Months

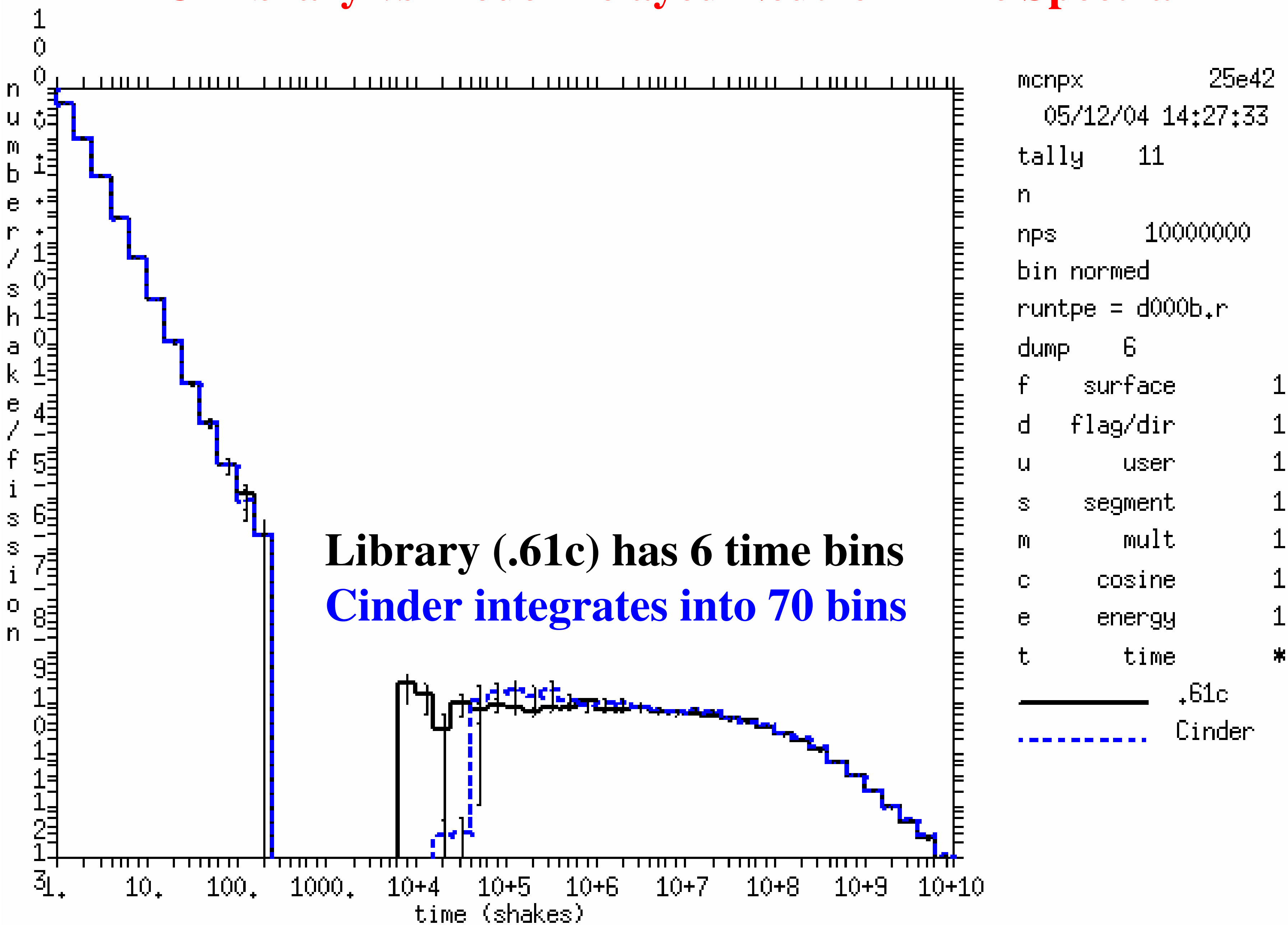
Delayed Neutron/Gamma Capability

- 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

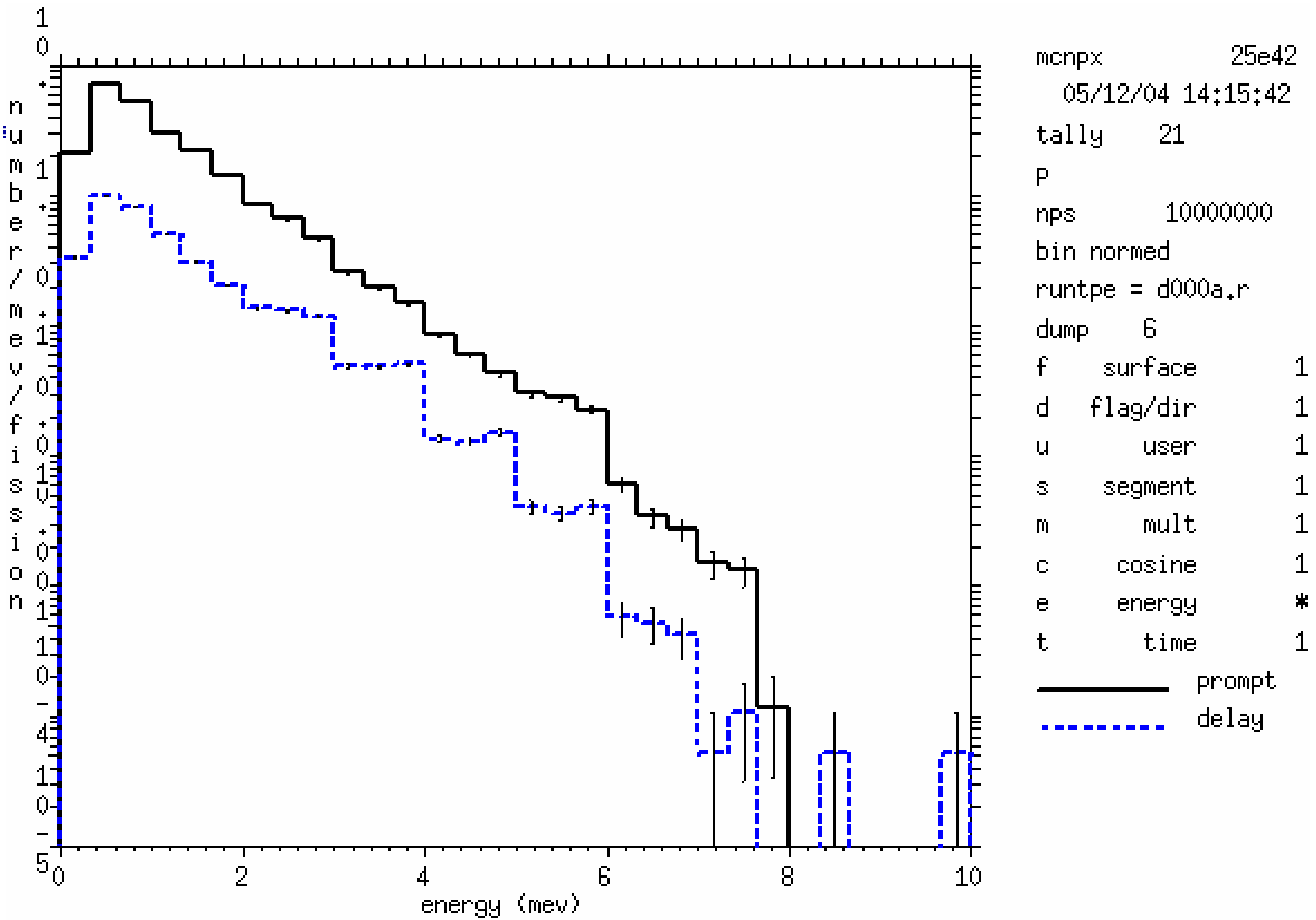
^{235}U Library vs Model Delayed Neutron Energy Spectra



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



^{235}U Delayed Gamma Production per Fission



^{235}U Delayed Gamma Production per Fission