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Title: MCNP6 Advanced Tallies Tutorial

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MCNP6 Advanced Tallies Tutorial

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Outline

- Energy Deposition Overview
  - P,E problems
  - N problems
- PHL
  - Basic F8 Pulse Height Tally
  - PHL with Simple Pulse - photons
  - Coincidence
  - Neutron Detectors
- ROC
- Tagging
- Other Tallies

Focus will be on F8 and F6 Tallies

- F6:<pl> Energy deposition averaged over a cell
  - F6 units MeV/g
  - *F6 units jerks/g
  - +F6 Collision heading units of MeV/g
    - Applies to all partials in the problem
- F8:<pl> Energy distribution of pulses created in a detector by radiation
  - F8 units pulses
  - *F8 units MeV
  - +F8 Charge deposition units of charge

- jerks (1jerk=1GJ=1e9J)

Energy Deposition

- Start a 2-Mev photon in very large water volume (no escape).
- How much energy is deposited from introducing 2 MeV photons into the sphere? *F8:p
- How much energy would the photon tracks expect to deposit as they move through the volume? F6:p
- How much energy do electrons deposit (lose to the material)?   F6:e

Energy Deposition – cont.

- Just tell me how much energy is deposited. Period. +F6

- The different tally types answer different questions about how energy is deposited.
- Remember:
  - Neutral particles (n,p) use track-length heating.
  - Charged particles follow energy loss over the course of transport.
  - When both are transported, the code will use a hybrid of both methods!

Energy Deposition Example (erg_ex)

```
Test Energy deposition
1   1     -1.0    -1     imp:n=1
2   0              1     imp:n=0

1   so 1000

m1     1001 1 8016 2
sdef par=p erg=2
nps    5000
mode p e
print
c
*f8:e 1
c
f6:p 1
sd6 1
c
f16:e 1
sd16 1
c
+f26 1
sd26 1
```

Results

1tally fluctuation charts

	tally 26					tally 6					tally 8			
nps	mean	error	vov	slope	fom	mean	error	vov	slope	fom	mean	error	vov	slope	fom
1000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30	1.9521E+00	0.0219	0.0060	10.0	18638	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
2000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30	1.9696E+00	0.0154	0.0029	10.0	18869	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
3000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30	1.9725E+00	0.0127	0.0018	10.0	18609	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
4000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30	1.9556E+00	0.0111	0.0013	10.0	18328	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
5000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30	1.9615E+00	0.0099	0.0011	10.0	18176	2.0000E+00	0.0000	0.0000	10.0	1.0E+30

Why not 2.0???

	tally 16				
nps	mean	error	vov	slope	fom
1000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
2000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
3000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
4000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30
5000	2.0000E+00	0.0000	0.0000	10.0	1.0E+30

```
1tally       6       nps =      1000000
      tally type 6    track length estimate of heating.          units   mev/gram
      particle(s): photons

      masses
           cell:       1
               1.00000E+00

 cell  1
           2.00009E+00 0.0007
```

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From the Manual

Aside: Energy Deposition Tally (F6)

In the energy range where nuclear data tables are available, the neutron, photon, and proton energy deposition is determined using the heating numbers from the nuclear data tables . These heating numbers are estimates of the energy deposited per unit track length. In addition, the de/dx ionization contribution for electrons and/or protons is added in for MODE E or MODE H.

More information given in section 3.3.5.1.1.

F6 Tally

- F6 will allow multiple particle types.
  - F6:p,e 1
  - What will this do?
  - Is it right?

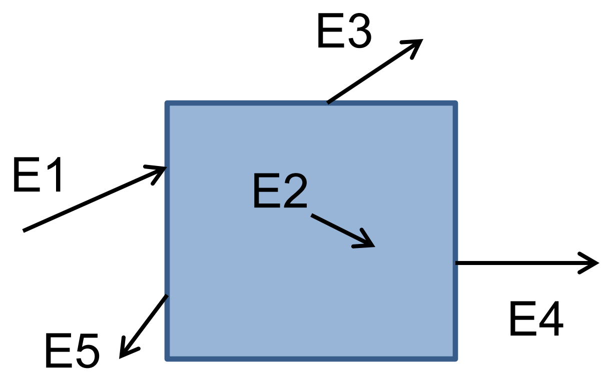
F6 Tally

- F6:e,p 1 – This does not work!
- Photon and electron energy deposition is not independent.

- Recommendation:
  - Use +F6 for total energy deposition for all transported particles.
  - Use independent F6 tallies for individual particle types.

F8 Tally

- The F8 Tally can be used to report pulse behavior.
- The magnitude of the pulse is summed from contributions made within a given history
- But it does so based on surface crossings of the cell in question.
- Pulse energy = (E1+E2) - (E3+E4+E5)



PHL Detector Option

- What if…
  We could create pulses from F6 tallies as energy is deposited within the cell.
- The PHL option allows us to create pulse-height accounting of energy but without the restriction of using cell-crossing accounting.

Example 1: F8 Tally

- 15x15x7.5 mm $Cd_{0.8}Zn_{0.2}Te_{1.0}$ crystal.
- Start with Cs-137 gamma source and use an F8 tally.
- F8 can only register a pulse based on cell accounting and account for statistical variation of charge collection with Gaussian Energy Broadening (GEB).
- GEB parameters based on specific crystal response.
- GEB a b c which defines FWHM.

$$FWHM = a + b\sqrt{E + cE^2}$$

```
F8:p 1
FT8 GEB 3.6e-3 1.5e-1 0.1 $ Values for CZT
```

Pulse Height Tally (phl_ex1)

```
F8 tally usage
1  1 -1  -1  imp:p=1   $ 15x15x7.5 mm3 CZT crystal
2  0  1 -2   imp:p=1   $ void around crystal
99  0  2     imp:p=0   $ outside world

1 rpp -.75 .75 -.75 .75 -.375 .375
2 so 10

mode p e
m1  48000 0.8  30000 0.2  52000 1  $ CZT Cd 0.8 Zn 0.2 Te 1
sdef pos = -1 0 0 erg=d1 par=p
prdmp 2j 1
print
#          si1          sp1     $Cs-137
             L            D
         0.00447       0.91
         0.031817      1.99
         0.032194      3.64
         0.036304      0.348
         0.036378      0.672
         0.037255      0.213
         0.28351       5.8E-4
         0.661657      85.10
c
#          si2          sp2     $Co-57
             L           D
         0.12206      85.60
         0.13647      10.68
f8:e 1
e8 0 1e-6 400i 0.8
ft8 GEB 3.6e-3 1.5e-2 0.1
nps 1e6
```

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Example 1: F8 Tally

- Copy C:\MCNP6\EXAMPLES\phl_ex1
- Run the example:

```
mcnp6 i=phl_ex1 n=ex1.
```

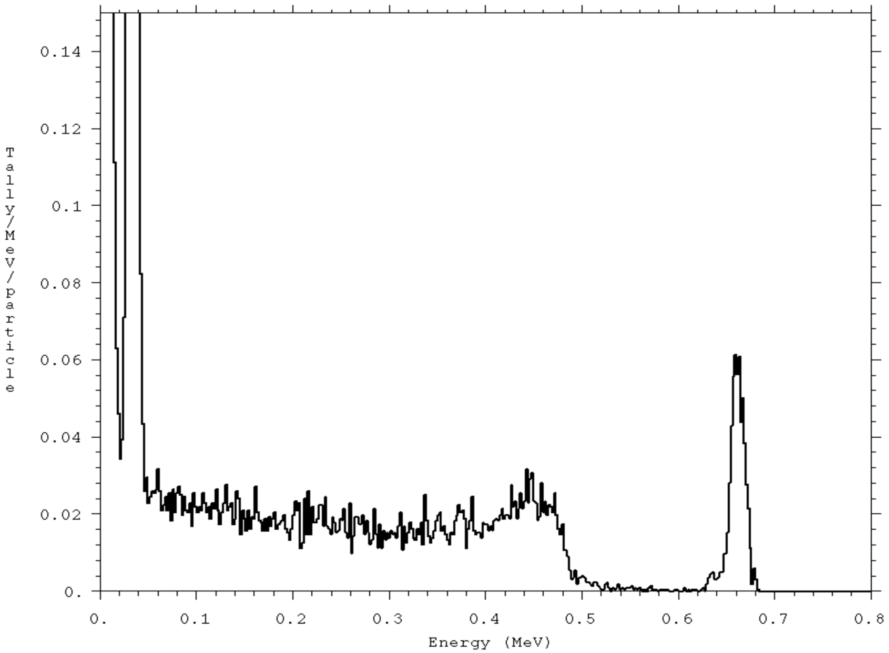
- Display results in plotter:

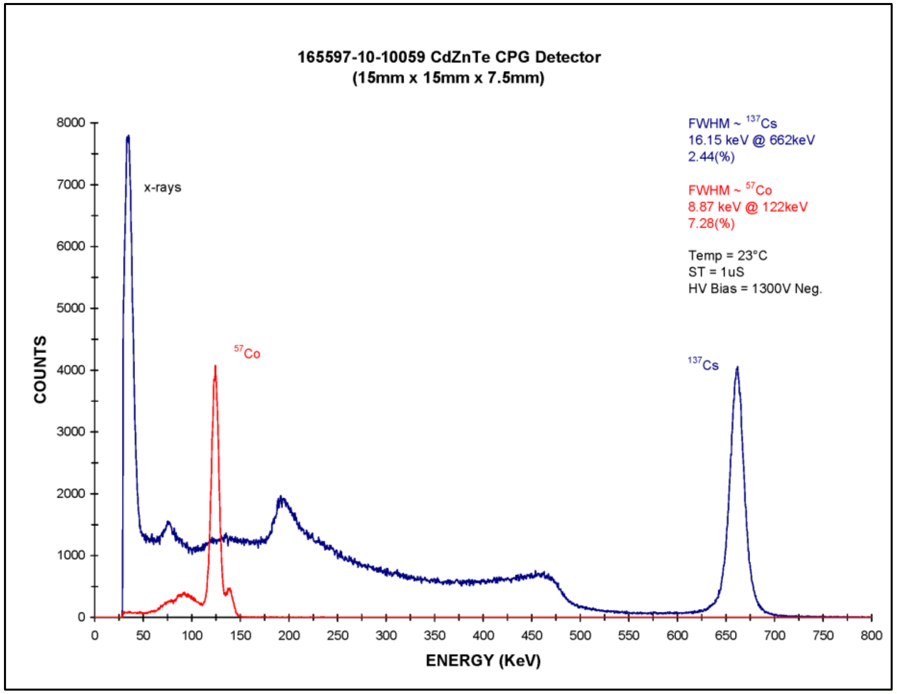
```
mcnp6 z run=ex1.r

mcplot> tal 8 ylims 0 0.15 linlin
```

Example 1: F8 Tally

- Results compared with published vendor spectrum.





FT PHL Tally

- Uses F6 energy deposition tallies to create pulses.
- Allows more physics detail to be incorporated into pulses.
  - DE/DF
  - Time
  - Triggering
- Allows tallies to be added together.

FT PHL Tally - Syntax

$$
\begin{array}{llllllllll}
\mathtt{PHL} & [\mathtt{n} & \mathtt{t}_{a1} & \mathtt{b}_{a1} & \mathtt{t}_{a2} & \mathtt{b}_{a2} & \ldots & \mathtt{t}_{an} & \mathtt{b}_{an}] & [\mathtt{det}_1] \\
 & [\mathtt{m} & \mathtt{t}_{b1} & \mathtt{b}_{b1} & \mathtt{t}_{b2} & \mathtt{b}_{b2} & \ldots & \mathtt{t}_{bm} & \mathtt{b}_{bm}] & [\mathtt{det}_2] \\
 & [\mathtt{j} & \mathtt{t}_{c1} & \mathtt{b}_{c1} & \mathtt{t}_{c2} & \mathtt{b}_{c2} & \ldots & \mathtt{t}_{cj} & \mathtt{b}_{cj}] & [\mathtt{det}_3] \\
 & [\mathtt{k} & \mathtt{t}_{d1} & \mathtt{b}_{d1} & \mathtt{t}_{d2} & \mathtt{b}_{d2} & \ldots & \mathtt{t}_{dk} & \mathtt{b}_{dk}] & [\mathtt{det}_4] \quad [\mathtt{TDEP\ tg\ tt}]
\end{array}
$$

# of F6 tallies for each detector region

Optional detector description

Pairings of tally number and F-bin number for the n F6 tallies of each detector region

Optional trigger keyword, The first entry (tg) specifies the trigger tally number, the second (tt) specifies an energy threshold (MeV).

Very complicated!!

FT PHL Tally - Syntax

```
PHL [n t_a1 b_a1] 0
```

Let's start simple with one region and one tally.

```
PHL 1 6 1 0
```

n=1 means one tally. The 6 means tally F6 will be used.
The next '1' means the first F-bin (cell bin) of that tally.
'0' ends the input.

```
F6:e 1   $ Here's the F6 tally we'll use
F8:p 1   $ F8 tally, particle, cell designators are placeholders only
FT8 PHL 1 6 1 0  $ PHL definition
E8   0 1023i 8  $ energy bins for pulses
```

Now we have defined an F8 tally which is fed by a F6.
This case duplicates the function of a normal F8 PHT.

Example 2: Simple F8 PHL

- Copy file phl_ex2 and note the added electron tally and F8 PHL to gather electron energy. GEB is included as before:

```
F6:e 1
F18:p 1
FT18 PHL 1 6 1 0 GEB  3.6e-3   1.5e-1   0.1
E18  0 1e-6 400i 0.8
```

- Run the problem:

```
mcnp6 i=example2 n=ex2.
```

Example 2: Simple F8 PHL (phl_ex2)

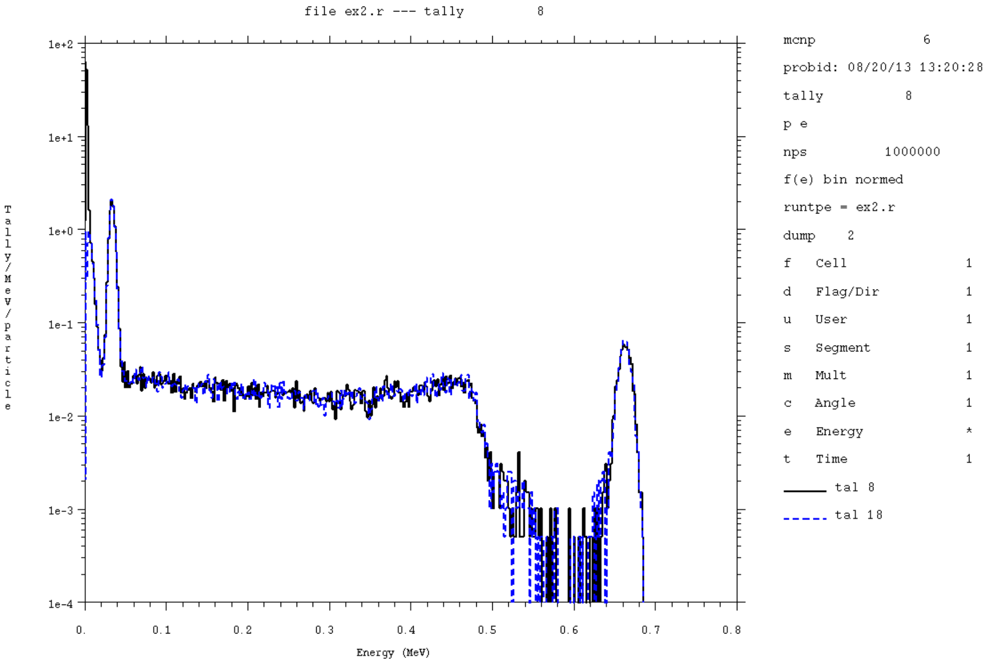
```
F8 tally usage
1  1 -1  -1  imp:p=1   $ 15x15x7.5 mm3 CZT crystal
2  0  1 -2   imp:p=1   $ void around crystal
99  0  2     imp:p=0   $ outside world

1 rpp -.75 .75 -.75 .75 -.375 .375
2 so 10

mode p e
m1  48000 0.8  30000 0.2  52000 1  $ CZT Cd 0.8 Zn 0.2 Te 1
sdef pos = -1 0 0 erg=d1
prdmp 2j 1
print
#          si1          sp1     $Cs-137
             L            D
         0.00447       0.91
         0.031817      1.99
         0.032194      3.64
         0.036304      0.348
         0.036378      0.672
         0.037255      0.213
         0.28351       5.8E-4
         0.661657      85.10
f8:e 1
e8 0 1e-6 400i 0.8
ft8 GEB 3.6e-3 1.5e-2 0.1
nps 1e6
 f6:e 1
 f18:p 1
 e18 0 1e-6 400i 0.8
 ft18 phl 1 6 1 0 geb 3.6e-3 1.5e-2 0.1
```

Example 2: F8 PHL (cont.)

- If no response function is used, results of F8 and F8 PHL should match almost exactly.




```
mcplot>  tal 8 la "tal 8" cop tal 18 la "tal 18"
```

DE/DF Response for F8 PHL

- Dose energy (DE) and Dose function (DF)
- A DE/DF card can be added to a F6 tally to adjust the magnitude of energy deposited to allow for larger/smaller scores (pulses) based on energy of electron.
- Example:
  - `DE6   0.1 0.5 0.80 1.0`
  - `DF6   0.8 0.9 0.95 1.0`
- Creates lower-energy pulses from energy deposited by electrons at lower energies.
- Reflects (in)efficiencies in scintillation light, ionization pair, electron hole pair production, etc.

Photon Material Response for PHL

- Some material response functions have been included in MCNP6.
- These adjust the DE/DF responses automatically.
- Can be added as specification on PHL line.
- See Section 3.3.5.18 of MCNP6 manual.
- No function for CZT available.

Table 3-99. Detector Descriptors for the FT PHL Option

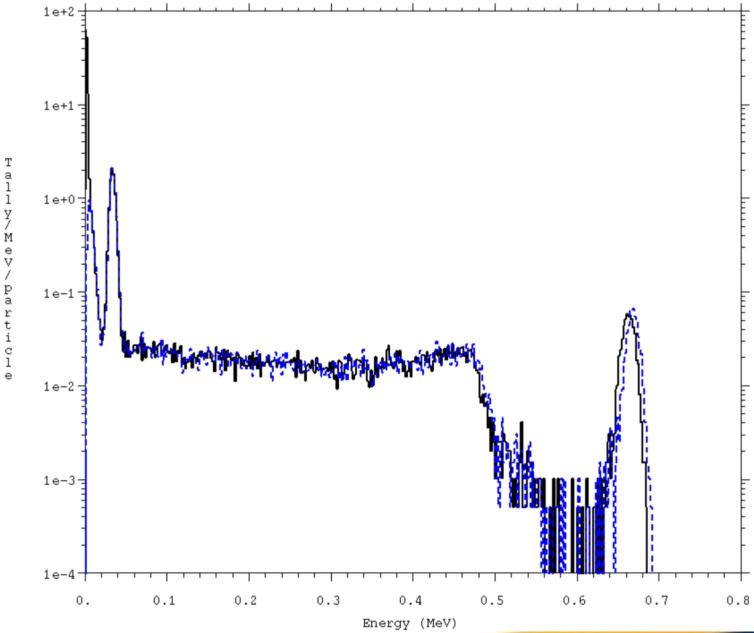
Descriptor	Description
HE3-1	He-3 neutron detector, option 1
BF3-1	BF3 neutron detector, option 1
LIG-1	Li glass neutron detector, option 1
LII-1	LiI neutron detector, option 1
ZNS-1	ZnS neutron detector, option 1
NAI-1	NaI photon detector, option 1
BGO-1	BGO photon detector, option 1
CSI-1	CsI photon detector, option 1
BC4-1	BC400 photon detector, option 1
HPG-1	HPGe photon detector, option 1

Example 3: Photon Material Response for PHL

- Add CSI-1 response keyword to detector in Example 2.

```
ft18 phl 1 6 1 0 csi-1 geb 3.6e-3 1.5e-2 0.1
```

- Small shift in pulse is introduced.



Example 3: Response (phl_ex3)

```
F8 tally usage
1  1 -1  -1  imp:p=1   $ 15x15x7.5 mm3 CZT crystal
2  0  1 -2   imp:p=1   $ void around crystal
99  0  2     imp:p=0   $ outside world

1 rpp -.75 .75 -.75 .75 -.375 .375
2 so 10

mode p e
m1  48000 0.8  30000 0.2  52000 1  $ CZT Cd 0.8 Zn 0.2 Te 1
sdef pos = -1 0 0 erg=d1
prdmp 2j 1
print
#         si1        sp1     $Cs-137
           L          D
        0.00447      0.91
        0.031817     1.99
        0.032194     3.64
        0.036304     0.348
        0.036378     0.672
        0.037255     0.213
        0.28351      5.8E-4
        0.661657     85.10
f8:e 1
e8 0 1e-6 400i 0.8
ft8 GEB 3.6e-3 1.5e-2 0.1
nps 1e6
 f6:e 1
 f18:p 1
 e18 0 1e-6 400i 0.8
 ft18 phl 1 6 1 0 csi-1 geb 3.6e-3 1.5e-2 0.1
```

Coincidence/Anti-coincidence

- It is possible to use multiple F6 tallies/tally regions to build F8 tallies.
- Multiple F6 tallies can be added together.
- Or multiple F6 tallies can used in combination to create a matrix of results.

FT PHL Tally - Syntax

```
PHL [n t_a1 b_a1]
    [m t_b1 b_b1] 0
```

PHL $[n\ t_{a1}\ b_{a1}]$ $[m\ t_{b1}\ b_{b1}]$ 0

Now we'll use two regions, 1 tally per region.

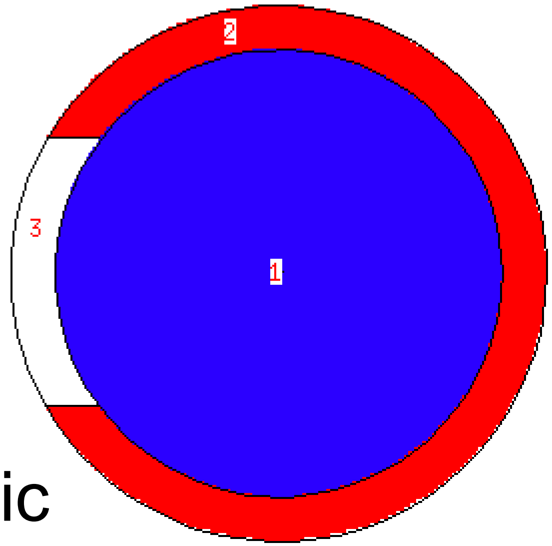
```
PHL 1 6 1
    1 16 1 0
```

As before, but now a second region is defined using F16.
Example:

```
F6:e 1
F16:e 2  $ Two F6 tallies
F8:p 1
FT8 PHL 1 6 1
        1 16 1 0  $ two region PHL definition
E8    0 1023i 8   $ energy bins for 1st region
FU8   0 1023i 8   $ energy bins for 2nd region
```

Example 6: Anti-Coincidence

- Copy C:\MCNP6\EXAMPLES\phl_ex6
- Multiple F6 tallies can be combined to do anti-coincidence.
- Sphere of BGO surrounded by plastic scintillator.
- Source inward-directed 1 MeV photons.
- Two energy bins for plastic, detailed energy bins for BGO.
- Want energy in BGO and not plastic




```
mcnp6 i=phl_ex6 n=ex6.
```

Example 6: Anti-Coincidence

```
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  500000
m1   83000 -0.671 32000 -0.175 8000 -0.154
m2   6000 -0.9153 1000 -0.0847
f26:e  2               $ Plastic energy dep.
f36:e  1               $ BGO energy dep.
f18:e  1               $ Plastic/BGO PHT
e18   0. 199i 1.2
fu18    0. 1.2
ft18   phl 1 36 1 1 26 1 0 GEB 0 0.1098 0
fq18   e u
```

Example 6: Anti-Coincidence

```
1tally        18         nps =       500000
           tally type 8    pulse height distribution.                  units    number
           particle(s): photons   electrons
           this tally is modified by    ft   geb   phl
```

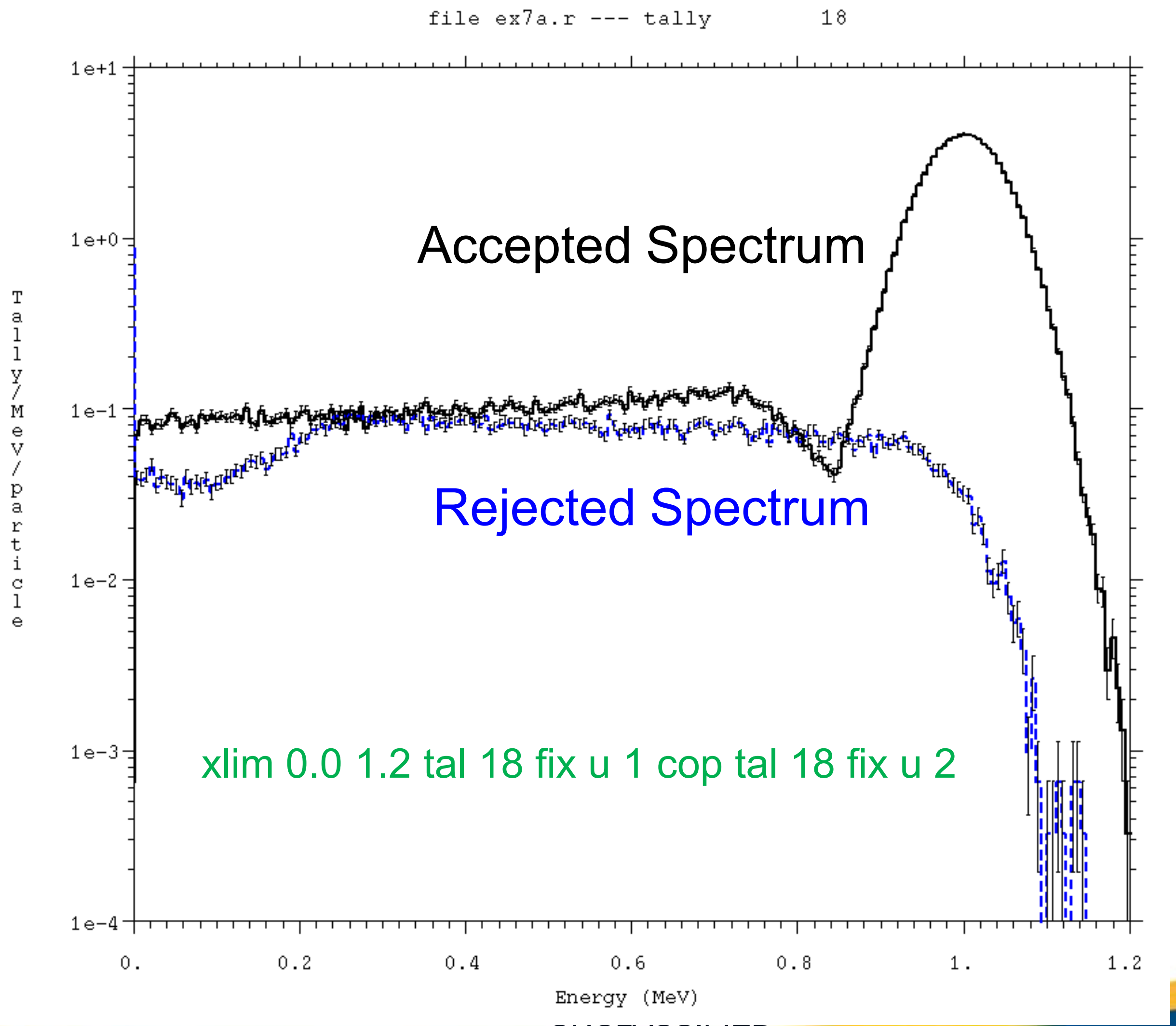
No energy deposited in plastic | Energy deposited in plastic

Plastic

B G O

```
 cell  1
     user bin:       0.0000E+00          1.2000E+00                total
      energy
    0.0000E+00   7.20000E-05 0.1667   8.93340E-02 0.0045   8.95240E-02 0.0045
    6.0000E-03   3.72000E-04 0.0733   1.90000E-04 0.1026   5.46000E-04 0.0605
    1.2000E-02   4.14000E-04 0.0695   2.08000E-04 0.0980   6.64000E-04 0.0549
    1.8000E-02   4.42000E-04 0.0673   2.40000E-04 0.0913   7.50000E-04 0.0516
    2.4000E-02   4.94000E-04 0.0636   2.20000E-04 0.0953   7.14000E-04 0.0529
    3.0000E-02   5.26000E-04 0.0616   2.34000E-04 0.0924   6.70000E-04 0.0546
    3.6000E-02   4.32000E-04 0.0680   2.50000E-04 0.0894   7.12000E-04 0.0530
    4.2000E-02   4.48000E-04 0.0668   2.24000E-04 0.0945   6.96000E-04 0.0536
    4.8000E-02   5.68000E-04 0.0593   1.88000E-04 0.1031   7.32000E-04 0.0523
    5.4000E-02   5.64000E-04 0.0595   2.02000E-04 0.0995   7.20000E-04 0.0527
    6.0000E-02   4.82000E-04 0.0644   2.00000E-04 0.1000   6.86000E-04 0.0540
    6.6000E-02   4.46000E-04 0.0670   2.06000E-04 0.0985   6.50000E-04 0.0555
    7.2000E-02   5.28000E-04 0.0615   1.60000E-04 0.1118   7.34000E-04 0.0522
    7.8000E-02   5.46000E-04 0.0605   2.04000E-04 0.0990   7.06000E-04 0.0532
    8.4000E-02   5.32000E-04 0.0613   2.16000E-04 0.0962   7.36000E-04 0.0521
    9.0000E-02   5.16000E-04 0.0622   1.54000E-04 0.1140   6.82000E-04 0.0541
    9.6000E-02   5.22000E-04 0.0619   1.74000E-04 0.1072   6.78000E-04 0.0543
    1.0200E-01   5.32000E-04 0.0613   1.66000E-04 0.1098   7.24000E-04 0.0525
    …            …                    …                    …
```

Example 6: Anti-Coincidence



FT PHL Tally - Syntax

```
PHL [n ta1 ba1 ta2 ba2 ... tan ban]
```

$PHL\ [n\ t_{a1}\ b_{a1}\ t_{a2}\ b_{a2}\ \ldots\ t_{an}\ b_{an}]$

What if we used two tallies per region?

```
PHL 2 6 1  16 1  0
```

Now the response of the two F6 tallies are summed.

```
F6:e 1
F16:e 1  $ Two F6 tallies
F8:p 1
FT8 PHL 2 6 1 16 1 0  $ two tally region PHL definition
E8   0 1023i 8        $ energy bins for 1st region
```

Modeling Neutron Detectors (n capture)

- He-3, B-10, Li-6
- Can use flux multiplied by reaction of interest.
- Or…
- More detailed model can use emission of the charged particles for tracking and pulse modeling.
- Need to use PHL and extra physics options.

He-3 detector model

- Assume a region (cell 5) is the sensitive region of the detector.
- Add protons, tritons, deuterons to mode card.
- Reduce energy cutoffs to minimum (1e-3 MeV)
- Turn on NCIA (phys:n 7th entry)
  - Neutron Capture Ion Algorithm (NCIA)
- Add tallies to collect charged particle energies (f6:h 5, f16:t 5, f26:d).

He-3 Detector model, cont.

- Add F6 tallies into F8 PHL tally.
- Now we can run this model.
- Results will show pulse shape from energy deposited by charged secondary particles.

He-3 tube wrapped in Poly (he3_ex)

```
He-3 Detector Model
5 1  -1e-3   -5   imp:n=1
6 2     -1   5 -6  imp:n=1
10 0         6 -99 imp:n=1
99 0            99 imp:n=0

5 rcc  -5 0 0 10 0 0 1  $ He-3
6 rcc  -5 0 0 10 0 0 2  $ poly
99 so 25

sdef pos 0 -10 0  erg=2 vec 0 1 0 dir=1
nps 50000
M1 2003 1
M2   1001 2 6012 1
MX2:n  j    6000
mode n h t d
cut:h,t,d j 1e-3
phys:n 6j 4  $ elastic recoil and NCIA
F6:h 5
F16:t 5
F26:d 5
F8:n 5
FT8 PHL 3 6 1 16 1 26 1 0
E8 0 99i 1
```

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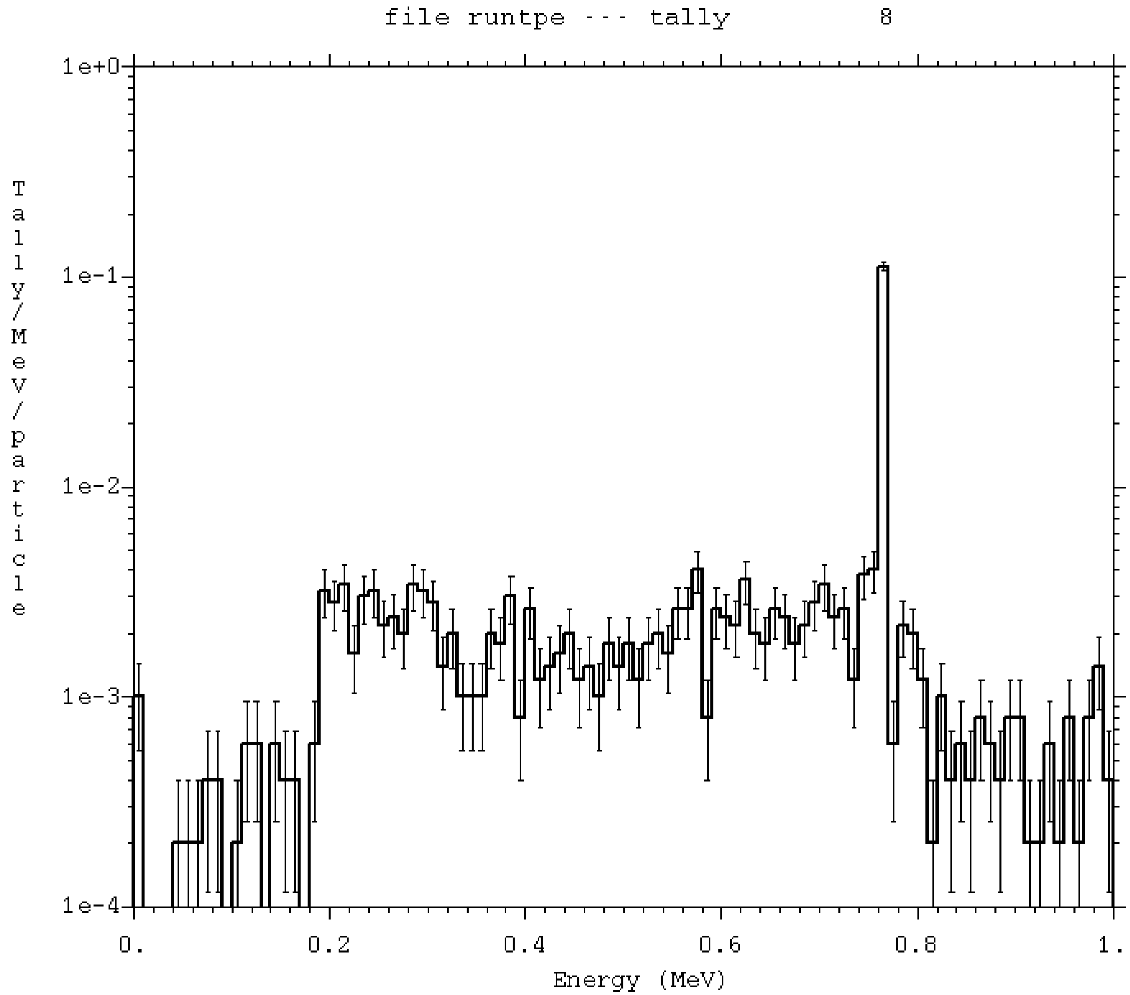
Results…



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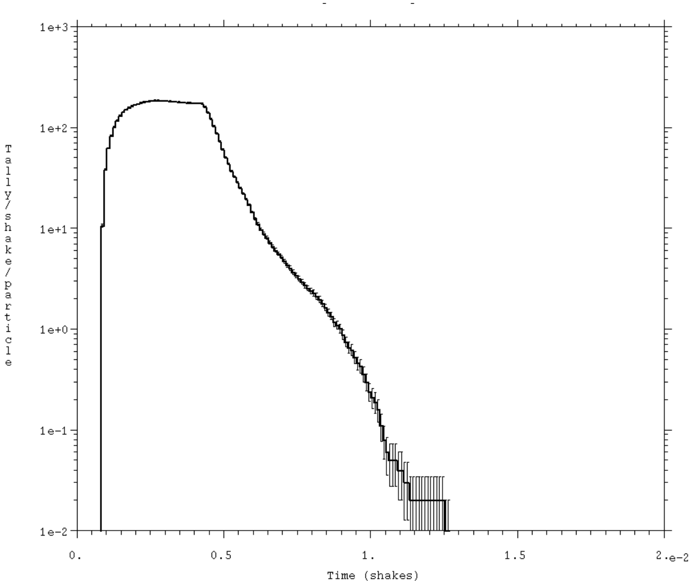
Notes

- NCIA option can create charged secondary particles with correct energy distribution and correlated (opposite) angular distribution.
- Only works for He-3, B-10 and Li-6.

Example 7: Time Binning on F8

- It is possible to subdivide F8 PHL into time bins since F6 records the time structure of energy deposition.
- The file phl_ex7 is the same as phl_ex2 but with time bins added.
  - `T18 0 199i 2e-2` (shakes).



- 1 pulse is distributed over time by ratio of energy in those time bins.
- Time structure of electron pulses.

Example 7: Time Binning (phl_ex7)

```
F8 tally useage: Time binning
1  1 -1  -1  imp:p=1   $ 15x15x7.5 mm3 CZT crystal
2  0  1 -2   imp:p=1   $ void around crystal
99  0  2     imp:p=0   $ outside world

1 rpp -.75 .75 -.75 .75 -.375 .375
2 so 10

mode p e
m1  48000 0.8  30000 0.2  52000 1   $ CZT Cd 0.8 Zn 0.2 Te 1
sdef pos = -1 0 0 erg=d1
prdmp 2j 1
print
#        si1        sp1     $Cs-137
          L          D
        0.00447      0.91
        0.031817     1.99
        0.032194     3.64
        0.036304     0.348
        0.036378     0.672
        0.037255     0.213
        0.28351      5.8E-4
        0.661657     85.10
f8:e 1
e8 0 1e-6 1024i 2
ft8 GEB 3.6e-3 1.5e-2 0.1
nps 1e6
f6:e 1
f18:p 1
e18 0 1e-6 1024i 2
ft18 phl 1 6 1 0 geb 3.6e-3 1.5e-2 0.1
t18 0 199i 2e-2
```

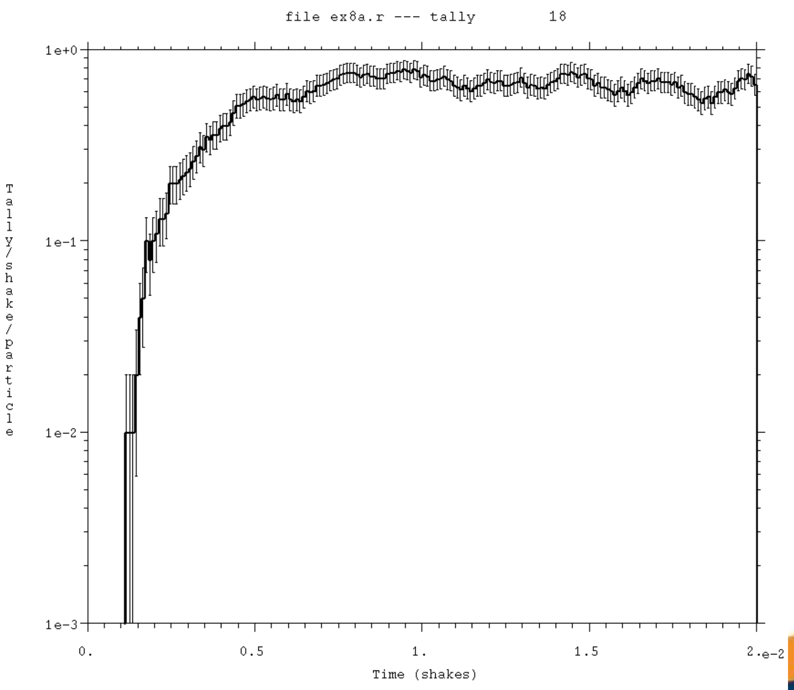
Time Trigger Option

```
PHL [n ta1 ba1 ta2 ba2 ... tan ban] [det1] [TDEP tg tt]
```

- A ‘TDEP’ keyword can be used on the F8 PHL to set a trigger region and energy threshold.
- Usually more useful for neutron tallies.
- By default, the F8 tally with the tdep is used with zero energy threshold.

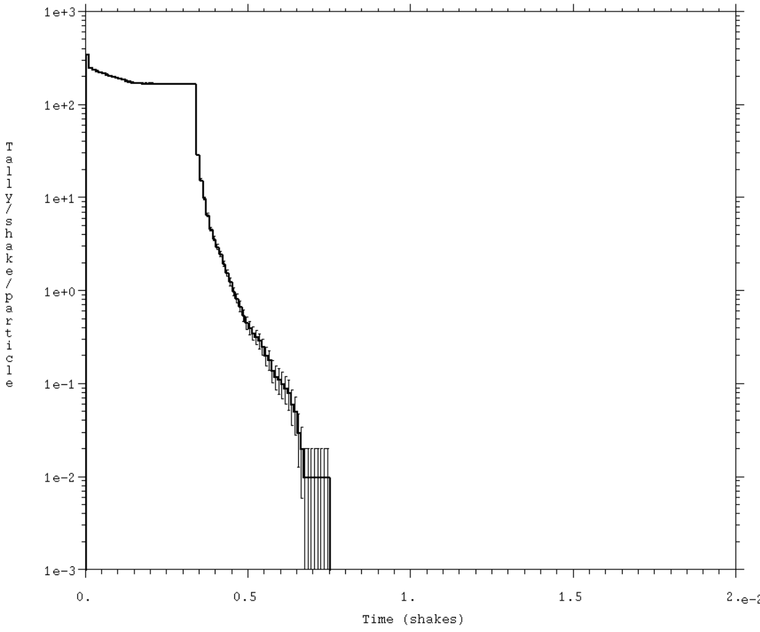
Example 8: Time Trigger (Step 1)

- Starting with example 7 and create time-dependent source from 0 to 1 shake.
- Run this and note results
- Result: flat distribution out to 2e-2 shakes (and beyond).



Example 8: Time Trigger (Step 2)

- Add TDEP card to F8 PHL tally to make time bins relative to when first energy score is recorded.
- `ft18 phl 1 6 1 0 tdep 18 0 geb 3.6e-3 1.5e-2 0.1`
- TDEP 18 0 will cause tally to trigger on itself (i.e all time-dependent results will be reset to the same relative point in time.
- Results: Similar to Example 7 but the early time bins are all non-zero.



Example 8: Time Trigger (phl_ex8)

```
F8 tally useage: Time binning and time trigger
1  1 -1  -1  imp:p=1   $ 15x15x7.5 mm3 CZT crystal
2  0  1 -2   imp:p=1   $ void around crystal
99  0  2     imp:p=0   $ outside world

1 rpp -.75 .75 -.75 .75 -.375 .375
2 so 10

mode p e
m1  48000 0.8  30000 0.2  52000 1  $ CZT Cd 0.8 Zn 0.2 Te 1
sdef pos = -1 0 0 erg=d1 tme=d3
prdmp 2j 1
print
#         si1        sp1     $Cs-137
           L          D
        0.00447      0.91
        0.031817     1.99
        0.032194     3.64
        0.036304     0.348
        0.036378     0.672
        0.037255     0.213
        0.28351      5.8E-4
        0.661657     85.10
si3 0 1
sp3 0 1
f8:e 1
e8 0 1e-6 1024i 2
ft8 GEB 3.6e-3 1.5e-2 0.1
nps 1e6
f6:e 1
f18:p 1
e18 0 1e-6 1024i 2
ft18 phl 1 6 1 0 tdep 18 0 geb 3.6e-3 1.5e-2 0.1
t18 0 199i 2e-2
```

Use of TF Card

- The tally fluctuation (TF) card can be used to specify the bin for which the tally fluctuation chart statistical information is calculated.
- The TF card can be used to indicate which F6 bins should contribute to the F8 PHL.
- Multiple bins can be used on the F6 tallies and can be referred to on the PHL interface.

Receiver Operator Characteristic (ROC) Curves

```
Detectability of a UF6 sphere
1 1 -5.1    -1          imp:n=1 imp:a=1 imp:h,d,t,s=0
2 2 -1.2e-3  1 -2 (5:-6) imp:n=1 imp:a=0 imp:h,d,t,s=0
3 3 -1.2e-3  -3         imp:n=1 imp:a=0 imp:h,d,t,s=1
4 4 -1.0      3 -4 6    imp:n=1 imp:a=0 imp:h,d,t,s=0
5 5 -8.65     4 -5 6    imp:n=1 imp:a=0 imp:h,d,t,s=0
6 0           2         imp:n=0 imp:a=0 imp:h,d,t,s=0

1 so 3.0
2 so 200.0
3 sph 16.0 0 0  5.0
4 sph 16.0 0 0  12.0
5 sph 16.0 0 0  12.1
6 px 8

m1 92235 .90  92238 .1 9019 6
mx1:a model model 9019.12a
m2 7014 -.755 8016 -.232 6012 -.013
m3 2003 1
mx3:h model
mx3:d model
mx3:t model
mx3:s model
m4 1001 2 6012 1
m5 48113 1
mphys on
mode n h d t s a
phys:n 1000 1000 1 3j 4
cut:n  2j 0 0
cut:a       j 2 0 0
cut:h,d,t,s j 0 0 0
act fission=none nonfiss=a
```

```
nps 28678386000
print
prdmp j 2867838600 j j 286783860
dbcn 9j 1e30 44j -1e11
sdef par=d1 sur=fpar d2 pos=0 0 0 rad=fpar d3 nrm=-1 loc=36 -106 -1
c sa/s = 2.817e7+4.930e5 = 2.867e7
c bn/s = PI*200*200*6.673e-2 = 8.386e3
c sf/s = 2.817e7*7.2e-11+4.930e5*5.5e-7 = 0.273
c total = 28678386
si1 L       sa       -bn   -sf
sp1    0.999710  0.000290  1e-8
ds2 L        0         2     0
ds3 S        4         0     4
si4  0 3.0
sp4  -21 2
```

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Receiver Operator Characteristic (ROC) Curves

```
c total He-3 signal
f16:h 3
f26:t 3
f36:s 3
c He-3 signal from BN
f106:h 3
ft106  SCX 1
tf106  1 1 2
f206:t 3
ft206  SCX 1
tf206  1 1 2
f306:s 3
ft306  SCX 1
tf306  1 1 2
c He-3 signal from BN that collided in UF6 (negative)
f116:h 3
ft116  SCX 1
cf116  -1              $ requires fatal option
fm116  -1
tf116  1 2 2
f216:t 3
ft216  SCX 1
cf216  -1
fm216  -1
tf216  1 2 2
f316:s 3
ft316  SCX 1
cf316  -1
fm316  -1
tf316  1 2 2
```

```
c He-3 pulse-height tally
f8:h,t,s 3
ft8  PHL 3  16 1  26 1  36 1
        6 106 1 206 1 306 1 116 1 216 1 316 1
        0
    ROC 286783860 1000 $ 10 s count time
e8   0.1 100
fu8  0.1 100
fq8  e u
tf8  1 1 3 1 1 1 2 1
     1 1 2 1 1 1 2 1
```

Receiver Operator Characteristic (ROC) Curves

```
1roc curve for tally    8   100 batches, signal mean= 1.721E+01 noise mean= 9.640E+00 nps = 28678386000  print table 163

 abscissa          ordinate             plot of probability of detection versus probability of false alarm - 0 to 100 percent
  noise              signal:--------10--------20--------30--------40--------50--------60--------70--------80--------90-------100
    1.000          50.500|         |         |         |         |         |x        |         |         |         |         |
    2.000          64.000|         |         |         |         |         |         |   x     |         |         |         |
    3.000          70.000|         |         |         |         |         |         |         x         |         |         |
    4.000          76.000|         |         |         |         |         |         |         |     x   |         |         |
    5.000          76.889|         |         |         |         |         |         |         |      x  |         |         |
    6.000          77.778|         |         |         |         |         |         |         |       x |         |         |
    7.000          78.667|         |         |         |         |         |         |         |        x|         |         |
    8.000          79.556|         |         |         |         |         |         |         |         x         |         |
    9.000          80.444|         |         |         |         |         |         |         |         x         |         |
   10.000          81.333|         |         |         |         |         |         |         |         |x        |         |
   11.000          82.222|         |         |         |         |         |         |         |         | x       |         |
   12.000          83.111|         |         |         |         |         |         |         |         |  x      |         |
   13.000          84.000|         |         |         |         |         |         |         |         |   x     |         |
   14.000          85.222|         |         |         |         |         |         |         |         |    x    |         |
   15.000          86.444|         |         |         |         |         |         |         |         |     x   |         |
   16.000          87.667|         |         |         |         |         |         |         |         |       x |         |
   17.000          88.889|         |         |         |         |         |         |         |         |        x|         |
   18.000          90.111|         |         |         |         |         |         |         |         |         x         |
   19.000          91.333|         |         |         |         |         |         |         |         |         |x        |
   20.000          92.556|         |         |         |         |         |         |         |         |         |  x      |
   21.000          93.778|         |         |         |         |         |         |         |         |         |   x     |
   22.000          95.000|         |         |         |         |         |         |         |         |         |    x    |
   23.000          95.667|         |         |         |         |         |         |         |         |         |     x   |
   24.000          96.333|         |         |         |         |         |         |         |         |         |     x   |
   25.000          97.000|         |         |         |         |         |         |         |         |         |      x  |
   26.000          97.062|         |         |         |         |         |         |         |         |         |      x  |
   27.000          97.125|         |         |         |         |         |         |         |         |         |      x  |
   28.000          97.187|         |         |         |         |         |         |         |         |         |      x  |
   29.000          97.250|         |         |         |         |         |         |         |         |         |      x  |
   30.000          97.313|         |         |         |         |         |         |         |         |         |      x  |
   31.000          97.375|         |         |         |         |         |         |         |         |         |      x  |
   32.000          97.437|         |         |         |         |         |         |         |         |         |      x  |
   33.000          97.500|         |         |         |         |         |         |         |         |         |       x |
   34.000          97.562|         |         |         |         |         |         |         |         |         |       x |
   35.000          97.625|         |         |         |         |         |         |         |         |         |       x |
   36.000          97.687|         |         |         |         |         |         |         |         |         |       x |
   37.000          97.750|         |         |         |         |         |         |         |         |         |       x |
   38.000          97.813|         |         |         |         |         |         |         |         |         |       x |
   39.000          97.875|         |         |         |         |         |         |         |         |         |       x |
   40.000          97.937|         |         |         |         |         |         |         |         |         |       x |
   41.000          98.000|         |         |         |         |         |         |         |         |         |       x |
   42.000          98.125|         |         |         |         |         |         |         |         |         |       x |
   43.000          98.250|         |         |         |         |         |         |         |         |         |       x |
   44.000          98.375|         |         |         |         |         |         |         |         |         |       x |
   45.000          98.500|         |         |         |         |         |         |         |         |         |        x|
   46.000          98.625|         |         |         |         |         |         |         |         |         |        x|
   47.000          98.750|         |         |         |         |         |         |         |         |         |        x|
   48.000          98.875|         |         |         |         |         |         |         |         |         |        x|
   49.000          99.000|         |         |         |         |         |         |         |         |         |        x|
   50.000          99.062|         |         |         |         |         |         |         |         |         |        x|
   51.000          99.125|         |         |         |         |         |         |         |         |         |        x|
   52.000          99.187|         |         |         |         |         |         |         |         |         |        x|
   53.000          99.250|         |         |         |         |         |         |         |         |         |        x|
   54.000          99.313|         |         |         |         |         |         |         |         |         |        x|
   55.000          99.375|         |         |         |         |         |         |         |         |         |        x|
   56.000          99.438|         |         |         |         |         |         |         |         |         |        x|
   57.000          99.500|         |         |         |         |         |         |         |         |         |         x
   58.000          99.562|         |         |         |         |         |         |         |         |         |         x
   59.000          99.625|         |         |         |         |         |         |         |         |         |         x
   60.000          99.687|         |         |         |         |         |         |         |         |         |         x
   61.000          99.750|         |         |         |         |         |         |         |         |         |         x
   62.000          99.813|         |         |         |         |         |         |         |         |         |         x
   63.000          99.875|         |         |         |         |         |         |         |         |         |         x
   64.000          99.938|         |         |         |         |         |         |         |         |         |         x
   65.000         100.000|         |         |         |         |         |         |         |         |         |         x
```

Receiver Operator Characteristic (ROC) Curves

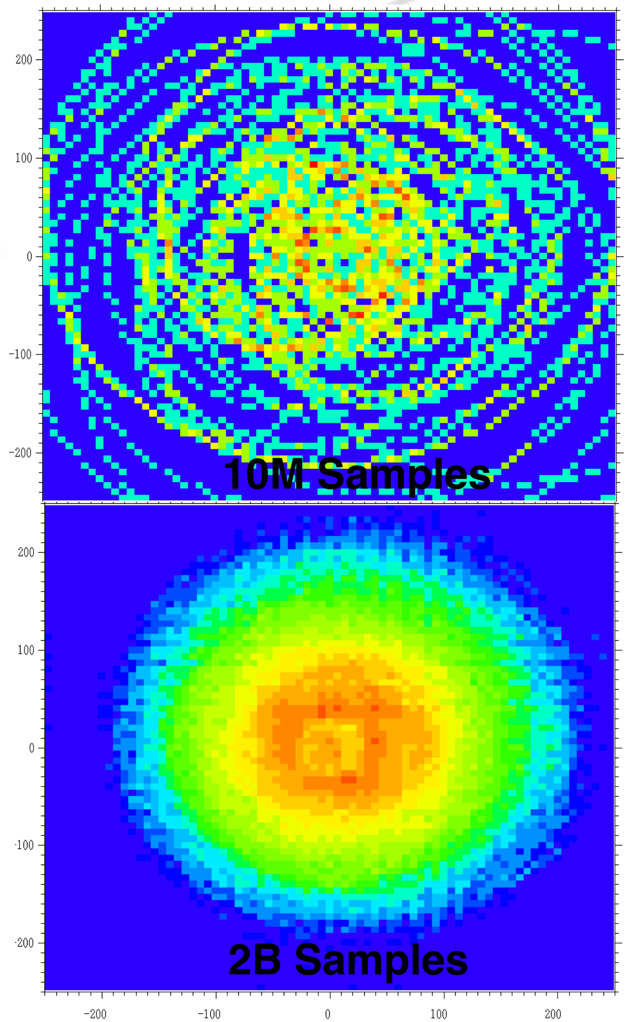
- Average number of counts accumulated in a single batch should match the physical number of counts expected.
- This ensures the width of statistically sampled counts matches expected spread in measurements.

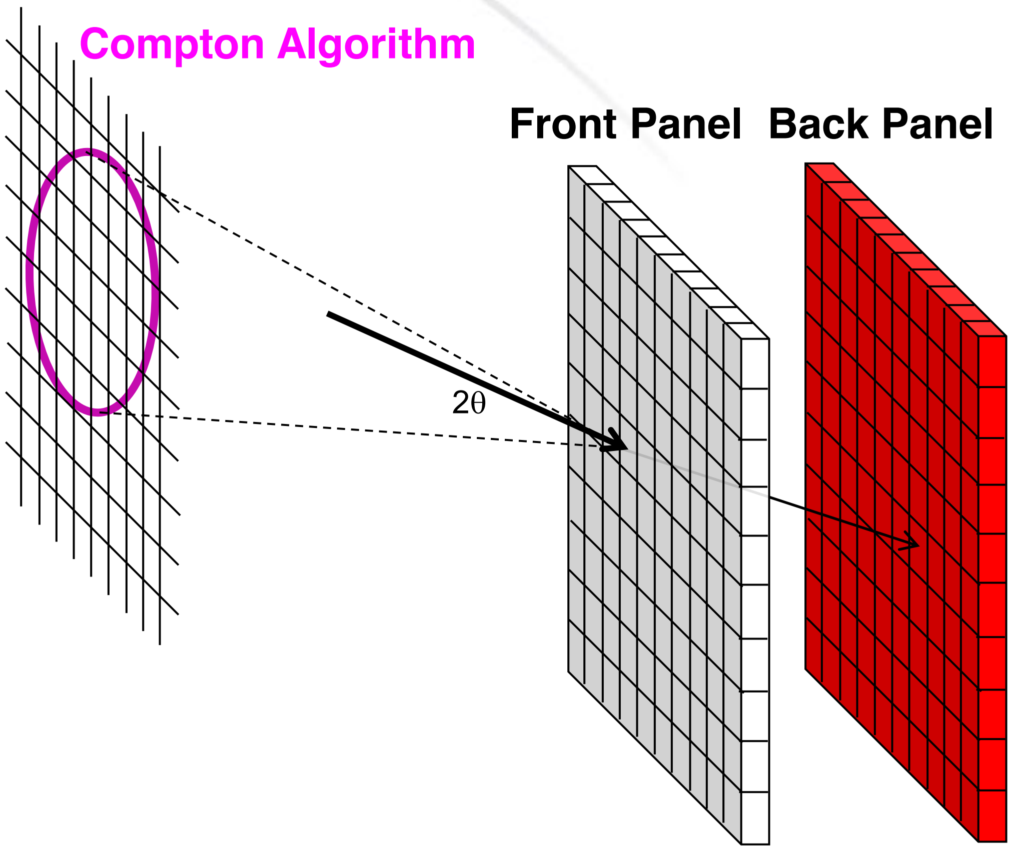
Other Tally Options

- Compton Image Tally
- First Fission Tally (FFT)
- Tagging

Compton Image Tally

- The FT8 COM tally option produces a Compton image stored in an associated FIR radiography tally t using algorithm a (optional, currently there is one algorithm so a=1).
- The Compton image is formed from a FT8 PHL specification of dual-region coincidences of planar lattice tallies. At the end of each particle history, Compton/photoelectric energy deposition in the front/back of these dual-panel detectors is used to create a circular “image” of the incident photon on a specified image plane.
- The FT8 PHL enhancement is used to obtain coincidences of front-panel energy deposition with back-panel energy deposition, on a voxel-by-voxel (or element-by-element) basis.





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Compton Image Tally

```
2-MeV photons into Si grid
1 1 -2.3 -1 lat=1 u=1        imp:p=1
           fill=0:0 -2:2 -2:2 1 24r
2 1 -2.3 -2 lat=1 u=2        imp:p=1
           fill=0:0 -2:2 -2:2 2 24r
3 0      -3   fill=1         imp:p=1
4 0      -4   fill=2         imp:p=1
5 0      -5 4 3              imp:p=1
6 0       5                  imp:p=0

1 rpp  -1 1  -1 1  -1 1
2 rpp   4 6  -1 1  -1 1
3 rpp  -1 1  -5 5  -5 5
4 rpp   4 6  -5 5  -5 5
5 sph  0 0 0  100
```

```
m1  14028 1
mode p e
cut:p,e 2j 0 0 $ Analog capture
sdef par=p pos=-5 3 3 erg=2
fir5 -5 0 0  0  0 0 0  1 1 1
FS5 -10 9i 10
CS5 -10 9i 10
f16:e (1<1[0:0 -2:2 -2:2]<3)
f26:e (2<2[0:0 -2:2 -2:2]<4)
f8:e  1
ft8   PHL 1 16 0    $ Region 1
          1 26 0    $ Region 2
          0
      COM 5 1
e8   0.2 100 NT
fu8  0.2 100 NT
tf8  j j 2 j j j 2 j
```

First Fission Tally

- Used with a special tally treatment (FT) card.
- Enables a flagged tally in which the flag is set based on a fission event rather than surface or cell crossing.
- Options are available to specify the fissioning isotope or whether (n,xn) reactions are used.

Tally Tagging

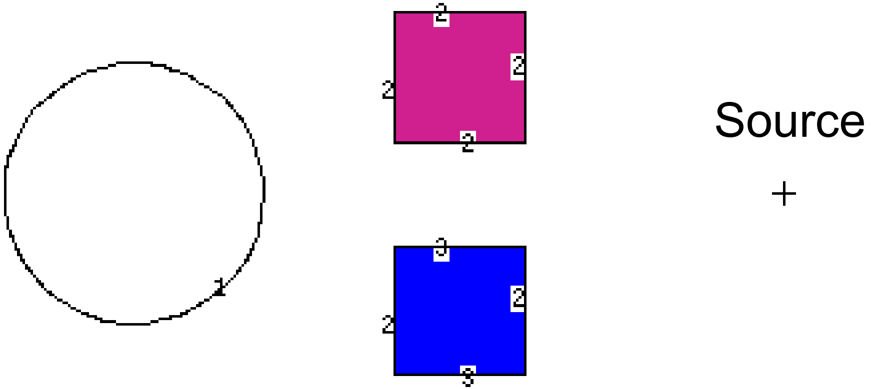
- Particle can be assigned a “Tag” at creation which is specific to cell, isotope and reaction.
- Option can be set to control how scatter is treated (whether tag is reset).
- Special tags for sources, delayed particles, muon physics, etc.

Tally Tagging - Example

```
Tagging example
1   0          -1   imp:n=1
2   1    -1    -2   imp:n=1
3   2    -1    -3   imp:n=1
4   0    1 2 3 -4   imp:n=1
99  0           4   imp:n=0

1 so 5
2 rpp  2  7   -2 2  10 15
3 rpp -7 -2   -2 2  10 15
4 so 50

sdef pos=0 0 25
nps 1e6
f1:n 1
ft1 tag 3
fq1 u f
fu1  -1   200000.00016   13027. 300000.  26056.    1e10
c    src  cell 2,(n,2n)   Al     cell 3   Fe    Everything else
m1 26056 1
m2 13027 1
```



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Tally Tagging - Results

```
1tally        1        nps =     1000000
           tally type 1    number of particles crossing a surface.
           particle(s): neutrons
           this tally is modified by   ft  tag

      surface:          1
    user bin
   -1.0000E+00   2.01462E-02 0.0099        $ Source
    2.0000E+05   1.87143E-05 0.3162        $ Cell 2, (n,2n)
    1.3027E+04   5.41891E-05 0.1796        $ Al-27
    3.0000E+05   0.00000E+00 0.0000        $ Cell 3
    2.6056E+04   3.36933E-05 0.2357        $ Fe-56
    1.0000E+10   0.00000E+00 0.0000        $ Everything else
      total      2.02528E-02 0.0099
```

Supplemental Materials

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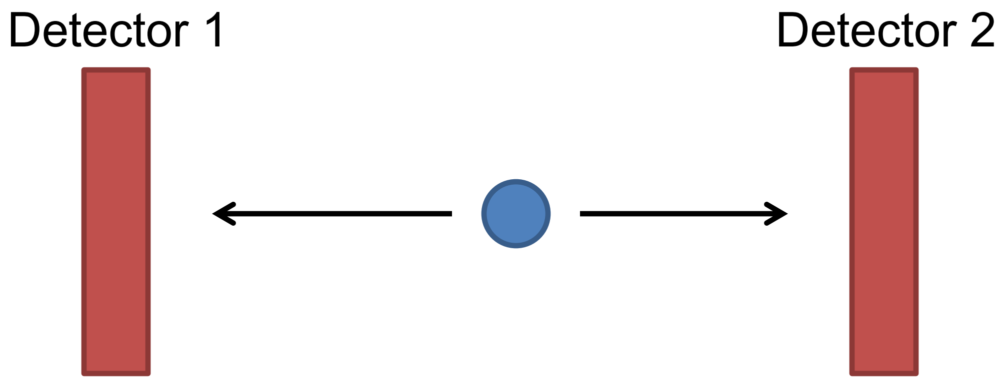
Coincidence Detection

- FT8 PHL Tally can be used to create pulses which register two simultaneous (within same history) events.



- This is more useful for neutrons and less useful for photon events given limitation in MCNP6 correlated photon emissions.

Example 4 – Coincidence Detection

- Copy C:\MCNP6\EXAMPLES\phl_ex4
- Example 4 creates two CZT detectors around spontaneous photons (SP) Co-60 source (illustration on previous slide).
- This source simulates decay of Co-60 but samples energy of each photon independently.
- F8 Energy bins are simplified to two bins (zero and non-zero)
- Examine and run Example 4.

```
mcnp6 i=phl_ex4 n=ex4.
```

Example 4 – Coincidence Detection

- Each region has only two energy bins.
- Results are shown in matrix form (score/not-score):

Detector 1

Detector 2

```
cell  1
     user bin:        0.0000E+00          2.0000E+00           total
      energy
    0.0000E+00   2.00000E-05 0.7071   4.56900E-02 0.0145   4.57600E-02 0.0144
    2.0000E+00   4.59200E-02 0.0144   2.41000E-03 0.0643   4.82800E-02 0.0140
      total      4.59400E-02 0.0144   4.81000E-02 0.0141   9.40400E-02 0.0098
```

Example 5 – Coincidence Detection

- Extra Credit:
- Design F8 PHL tally to test emission of specific energies from Co-60 SP source.
- Hint: Refine energy bin structure in Example 4.

cell 1

user bin: energy	0.0000E+00		1.1000E+00		1.2000E+00		1.3000E+00		1.4000E+00	
0.0000E+00	3.372E-05	0.2582	2.760E-02	0.0089	2.965E-03	0.0275	5.395E-05	0.2041	1.965E-03	0.0338
1.1000E+00	2.781E-02	0.0089	8.610E-04	0.0511	1.326E-04	0.1302	4.496E-06	0.7071	2.922E-05	0.2773
1.2000E+00	3.181E-03	0.0265	1.169E-04	0.1387	**4.496E-06**	0.7071	0.000E+00	0.0000	**2.248E-06**	1.0000
1.3000E+00	5.845E-05	0.1961	2.248E-06	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
1.4000E+00	1.980E-03	0.0337	1.573E-05	0.3780	**2.248E-06**	1.0000	0.000E+00	0.0000	**2.248E-06**	1.0000
2.0000E+00	7.419E-05	0.1741	2.248E-06	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
total	3.314E-02	0.0081	2.860E-02	0.0087	3.104E-03	0.0269	5.845E-05	0.1961	1.998E-03	0.0335

Two 1.33 gammas
One 1.17 and one 1.33
Two 1.17 gammas