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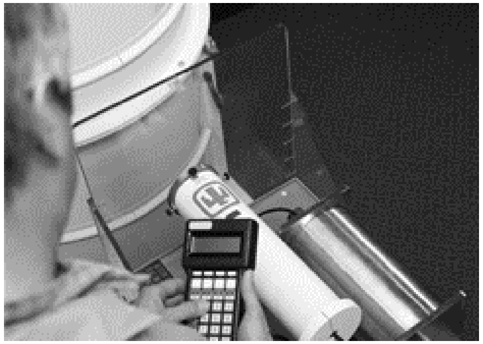

Linking External Radiation Transport Codes with GADRAS

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Motivation

- GADRAS has library of accurate detector response functions
  - Based on first principles + empirical adjustments based on characterization
- Most users of GADRAS use 1D Model, but not always applicable
  - Model is too complicated for 1D
  - Model is already built with another transport code
  - User is more familiar with other transport code
- Linkage from external transport codes to GADRAS is useful for the community
- Discussion will use MCNP as an example, but can be any transport code capable of giving similar results

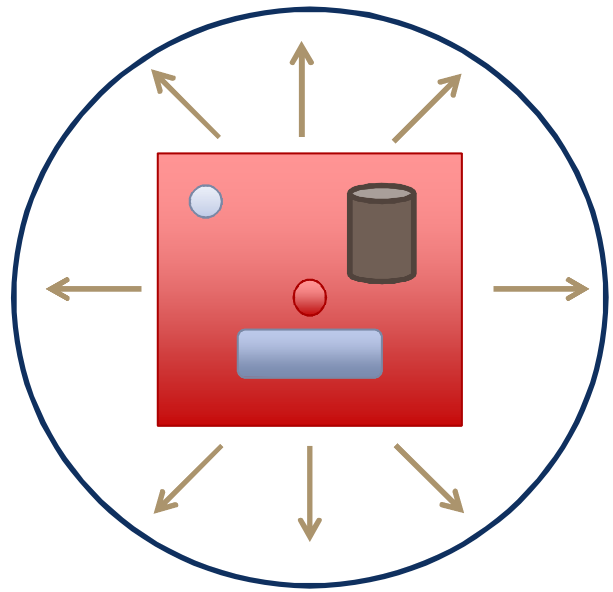
Previous Work

- MCNP calculated 3D flux and gave GADRAS equivalent point source model [1]
  - Flux into 4π was collapsed and processed as if point source
  - Method worked well for distant sources
  - Scatter was computed by GADRAS
- Limitations:
  - Detector Response Function is based only on radiation entering through front of detector
  - Computed response was inaccurate for near-by, large sources

1) Published as Los Alamos National Laboratory report LA-UR-12-25637
Title: "Combined MCNP/GADRAS Simulation of HPGe Gamma Spectra"
Author(s): Mohini Rawool-Sullivan, John Mattingly, Dean Mitchell, and Jesson Hutchinson

The Conference Record (CR) of 2012 Nuclear Science Symposium, Medical Imaging Conference
2012 Nuclear Science Symposium, Medical Imaging Conference & Workshop
on Room-Temperature Semiconductor X-Ray and Gamma-Ray Detectors,
2012-10-29/2012-11-03 (Anaheim, California, United States)

Previous Work



New Method

- Use current density (current per unit area, not flux!) on all sides (facets) of the detector as input to GADRAS
- GADRAS computes interactions within detector crystal and scattering that occurs within the detector housing
- External code should compute room scatter
- Environmental scatter computation from GADRAS should be suppressed

MCNP-GADRAS Coupling

- Multi-faceted GAM files allow MCNP tallies to be input into GADRAS' detector response function

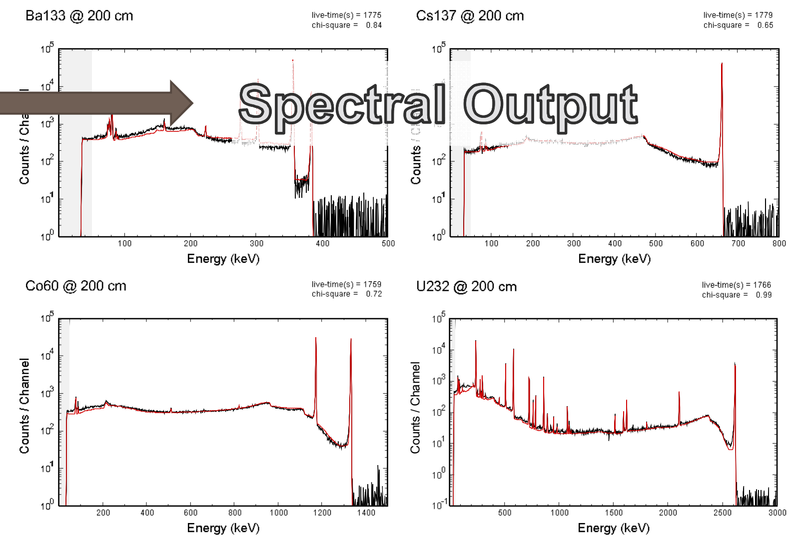
```
Simple Example Input Deck
1 0 -1 imp:p=0 $ detector volume
2 1 -0.0012 -2 1 imp:p=1 $ surrounding air
3 0 2 imp:p=0

1 rcc 100 0 0  10 0 0  10 $ detector surfaces
2 so 1000 $ universe sphere

mode p
sdef par=p pos=0 0 0 erg=0.6617
m1   7014 -75 $ air
     8016 -25
f1:p 1.1  $ side of cylinder, side of detector
f11:p 1.2 $ bottom of cylinder, front face of detector
f21:p 1.3 $ top of cylinder, back face of detector
e0 {insert values from MCNPbins.dat}
```

MCNP Input → **Detector Current Tally Output**

```
flagged tallies
2.9670E-02   2.65636E-09 0.1876
2.9890E-02   5.26597E-09 0.1377
3.0510E-02   8.87310E-09 0.1034
3.0730E-02   3.70349E-09 0.1582
3.0860E-02   1.77849E-09 0.2331
3.1080E-02   3.24170E-09 0.1803
3.8550E-02   4.01838E-06 0.0045
3.8770E-02   1.29203E-10 1.0000
3.9390E-02   2.58406E-10 0.7071
3.9610E-02   2.58406E-10 0.7071
4.0010E-02   0.00000E+00 0.0000
```

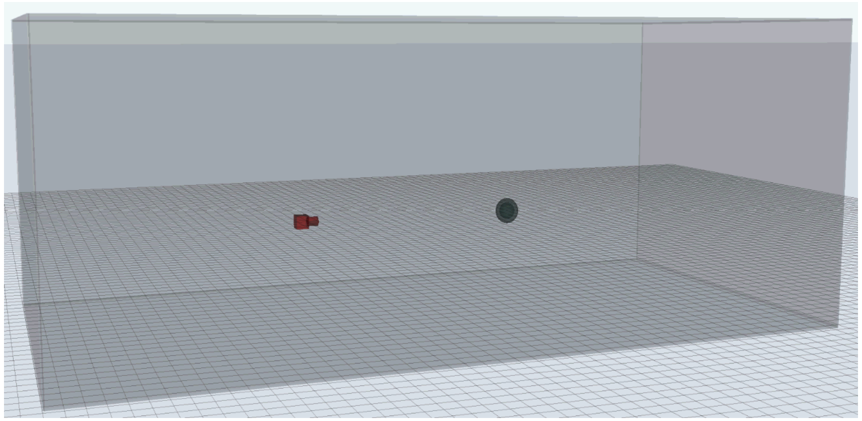
GADRAS Input → **Spectral Output**

```
0 5 ! NewFormat,ModelGeometry
0 1475 78 ! PhotonLines, PhotonGroups, NeutronGroups
2.000E+02   3.952E+04   4.155E+01   1.063E+02  ! photon groups
2.935E+02   1.222E+01   2.138E+00   7.240E-01
2.957E+02   2.742E-01   1.290E-01   2.181E-01
…
1.179E+04   0.000E+00   0.000E+00   0.000E+00
1.200E+04   0.000E+00   0.000E+00   0.000E+00
1.965E+07   0.000E+00   7.831E-03   3.073E+00  ! neutron groups
1.733E+07   3.016E-01   4.618E+00   2.870E+01
…
5.000E-03   9.419E+00   2.706E-06   0.000E+00
2.000E-03   4.727E-02   9.549E-08   0.000E+00
5.000E-04   1.149E-03   0.000E+00   9.003E+03
1.000E-05   4.277E+04   0.000E+00   0.000E+00
```



Tallies and Conversions

- External transport code records separate tallies for front, side, and back of detector
  - Must be F1 tally
  - F8 tally uses MCNP's DRF
- Units differ between MCNP and GADRAS
  - Photon energy
    - MeV in MCNP
    - keV in GADRAS
  - Neutron energy
    - MeV in MCNP
    - eV in GADRAS
  - Tally/GAM file input
    - probability of particle entering cell in MCNP
    - particle/s/m^2 in GADRAS



Tallies and Conversions

- Equations for converting between MCNP output and GADRAS input:
  - MCNP gives probability per source particle
  - Necessary info: source activity and facet surface area

$$\{\texttt{front current density}\} = \left\{\frac{front\ current}{source\ particle}\right\} * \frac{(1\times10^{-6}\ Ci)\left(3.7\times10^{10}\frac{Bq}{Ci}\right)\left(1\,\frac{1/s}{Bq}\right)}{\pi(10\ cm)^2\left(\frac{1\ m}{100\ cm}\right)^2}$$

$$\{\texttt{side current density}\} = \left\{\frac{side\ current}{source\ particle}\right\} * \frac{(1\times10^{-6}\ Ci)\left(3.7\times10^{10}\frac{Bq}{Ci}\right)\left(1\,\frac{1/s}{Bq}\right)}{2\pi(10\ cm)(10\ cm)\left(\frac{1\ m}{100\ cm}\right)^2}$$

$$\{\texttt{back current density}\} = \left\{\frac{back\ current}{source\ particle}\right\} * \frac{(1\times10^{-6}\ Ci)\left(3.7\times10^{10}\frac{Bq}{Ci}\right)\left(1\,\frac{1/s}{Bq}\right)}{\pi(10\ cm)^2\left(\frac{1\ m}{100\ cm}\right)^2}$$

GAM File Structure

```
0 5 ! NewFormat,ModelGeometry
0 1476 78 ! PhotonLines, PhotonGroups, NeutronGroups
20.000    6.209E+01   1.416E+02   1.568E-02 ! photon groups
29.350    6.246E+00   9.240E-05   1.313E-03
29.570    2.240E-05   1.592E-11   1.369E-10
…
11790.000   0.000E+00   0.000E+00   0.000E+00
12000.000   0.000E+00   0.000E+00   0.000E+00
1.965E+07   3.501E-14   5.322E-13   5.340E-10 ! neutron groups
1.733E+07   0.000E+00   3.836E-12   5.535E-11
…
5.000E-03   3.114E+03   5.722E+02   3.873E+02
2.000E-03   1.053E+04   1.126E+03   8.363E+02
5.000E-04   7.401E+03   3.388E+02   2.243E+02
1.000E-05   0.000E+00   0.000E+00   0.000E+00
```

Energy Front Sides Back

GAM File Structure

- Photon energy bins
  - Listed in ascending order (keV)
  - Bin defines lower bound of energy group (MCNP is opposite)
- Neutron energy bins
  - Listed in descending order (eV)
  - Bin defines upper bound of energy group
- Side current
  - GADRAS represents detectors as if they are symmetric normal to the detector axis
  - Current coming through top, bottom, left, and right sides are averaged together to give “side current density”

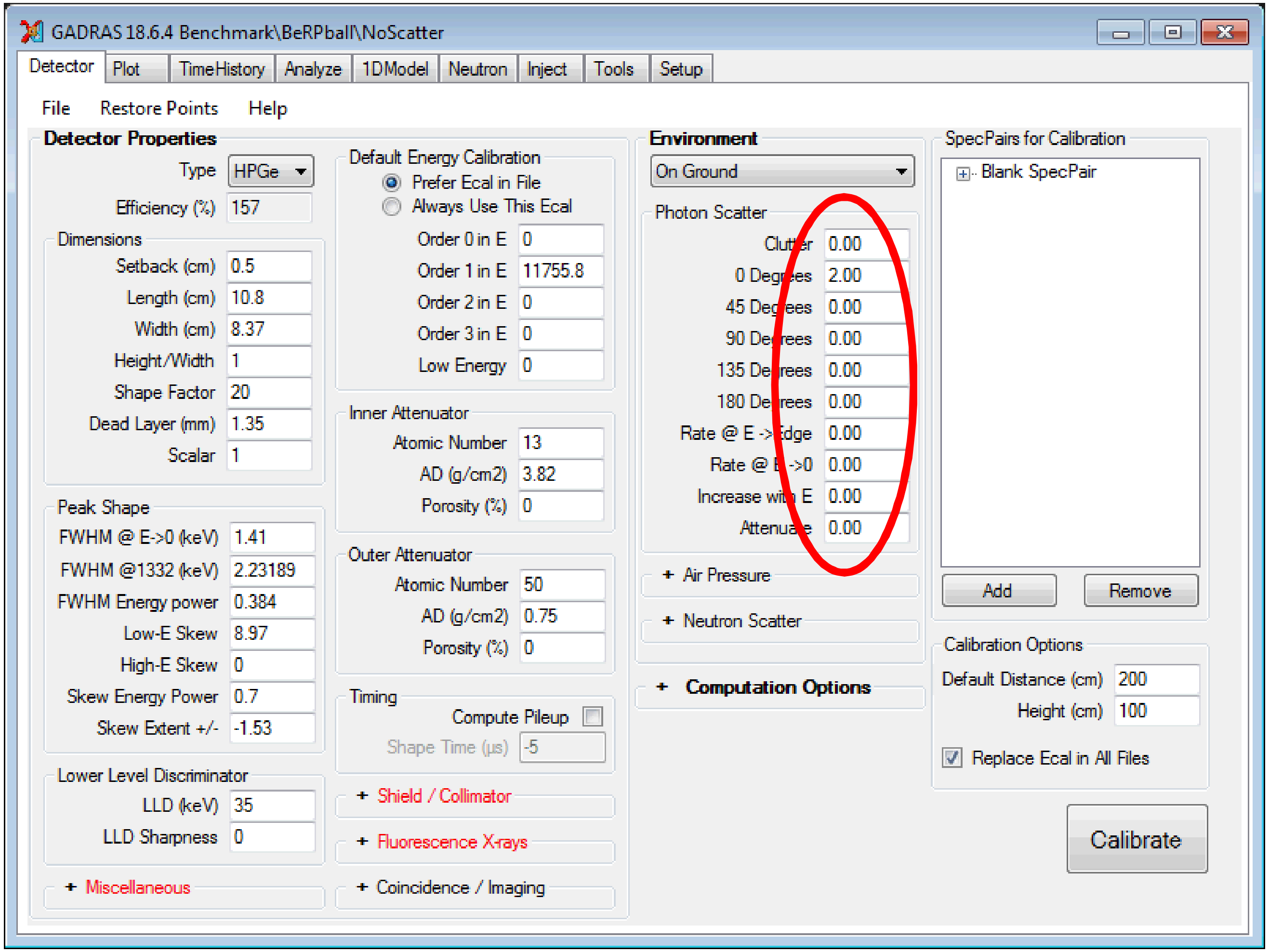
Capabilities

- Current densities can be used for multiple detectors
  - The same MCNP results can be used for different detectors
  - If source-detector distance changes significantly, new MCNP models should be used
  - Detector size in MCNP model doesn’t matter unless source-detector distance is small
- Energy bin structure is not mandated, but results are rebinned according to default structure
  - Recommended photon structure in MCNPbins.dat

GADRAS Scattering

- Scattering traditionally estimated with calibration spectra
- Parameters correspond to radiation scatter angles
- Two types of scattering:
  - Environmental scattering within room
  - Internal scattering in the detector
- Collimators are not yet implemented

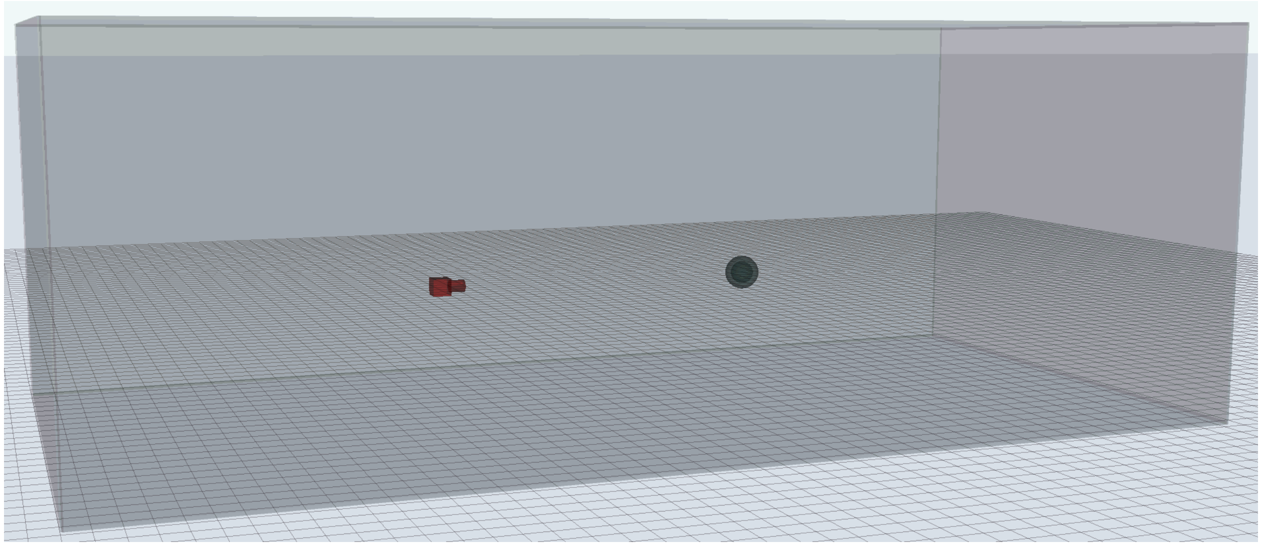
Detector Settings

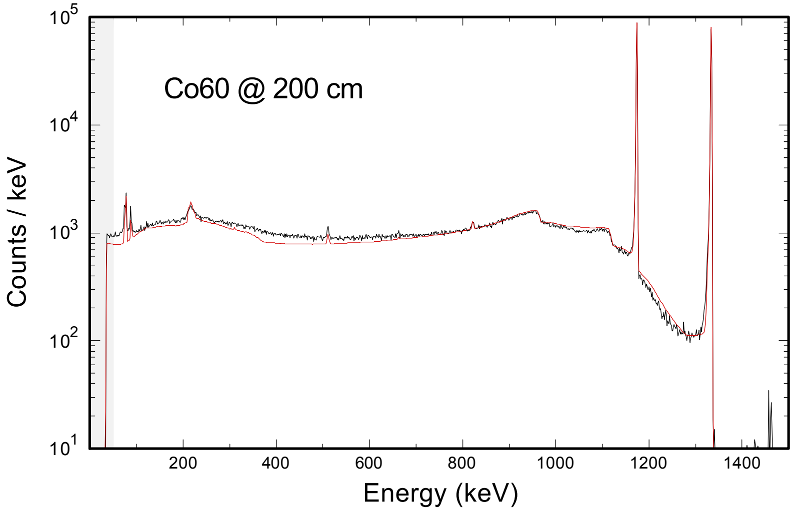


Experimental Verification

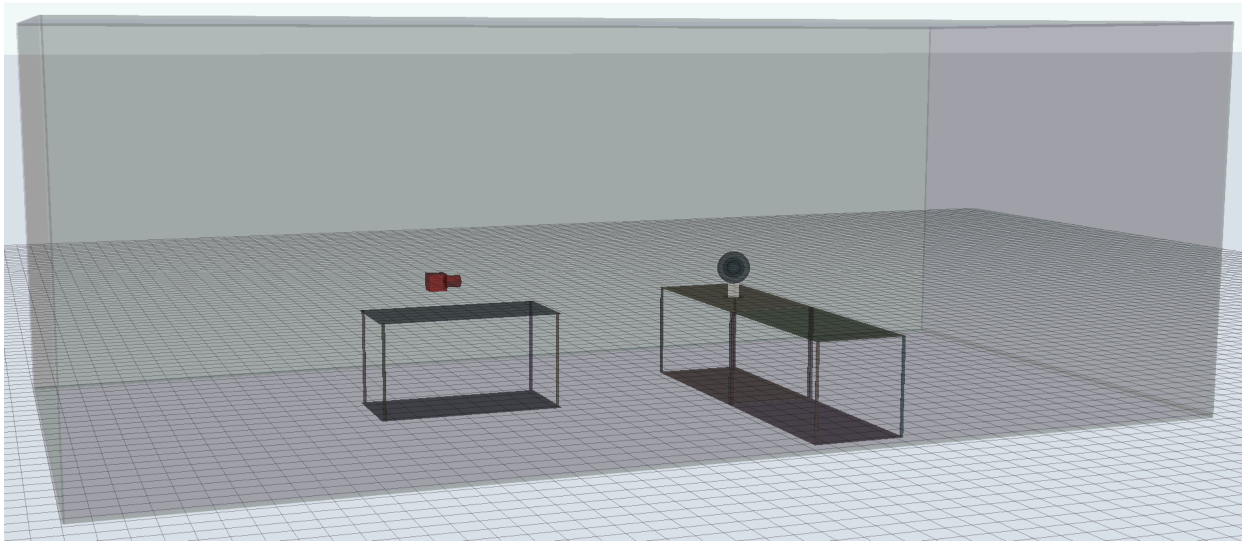
- Data taken at Nevada National Security Site (NNSS)
  - HPGe – 150%
- Basic MCNP model incorporated walls, floor, and ceiling
- Advanced model incorporated steel carts, legs, other detectors, and electronics modules
- 200 cm source-distance, 100 cm above ground
- ^{137}Cs, ^{133}Ba, ^{60}Co, ^{232}U, ^{252}Cf moderated and unmoderated, BeRPBall moderated and unmoderated

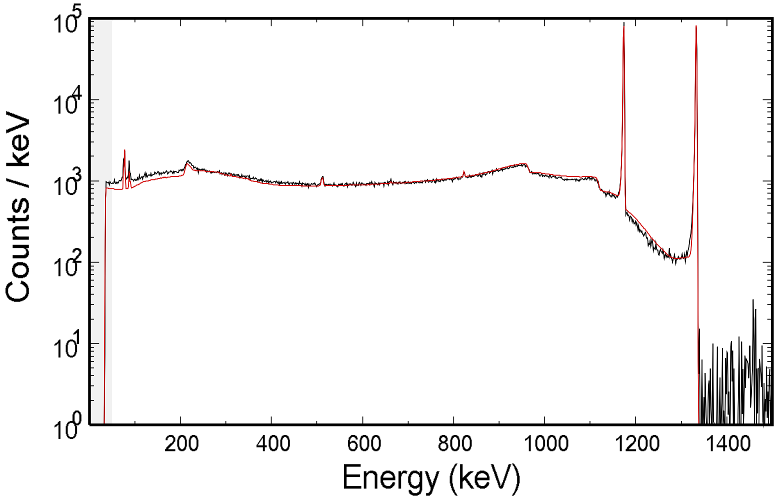
MCNP Model



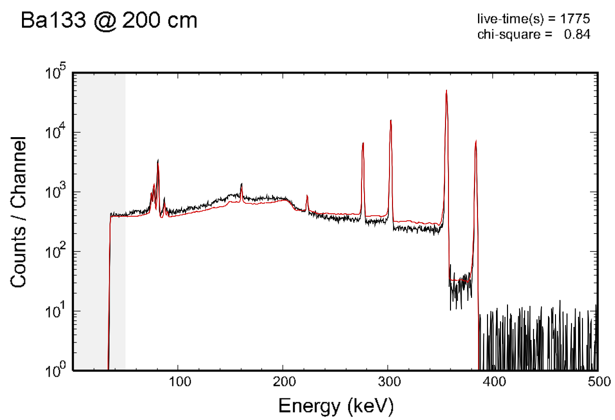

Co60 @ 200 cm
Counts / keV
Energy (keV)
200
400
600
800
1000
1200
1400

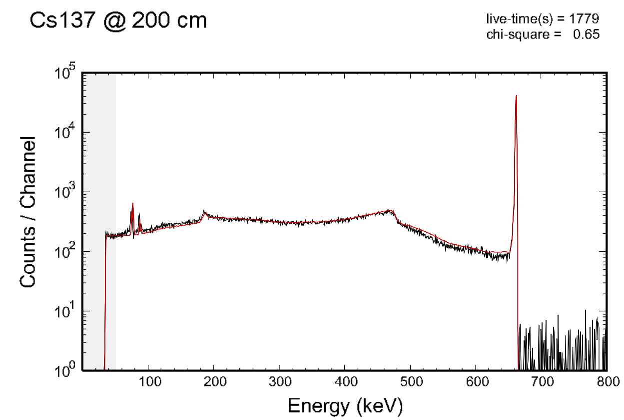
MCNP Model

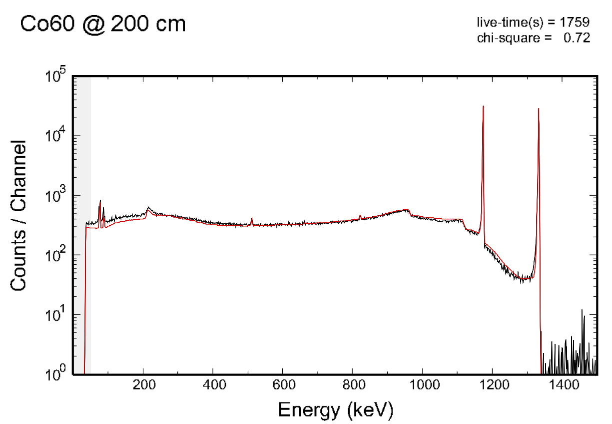


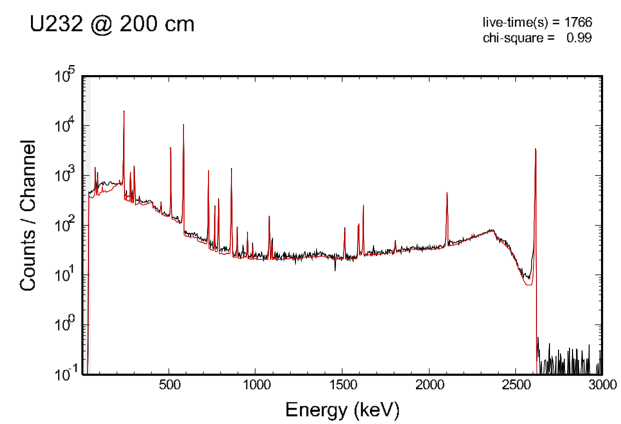

Counts / keV
Energy (keV)
10^5
10^4
10^3
10^2
10^1
10^0
200
400
600
800
1000
1200
1400

Gamma Models

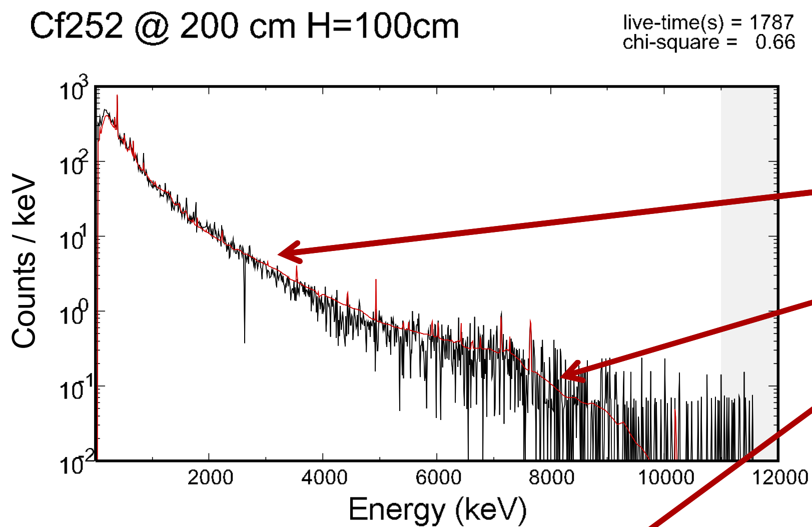






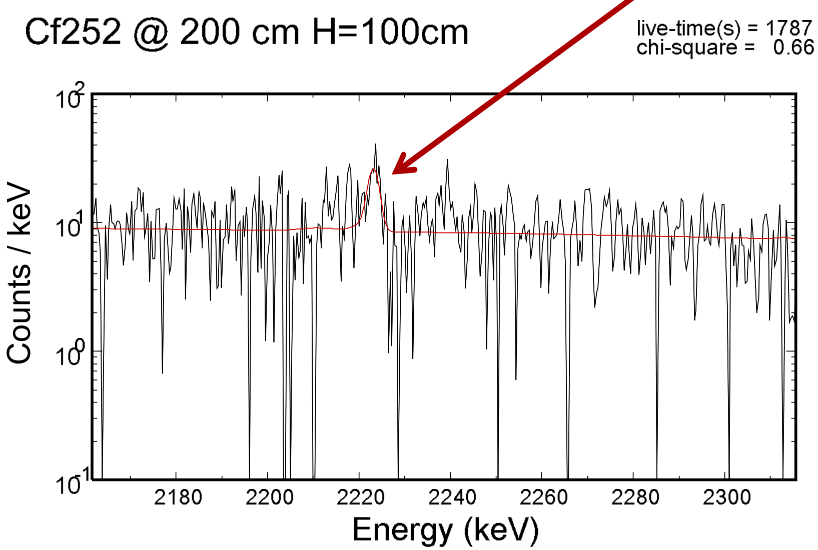


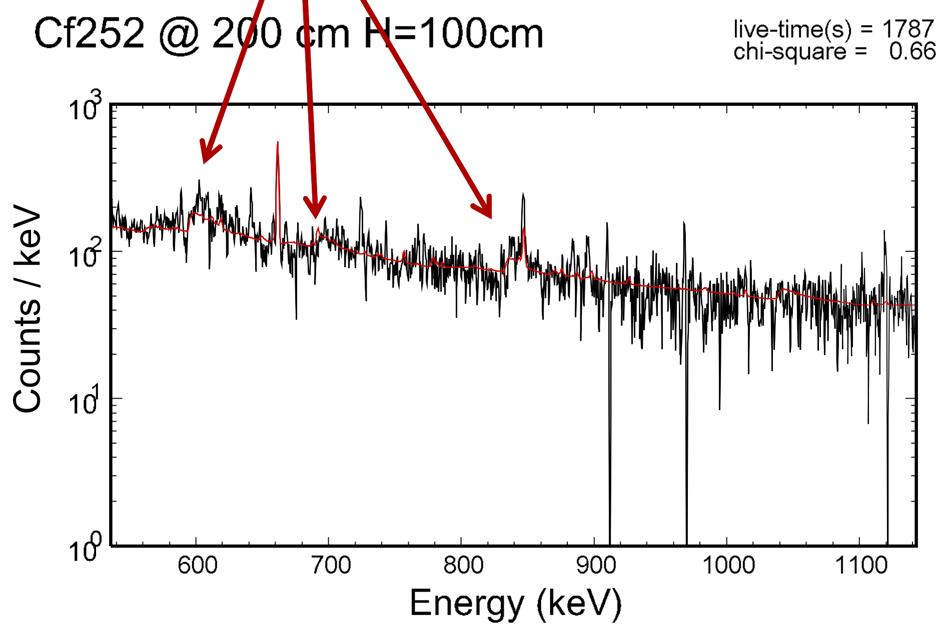
Cf-252



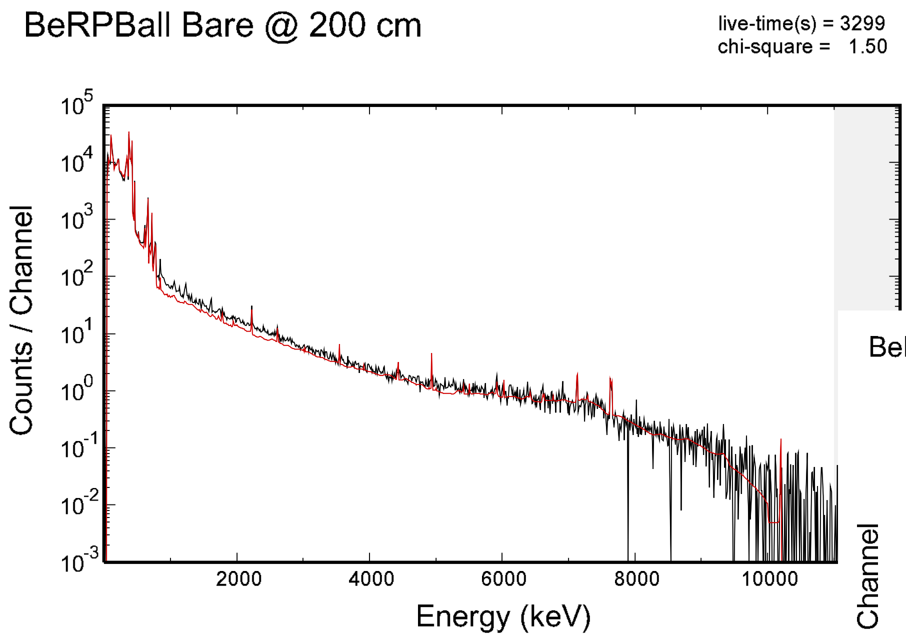
Features replicated:

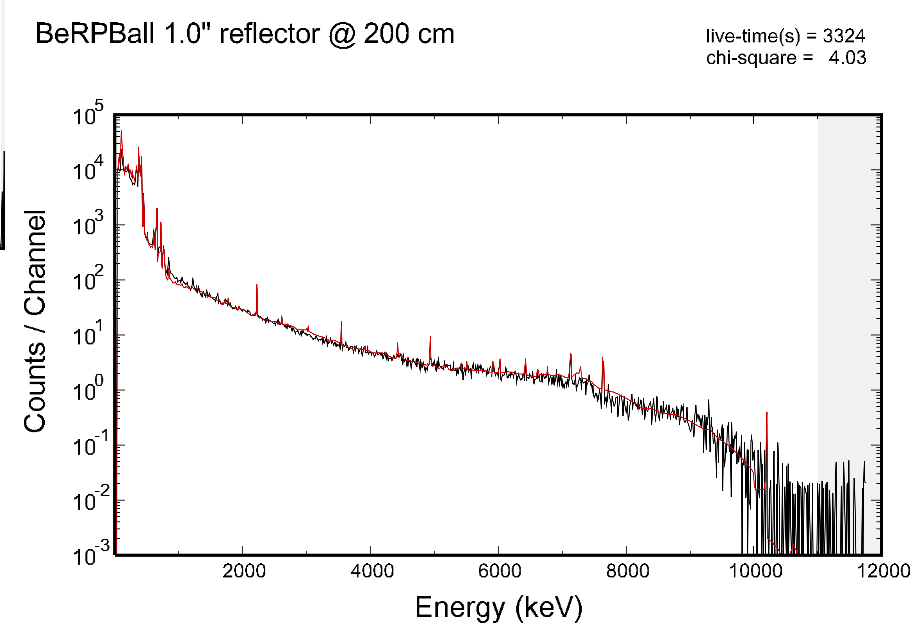
- Continuum from
  - Fission gammas
  - Neutron capture in HPGe
- Neutron capture reactions
- Inelastic scatter





BeRPBall


BeRPBall Bare @ 200 cm
live-time(s) = 3299
chi-square = 1.50
Counts / Channel
Energy (keV)
2000
4000
6000
8000
10000


BeRPBall 1.0" reflector @ 200 cm
live-time(s) = 3324
chi-square = 4.03
Counts / Channel
Energy (keV)
2000
4000
6000
8000
10000
12000

Common Pitfalls

- Not turning off scattering in GADRAS' DRF
- Gamma group structure does not capture discrete lines
  - Lines were left out because thought not important
  - Line groups are too wide
  - Line group energy bin doesn't match up with actual source energy
- Source term incorrect
  - Some users use GADRAS' 1DModel to generate MCNP input