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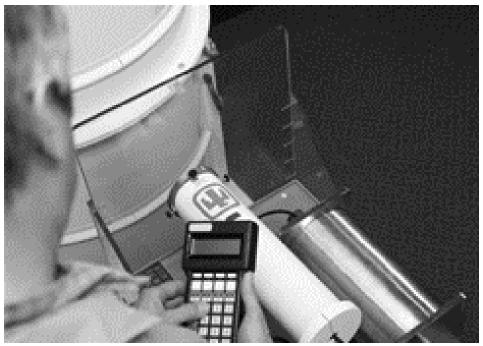

Rapid 3-D Gamma Response Calculations

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September 10, 2014

U.S. Department of Energy
NNSA National Nuclear Security Administration

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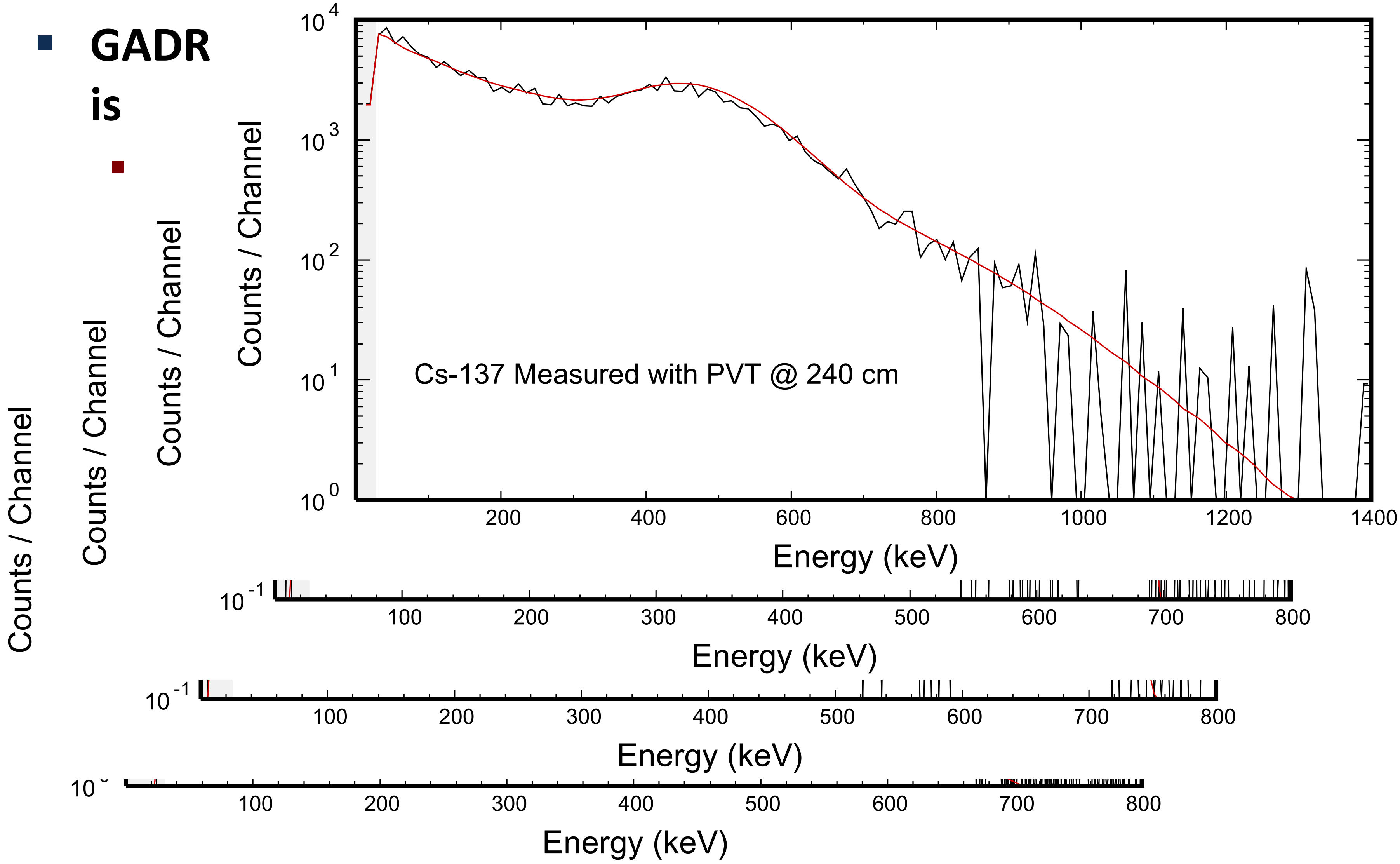
Detector Response Function (DRF)

- **Interactions are represented by analytic expressions**
  - Nested loops describe sequential events
- **Approximations are applied to enable rapid solution**
  - Probabilities are represented rather than individual interactions
- **Databases interpolated for some phenomena**
  - Database for scattered gamma rays and neutrons modeled with MCNP
- **Continuous functions applied to all phenomena**
  - Parameters can be evaluated by standard regression methods
- **Empirical parameters describe some phenomena**
  - Resolution, energy calibration, non-linear response, local scatter
- **DRF and radiation transport calculations tightly coupled**
  - Ray-trace and discrete ordinates calculations are combined by the DRF to compute spectra for macroscopic sources

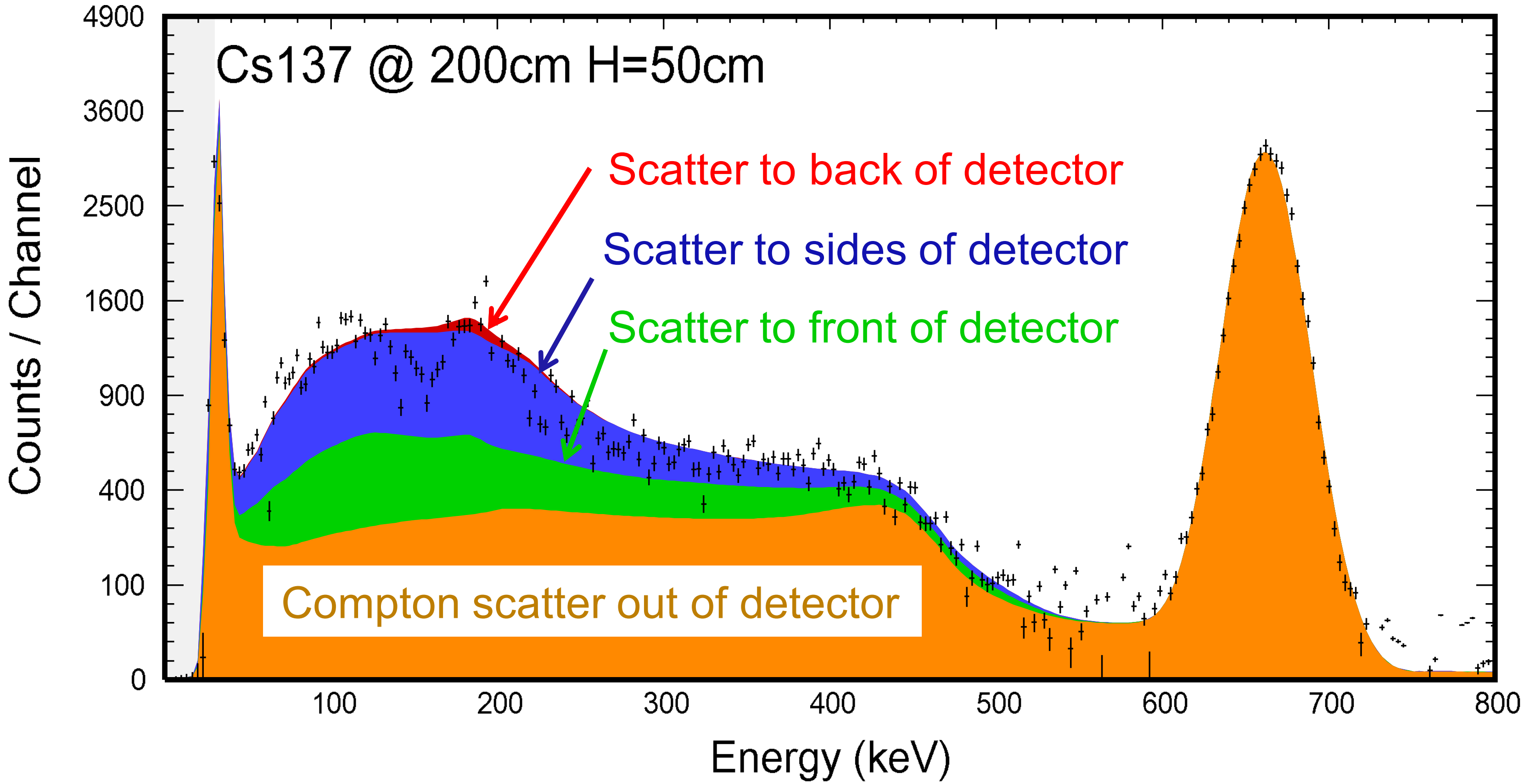
DRF Examples

- **GADR is**
  -



Multi-Faceted Scatter Database

- Scatter database gives flux on front, sides and back of detector as function of distance and height
- This is particularly important for 3-D response calculations



Traditional 3D Calculations

- **Monte Carlo methods**
  - Start particles with random trajectories and track through series of scatter events until particle escapes or is absorbed
  - Most of the tracks correspond to scatter events
  - Few particles reach detector volume
- **Deterministic methods**
  - Solve discretized radiative transfer equation for all space intervals
  - The number of mesh intervals is large for most 3-D models
- **Both methods require hours to days of CPU time**
- **Current on detector may not be accurate without complete description of environment**
- **Synthesis of the detector response may not be accurate**
  - Particle current can be interfaced with external DRF

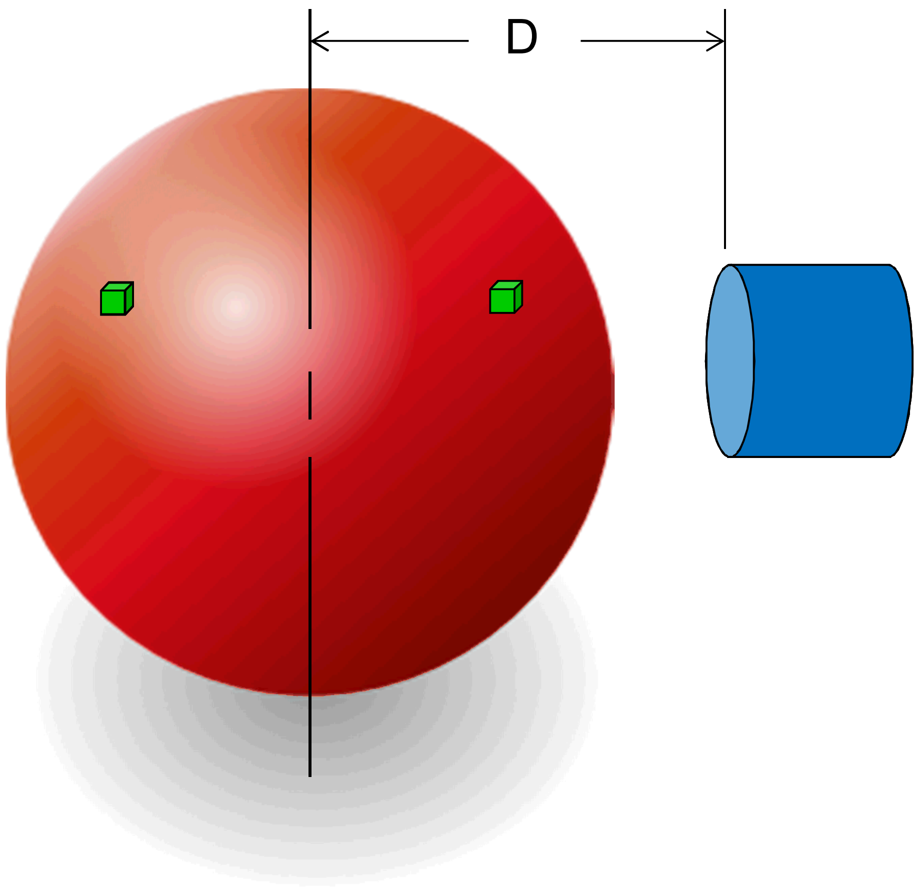
GADRAS/RayTrace3D Concept

- **GADRAS in 1-D (used and improved since late 1980s):**
  - Models (1DM files) are created to represent nested shells
  - 1-D neutron radiation transport calculations are performed with LANL Partisn and SOURCES 4C codes and GADRAS/RayTrace
    - 1 to a 3 seconds of computational time per source object
    - Discrete ordinates calculations and ray-trace are combined within DRF
- **GADRAS/RayTrace3D (under development since 2012):**
  - Volumetric source terms for 1-D models saved for 3-D calculations
    - This files enable calculations for cylinders and slabs (3-D for one object)
  - 3-D scenarios (3DM files) are created as collections of 1DM files
  - Positions and rotations are specified relative to detector
- **Estimate neutron induced source terms between models**
  - Crude energy group structure applied for non-fission sources such as steel tables and containers (100 – 200 ms per object)

RayTrace3D Concept (continued)

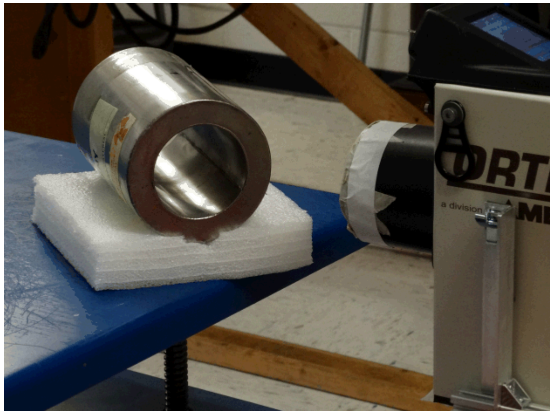
- **Only rays from source object to detector are computed**
  - No need to compute majority of emissions, which are indirect
- **Each ray has associated intervening materials described by leakage-weighted atomic number and areal density {AN, AD}**
  - Radiation continuum is derived from {AN,AD}
  - Every ray “scores” with associated current, AN, and AD
- **Scatter from environment and detector housing are characterized as part of the DRF**
  - Each spatial point and gamma ray could have a different DRF if location is enclosed or obstructed by other objects
  - Rather than computing tallies on the detector surfaces, the detector response is computed directly
  - Scattered gamma rays from object produces additional scattering by interaction with environment

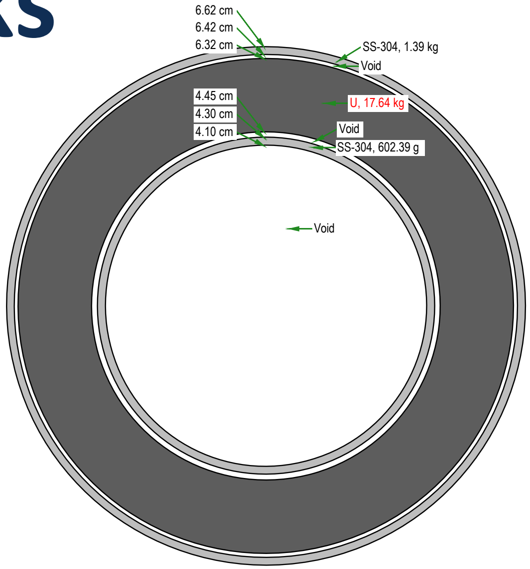
Even Spheres are 3-D if Close

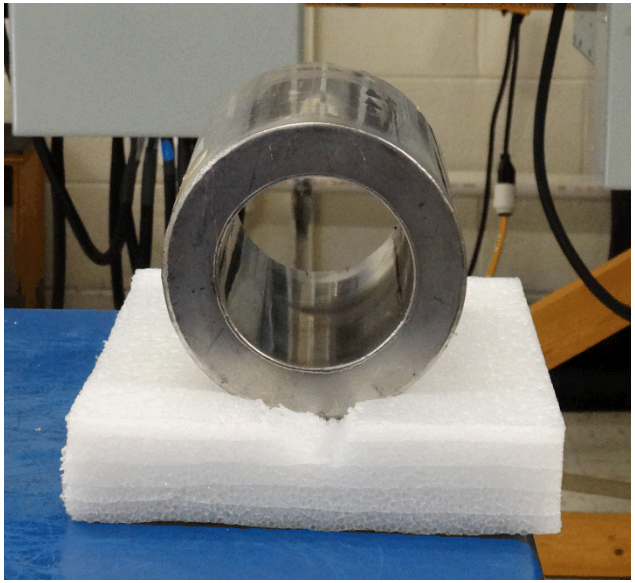


- **The solid angle varies with location of volume element**
  - Ω independent of location for point-source approximation
- **Radiation can strike the sides of the detector**
  - Direct radiation only strikes front surface if far away
- **Slant angles differ when the detector is near the source**

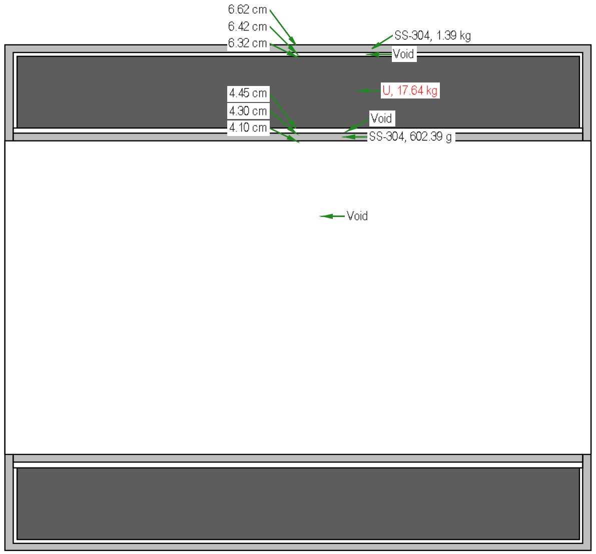
DU Cylinder Benchmarks







18 kg DU Annulus (ORNL)



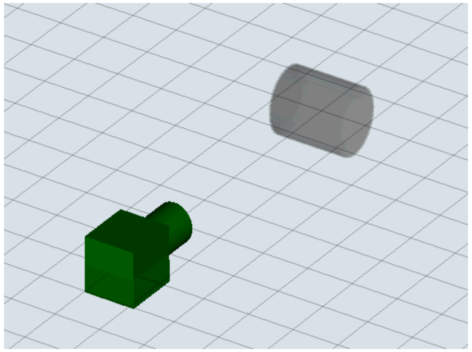
GADRAS DuCasting Model

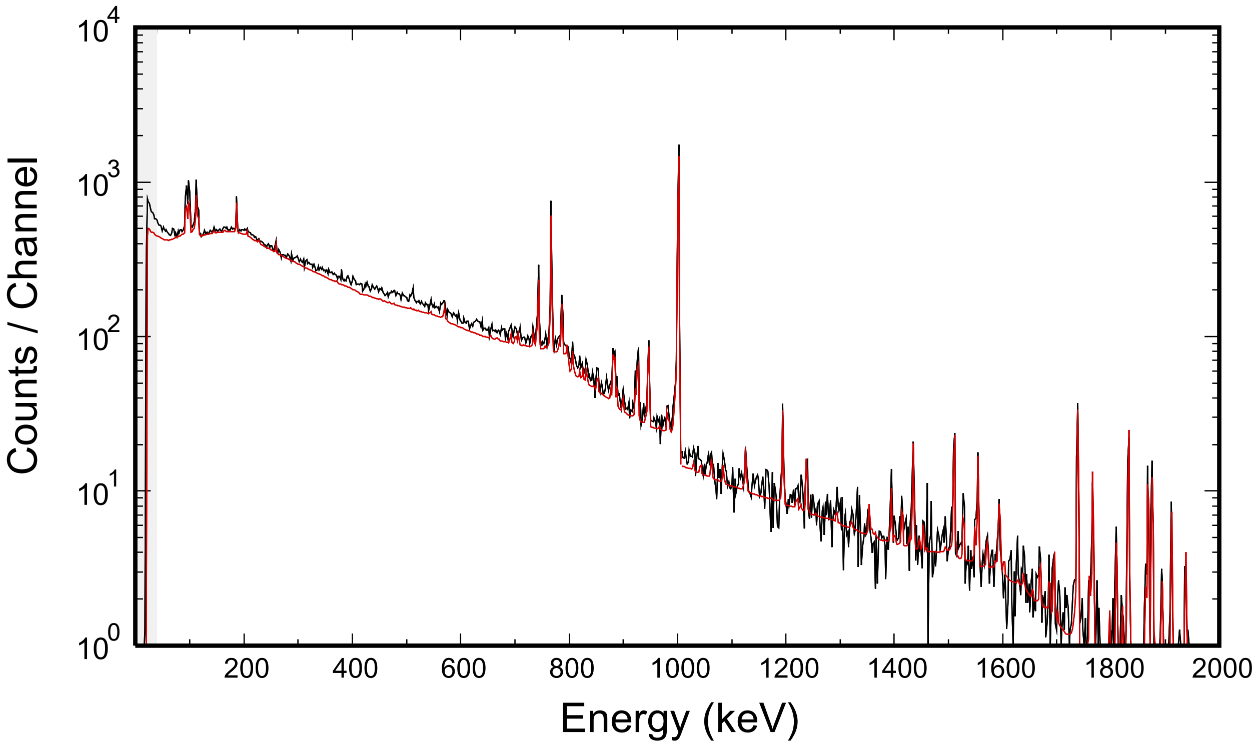
Spectra for DU Cylinder

Detective-DX100 at:

Distance: 93 cm
Height: 50 cm
Cylinder angle: 0°
Source line: DuCasting,1C

Computation Time: ~ 2 seconds





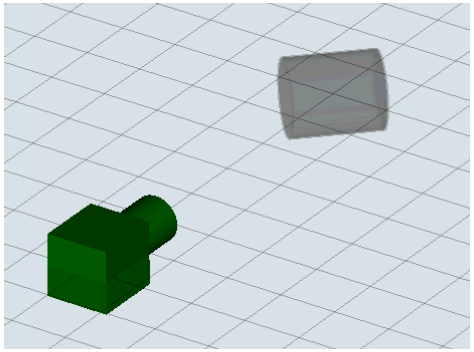
Spectra for DU Cylinder

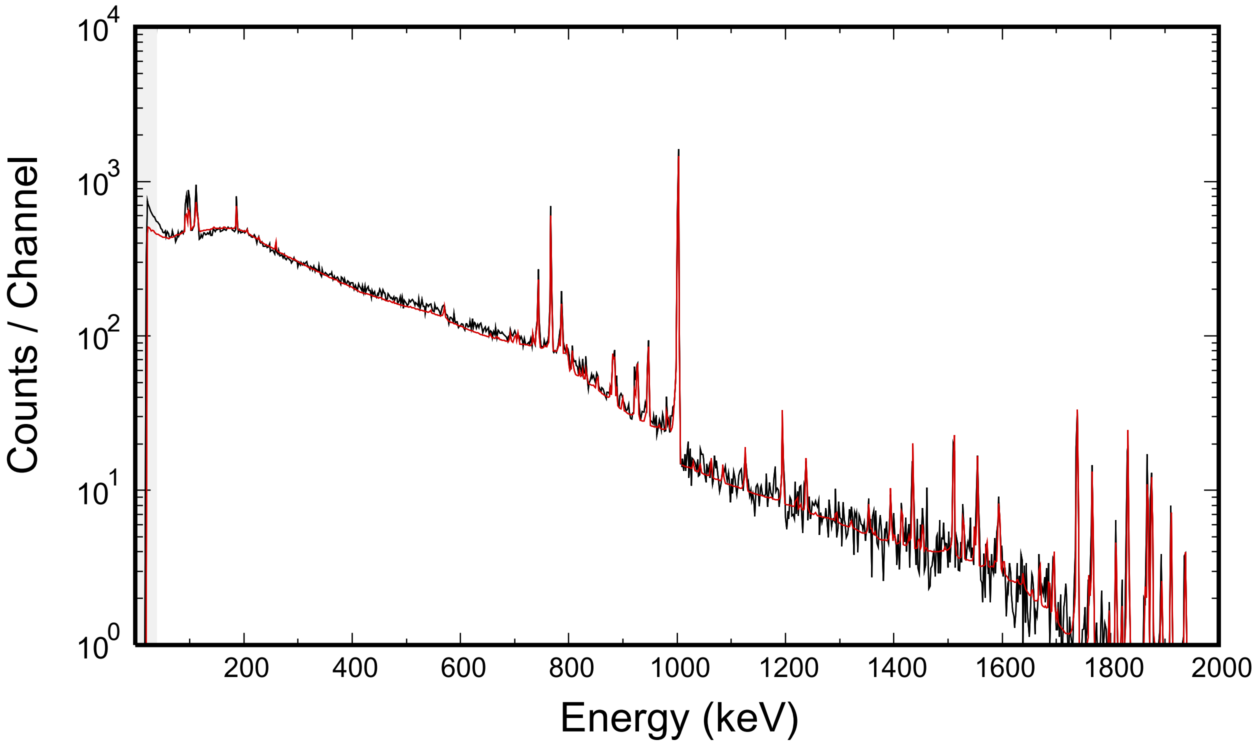
Detective-DX100 at:

Computation Time: ~ 2 seconds

Distance:	93 cm
Height:	50 cm
Cylinder angle:	45°
Source line:	DuCasting,1C{,,,,,,45}

Rotation angle





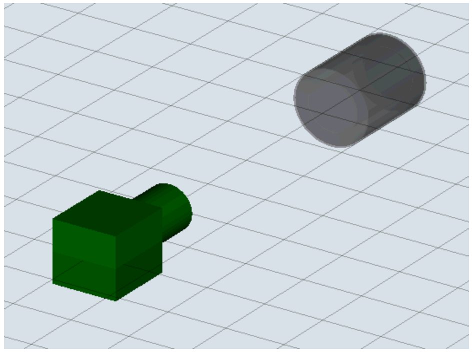
Spectra for DU Cylinder

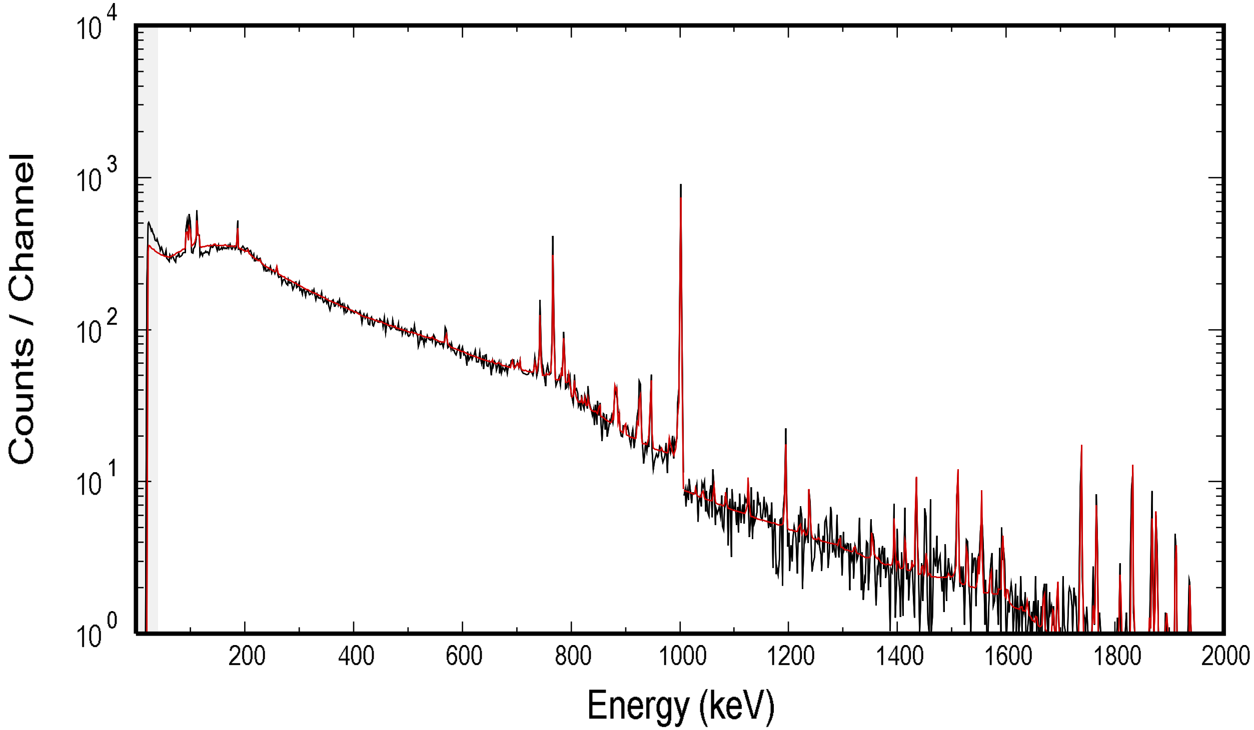
Detective-DX100 at:

Distance: 93 cm
Height: 50 cm
Cylinder angle: 90°
Source line: DuCasting,1C{,,,,,,90}

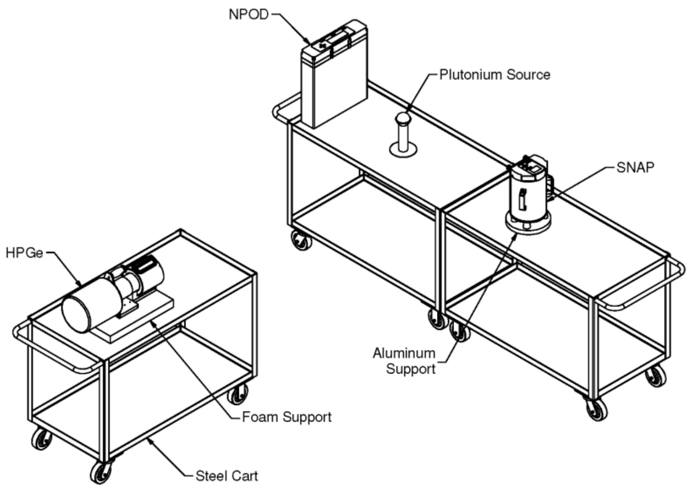
Rotation angle

Computation Time: ~ 2 seconds

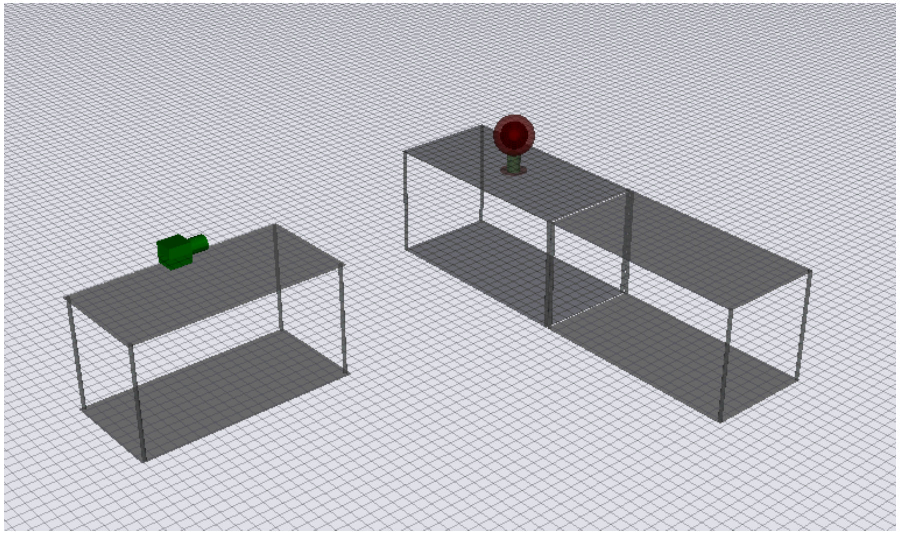




BeRP Ball Experiment Model



Drawing of Experiment



GADRAS 3DM Model Visualization

BeRP Ball in 6 in. PE

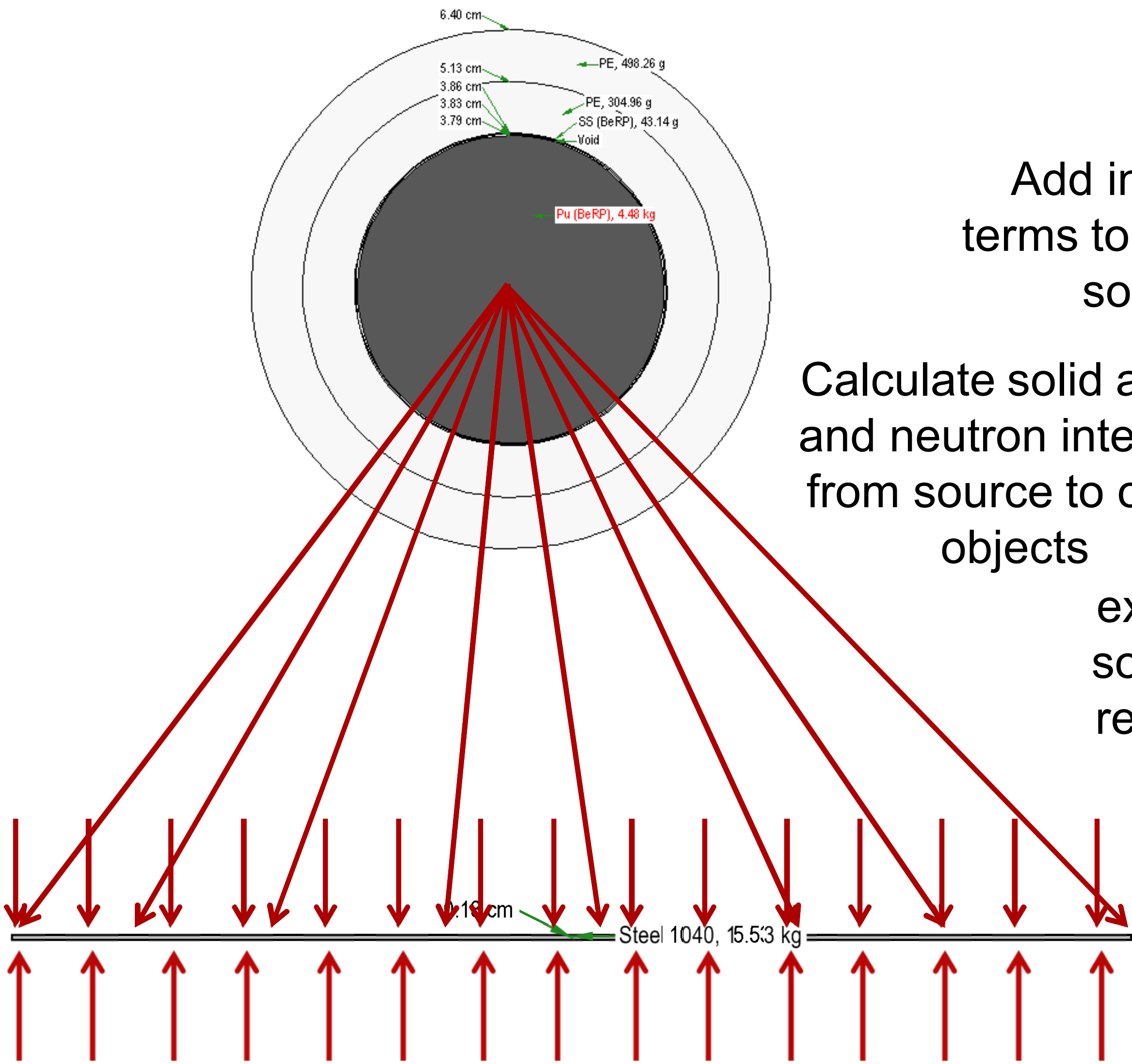
3DM File

```
BeRPball-3inPE
0 0 0 0 0 0
al-stand-top-3in
0 -16 0 0 0 90
al-stand-bottom-3in
0 -21 0 0 0 90
steelcart
0 -21 0 90 90 0 1
...
```

Five models translated and rotated into position

Neutron interactions between models

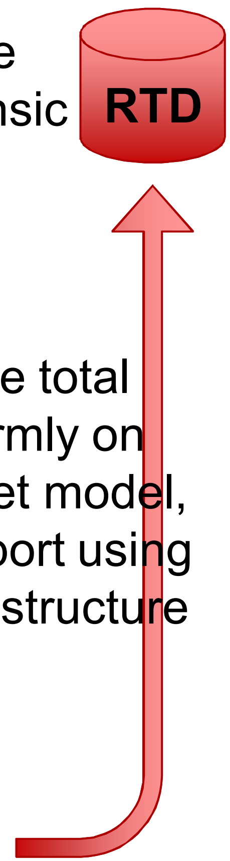
BeRP Ball / PE



Steel Table

Calculate solid angle and neutron intensity from source to other objects

Impose same total current uniformly on exterior of target model, solve 1D transport using reduced group structure



Add induced source terms to existing intrinsic source terms

RayTrace3D

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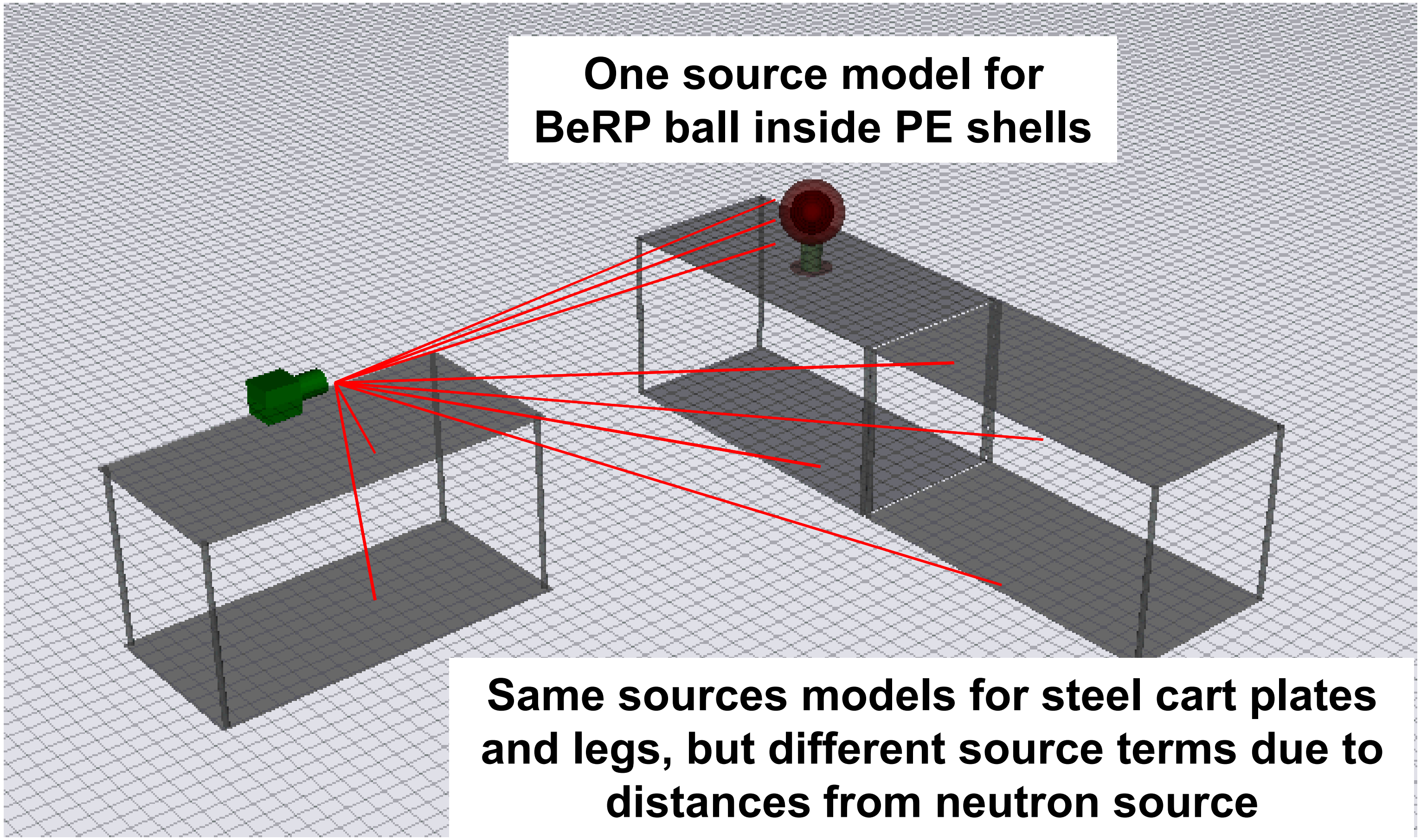
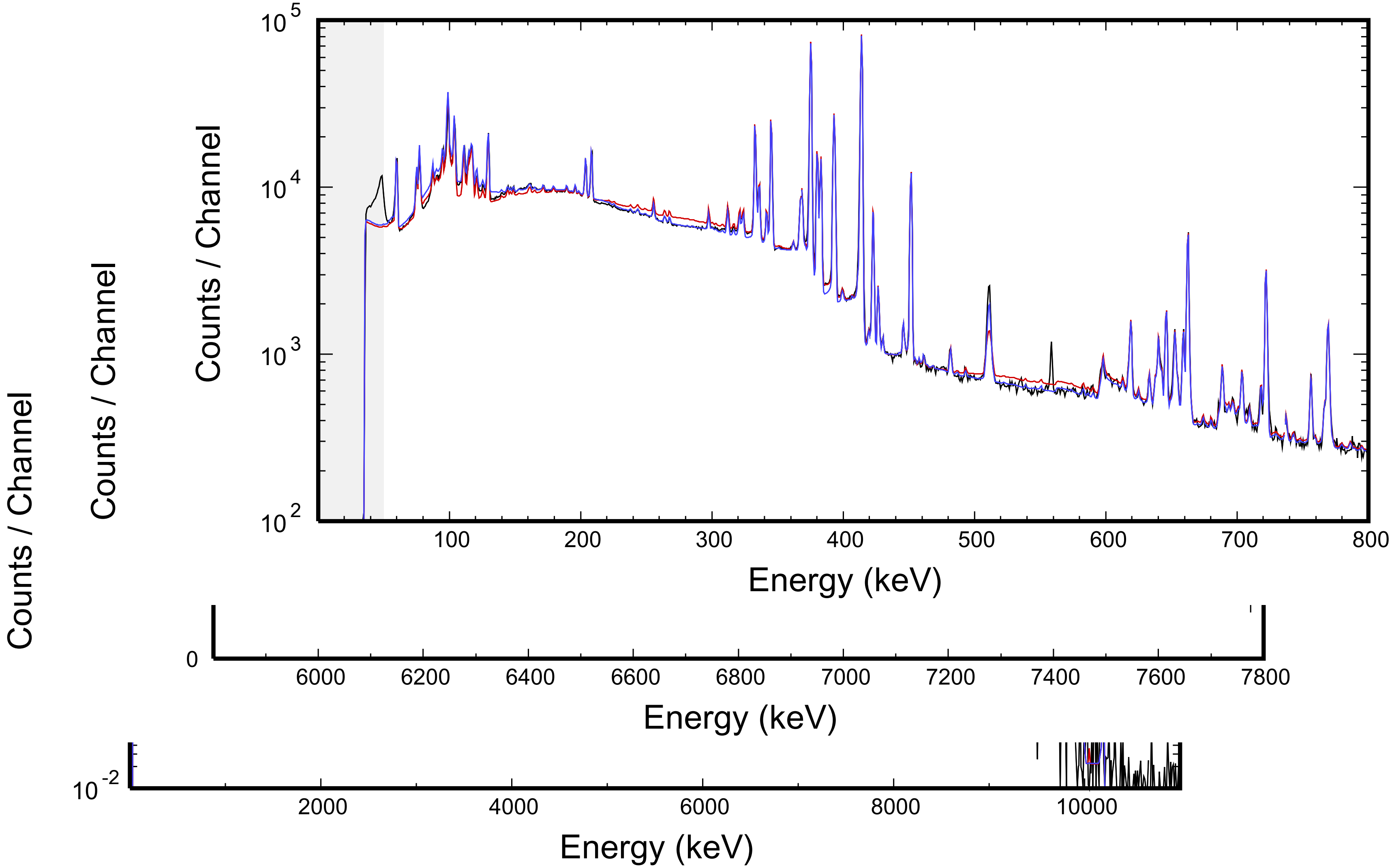


Rays are traced from source volumes through 3D geometry to detector surfaces, tracking attenuating materials

Spectral distribution of count rates computed for discrete and continuous emissions associated with each ray

1-D vs. 3-D for BeRP Ball in 3″ PE



Continuum in Detector Response

- Intrinsically continuum (e.g. bremsstrahlung, fission gammas)
  - Ray tracing yields uncollided contribution from each group
- Scattering within source object
  - Interpolated from scatter library based on {AN,AD}
  - Scattered radiation from source produces additional scatter by interaction with environment and detector housing
- Environmental scattering (from walls, floor, etc.)*
  - Estimated using Green's Functions on scattering surfaces
- Scattering in detector housing*
  - Empirically derived from fitting scatter parameters to calibration source measurements
- Partial energy deposition in active detection volume
  - Derived from first principles

** These components are not entirely segregated*

Collimated Detectors

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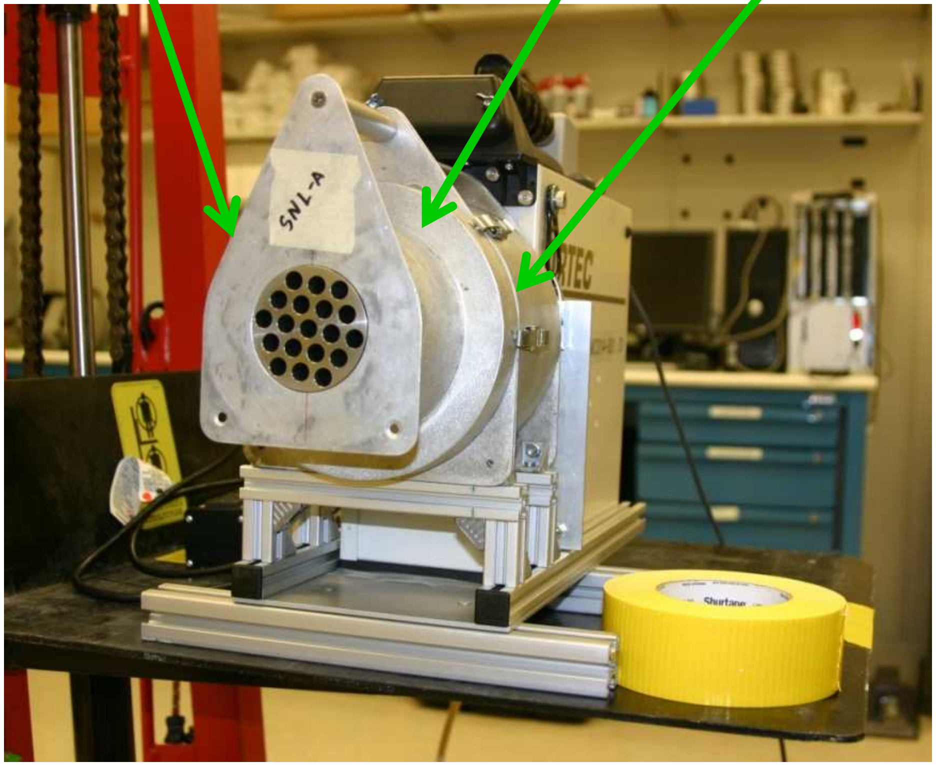
- Previous detector response function assumed sources on detector axis
- Current response function allows specification of source position in 3-D relative to detector face
- Tightly collimated detectors, such as configuration shown here, are less accurate than desirable
- Collimators enable identification of weak sources in presence of large-area radiation background

Detective DX100 (35% HPGe) with shield and collimator

Narrow collimator uses tungsten insert

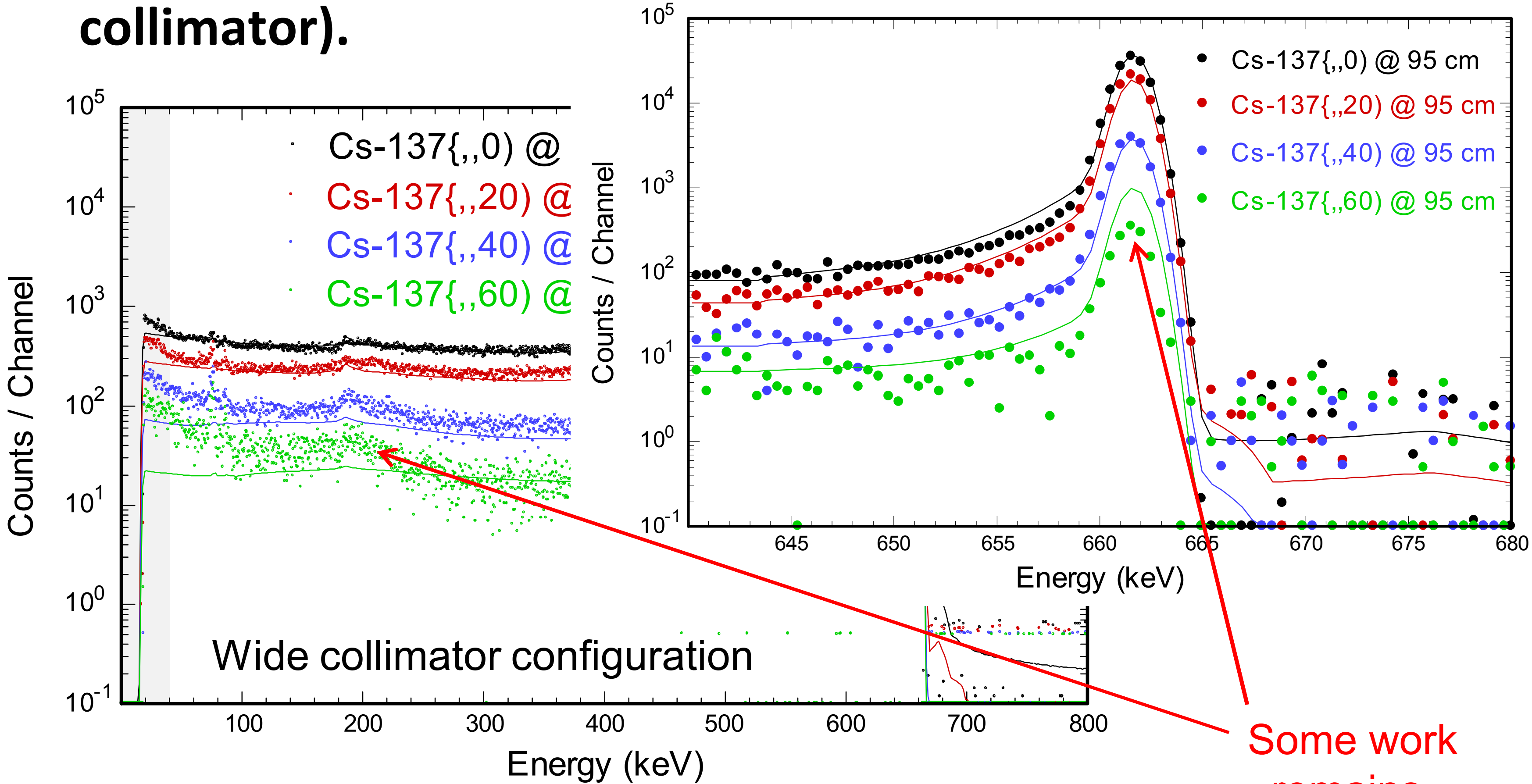
Wide collimator uses only bismuth cylinder

Bismuth shield



Collimated Response Function

- **Collimated detectors are modeled as detectors with extra-long side shields (>100% of sides covered represents collimator).**



Some work remains, but close

Summary

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- **GADRAS/RayTrace3D approach executes very quickly relative to other 3-D methods**
- **Computational accuracy is good for limited number of available benchmark-quality data sets**
  - Numerous approximations that must be validated
  - Minor “tweaking” required for scattered radiation
- **Graphic user interface must be simplified and more comprehensive**
  - Simple <u>AND</u> comprehensive are challenging objectives
  - Generation of environmental description can be obscure
    - Environment currently defined by text file
    - Graphic depiction of detector respect to floor and walls in development
- **GADRAS has export control restrictions**
  - Less restrictive version, to be released soon, will not have RayTrace3D