SNAP-3 Response Function and Its Application

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Objectives

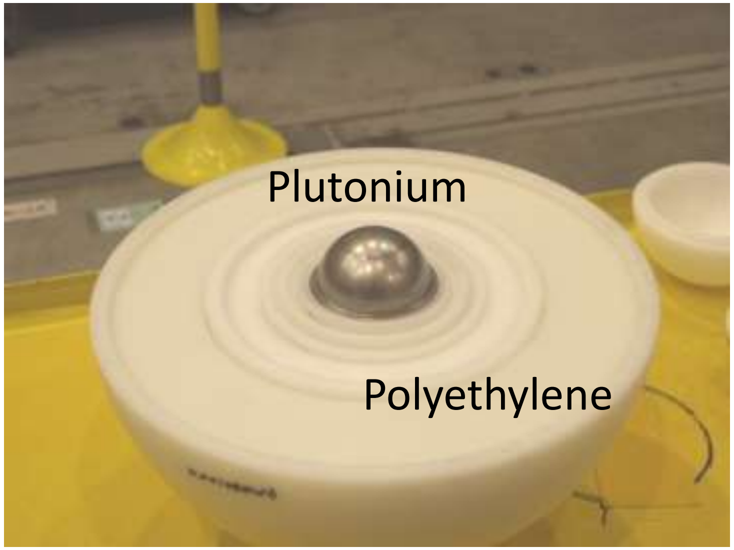
- Present a simple procedure for computing neutron detector response functions
  - Includes neutron interactions with surrounding environment in response function
  - Enables (within limits) complex problems to be approximated using simple transport models

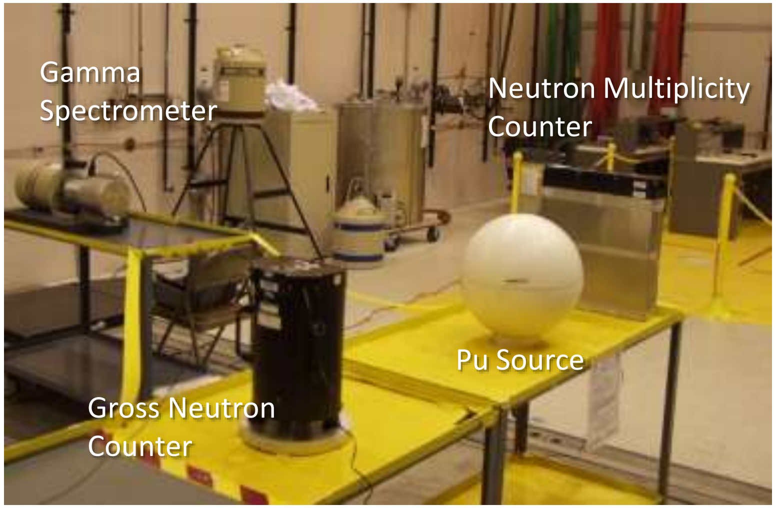
- Test the detector response functions using a set of well-documented experiments (SNAP measurements of BeRP ball)

- Apply the detector response functions to solving an inverse transport problem

Experiment setup

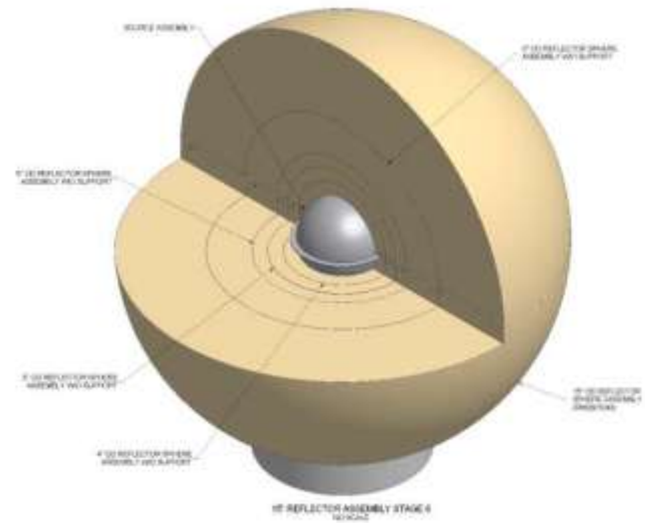
- Source
  - Weapons-grade plutonium metal
  - Reflected by polyethylene
- Detectors
  - Neutron multiplicity counter
  - Gross neutron counter
  - High-resolution gamma spectrometer

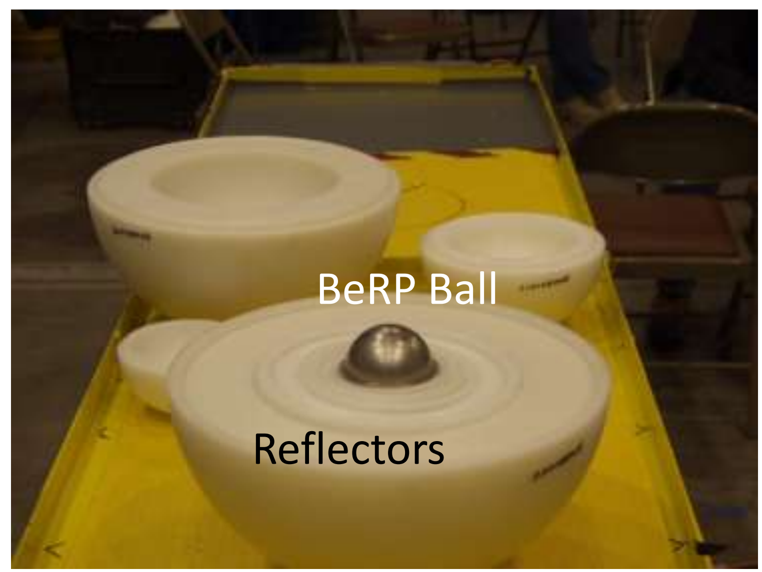




Plutonium source

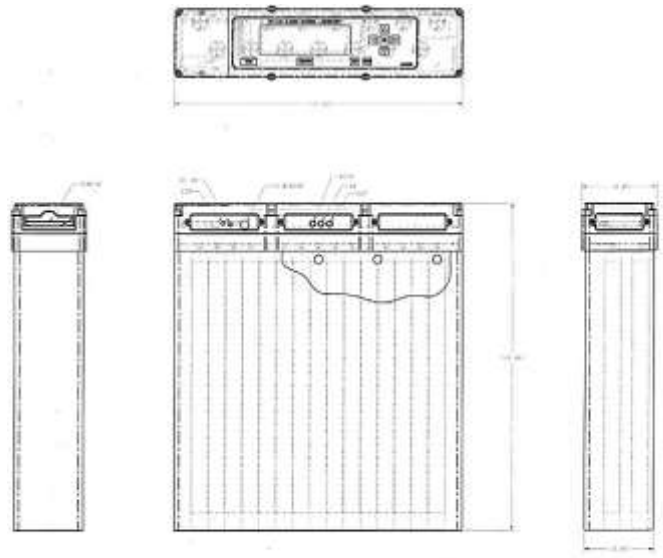
- BeRP ball
  - 4.5 kg α-phase plutonium metal
  - 94% Pu-239 / 6% Pu-240
- Polyethylene reflectors
  - High-density polyethylene
  - Nesting spherical shells with total thickness 1.3, 2.5, 3.8, 7.6, and 15.2 cm

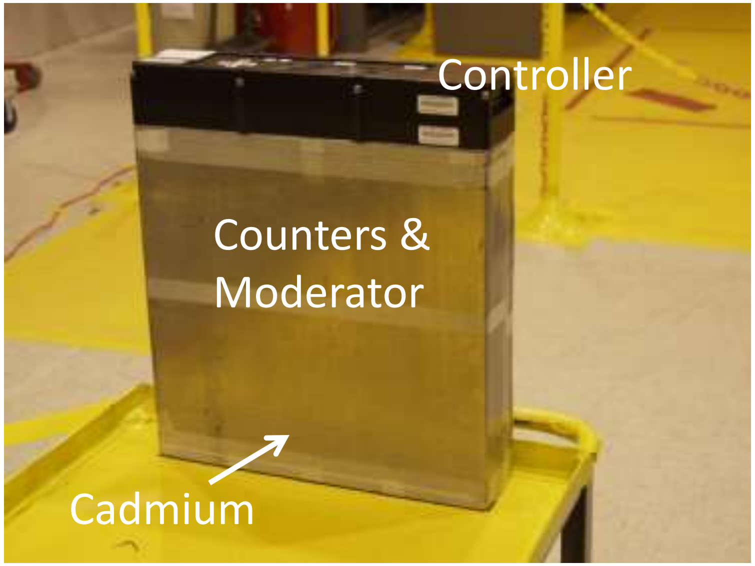




Neutron multiplicity counter (nPod)

- nPod multiplicity counter designed and built by LANL
- 0.5 m from BeRP ball
- The nPod uses fifteen 15”-long × 1”-diameter 10-atm He-3 proportional counters in two rows
- The counters are embedded in a polyethylene moderator block wrapped in cadmium
  - The moderator gives the nPod a fairly flat neutron response
  - The cadmium makes the nPod relatively insensitive to reflected neutrons



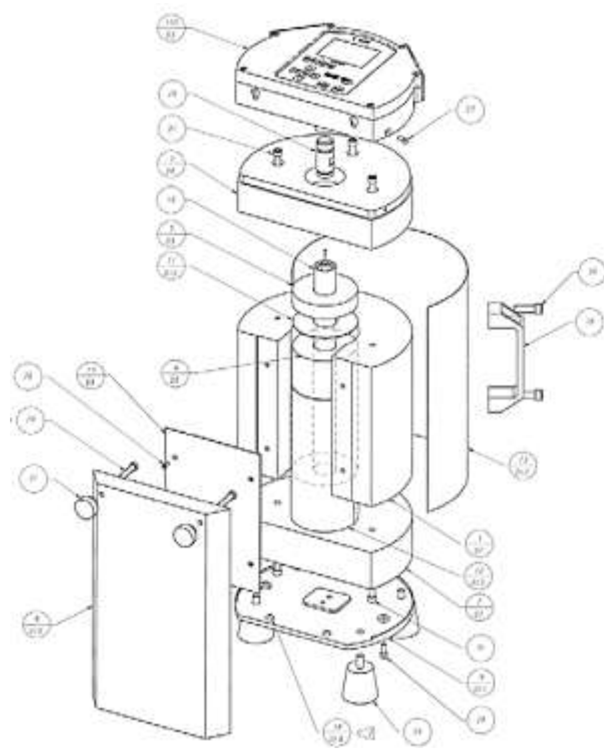


Gross neutron counter (SNAP)

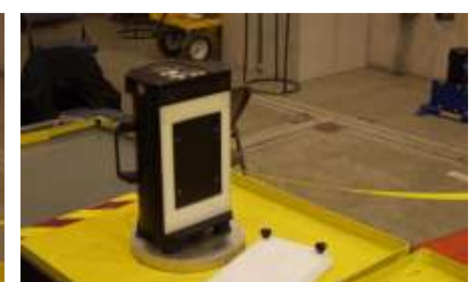
- SNAP counter designed and built by LANL
- 1 m from BeRP ball

- The SNAP uses one 4”-long × 1”-diameter 10-atm He-3 proportional counter
  - The counter is embedded in a layered polyethylene / cadmium / polyethylene moderator
  - The moderator gives the SNAP a flat response vs. neutron energy

- The front polyethylene cover can be removed to gauge the “hardness” of the neutron spectrum



Cover On

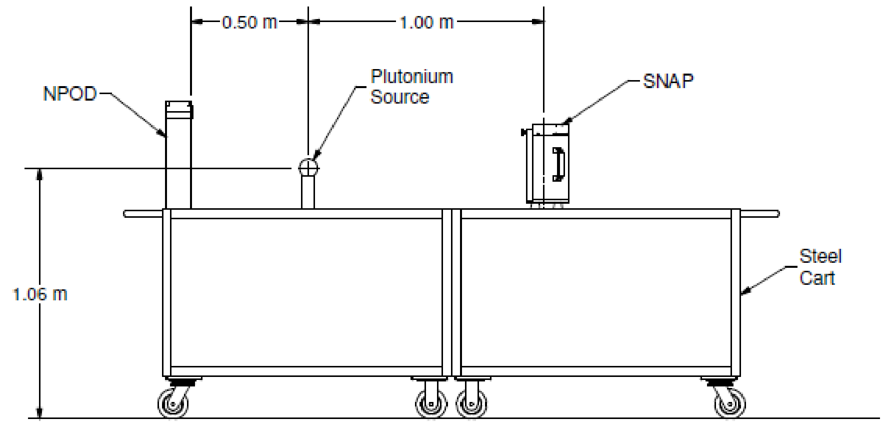


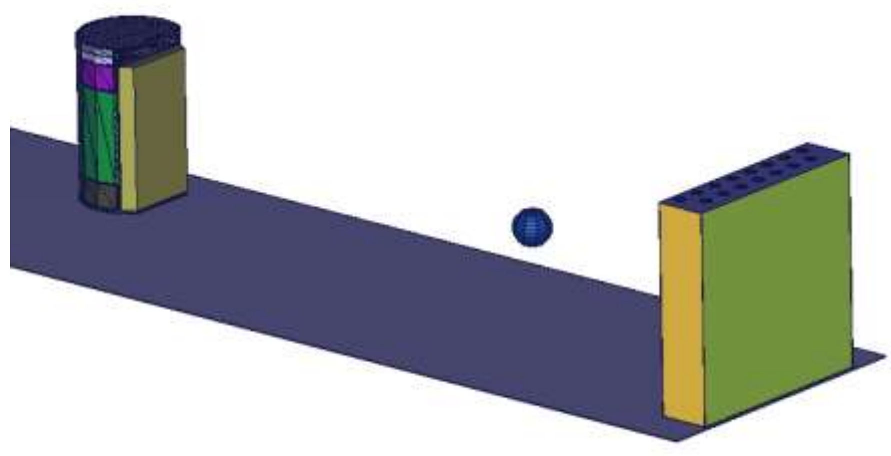
Cover Off

Response function calculations

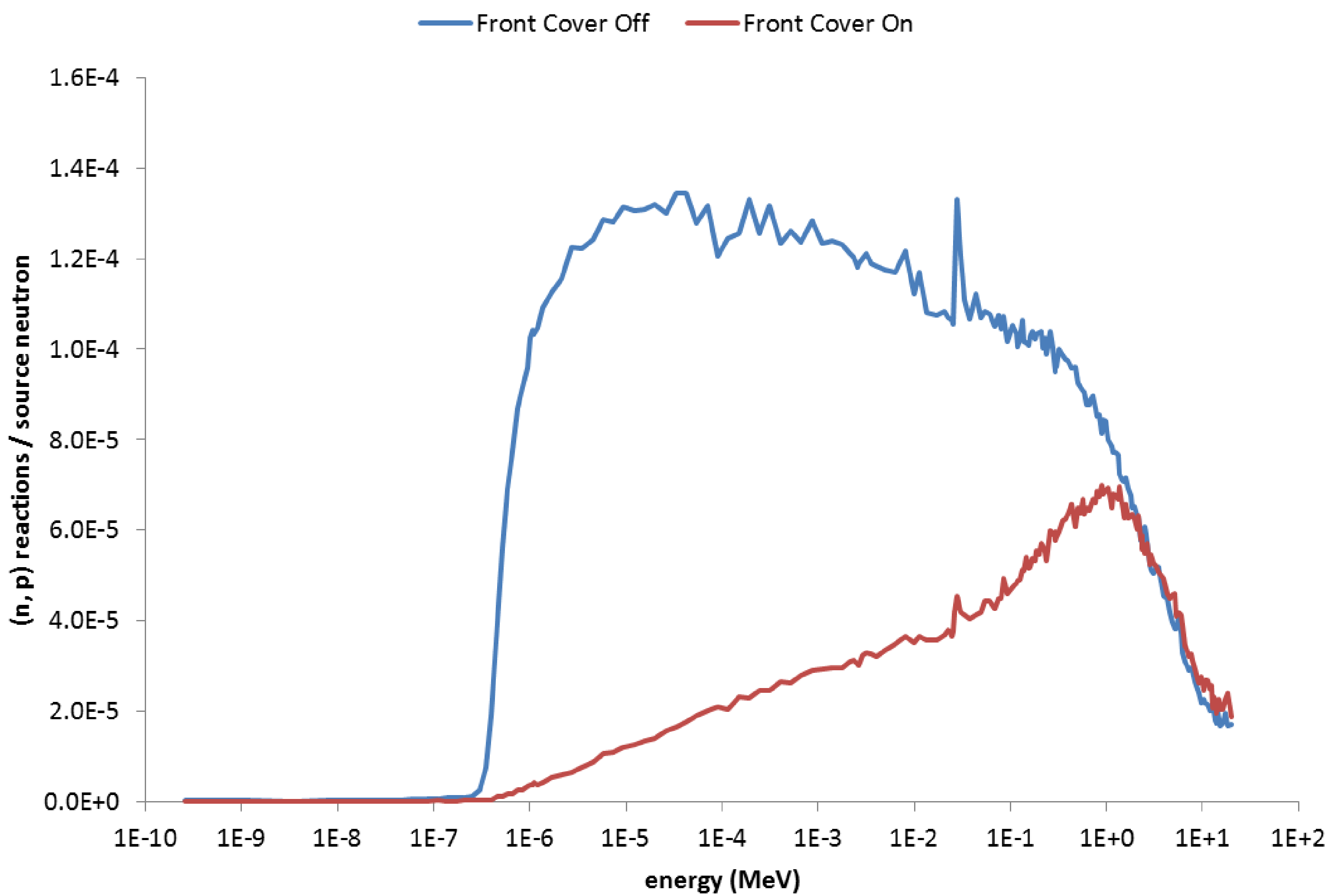
- Response functions were calculated using MCNP5
  - Point source with "flat" neutron spectrum
  - Tallied (n, p) reaction rate in SNAP He-3 counter vs. source energy bin (F4 tally)
  - Reaction rate divided source leakage current (F1 tally)

$$\epsilon(E_g) = \frac{V \int_{E_g}^{E_{g+1}} dE' \Sigma_{(n,p)}^{He3}(E')\phi(E')}{A \int_{E_g}^{E_{g+1}} dE' J(E')}$$



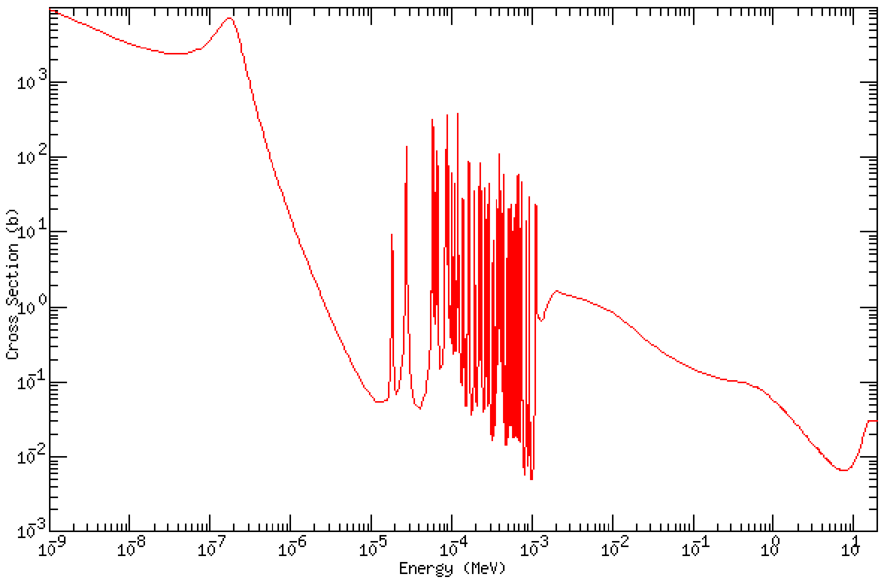


Computed response functions

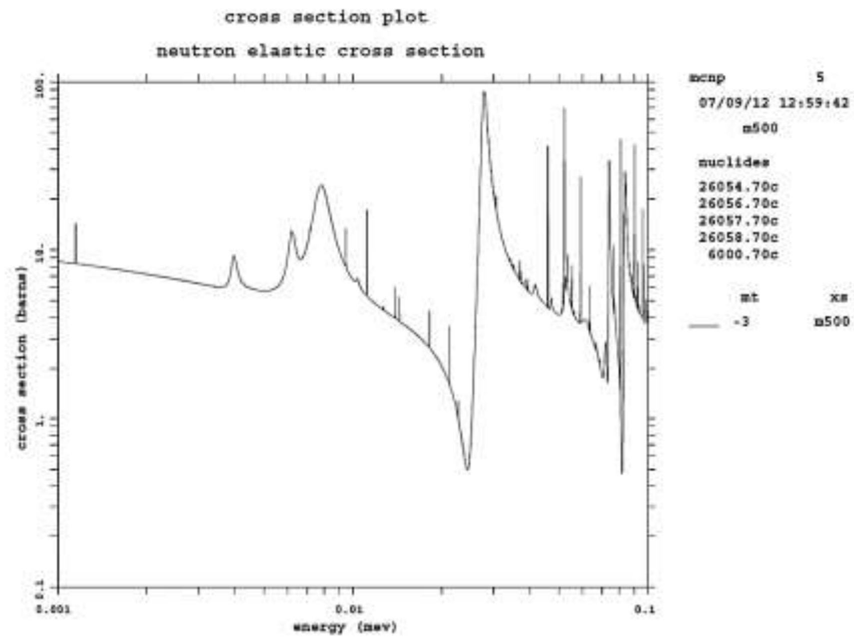


Structure in response functions

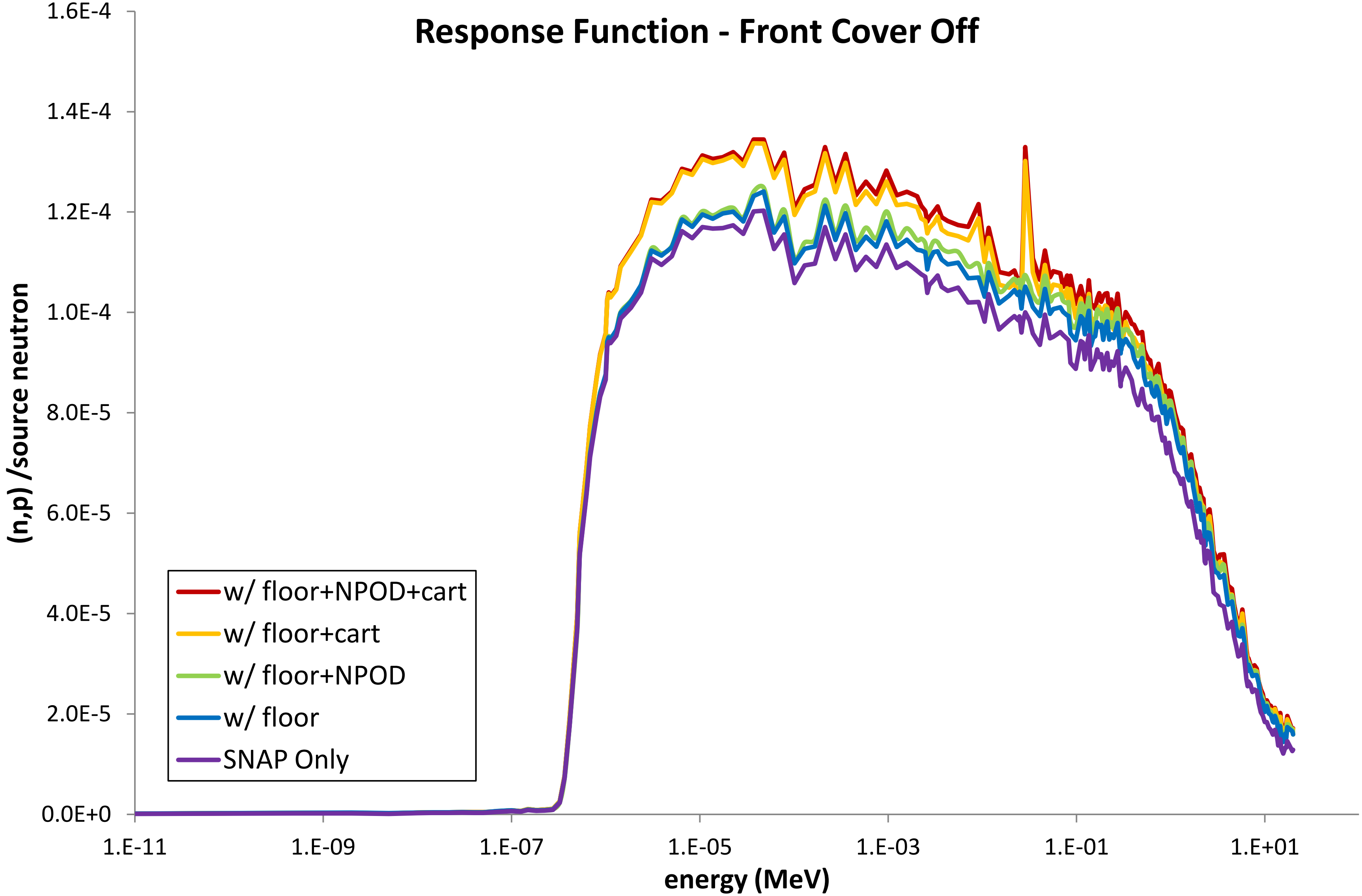
Cd absorption



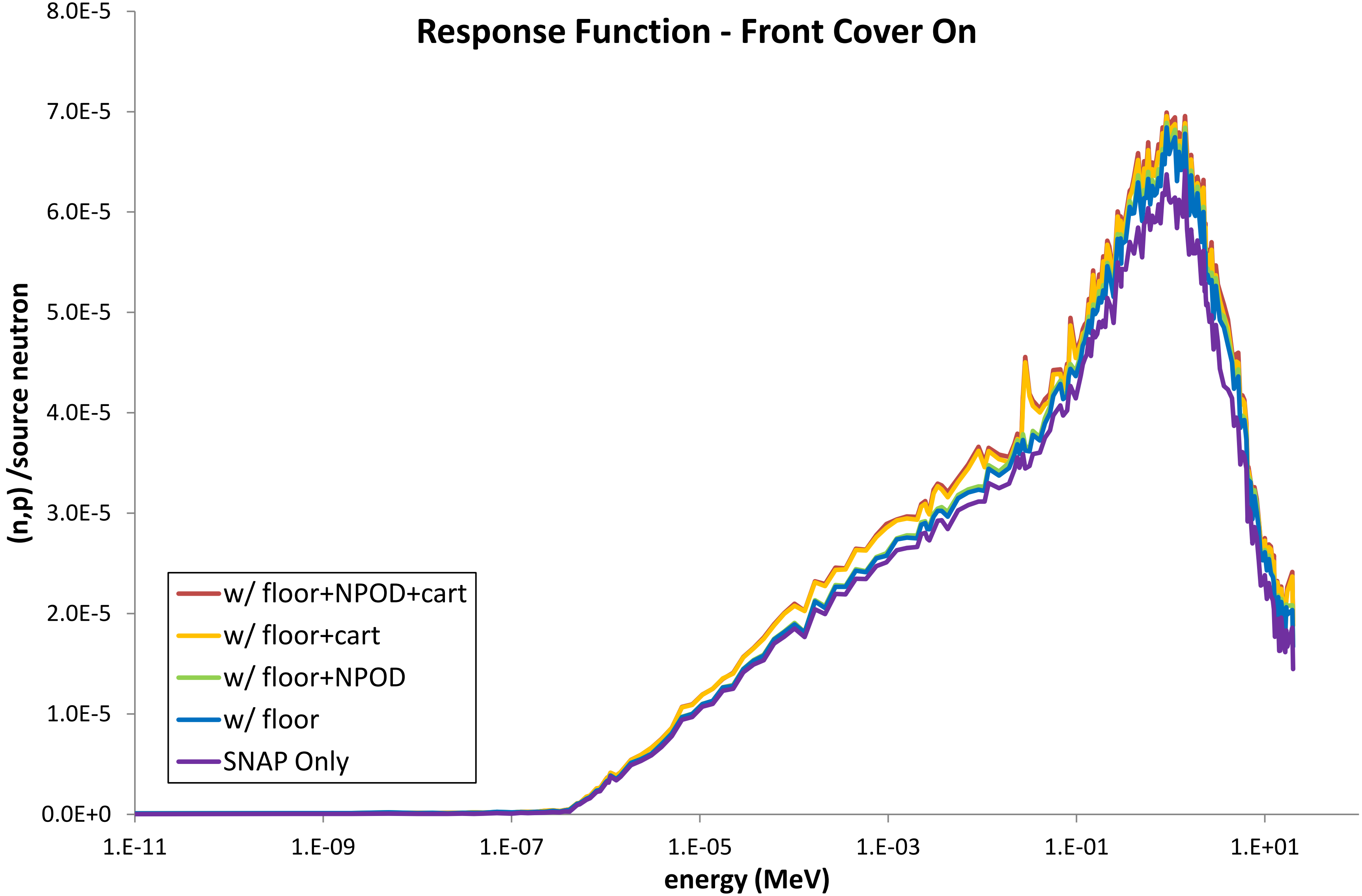
Fe elastic scatter



Factors affecting response function



Factors affecting response function



Response function V&V

- The count rate can be estimated by folding the response function ϵ with the leakage current J

$$\epsilon(E_g) = \frac{V \int_{E_g}^{E_{g+1}} dE' \Sigma_{(n,p)}^{He3}(E')\phi(E')}{A \int_{E_g}^{E_{g+1}} dE' J(E')} = \frac{V \cdot R(E_g)}{A \cdot J(E_g)}$$

$$V \cdot R = \sum_{g=1}^{G} \epsilon(E_g)\, A \cdot J(E_g)$$

- We verified the response functions against MCNP5 calculations with Cf-252 and the BeRP ball
- We also tested the response functions against measurements with Cf-252 and the BeRP ball

V&V results

Source	SNAP Cover	Worst Case	Measured Response (cps)	MCNP5 F4 Tally		Response Function	
				Calculated Response (cps)	Error	Calculated Response (cps)	Error
Cf-252	Off	15.2 cm reflector	1.9	2.1	11.8%	2.2	14.2%
	On	3.8 cm reflector	7.9	9.0	13.2%	9.0	13.8%
BeRP Ball	Off	3.8 cm reflector	116.2	129.7	11.6%	136.3	17.3%
	On	3.8 cm reflector	68.7	75.7	10.2%	79.2	15.2%

- MCNP5 F4 tally and response function calculations are similar
- Both over-predict measured response
- Response function error slightly higher than MCNP5 F4 tally

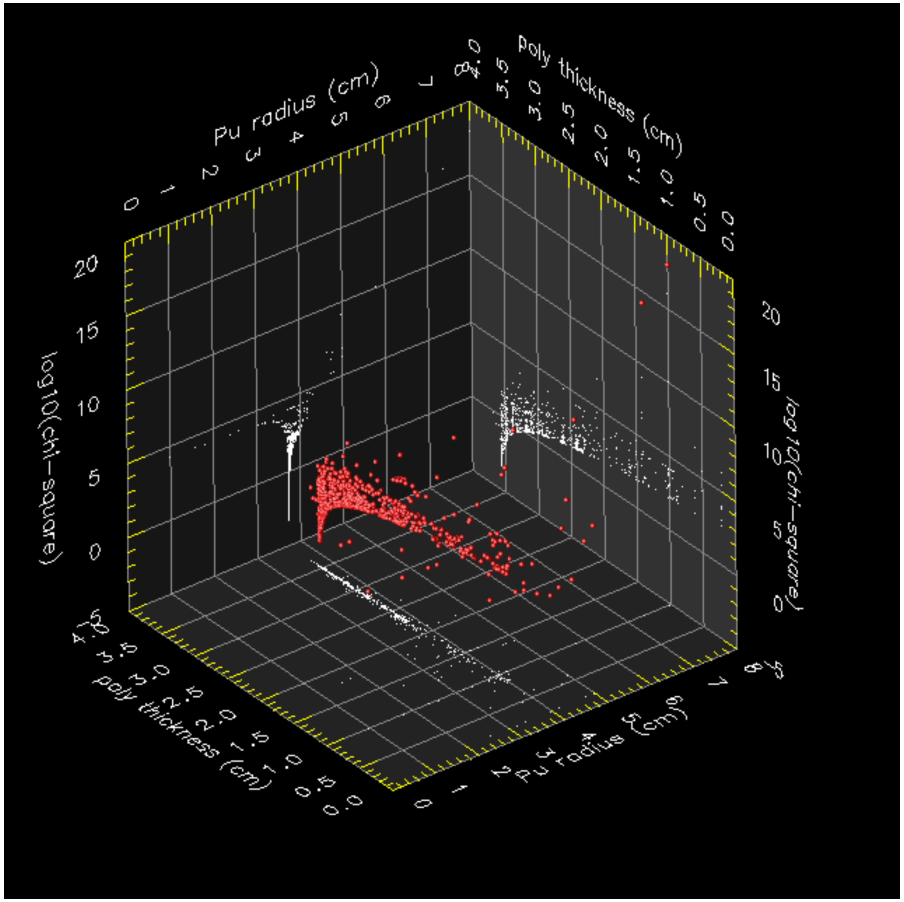
Application to inverse problem analysis

- Objective
  - Treat the reflected BeRP ball as an "unknown"
  - Estimate plutonium radius and poly thickness

- Approach
  - Compute neutron leakage current using simple 1D XSDRN model of poly-reflected Pu sphere
  - Calculate SNAP count rates by folding leakage current with detector response functions
  - Iteratively change Pu radius and poly thickness using mesh adaptive direct search (MADS)
  - Find Pu radius and poly thickness that minimizes error between calculation and measurement

Inverse problem solution using MADS

- MADS is a black-box optimization algorithm
  - Finds the XSDRN model that minimizes the error by iteratively changing the model dimensions
- Computes the error for several alternative solutions in a series of iterations
  - If a better solution is found in the current iteration, it coarsens the mesh around the current best solution
  - If no better solution is found, it refines the mesh about the previous best solution



MADS analysis

Poly Reflector	Pu Radius (cm)		Poly Thickness (cm)		XSDRN Runs
	Actual	Estimated	Actual	Estimated	
Bare	3.79	3.74	0	0.00	895
1.3 cm		3.75	1.24	1.10	371
2.5 cm		3.74	2.51	2.45	535
3.8 cm		3.75	3.78	3.54	1040
7.6 cm		3.66	7.59	5.05	416
15.2 cm		2.92	15.21	3.54	247

- All cases started with an initial guess of (Pu radius, poly thickness) = (1 cm, 1 cm)

Summary

- We presented a relatively simple way to compute neutron detector response functions using MCNP5 flux (F4) and leakage current (F1) tallies
  - The response function can be calculated using models that include the surrounding environment
  - Allows the count rate to be estimated from the source leakage
- We tested the SNAP response functions against MCNP5 calculations and measurements with Cf-252 and the BeRP ball
  - Response function calculations tended to over-predict the measured count rates
  - Typical errors were 5% - 10%, but worst cases had errors ~15%
- We applied the response functions in a MADS analysis to infer the BeRP ball radius and poly thickness from the SNAP count rates
  - The inferred dimensions were fairly accurate except in the most highly reflected cases
  - SNAP has essentially no sensitivity below cadmium cutoff
  - For the thickest reflectors, the competing effects of neutron multiplication and parasitic absorption make the solution non-unique

References on MADS and applications

1. Jerawan C. Armstrong and Jeffrey A. Favorite, "Identification of Unknown Interface Locations in a Source/Shield System Using the Mesh Adaptive Direct Search Method," American Nuclear Society Transactions, Vol. 106, 2012, pp. 375-377.
2. Charles Audet and J. E. Dennis, Jr., "Mesh Adaptive Direct Search Algorithms for Constrained Optimization," SIAM Journal on Optimization, Vol. 17, No. 1, 2006, pp. 188-217.
3. Sébastien Le Digabel, Christophe Tribes, and Charles Audet, "NOMAD User Guide Version 3.6.0," available from http://www.gerad.ca/nomad and SourceForge.net.