

Exceptional service in the national interest



# Updates on Enrichment Measurement of Uranium Hexafluoride Containing Cylinders Using Fast Neutron Signatures

Student: Michael Streicher

August 2, 2012

Mentor: Scott Kiff

B.S. Nuclear Engineering (Purdue University 2012)

Radiation and Nuclear Detection Systems (#8132)

PhD. Pre-Candidate in Nuclear Engineering and Radiological Sciences

Major Contributions from Mark Gerling

(University of Michigan)

Other Collaborators: Wond Mengesha and Peter Marleau

## Abstract

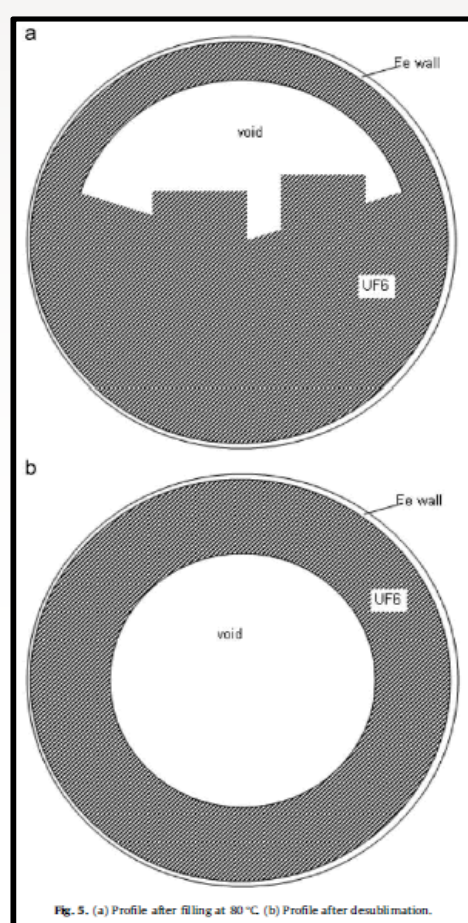
A major challenge in international nuclear safeguards exists at enrichment facilities where non destructive measurements of the isotopic concentration of uranium-235 are still being improved. This research evaluates the feasibility of using fast neutron imaging and spectroscopy to perform a holistic assay of a storage cylinder. Initial results indicate that these techniques could be an improvement over existing technologies.

## Introduction

- Enrichment facilities around the world require uranium hexafluoride ( $UF_6$ ) as an input and output of the enrichment process
- Highly enriched  $UF_6$  could be used to manufacture a nuclear weapon
- Thus, it is critical to monitor the enrichment levels of  $UF_6$  containers as they exit an enrichment facility to watch for material diversion
- Today, nuclear fuel enrichment is monitored by measuring gamma emissions; yet this can be problematic for the following reasons:
  - Only gives local enrichment of outer skin of  $UF_6$
  - Calculation depends on user-provided mass of  $UF_6$
  - Dependent on the geometry of the  $UF_6$
- $UF_6$  is generally housed in ANSI 30B cylinders

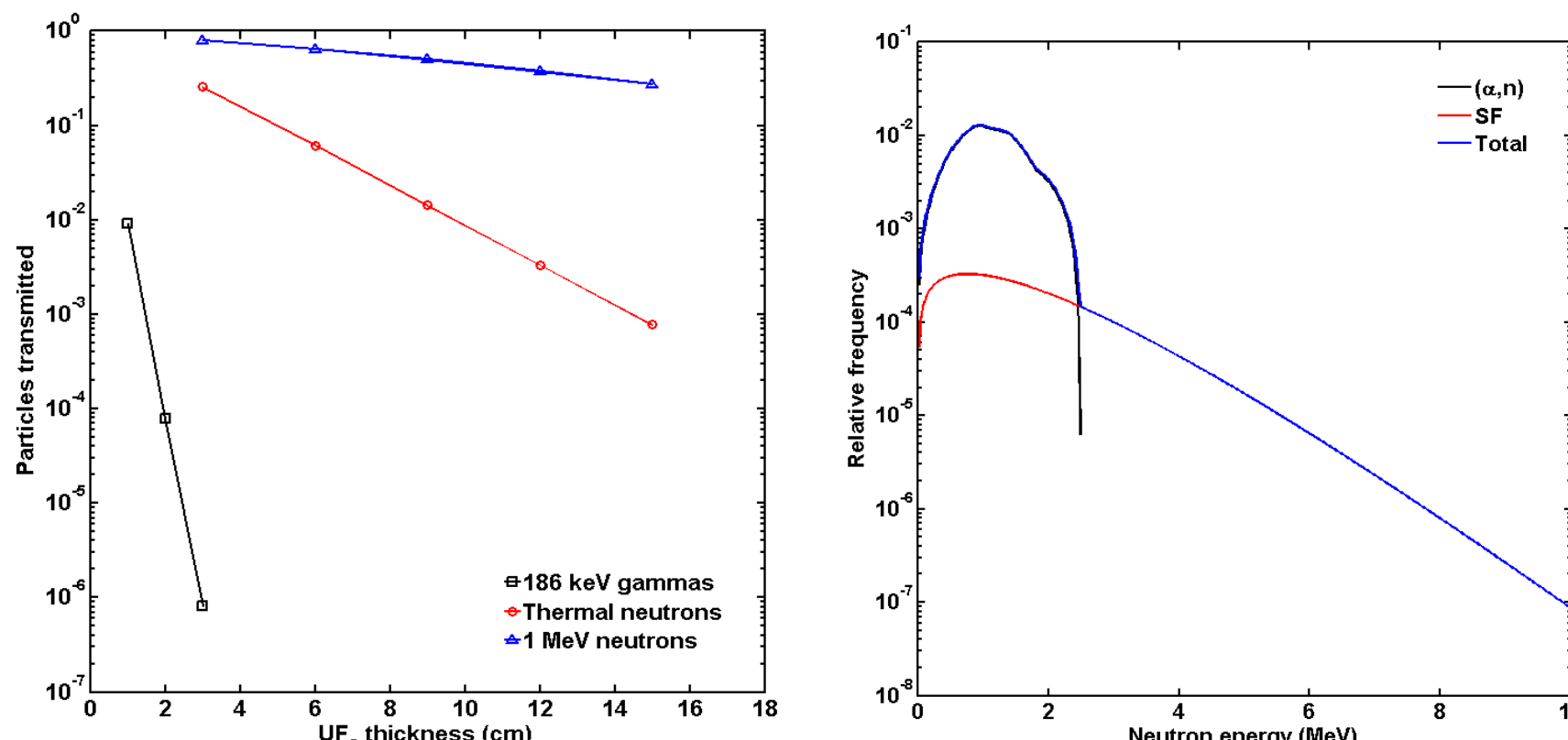
### $UF_6$ 30B Cylinder – size and filling extremes

The photograph to the right illustrates the current method of assay using gamma emission energy spectra. A HPGe detector is used at right to obtain the gamma spectra near at 30B Cylinder



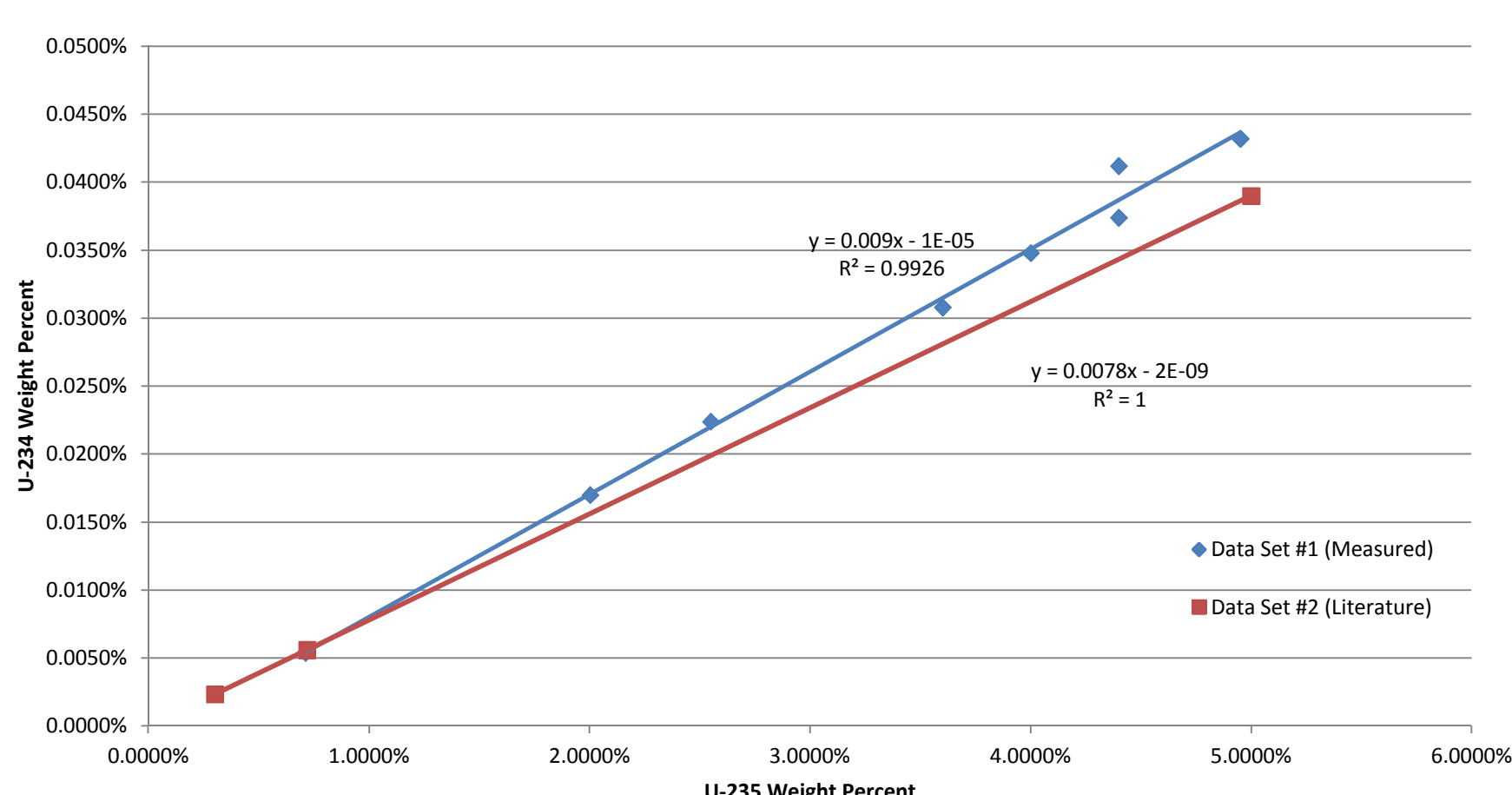
- Fast neutrons could be a potential improvement because they are more penetrating

### Penetrating Nature of Fast Neutrons and Spectral Differences



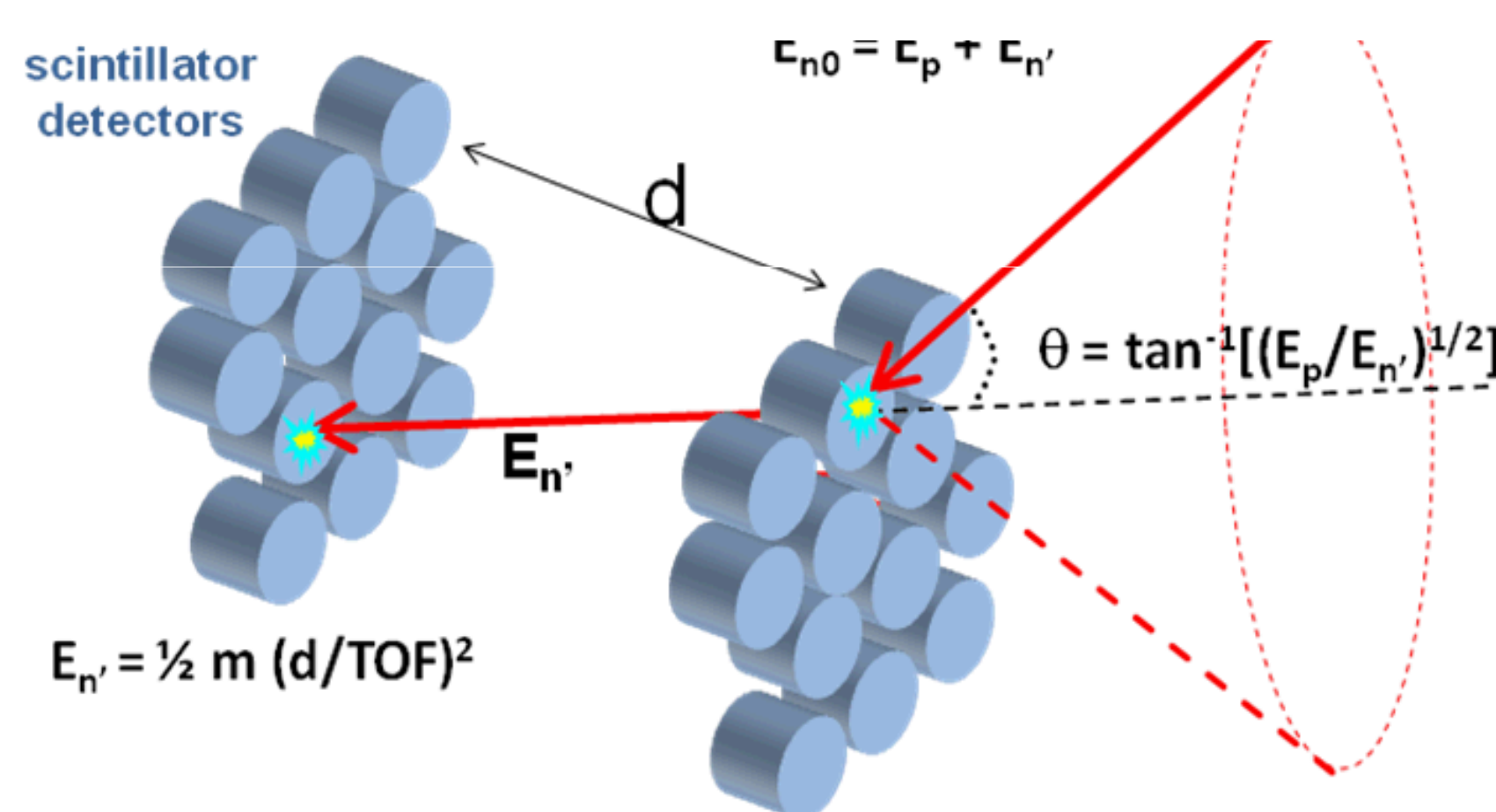
- U-234 and U-238 (naturally occurring isotopes within mined and milled uranium) release fast neutrons via two interactions – spontaneous fissions and ( $\alpha$ , n) reactions
- The energy spectrum of the fast neutrons varies based on the reaction which generated them
- Because U-234 and U-238 generate fast neutrons through different processes, the spectrum may provide information regarding the U-234 to U-238 ratio which can be correlated to the U-235 composition
- The ratio could be facility dependent as seen by the plot below

### U-234 Weight % vs. U-235 Weight %



## Measurement Methods

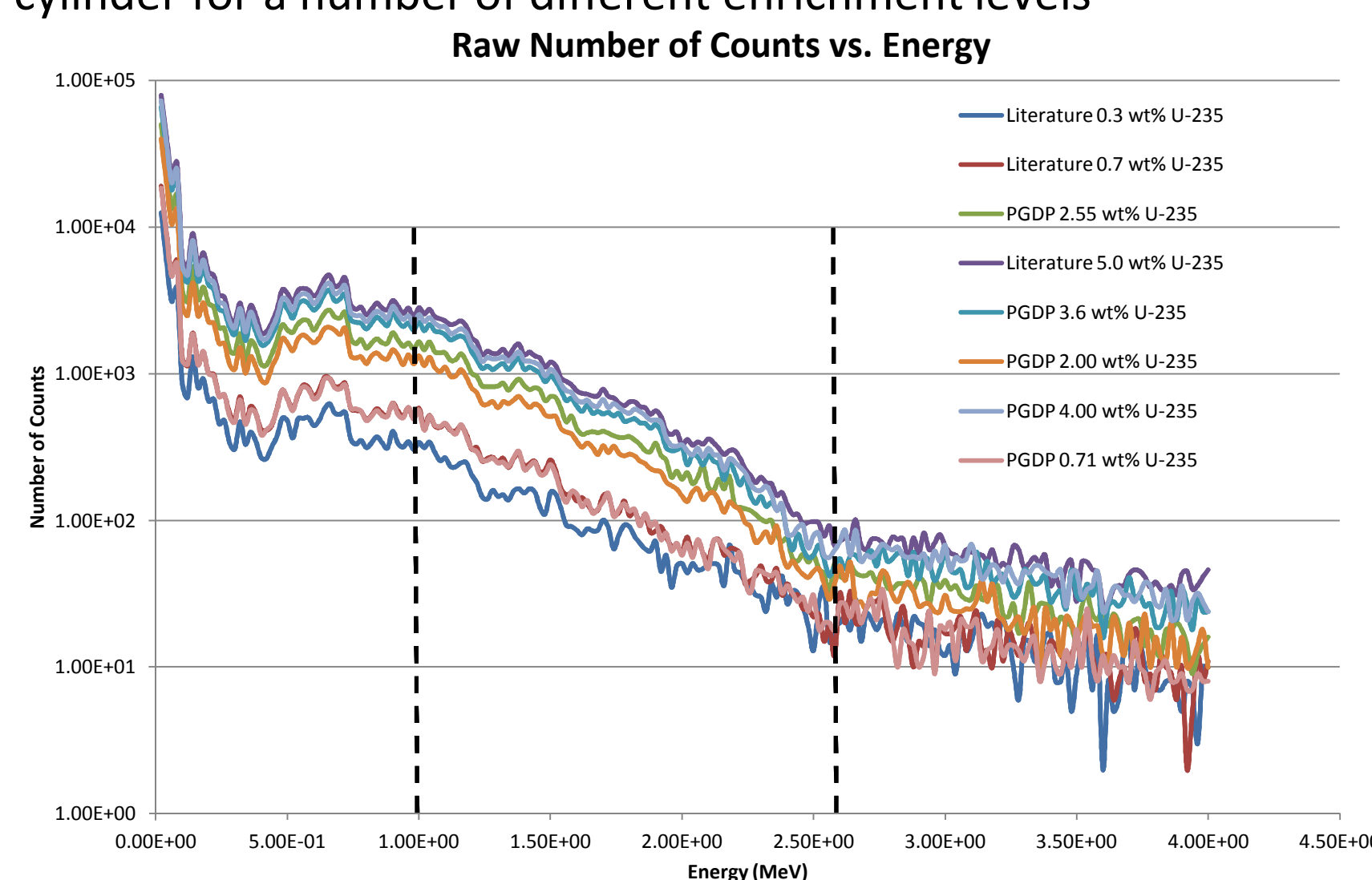
- Sandia deployed a radiation detection system to the Paducah Gaseous Diffusion Plant (PGDP) to measure neutron and gamma signatures in the vicinity of 30B Cylinders
- The deployed system included four liquid scintillators, a sodium iodide detector, and a helium-3 tube
- At a later deployment, the Neutron Scatter Camera (NSC), a fast neutron imaging device, will be operated near 30B Cylinders
- The NSC images and performs spectroscopy as follows:
  - A neutron scatters off a proton in the front plane of scintillators
  - The energy of the scattered proton is measured
  - The neutron interacts with a detector in the rear plane
  - The energy of the scattered neutron is determine using kinematics
  - The sum of the energies from the recoiling proton and recoiling neutron allow one to calculate the incident energy. The ratio of the interactions can be used to determine the incident angle
  - Many events allow one to determine the energy spectrum and locate the probable location of the neutron source



- Pulse Shape Discrimination (PSD) is used when processing to differentiate between gamma and neutron interactions

## Recent Results

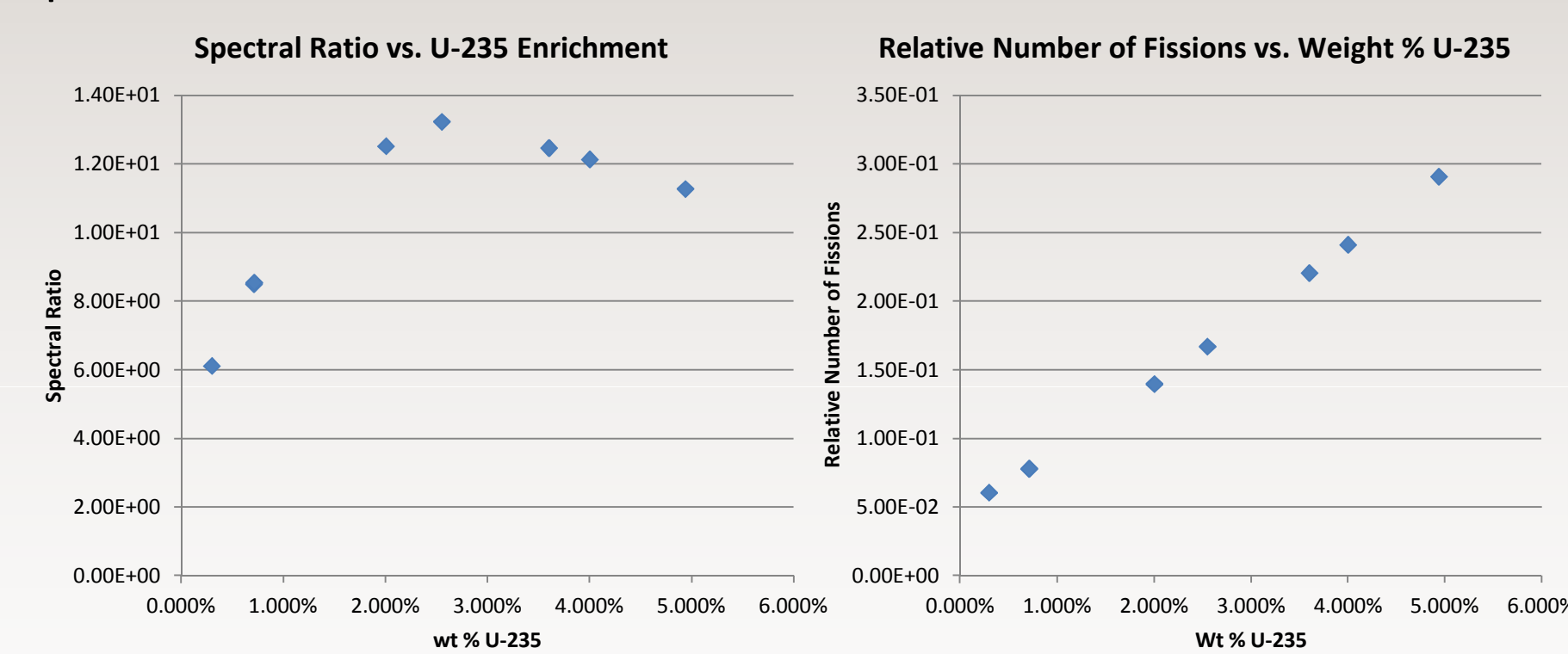
- With data obtained from PGDP, MCNP5 models of 30B cylinders were constructed to simulate the neutron spectra observed 1 m from the cylinder for a number of different enrichment levels



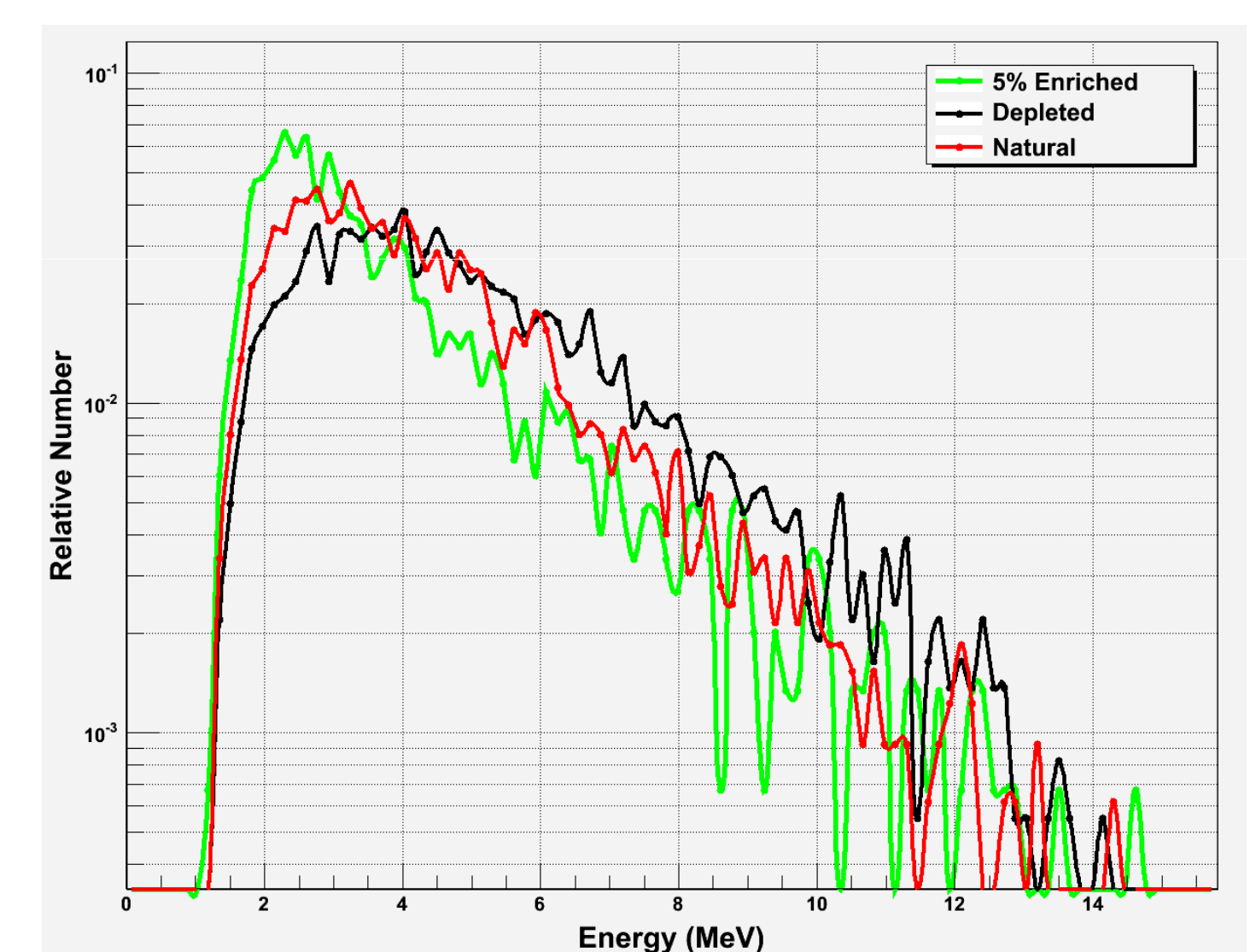
- A real detector will have a detection threshold, so we cut all neutrons with an energy below than 1 MeV
- The expected ( $\alpha$ , n) peak ends at 2.54 MeV
- A spectral ratio is defined as the number of events greater than 1 MeV but less than 2.54 MeV over the number greater than 2.54 MeV

## Recent Results

- The dependence on the spectral ratio is not a one-to-one function with respect to the uranium enrichment
- This means it will be difficult to determine the enrichment given the spectral ratio



- Although the low energy peak does grow as the enrichment increases, the greater enrichment produces more fission neutrons which accounts for the bending behavior of the spectral ratio
- There is evidence that the NSC can resolve the enrichment level
- The NSC was modeled in MCNP-PoliMi and the detector response was accounted for resulting in the following normalized plot:



- To overcome the spectral similarities and enhance possible imaging of the cylinders, a series of liquid scintillators surrounding a 30B cylinder was modeled in MCNP-PoliMi.
- This could allow for multiplicity counting and imaging through count rate differences
- Preliminary results show count rate differences exist

## Future Work

- PGDP data will need to be analyzed
- The fully integrated model should be used with information from PGDP to see if the trend in an observable larger relative low energy peak continues for differing enrichment
- The observed neutron spectra differences by enrichment level should be defined more mathematically and a monotonic function should be developed for predictive purposes
- The NSC has been deployed numerous times over the past year and should be recalibrated and tested prior to deployment to PGDP
- Continue to investigate the Radial Scatter Camera model

## References

- R. Berndt, E. Franke, and P. Mortreau, "235U enrichment or  $UF_6$  mass determination on  $UF_6$  cylinders with non-destructive analysis methods," *Nucl. Instr. Meth. A*, vol. 612 (2010), pp. 309-319.  
 N. Mascarenhas *et al.*, "A measurement of the flux, angular distribution and energy spectra of cosmic ray induced neutrons at fission energies," 2007 IEEE Nucl. Sci. Symp. Conf. Record, pp. 2050-2052.