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Fission Product γ -ray Measurements of ^{235}U and MCNP6 Predictions

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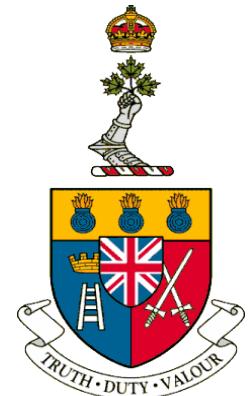
¹Royal Military College of Canada

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November 11, 2013

LA-UR-###



Delayed Neutron & Gamma Counting at RMCC

- DNC system was designed and built in 2010 for the analysis of DN emissions from ^{233}U , ^{235}U & ^{239}Pu .
- Upgraded in 2012 to accommodate measurement of gammas from SNM.
- This system analyzes the temporal behaviour of the delayed neutrons and gammas to discern which fissile isotope(s) is(are) present
- Complements existing nuclear analytical instrumentation at RMCC

Delayed gamma measurements from the fission of nat. U were compared to MCNP6 simulations.

Delayed Neutron & Gamma Counting System



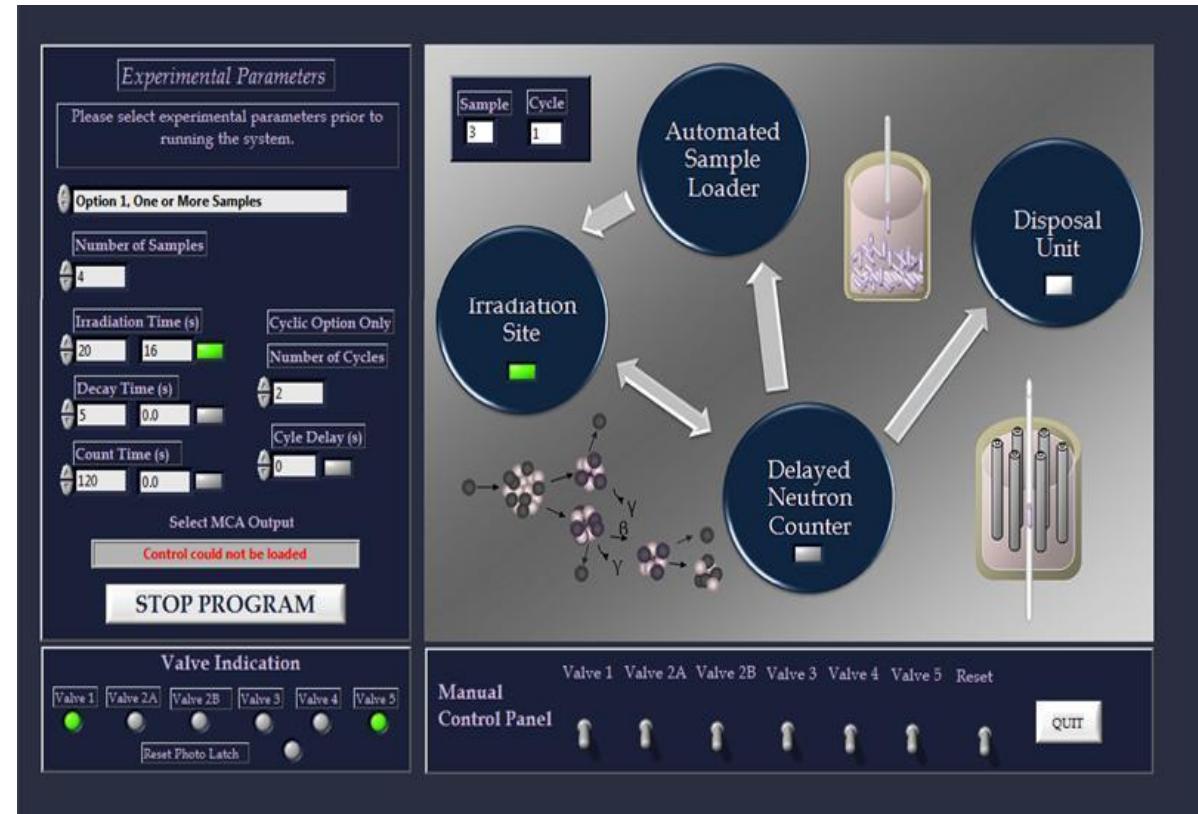
Aqueous samples containing fissile content is prepared from certified reference materials



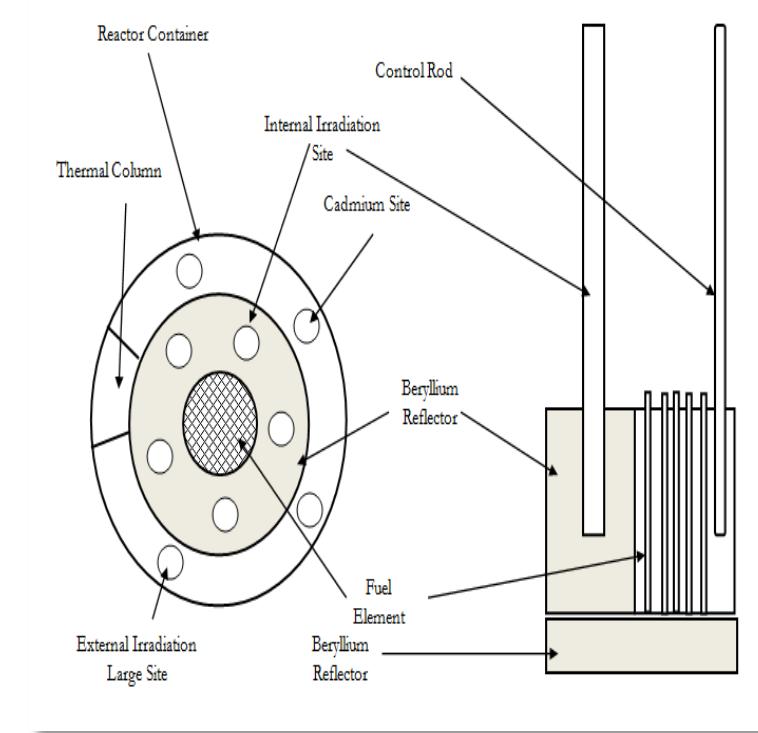
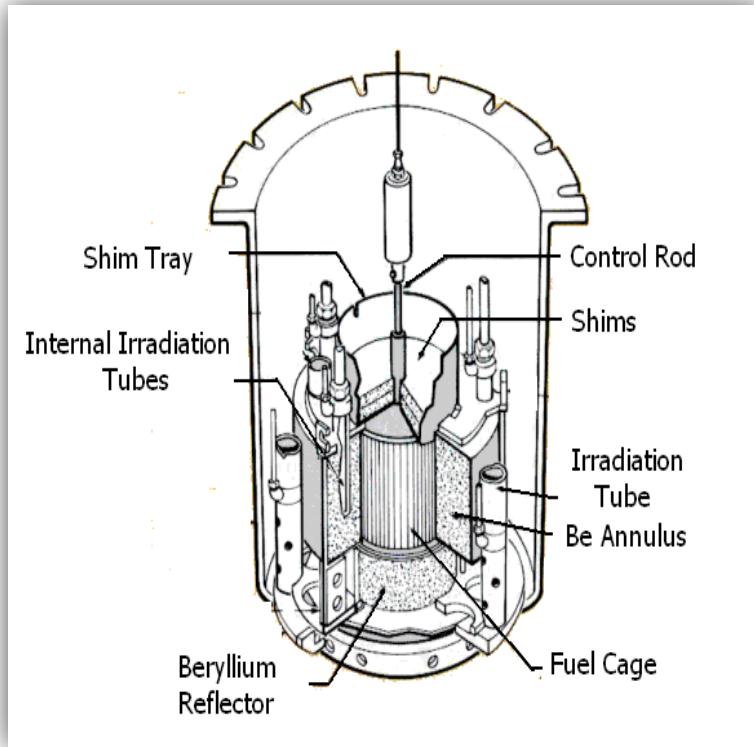
LabVIEW software controls data acquisition and hardware components.



User specifies:
Irradiation, decay, count time, count intervals and # of samples.

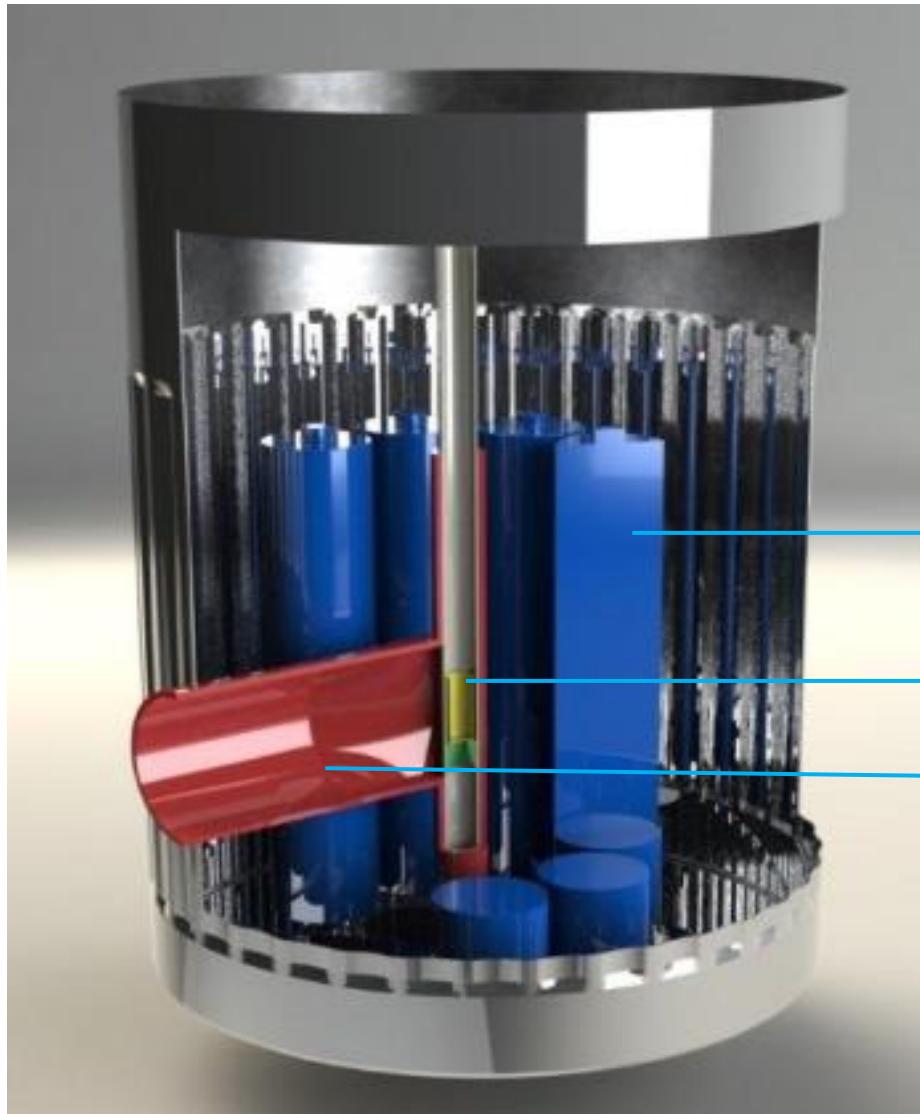


Irradiation in the SLOWPOKE-2 Reactor



20 kW research reactor enriched to 19.89 % ^{235}U

The Delayed Neutron & Gamma Counter



*Paraffin moderator
not shown.*

^3He Detector

Sample Tubing

HPGe position

Fissile Analysis: An Example

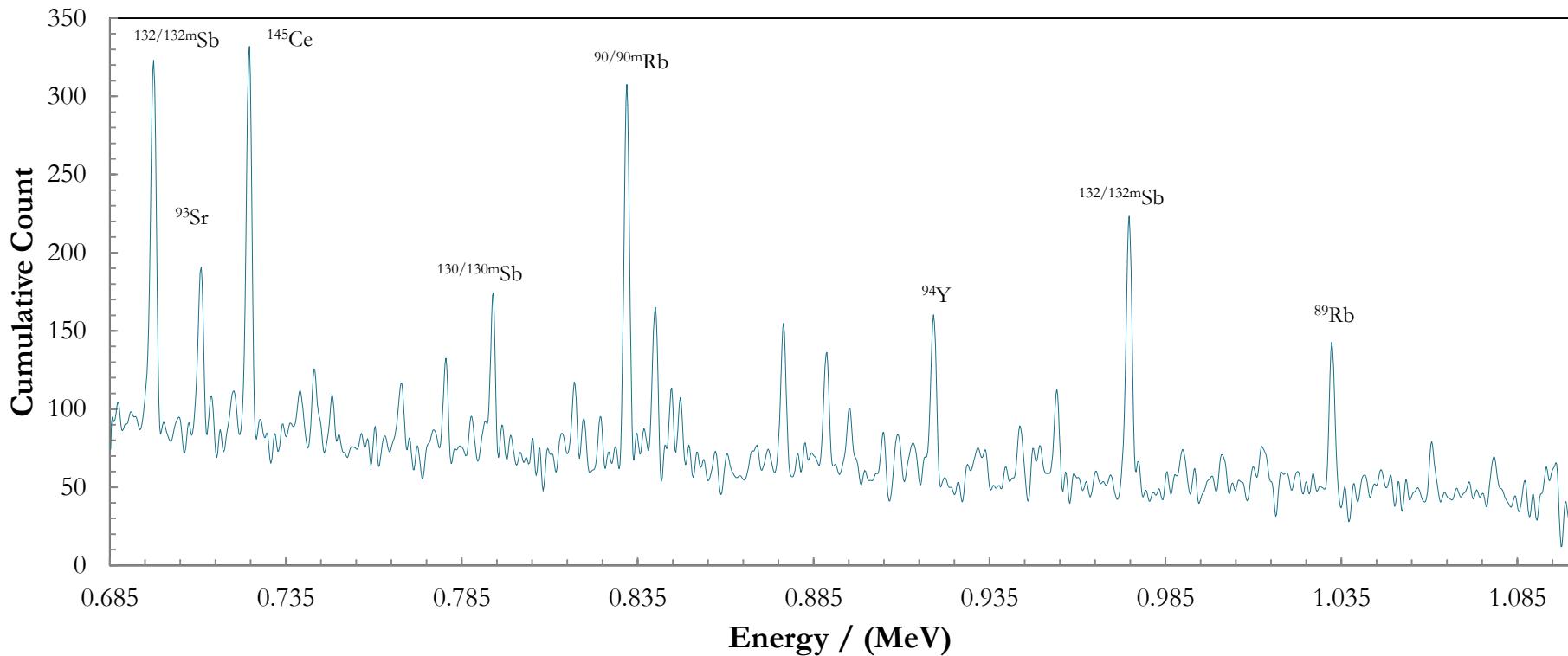
- Imports count files for neutrons and gammas:

SLOWPOKE Test Data					
11/04/2013	11:47 AM				
Standard? YES					
Sample #	Cycle #	Time	Energy Bin 1	...	Energy Bin N
1	1	30	100		50
		60	150		250
	
		600	200		4000

- Matlab script corrects for background, dead time, normalizes to counts per second

Fissile Analysis: An Example

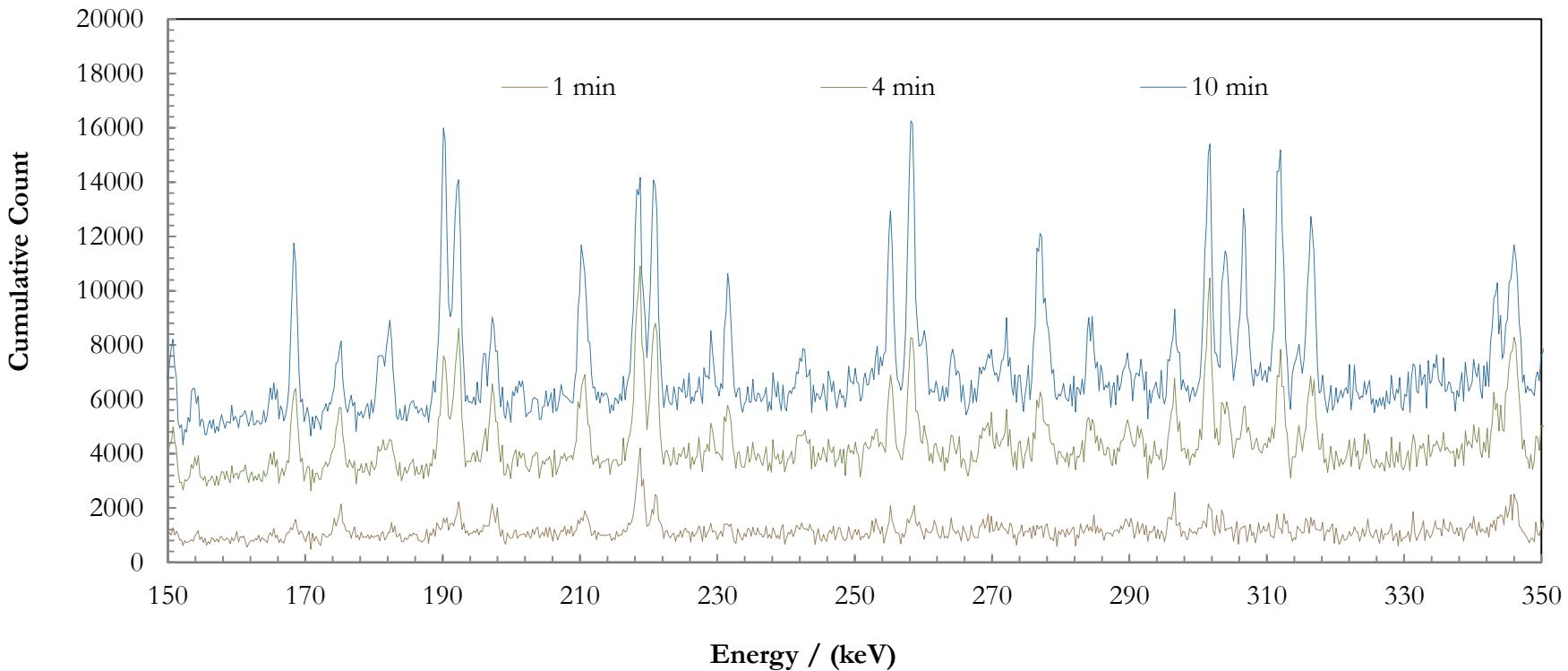
0.3 mg of natural U



- 60 s irradiation, 30 s decay, 570 s count.
- Background subtracted, corrected for dead time effects.

Fissile Analysis: An Example

0.3 mg of natural U



- 60 s irradiation, 30 s decay, 570 s count.
- Background subtracted, corrected for dead time effects.

Delayed Gamma Preliminary Measurements

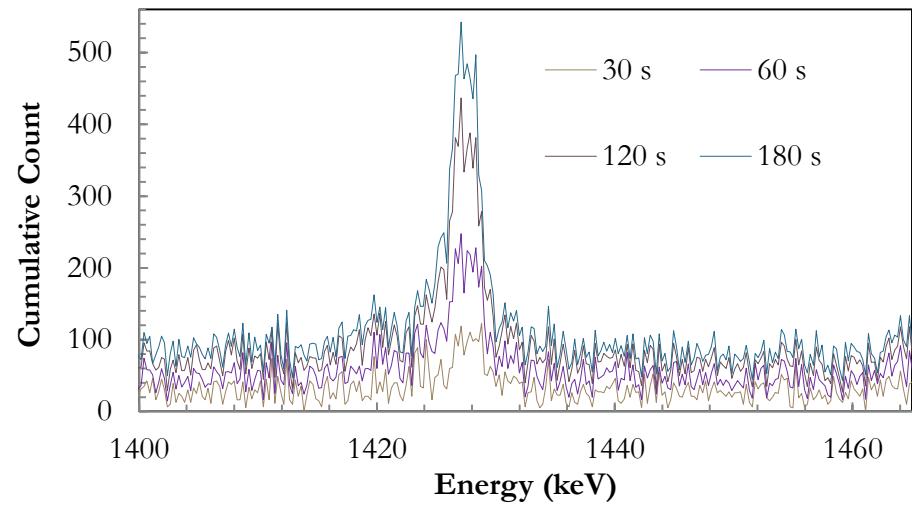
Measurements were collected and the following examples were analyzed:

A. ^{235}U Short Count

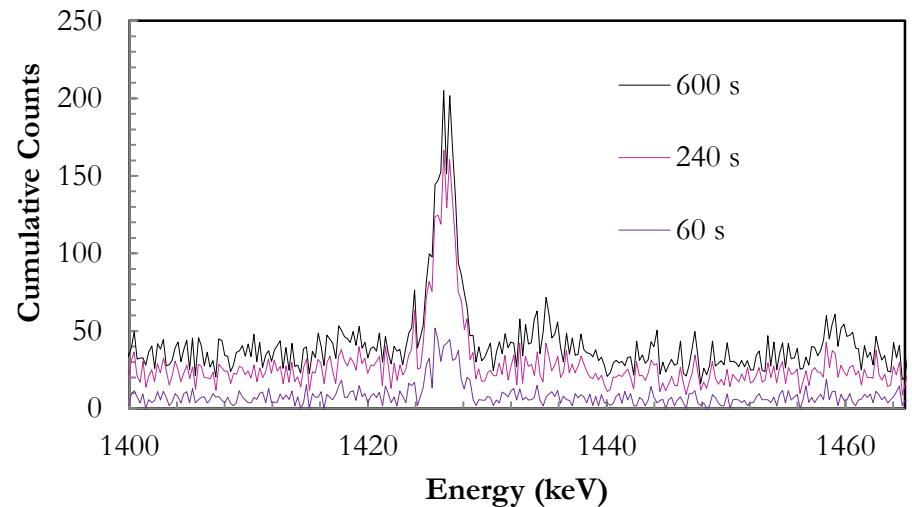
- Nat. U. in aqueous solution
- $t_{\text{irr}} - t_{\text{decay}} - t_{\text{count}} = 60 \text{ s} - 8 \text{ s} - 180 \text{ s}$
- Count times analyzed:
30 s, 60 s, 120 s, 180 s

B. ^{235}U Medium Count

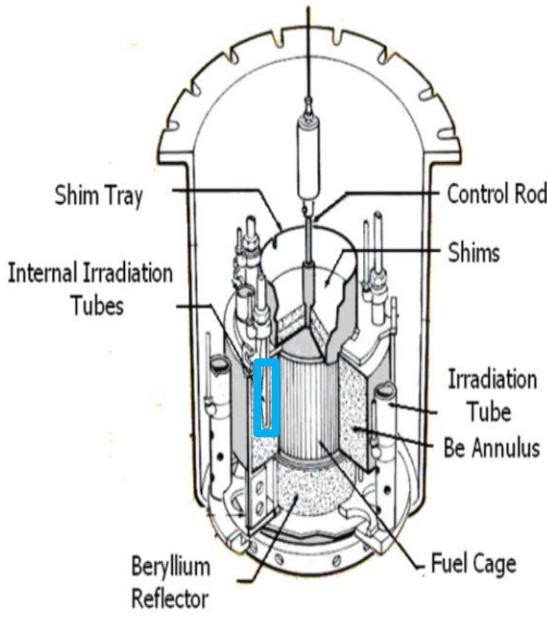
- Nat. U. in aqueous solution
- $t_{\text{irr}} - t_{\text{decay}} - t_{\text{count}} = 60 \text{ s} - 30 \text{ s} - 600 \text{ s}$
- Count times analyzed:
60 s, 240 s, 600 s



Sr-94 Peak (1427 keV, $t_{1/2} = 1.25 \text{ min}$)



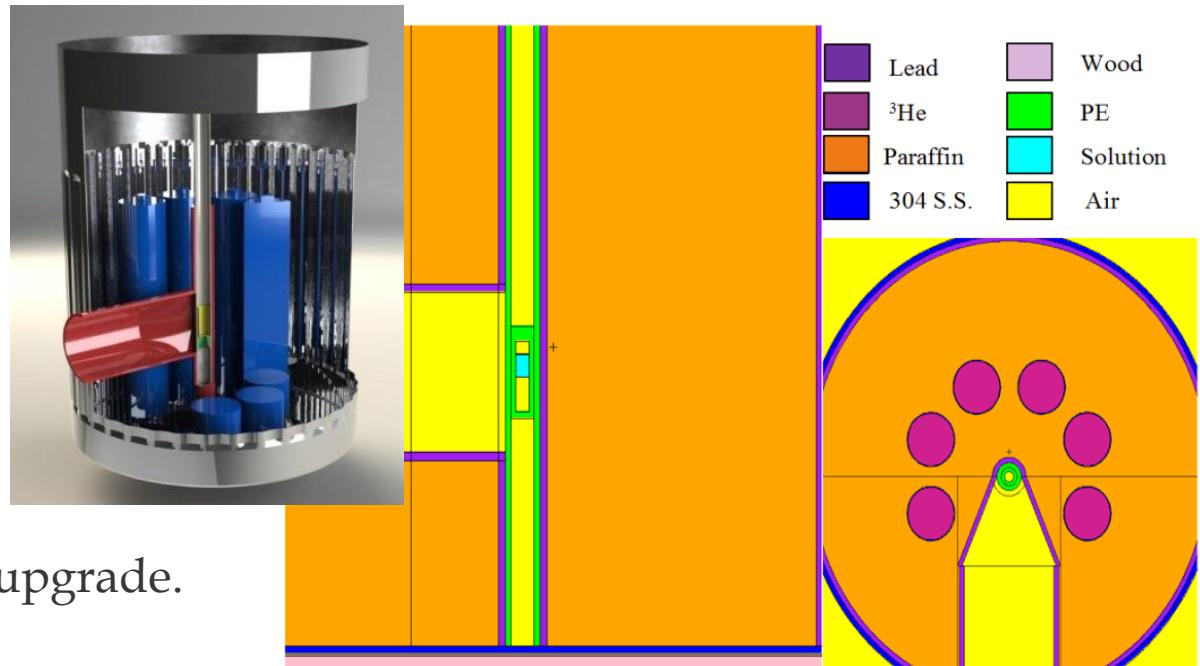
MCNP6 Model - Geometry



Irradiation:

SLOWPOKE-2 model provided by AECL

Vial placed inside irradiation site to determine neutron flux energy distribution.



Detection:

HPGe crystal modeled to manufacturer's specifications.

DNGC system modeled using dimensions measured during upgrade.

MCNP6 Model - Source & Tallies



Energy	60 s	90 s	660s
0.01 MeV	t_{irr}	t_{decay}	t_{count}
...			
1.99 MeV			
2.00 MeV			

Irradiation of Fissile Content

- Reproduces neutron flux distribution in SLOWPOKE-2 reactor.

DG Production

- DG=lines, sample DGs using models based on line emission data augmented by 25-group data.
- Surface current tally with time bins corresponding to experiments recorded emission energies and times.

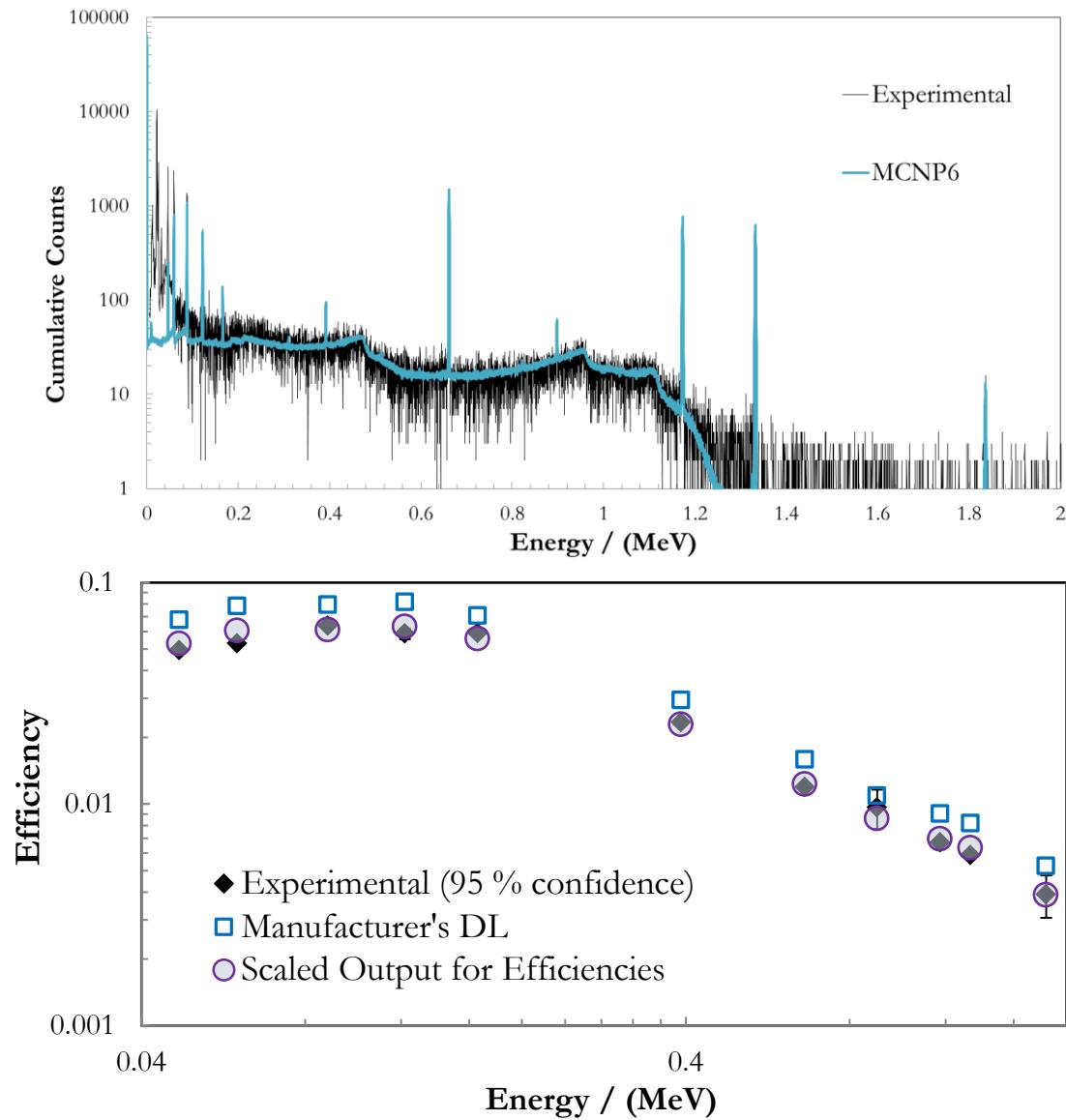
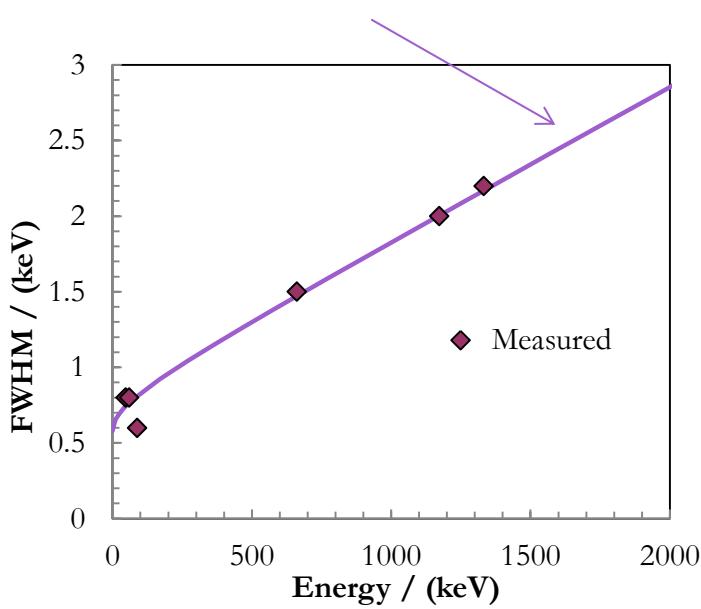
Detection

- Pulse height tally records energy depositions within HPGe crystal.

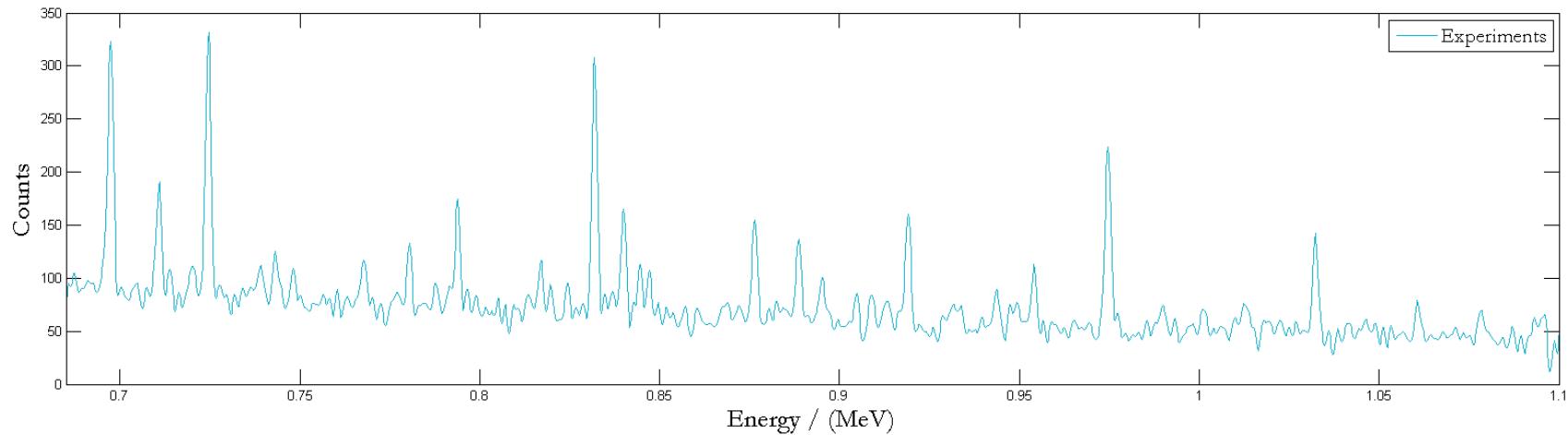
Multinuclide HPGe Detector Response in MCNP6

- Comparisons of MCNP & exp. FWHM and efficiencies were performed.
- *Gaussian Energy Broadening* (GEB) card used to reproduce energy resolutions.

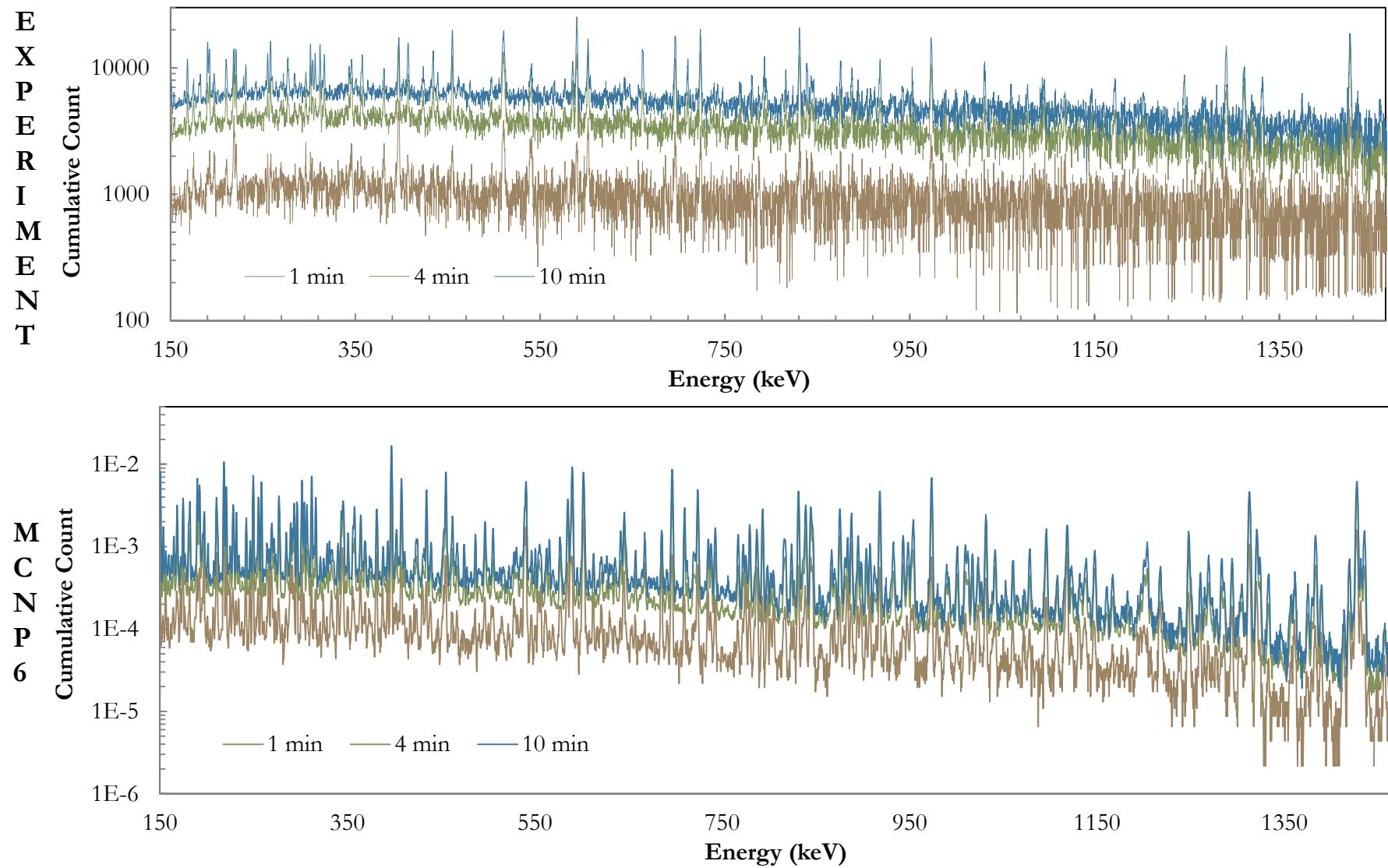
$$FWHM = a + b\sqrt{E + cE^2}$$



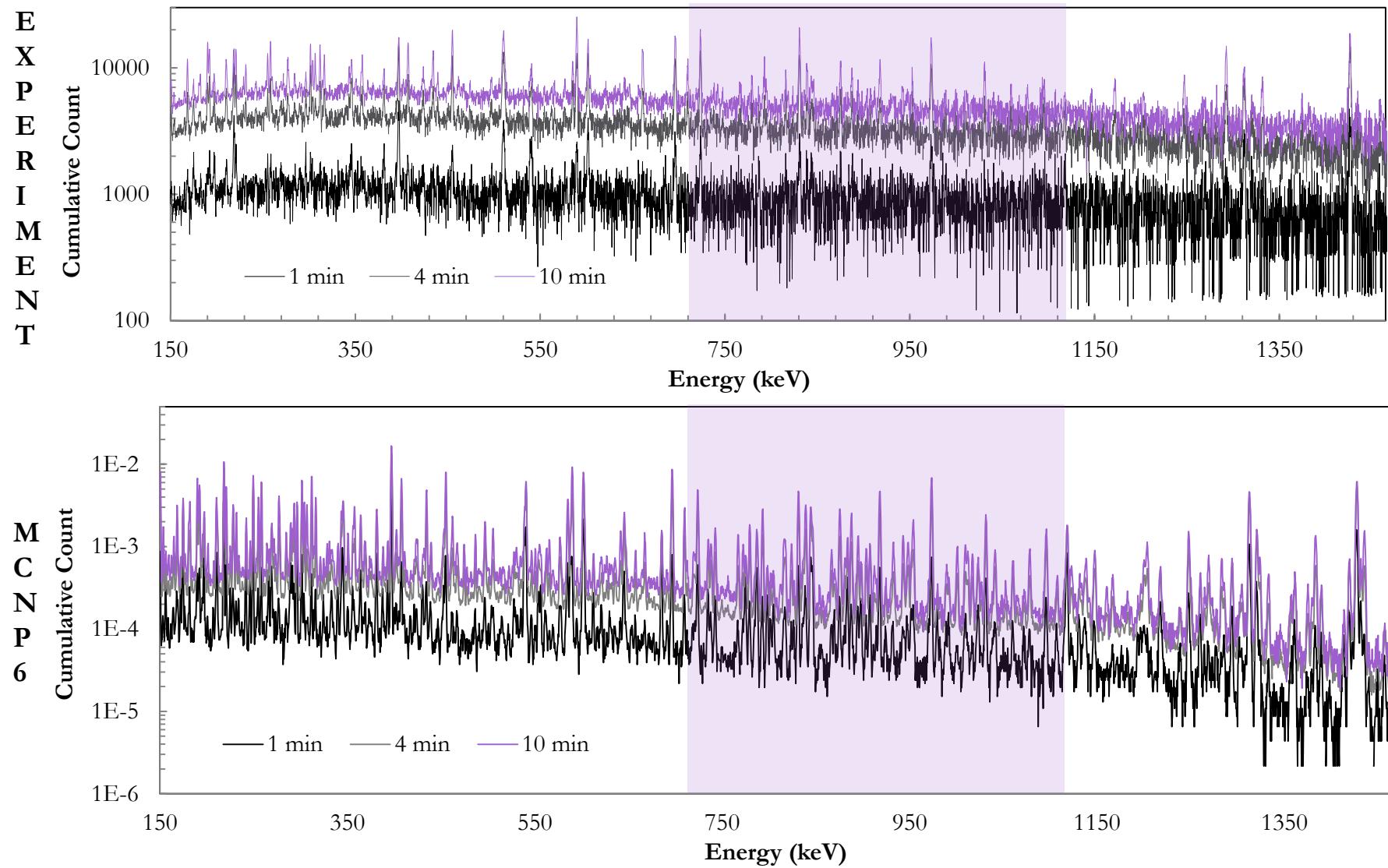
Fission Product γ -ray Spectra



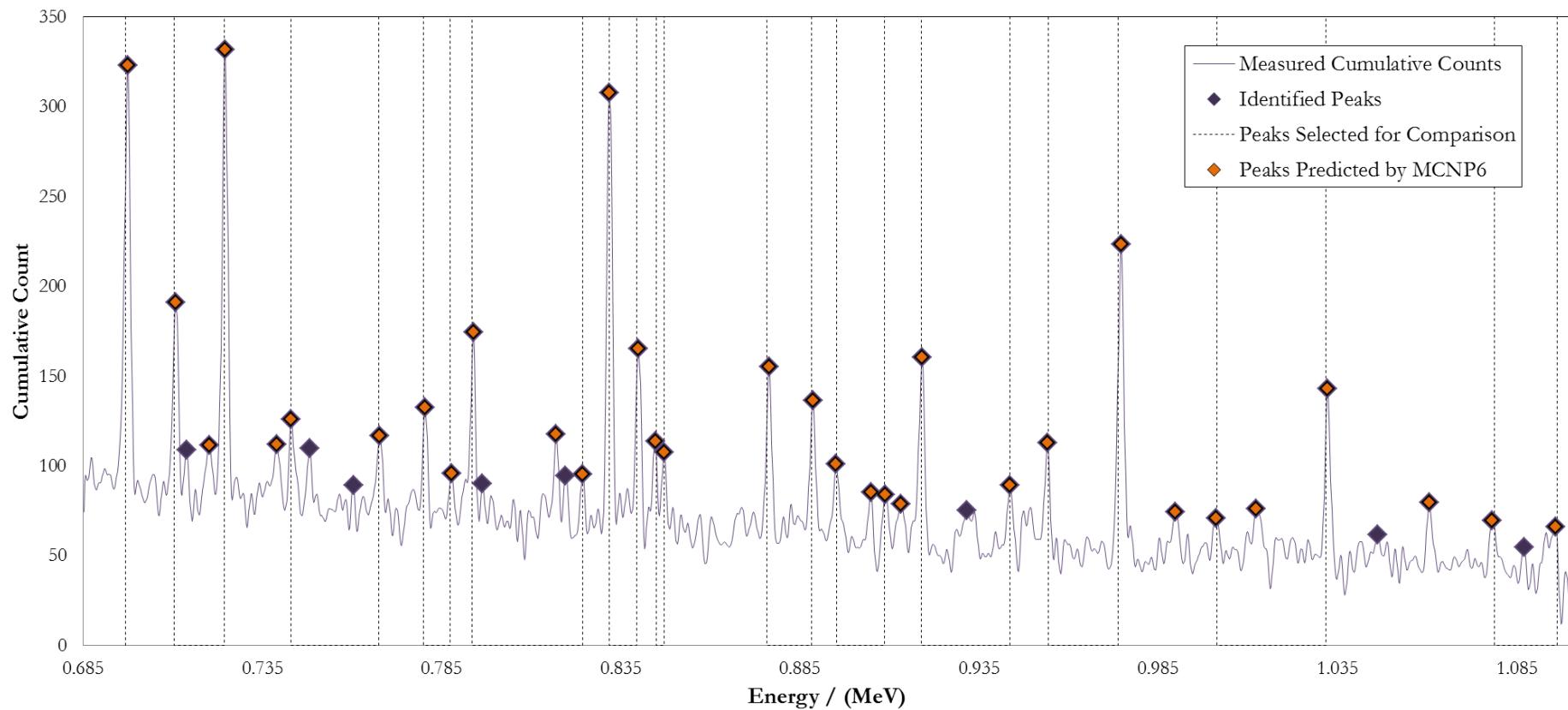
Delayed Gamma Modeling: Measurement Sets and their corresponding MCNP6 outputs



Delayed Gamma Modeling: Measurement Sets and their corresponding MCNP6 outputs



Fission Product γ -ray Spectra



- From 0.1 – 1.45 **176** Measured Peaks 130 Predicted by MCNP
- 25 selected for comparison in 0.685 – 1.1 MeV range

Fission Product γ -ray Relative Intensities

DG emission-spectra consist of two structures: multigroup and line data. All data are based on the ENDF/B-VI evaluation.
- (Durkee *et al.* *Nucl. Tech.* 180 (2012))

^{132}Sb 0.697 MeV

ENDFVI: 4.2 min 100 %
ENDFVII.1: 2.8 min 86 %

$^{132\text{m}}\text{Sb}$ 0.697 MeV

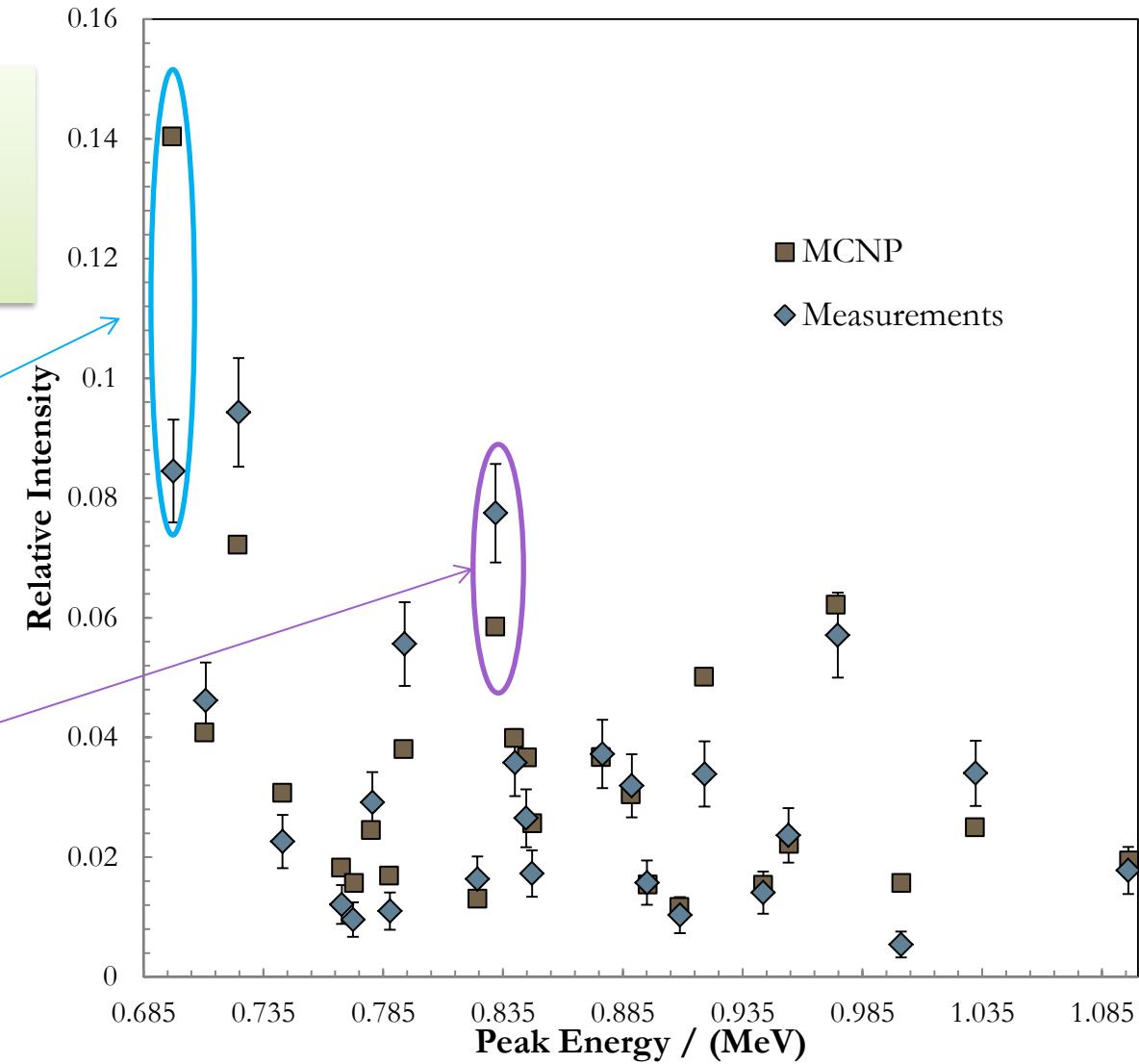
ENDFVI: 2.8 min 86 %
ENDFVII.1: 4.1 min 100%

^{90}Rb 0.832 MeV

ENDFVI: 28 %
ENDFVII: 40 %

$^{90\text{m}}\text{Rb}$ 0.832 MeV

ENDFVI: 97 %
ENDFVII: 94 %



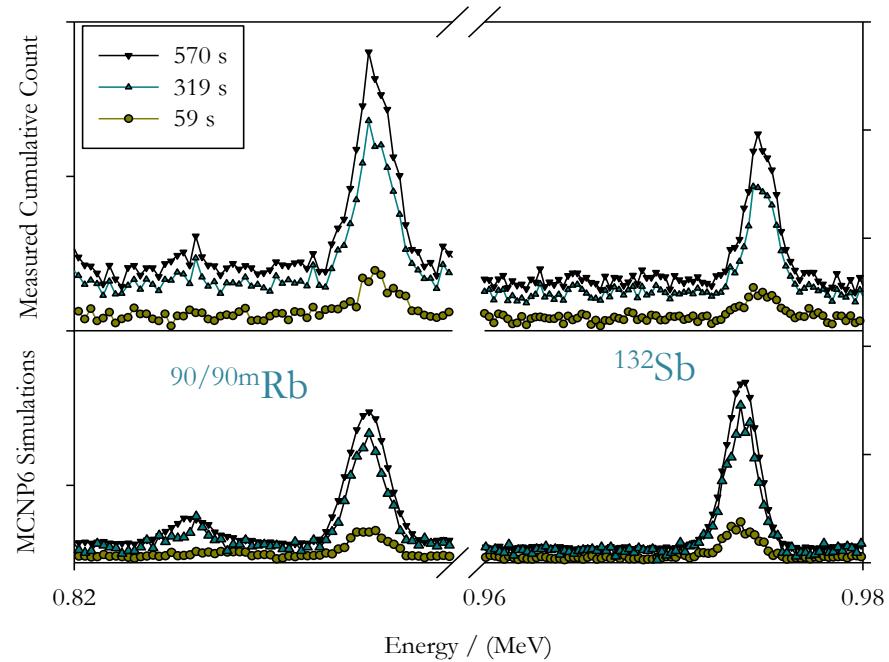
Future Work & Conclusions

Conclusions

- Preliminary comparisons of measured γ ray spectra of ^{235}U fission and MCNP6.1 are underway.
- MCNP predicted the presence of the majority of prominent measured peaks.
- Relative intensities of 25 most prominent peaks were in general agreement with several notable discrepancies, namely $^{90/90\text{m}}\text{Rb}$ and $^{132/132\text{m}}\text{Sb}$ peak energies.

Future Work

- MCNP6 comparisons with ^{239}Pu , ^{233}U underway
- Comparison of peak growth with respect to count time will also be included in future efforts.
- Will examine effects of updating cindergl.dat and cinder.dat with ENDFVII data for individual isotopes.



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C. McEwen and J. Shaw, Royal Military College of Canada



DG Production Procedure using Physics-Model Technique (Durkee et al. *Nucl. Tech.* 180 (2012) 336)

SOURCE-PARTICLE EMISSION AND INTERACTIONS

RESIDUAL PRODUCTION FOR FISSION AND ACTIVATION REACTIONS USING LIBRARY DATA OR PHYSICS MODELS

CALCULATE ATOM DENSITIES OF EACH RESIDUAL'S DECAY PRODUCTS USING CINDER'90

DELAYED NEUTRONS

USE PRE-CALCULATED CDFs FOR ENERGY SAMPLING, CALCULATE TOTAL DNs USING ATOM DENSITIES, DECAY CONSTANTS AND EMISISON PROBABILITIES

DELAYED GAMMAS

CALCULATE CDFs & TOTAL DGs USING ATOM DENSITIES, DECAY CONSTANTS, AND EMISSION PROBABILITIES

SAMPLE CDFs FOR NUMBER OF DELAYED NEUTRONS, THEIR EMISSION ENERGY, TIME, AND DIRECTION.

SAMPLE CDFs FOR NUMBER OD DELAYED GAMMAS, THEIR EMISISON ENERGY, TIME AND DIRECTION.

Relative Contributions from DU, Nat U, empty vials and HNO_3 solution

