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Title: MCNP6 Delayed Gamma Benchmark Using Experimental Data

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MCNP6 Delayed Gamma Benchmark Using Experimental Data

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An effort was undertaken in order to quantify the accuracy of the delayed photon capability in MCNP6. This validation process included comparing MCNP6 computed delayed gamma results to a quantifiable experimental benchmark. The benchmark utilized was an irradiation experiment conducted by A. W.Hunt, Vladimir Mozin, E.T.E. Reedy, H.A. Selpel and Steve Tobin at the Idaho Accelerator Center. This experiment involved a mono-energetic pencil electron beam impinged on a thin tungsten target resulting in bremsstrahlung photon production. These bremsstrahlung photons then strike a beryllium converter generating photoneutrons. Some of the photoneutrons then cause fission in a series of Pu targets resulting in delayed gamma emission.

Since the experiment consisted of two steps, the irradiation of the Pu sample and the delayed gamma detection, the simulation was also conducted in two steps: irradiation phase and detection phase. The first step modeled the electron beam which generated bremsstrahlung photons and subsequent photoneutrons creating fission events in the Pu targets. The delayed gamma energy and time dependent weight from induced interactions in the Pu target were tagged. The second step used tagged gammas to generate an emission source definition for the detection phase model. Several code and library enhancements were investigated in order to improve the delayed gammas computational accuracy of the MCNP.

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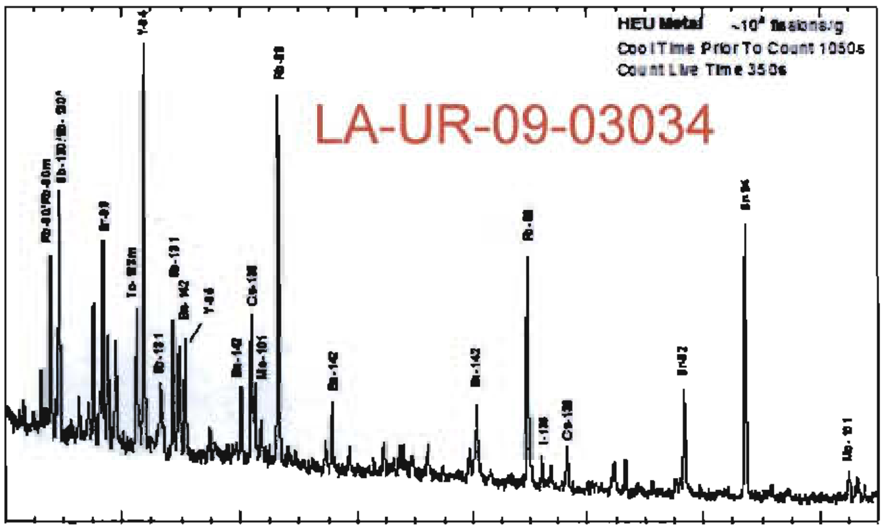
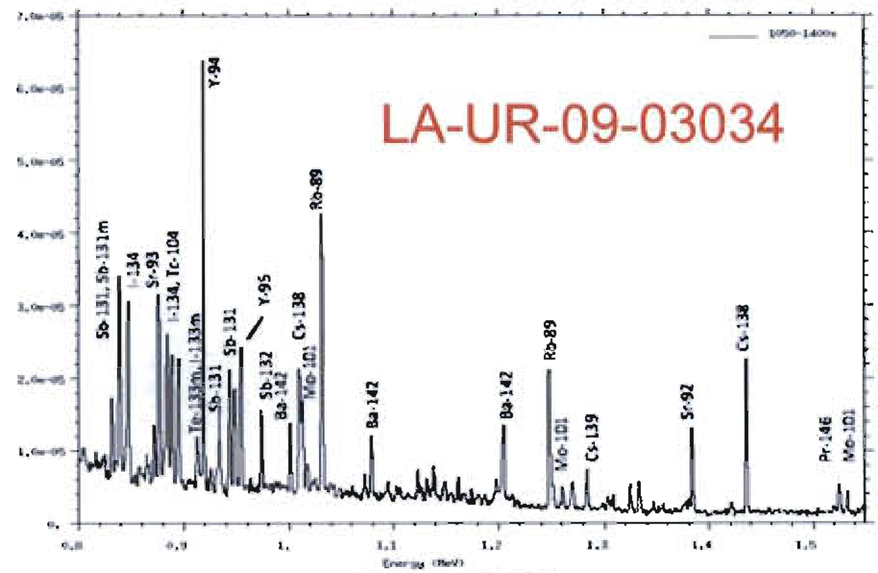
Outline

- MCNP6 Delayed Gamma History
- Experimental Setup
- MCNP6 Model
- Results
- Conclusions
- Future Work

History of the Delayed Gamma Feature



Beddingfield and Cecil, 1998



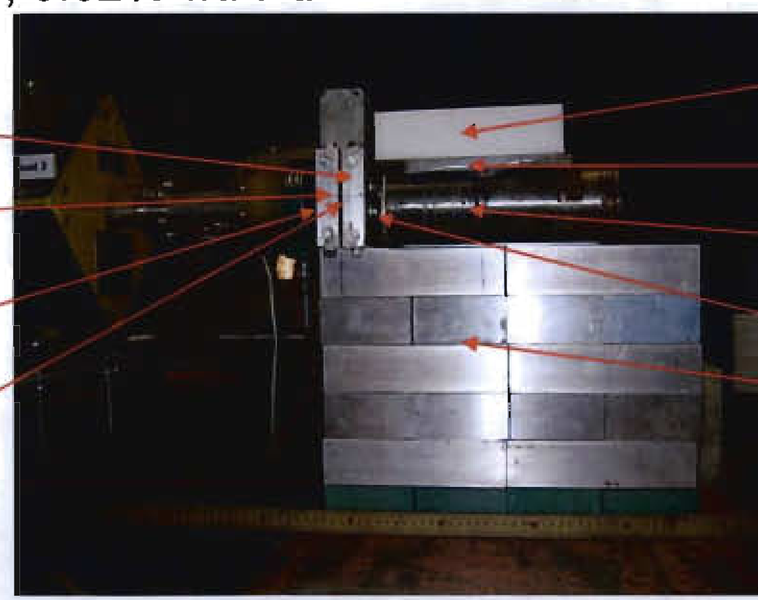
Durkee, 2009

- **Qualitative benchmark**
  - D.H. Beddingfield and F. E. Cecil, "Identification of fissile material from fission product gamma-ray spectra", *Nuclear Instruments and Methods in Physics Research*, A 417, 405-412 (1998)
  - J. W. Durkee, Jr., M. R. James, G. W. McKinney, H. R. Trellue, L. S. Waters, W. B. Wilson, "Delayed-gamma signature calculation for neutron-induced fission and activation using MCNPX, Part II: Simulations," *Progress in Nuclear Energy*, 51, pgs. 828-836 (2009)

Irradiation Setup

- **A delayed particle experiment was completed by V. Mozin, A. W. Hunt, E.T.E. Reedy, H.A. Selpel and S. Tobin at the Idaho Accelerator Center (IAC) in Pocatello, Idaho**
  - 30 min irradiation time
  - Plutonium targets were composed of 94.3% wt. Pu-239, 5.3% wt. Pu-240, 0.02% wt. Pu-241, and 0.2% wt. Am-241

Front view of irradiation setup



Side view of irradiation setup

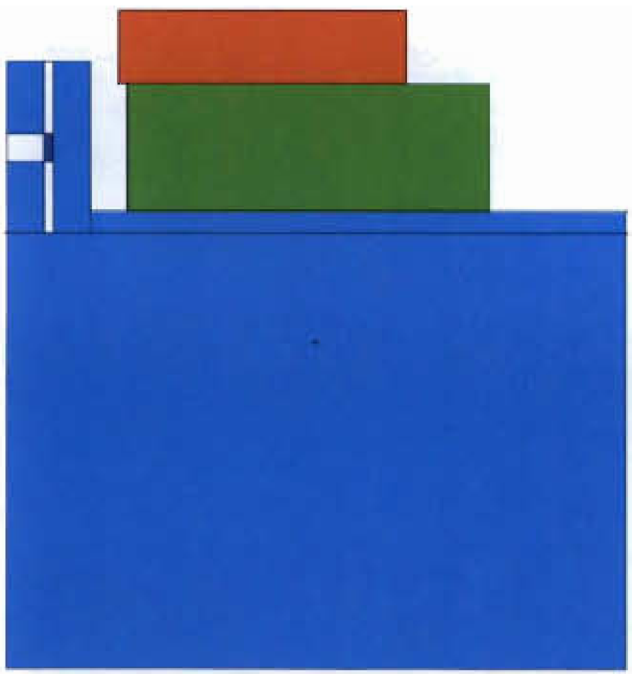
Delayed Gamma Detection Setup

- **Two Ortec HPGe Detectors**
  - Detectors encased in aluminum
  - Front face aluminum thickness 0.1 cm
  - Surrounding aluminum cylinder casing thickness10.16 cm
  - Target ~15 cm from detector face
- **~1 hour count time**

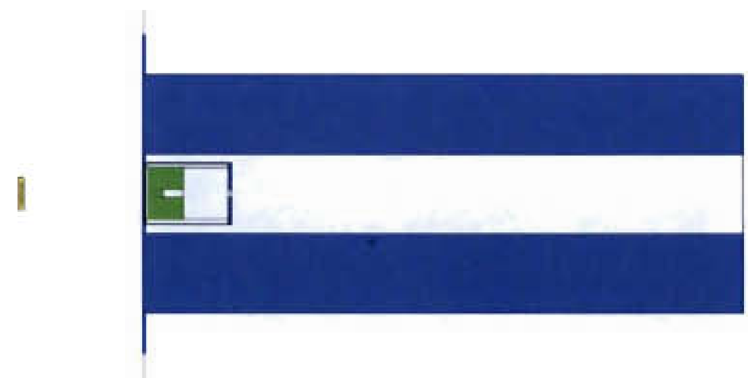
Detection setup

MCNP6 Model: Geometry

- MCNP6 model side view of irradiation phase

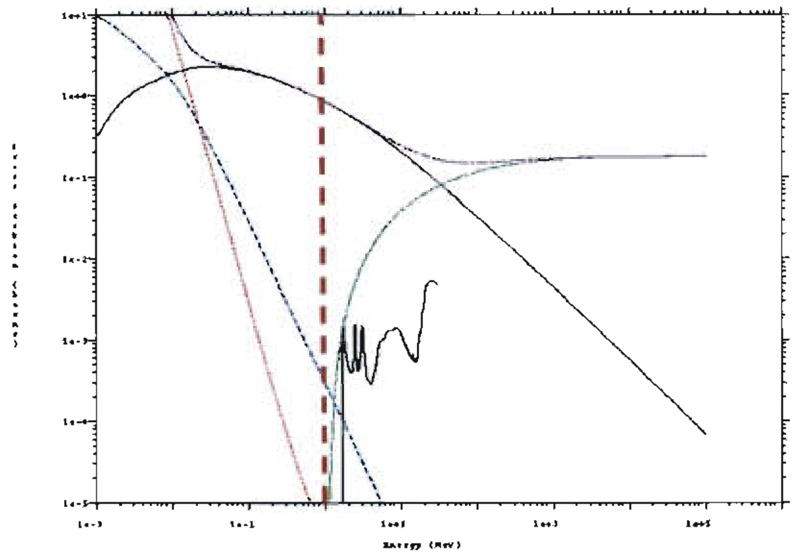


- MCNP6 model of detection phase

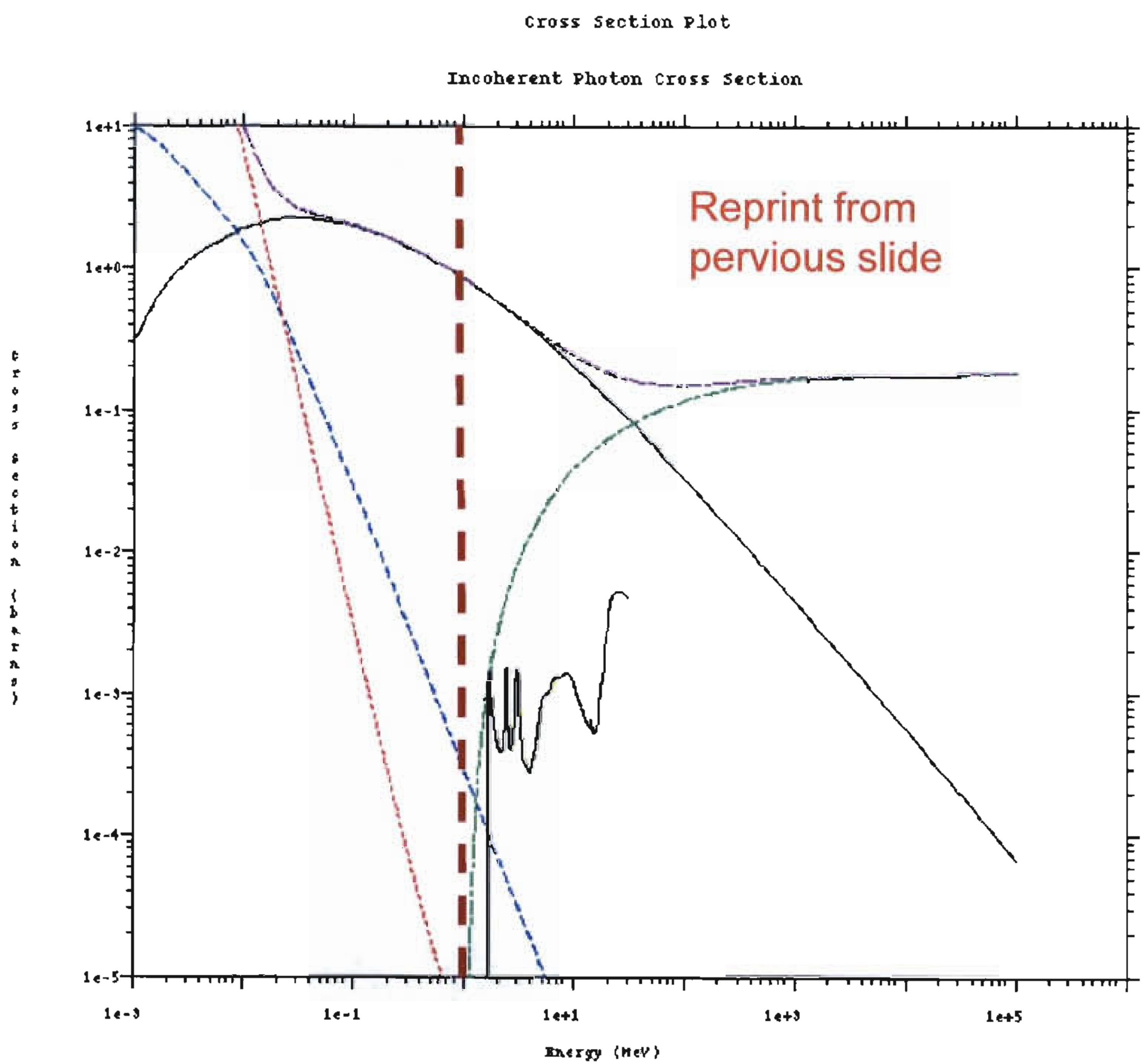


Physics Considerations

Photoatomic cross section	Type of reaction
————————	Incoherent
- - - - - - - -	Coherent
- - - - - - - -	Photoelectric
- - - - - - - -	Pair production
- - - - - - - -	Total
Photonuclear cross section	
————————	Total



- **2-3% of incident electrons create bremsstrahlung photons**
  - Bremsstrahlung creates a spectra of photon energies
- **Photonuclear cross section is 2.2 orders less than photoatomic**
  - Only those photons greater than ~1 MeV can create photoneutrons in Be
- **Not all photoneutrons interact with target**

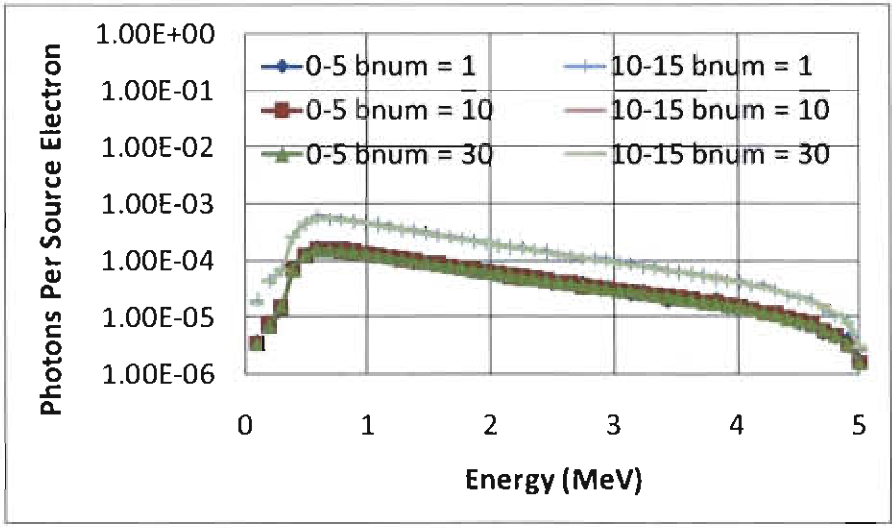

Cross Section Plot
Incoherent Photon Cross Section
Reprint from
pervious slide
1e+1
1e+0
1e-1
1e-2
1e-3
1e-4
1e-5
cross section (barns)
1e-3
1e-1
1e+1
1e+3
1e+5
Energy (MeV)

MCNP Model: Physics Biasing

- **BNUM controls production of bremsstrahlung photons**
  - bnum >0 → produce bnum times the analog number of bremsstrahlung photons
- **Biasing parameters used**
  - 0.95 MeV cut off for electrons
  - bnum = 50

BNUM	CTM	FOM	% Change
1	37	103	-
10	80	144	139
30	168	203	197

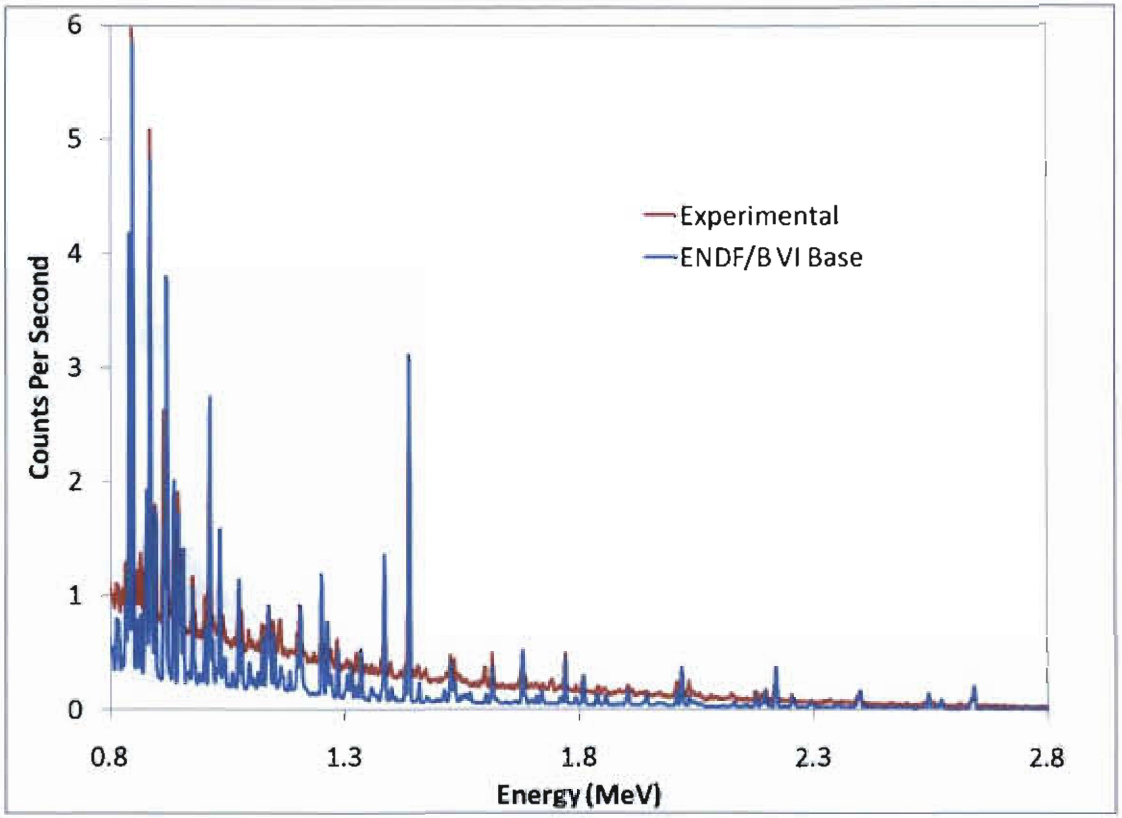
Results for cosine bin 0-5



Outgoing energy dependent photon current cosine bins 0-5 and 10-15

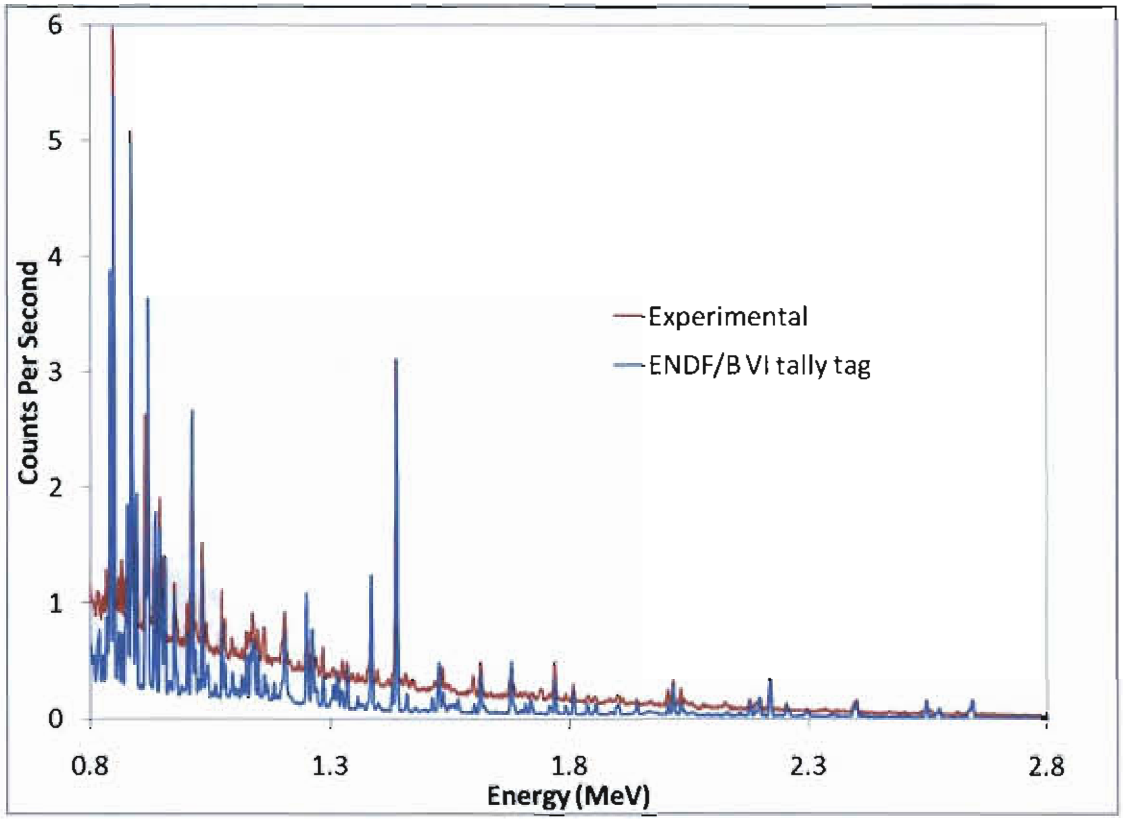
Initial Results

- **Parameters tested**
  - Photon tagging
  - Decay chain convergence criteria
  - Time integration sampling
  - Thermal vs. thermal and fast fission yields
  - ENDF/B VI.0 vs. ENDF/B VII.0 decay data sublibrary
- **Percent difference between simulation and experiment**
  - 1.01 MeV peak is 7.7%
  - 1.25 MeV peak is 17.5%
  - 1.38 MeV peak is 37.5%



Photon Tagging

- **Incoherent scattered photons now keep their tag**
- **Percent difference between simulation and experiment**
  - 1.01 MeV peak was improved by 3.0%
  - 1.25 MeV peak was improved by 10.5%
  - 1.38 MeV Peak was improved by 12.0%



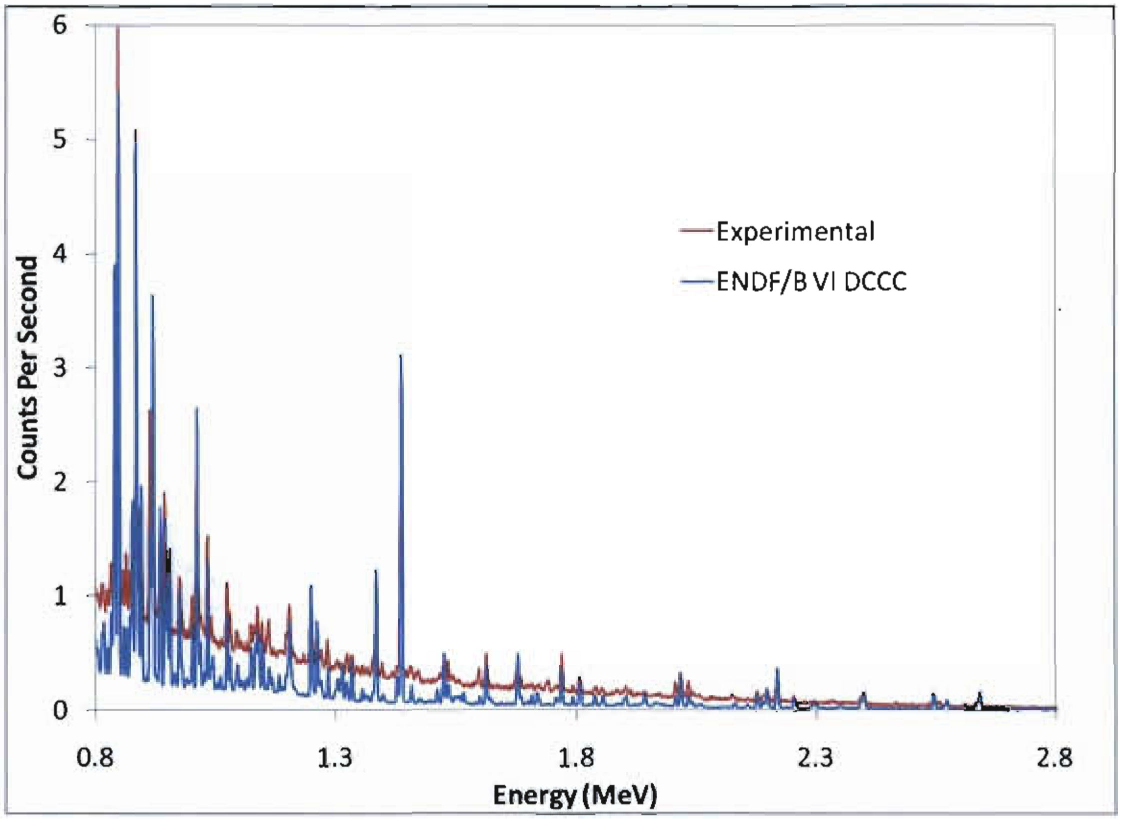
Decay Chain Convergence

- **Decay chain convergence criteria determines when a decay change is terminated**

$$\frac{dN_n}{dt} = -\beta N_n + \sum_{m \neq n} \gamma_{m \to n} N_m$$

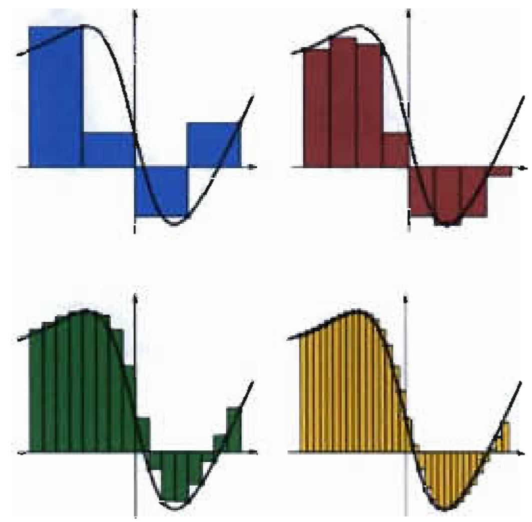
$$\int_{\Delta t} \beta N(t)dt > \epsilon$$

- **Percent difference between simulation and experiment**
  - 1.01 MeV peak was improved by 3.8%
  - 1.25 MeV peak was improved by 9.3%
  - 1.38 MeV Peak was improved by 13.2%



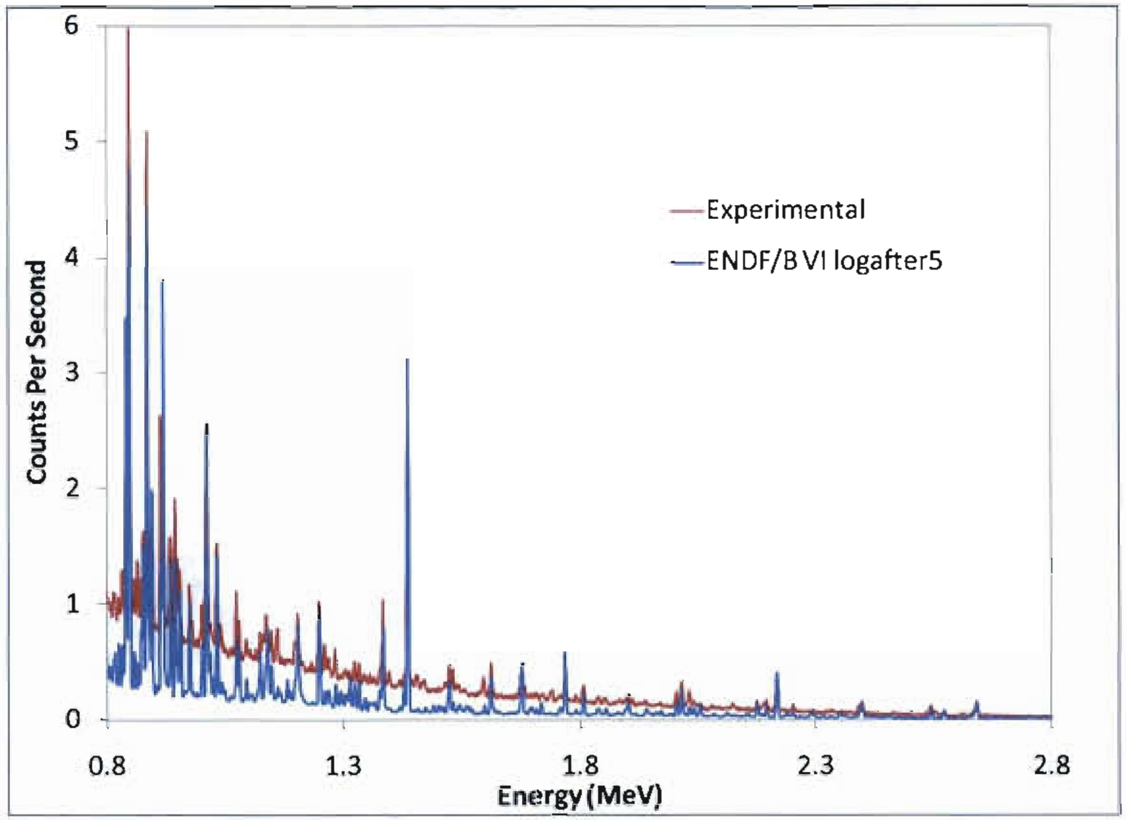
Time Integration Sampling

- **Time integration technique uses Riemann sums**
  - Total amount of gammas emitted over a time step
- **Currently**
  - Fine bins for time < 5 min
  - Coarse bins for time > 5min
- **Bin structure tested**
  - Original structure for time < 5 min and linear thereafter
  - Original structure for time < 5 min and logarithmic thereafter
  - Original structure for time < 15 min and logarithmic thereafter
  - Logarithmic



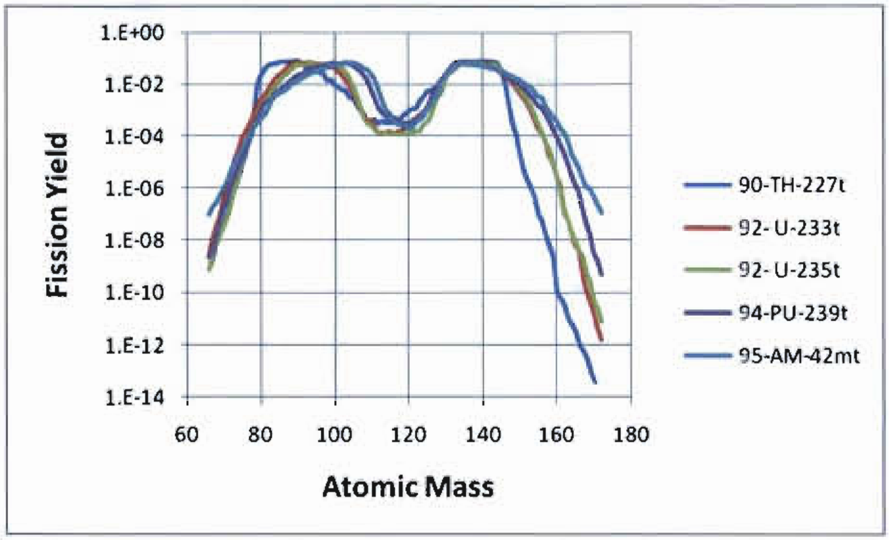
Time Integration Sampling Results

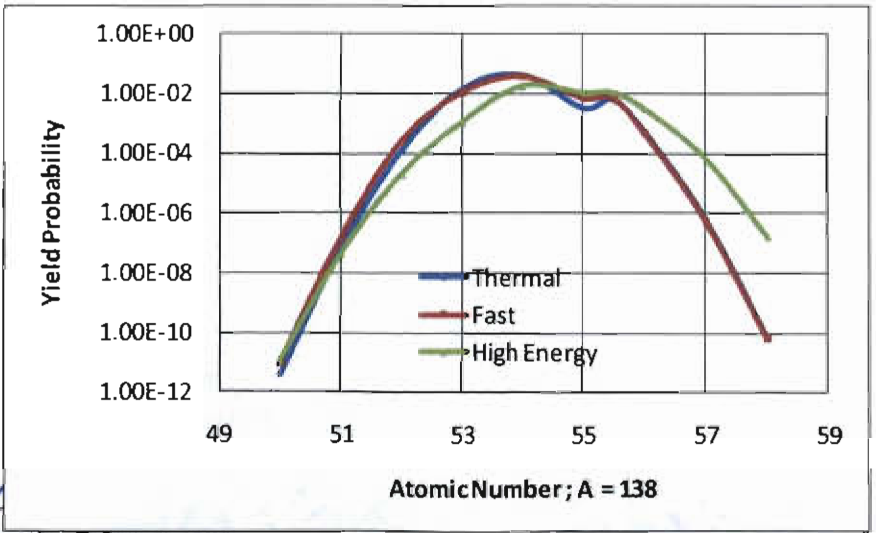
- **Logarithmic after 5 min**
- **Percent difference between simulation and experiment**
  - 1.01 MeV peak was improved by 7.2%
  - 1.25 MeV peak was improved by 7.4%
  - 1.38 MeV Peak was improved by 19.1%

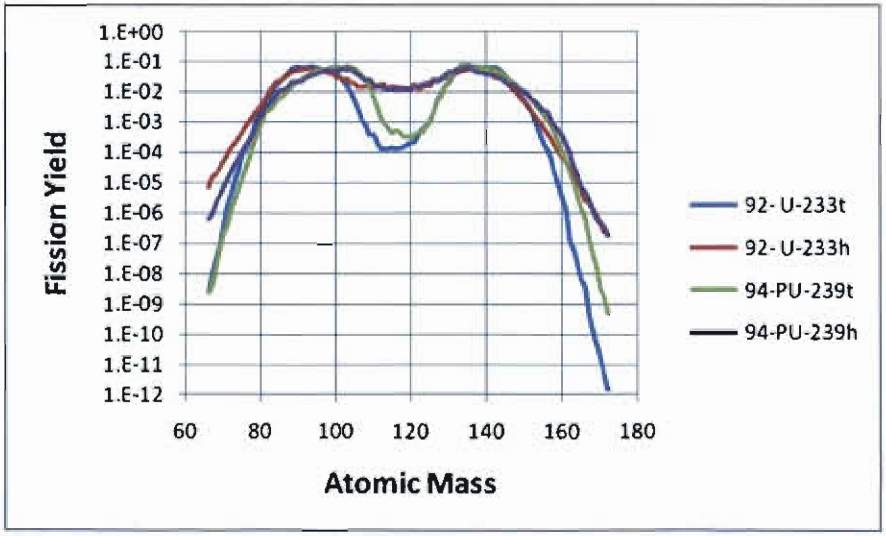


Fission Yields

- Fission yield for a given atomic mass have isotope energy dependence
- Within an isobar chain fission yields have roughly a Gaussian distribution

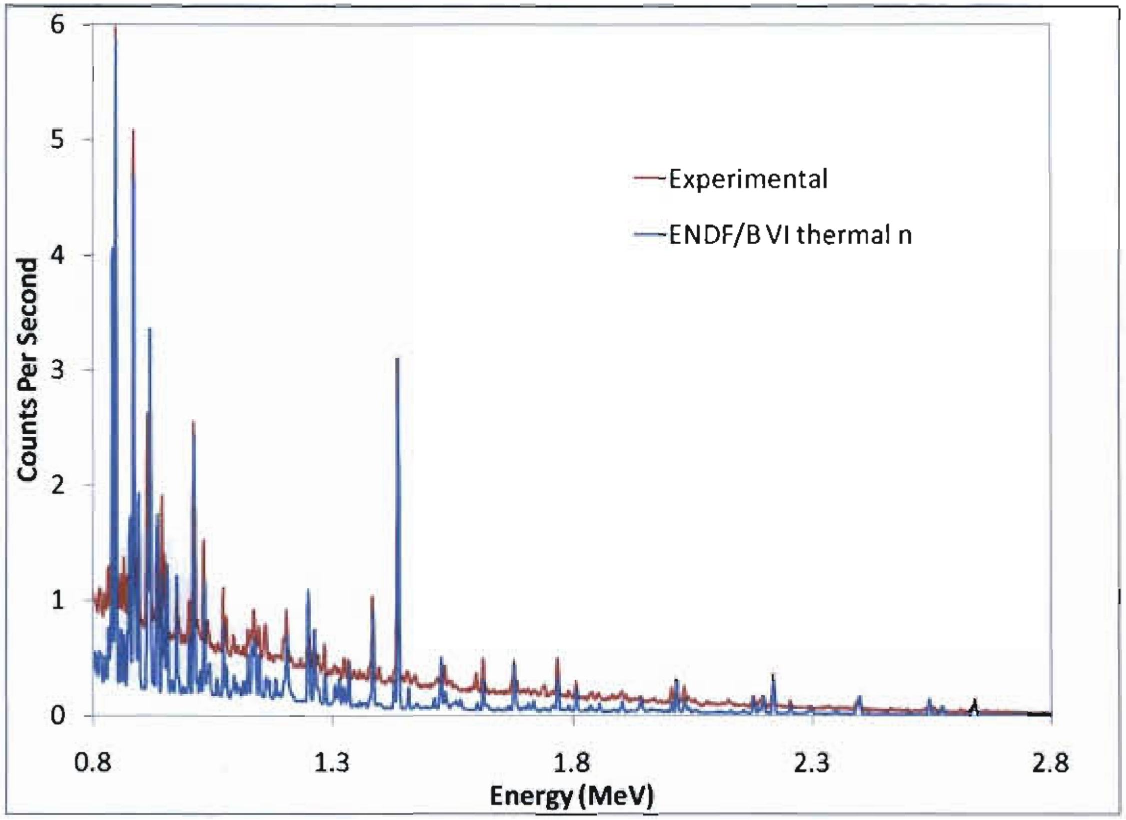






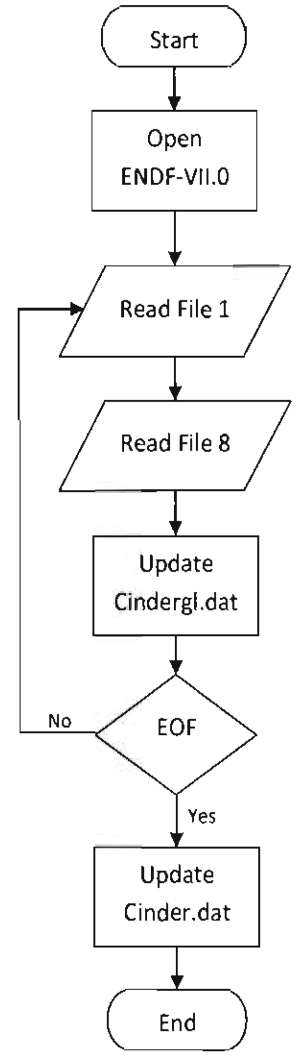
Fission Yields Results

- **Thermal, fast, or high energy fission yield**
  - Forced thermal fission yield
- **Percent difference between simulation and experiment**
  - 1.01 MeV peak was improved by 3.3%
  - 1.25 MeV peak was improved by 10.0%
  - 1.38 MeV Peak was improved by 27.3%



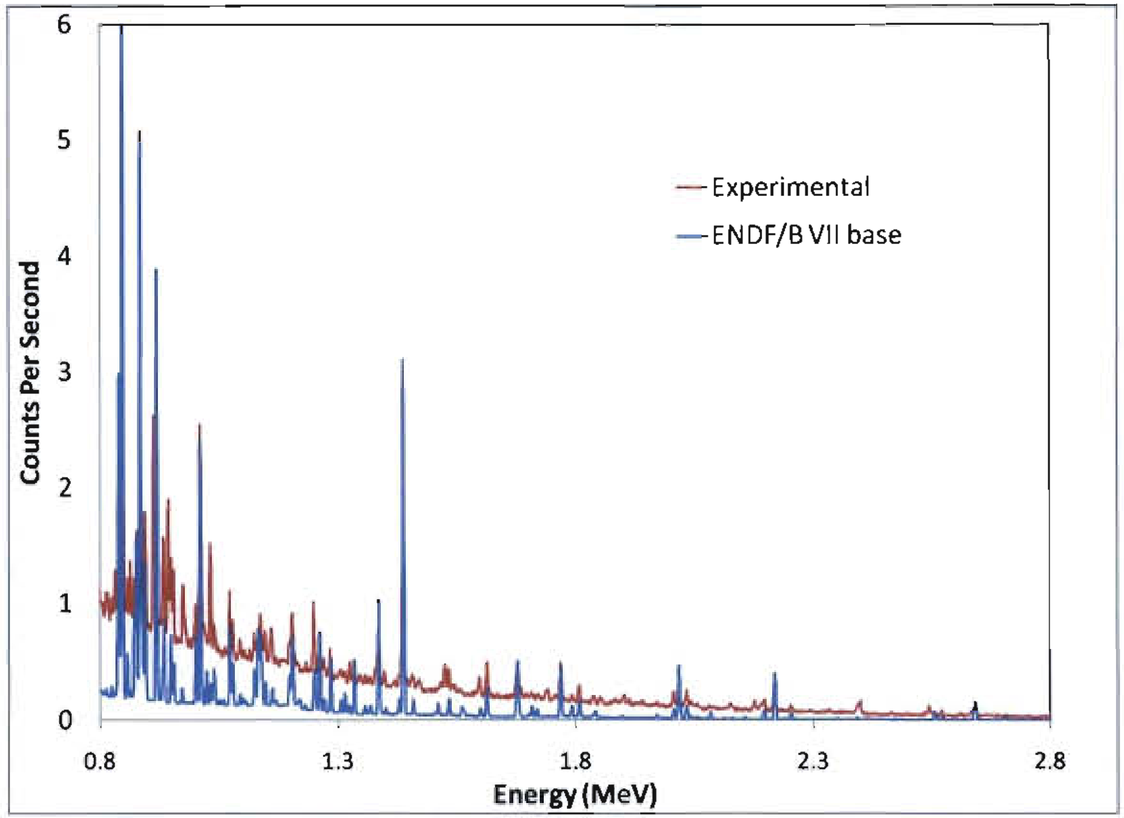
ENDF/B VI.0 and VII.0

- **ENDF2CINDER code**
  - Generates a new cindergl.dat from ENDF/B VII.0 decay data sublibrary
  - Updates cindergl.dat from 979 to 3507 nuclides
- **ENDF/B VII.0 decay sublibary format**
  - File 1 consists of "General Information"
  - File 8 contains the radioactive decay and fission yield data



ENDF/B VI.0 and VII.0 Results

- **Percent difference between simulation and experiment**
  - 1.01 MeV peak was improved by 5.2%
  - 1.25 MeV had a larger error of 40.1%
  - 1.38 MeV Peak was improved by 33.9%



Summary

- **The MCNP6 delayed gamma capability will provide a useful tool for nonproliferation/homeland security activities**
- **Each modification to the code was done separately**
  - Testing of upgrade combinations will be tested in the future
- **Both the time integration scheme that uses the original bins till 5 minutes implementing logarithmic interpolation to the final count time and the thermal fission yield modification lead to the greatest improvement**
  - Peaks: 1.01 MEV, 1.25 MeV and 1.38 MeV

Future Work/New Features

- Further test combinations of the mentioned upgrades
- Determine peaks of interest for applications and determine which modifications best improve those peaks
- Further examine results of systematic error and error in the modeling process.
- Integrate improvements for MCNP6 release in late summer 2011

Questions

We would like to acknowledge the sponsorship of the Defense Threat Reduction Agency