SAND2014-20239C

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Delayed Fission Gamma Characteristics of ^{235}U, ^{238}U, and ^{239}Pu

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Objectives

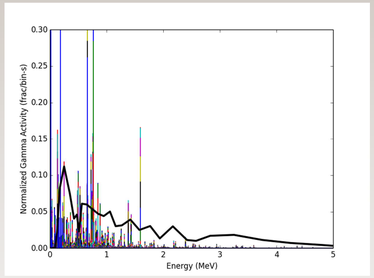
- How much fission energy is given off as photons?
- What is the time and energy dependence of this fission gamma energy?

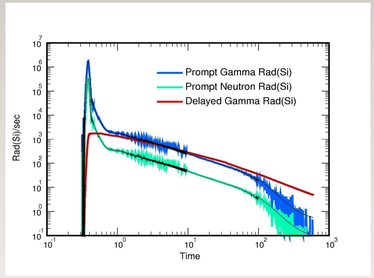
Why is this needed?

- Improved radiation-hardness requirements simulations.
- Improved photon dose characterization for radiation effects testing.

Applications

- High energy resolution simulation fluxes for qualification simulations.
- Diamond PCD Unfolding in the ACRR using GAMMA.





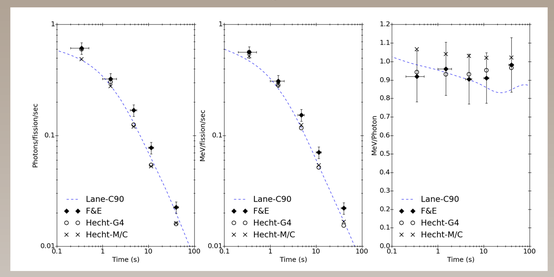
Approach

- SNL-Modified CINDER2008
- Tracks neutron and photon induced transmutation and fission, as well as natural decay.
- High energy resolution (7428 groups) vs typical 25 group.
- 1 microsecond Watt-spectrum mixed-field pulse isotropically incident on 1 cm^3 of material.
- 1 time step per decade from 1 us to 0.1 s.
- 10 log-spaced steps per decade out to 10^9 sec.

Validation

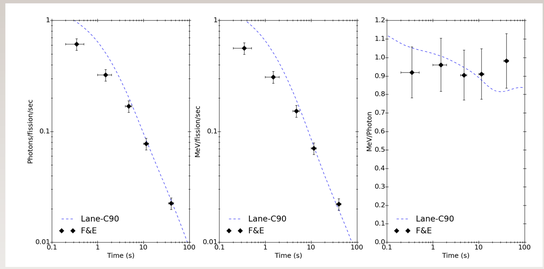
^{235}U

- Experimental Comparison (Fisher & Engle: GODIVA II)
- Comparison to Simulation (Hecht: Geant4, MCNP/CINDER)



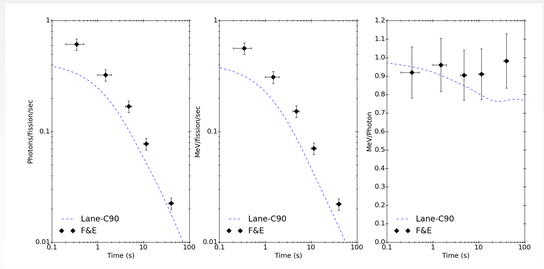
^{238}U

- Experimental Comparison (Fisher & Engle: GODIVA II)



^{239}Pu

- Experimental Comparison (Fisher & Engle: GODIVA II)



- P. C. Fisher, L. B. Engle, Delayed Gammas from Fast-Neutron Fission of ^{232}Th, ^{233}U, ^{235}U, and ^{239}Pu, *Physical Review*, Vol. 134, No. 4B, May 1964.
- A. A. Hecht, *et al.*, Comparison of Geant4 and MCNP6 for use in delayed fission radiation simulation, *Annals of Nuclear Energy*, Vol. 69, July 2014.

Results

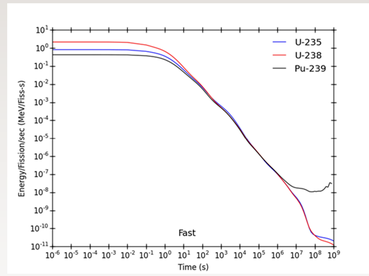
- The average number of photons per fission ($\bar{\nu}_\gamma$), average energy per photon (ϵ_γ), and total photon energy per fission ($E_{\gamma,tot}$) were calculated from CINDER.
- The table below compares results to the literature for ^{235}U.

Results	$\bar{\nu}_\gamma$ (per fission)	ϵ_γ (MeV)	$E_{\gamma,tot}$ (MeV)	Energy Range (MeV)
This work	9.45	0.73	6.91	0.001 – 30
Oberstedt *et al.*	8.19 ± 0.11	0.85 ± 0.02	6.92 ± 0.09	0.1 – 6.0
Verbinski *et al.*	6.70 ± 0.30	0.97 ± 0.05	6.51 ± 0.30	0.14 – 10.0
Pleasonton *et al.*	6.51 ± 0.30	0.99 ± 0.07	6.43 ± 0.30	0.09 – 10.0
Peelle *et al.*	7.45 ± 0.35	0.96	7.18 ± 0.26	0.14 – 10.0
ENDF/B-VII.1	6.86	0.96	6.58	0.10 – 10.0
Becker *et al.*	8.05	0.88	7.06	0.14 – 10.0
Regnier *et al.*	7.900 ± 0.005	0.840 ± 0.001	6.64 ± 0.012	0 – 13.5

- Table adapted from Oberstedt *et al.*, Improved values for the characteristics of prompt-fission γ-ray spectra from the reaction ^{235}U(n_{th}, f), *Phys. Rev. C*, 87, May 2013. DOI: 10.1103/PhysRevC.87.051602

- The $E_{\gamma,tot}$ for ^{238}U from this work, 8.27 MeV, aligns with the ENDF/B-VII.1 value of 8.25 MeV. But, there is a large discrepancy for ^{239}Pu (5.93 vs. 7.14). By plotting the time dependent gamma-ray energy release to 30 years, one can see that results will be affected after 10^7 sec (100 days) by the natural decay of ^{239}Pu.

This work	U-238	Pu-239
$\bar{\nu}_\gamma$ (per fission)	10.1	7.33
ϵ_γ (MeV)	0.82	0.81
$E_{\gamma,tot}$ (MeV)	8.27	5.93



Conclusions

- For ^{235}U, $\bar{\nu}_\gamma$ is higher than expected, however, $E_{\gamma,tot}$ agrees with literature.
- Many experiments do not account for lower energy photons and may skew results at longer time scales.
- Simulations that do not account for natural decay photons will become unphysical at long time scales.
- More data needed for ^{232}Th, ^{233}U, ^{238}U, and ^{239}Pu.