Improved Prompt and Delayed Decay Spectra for Advanced Fuels

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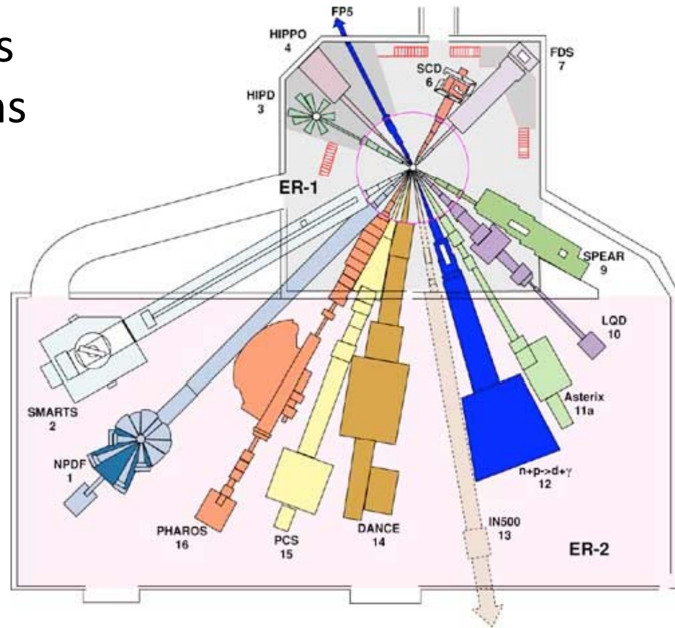
Goal & Approach

- **Characterize Radiation from Fission for Different Reactor Fuels**
  - Prompt gammas & neutrons
  - Delayed gammas & neutrons
  - Betas & Antineutrinos
  - Charged particles



High neutron flux available at LANSCE

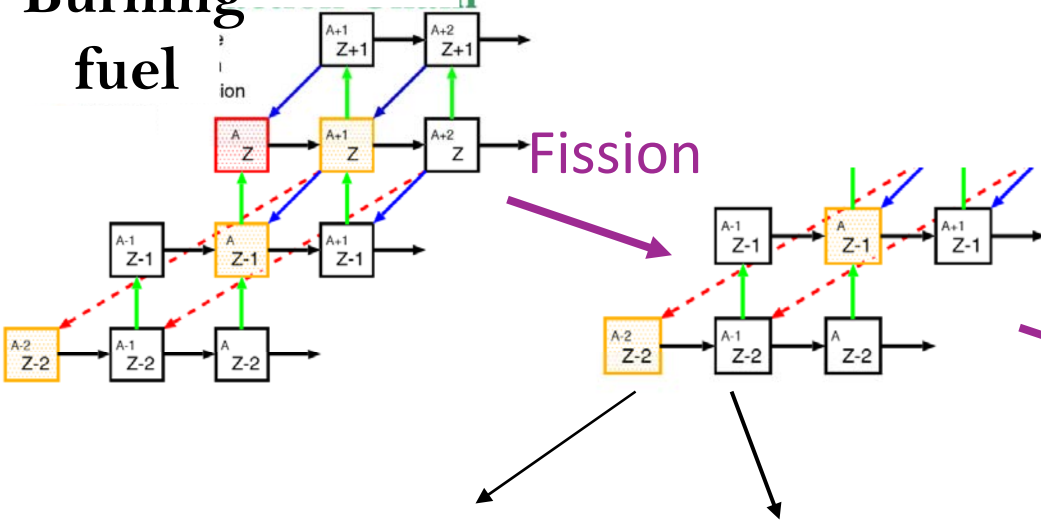
- **Applications :**
  - Stockpile Stewardship
  - Criticality Safety
  - Decay heat
  - Safeguards
  - Non-proliferation
  - Waste Management
  - Materials Damage
  - Fundamental Science

Prompt gammas measured at Dance BaF_2 Array at LANSCE

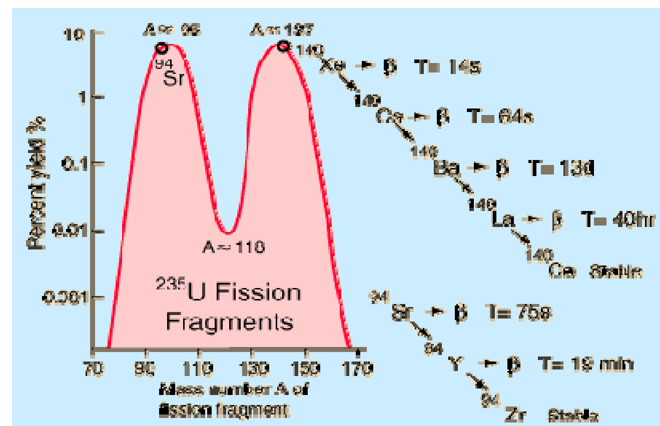
The project is a joint experimental-theoretical attack on the problem

Sources of Radiation & Time scales

Burning fuel



decay



Prompt γ–rays and neutrons

10^{-19} sec to micro-second

Delayed γ, n, β, ν

milliseconds- to years

Theory and Simulations

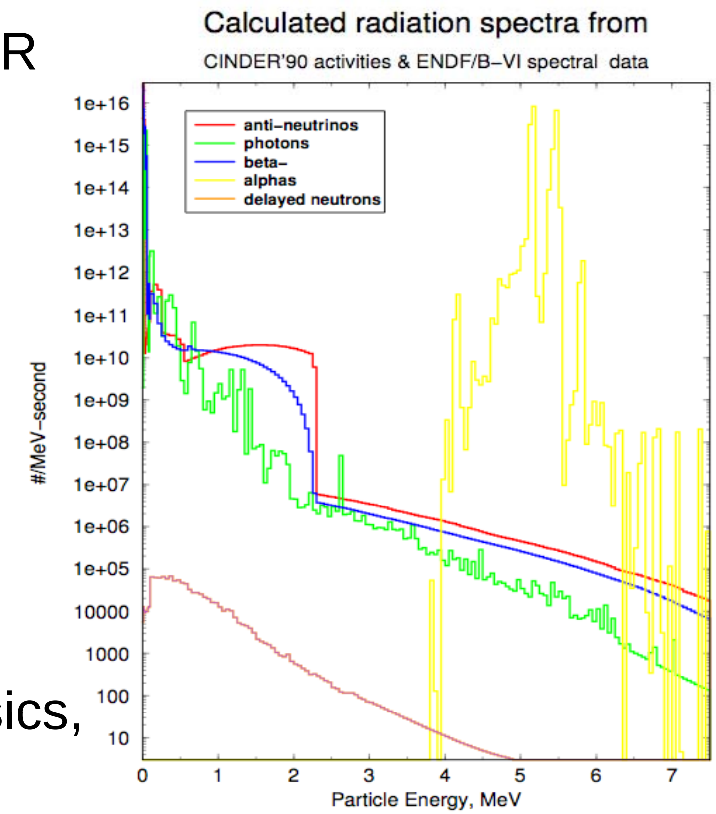
Radiation Involves n, α ,β, ν, γ

Depends on the fuel composition, irradiation history, and neutron flux

- Run reactor burn simulations using CINDER
- Track 3400 nuclides & isomers
- Calculate time- and energy-dependent decay spectra using ENDFB-VI and ENDFB-VII decay libraries

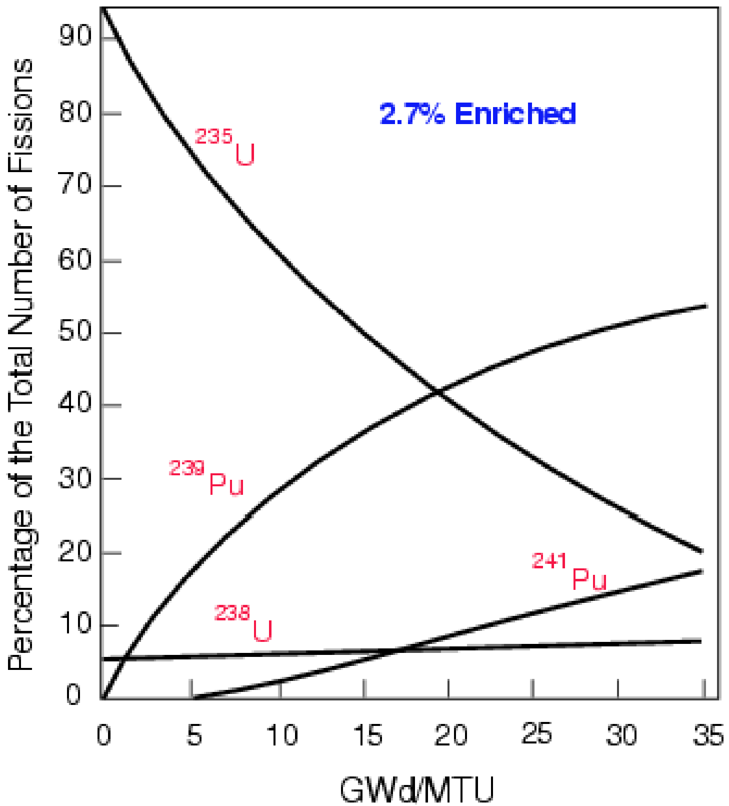
- Compare with macroscopic –microscopic model of Moller and Nix

- Examine implications for nuclear astrophysics, reactor monitoring, etc.

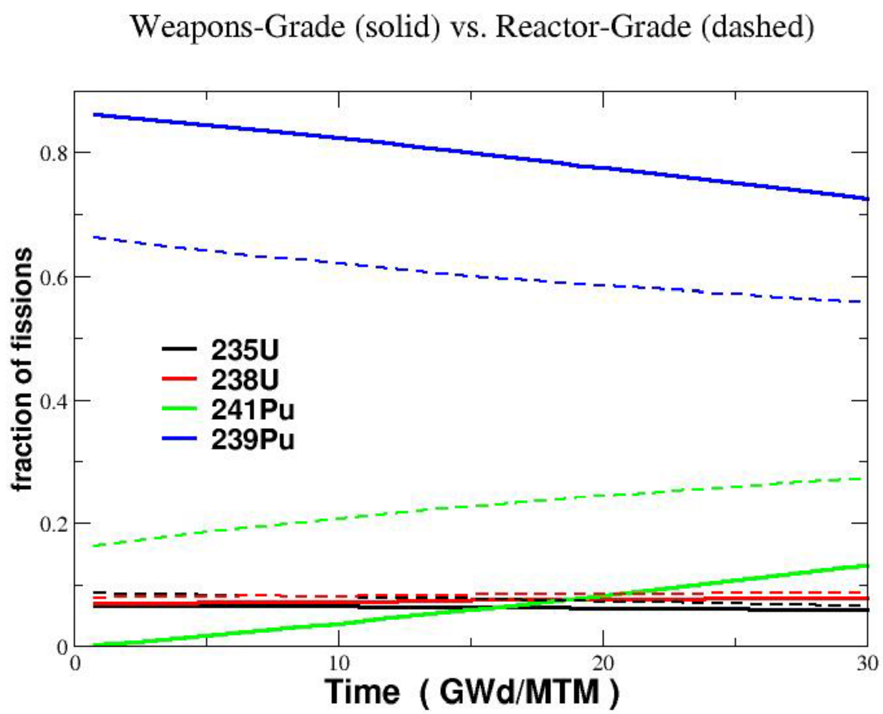


Simulation for WIPP Weapons grade Pu

As Burn Proceeds Different Combination of Isotopes Fission



PWR, lightly enriched uranium



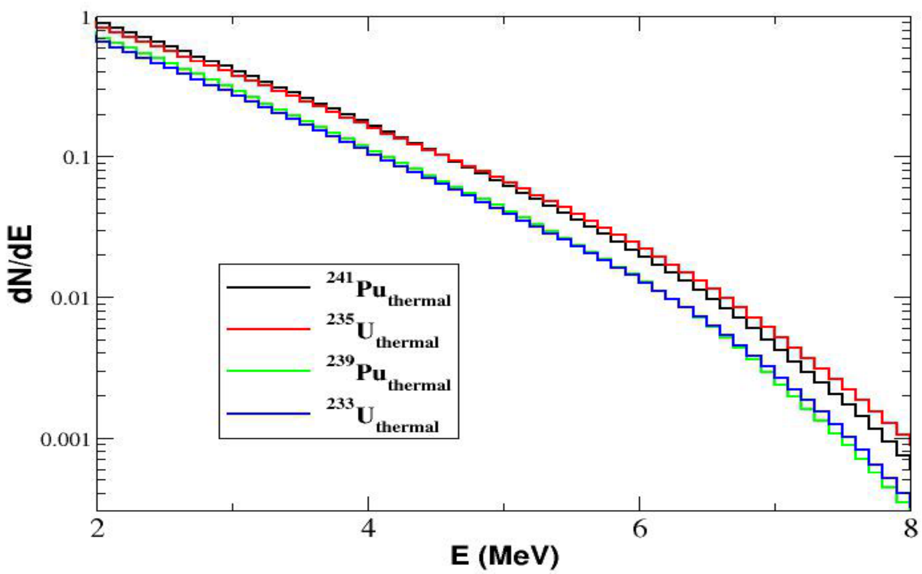
MOX Pu: **$U0_2$ + 5.3% PuO_2**

Aggregate Fission Beta and Antineutrino Spectra

Important for reactor monitoring, reactor heat, and neutrino oscillations

$$S_k(E) = \sum_{FF} Y_{FF}(Z,Z,m)S(E,Z,A,m)\text{;}\quad S(E,A,Z,m) = \sum_{i} B^i S(E,Z,A,m,E_0^i)$$

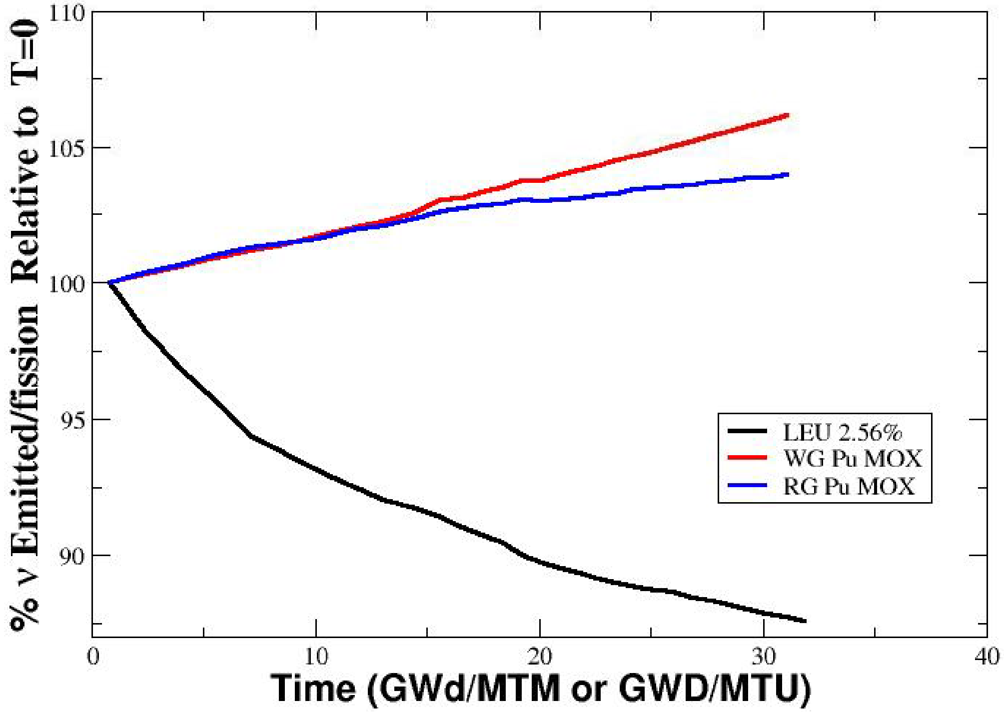
Sum over hundreds of fission fragments and thousands of end-point energies



Equilibrium aggregate beta spectra for thermal fission on U and Pu

Cumulative fission yields from England & Rider (LA-UR- 94-3106 ENDF-349)
Individual spectra from ENDFB-VI, both continuous and discrete data

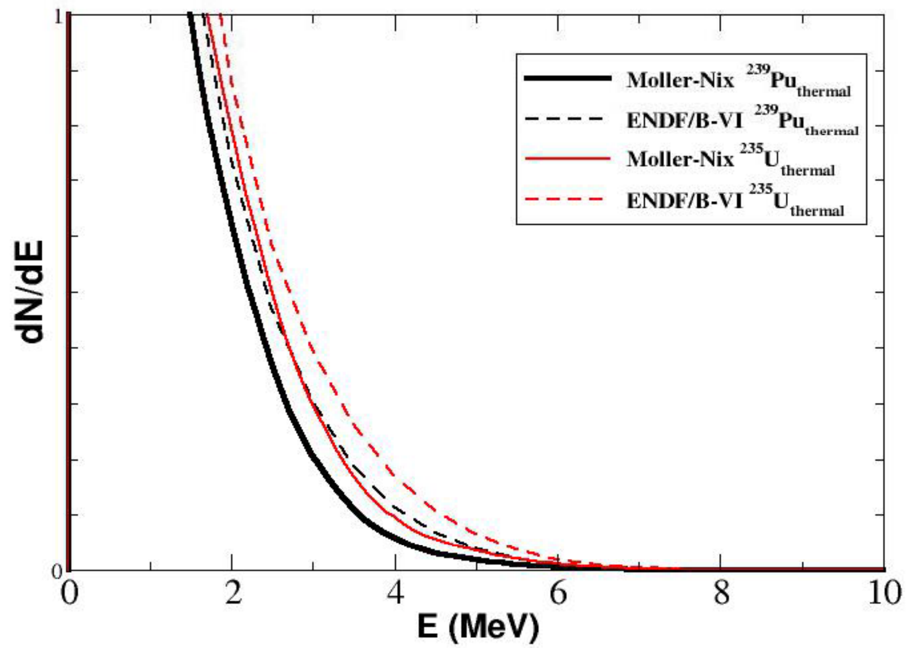
Implications for Reactor Antineutrino Monitoring



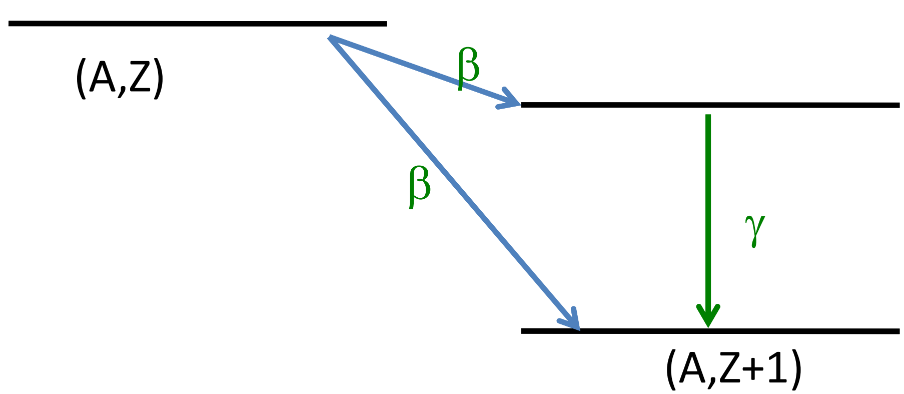
- Number of antineutrinos/fission ***decrease*** with burn of LEU
- Number of antineutrinos/fission ***increase*** with burn for MOX PU

Antineutrino monitoring could verify burning of MOX Pu with independent knowledge of thermal power

Comparison with Moller-Nix



- Average end-point energy predicted by Moller-Nix ~ 300 keV smaller than ENDF
- Moller-Nix predicts decay to excited states considerably more often than ENDF
- Consequently, more high-energy β-delayed gamma-rays emitted
- Implications for neutron star crust heating calculations from EC gammas



Prompt Spectra

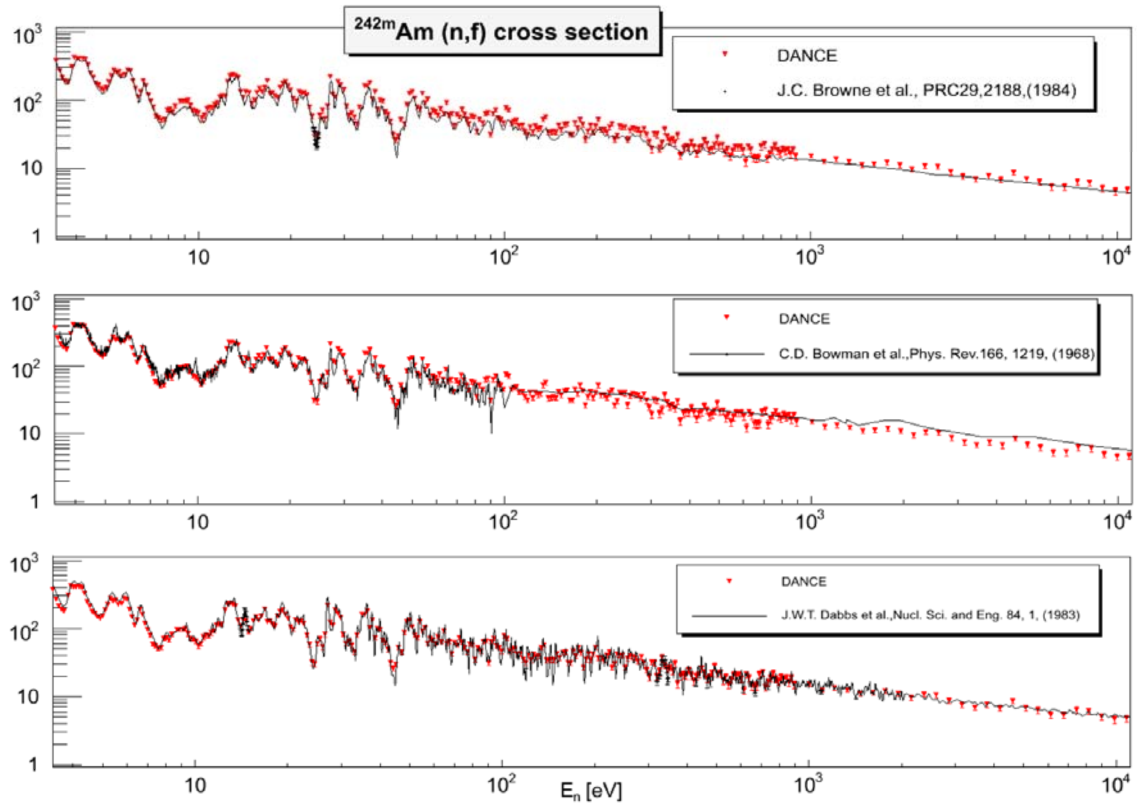
Prompt Gammas measured for ^{239}Pu, ^{241}Pu, ^{233}U, ^{235}U, ^{242m}Am

- Highly enriched samples used to prepare targets
- DANCE + high neutron flux
  => measurements possible on ~ 50 μg samples
- Gamma-ray multiplicity and energy measured
- Unfolding analysis used to extract the true multiplicity from the data

- Fission fragment detector used to identify prompt fission gamma-rays
- Delayed gammas also measurable

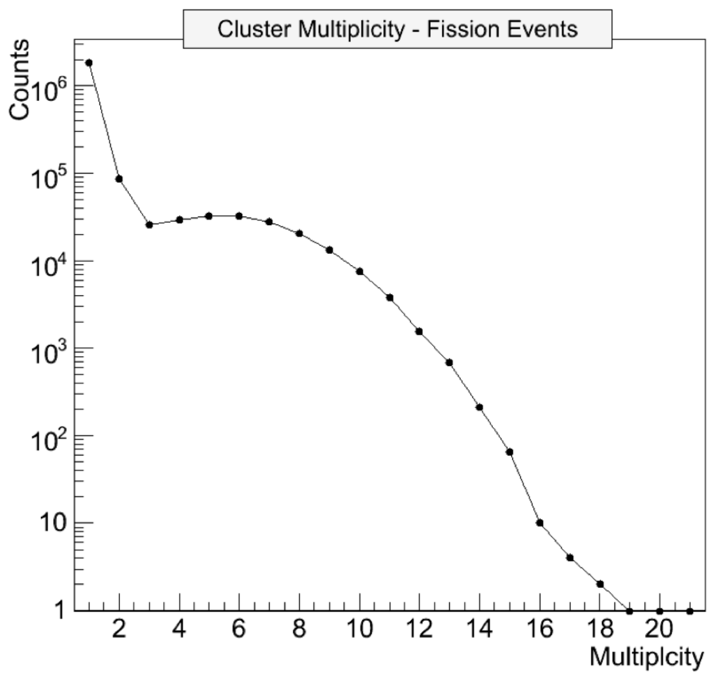
Example: ^{242m}Am

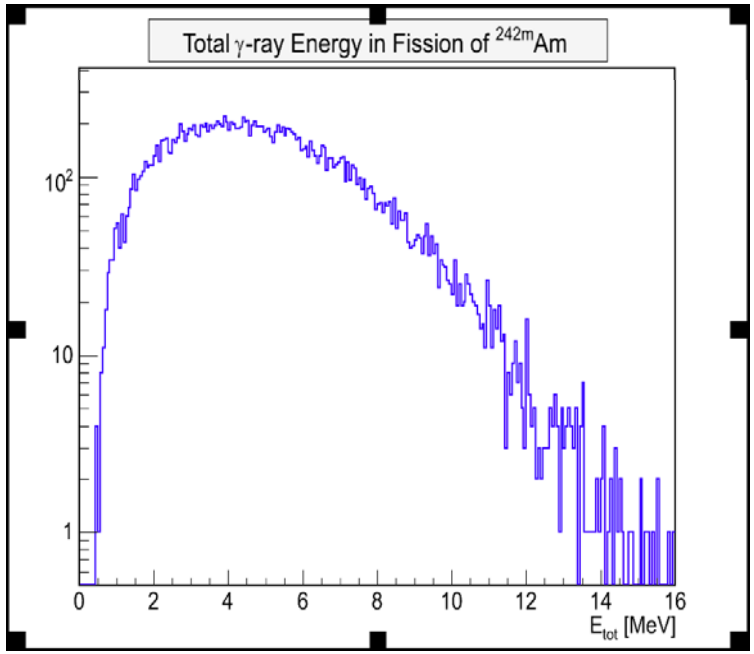
- LLNL recovered available ^{242m}Am and prepared 44μg enriched target (electroplated onto a 0.5 mil beryllium substrate)
- ^{242m}Am installed at DANCE with fission fragment detector
- Collected data for 14 days



Measured ^{242m}Am(n,f) cross section

Prompt Gamma-ray Energy and Multiplicity from Fission of ^{242m}Am, En=6 eV – 0.5 MeV





Currently analyzing data to unfold the true multiplicity from the exp data

Students and Postdoc Training

- LANL: Y.H. Lee (PD), Jainwei Hu (GS→PD), N. Jarrett (UGS), G. Wilburn (UGS), I. Wisher (UGS→GS)
- LLNL: A. Chyzh (PD), E. Kwan (PD), J. Gositic (PD)

Budget: LANL:	**Original $1098K**	**Remaining:**	**$290K**
LLNL:	**$592K**		**$80K**

Status of Deliverables

1. Data analysis for prompt γ-ray energy and multiplicity data for $^{233,235}U$ and ^{242m}Am
   Completed

2. Fabricate ^{241}Pu target **Completed**

3. Beta and antineutrino spectra for all Pu and U isotopes up to 15 MeV **Completed**

4. Finalize measured prompt spectra for $^{233,235}U$, ^{239}Pu, ^{242m}Am **Completed**

5. Beta and antineutrino spectra for all neutron-induced fissioning systems **On-going**

6. Detailed report on prompt and delayed decay data for $^{233,235}U$, ^{239}Pu, ^{242m}Am and ^{241}Pu (preliminary) **On-going**

Future Directions

Nuclear Physics

- Detailed measurements of delayed gamma spectra
- Accurate determination of antineutrino spectra for neutrino oscillations
- Implications for microscopic nuclear structure models (e.g., Moller-Nix)

Applied Physics Spin-offs:

- Antineutrino reactor monitoring (NA-22), with LLNL, SNL, MIT, and Chalk River
- Monitoring Plutonium Reprocessing Activities using Fission gases (NA-22), with Chalk River
- Improved prompt gamma diagnostics for Stockpile Stewardship (NNSA, C1), current LLNL and LANL team