# Precision Measurements of Fission-Product β Branching Ratios

NSSC Nuclear Science & Security Consortium

I.E. Hernandez[1], D.E.M. Hoff[2], K. Kolos[2], S. Neupane[2], N.D. Scielzo[2], M.A. Stoyer[2], A.P. Tonchev[2], V.E. Jacob[3], J.C. Hardy[3], D. Melconian[3], J.A. Clark[4], B. Longfellow[2], E.B. Norman[1], W.J. Ong[2], A. Richard[2], D. Santiago-Gonzalez[4], G. Savard[4,5]

[1]University of California, Berkeley, [2]Lawrence Livermore National Laboratory, [3]Texas A&M University, [4]Argonne National Laboratory, [5]University of Chicago

## Mission Relevance

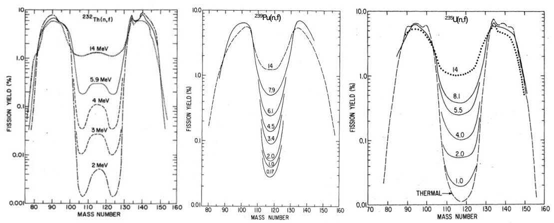
**An accurate and comprehensive nuclear database allows the prevention and deterrence of global nuclear proliferation**

β-decay following fission events provides detectable signatures to identify fission products and their respective yields.

- Measurements rely on precise knowledge of β-decay observables

This work looks along the A=111 mass decay chain

- Fission fragments that populate the “valley” in thermal fission product yields
- Yield increases as neutron energy increases in induced fission
- Provides direct forensic signature for presence of fast neutrons




Mass-yield curves for monoenergetic-neutron-induced fission of $^{232}$Th, $^{235}$U, and $^{239}$Pu
*(provided by L.E. Glendenin et al. 1980, J.E. Gindler et al. 1983, L.E. Glendenin et al. 1981)*

## Background

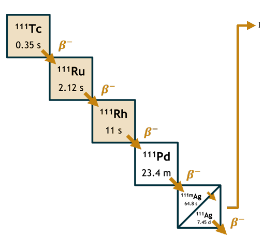
Fission products undergo $\beta^-$ decay and subsequentially emit gammas to reach stability

- The fraction of γ rays of a certain energy emitted during this process is known as the *γ branching ratio* or *intensity* ($BR_\gamma$)
- Fission product yields (FPY) can then be found based on the measured number of characteristic γ rays ($N_\gamma$):

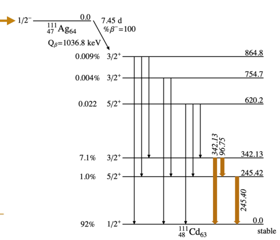
$$FPY \approx \frac{N_\gamma}{BR_\gamma} \qquad BR_\gamma = \frac{N_{\beta\gamma}}{N_\beta}\frac{1}{\epsilon_\gamma}\frac{\epsilon_{\beta_{tot}}}{\epsilon_{\beta_\gamma}}$$

- Many long-lived isotopes have large (3%-30%) uncertainties in their γ-ray intensities contribute to the absolute uncertainty for FPY measurements

**Our work aims to provide precision measurements (known to <1%) of the γ branching ratios from long-lived fission products, specifically in $^{111}$Ag.**




Decay chain of fission daughter products

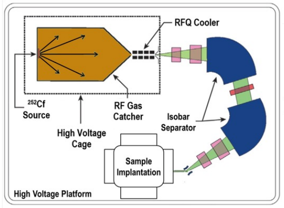



$^{111}$Ag $\beta^-$ decay scheme to $^{111}$Cd

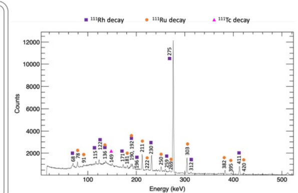
## Experimental Approach

**Sample harvested at Californium Rare Isotope Breeder Upgrade (CARIBU) at Argonne National Laboratory (ANL)**

- Fission products from $^{252}$Cf spontaneous fission source collected into beam
- Beam is then accelerated and filtered through isobars for mass purification
- Relevant fission products implanted on a 200 nm thick carbon foil
- $^{111}$Ag purity in extracted sample approximately 99.94%




Simplified graphic of CARIBU beam line




γ-ray spectrum of isotopes produced during collection

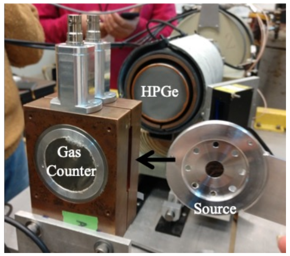
**Source shipped to Texas A&M University (TAMU) for γ-ray spectroscopy**

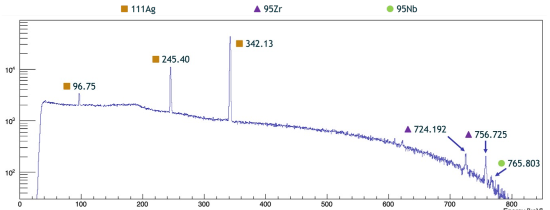
Precisely calibrated HPGe detector coupled with 4$\pi$ gas counter provides β-γ coincidence analysis

- HPGe absolute efficiency known to 0.2% over 5—1400 keV

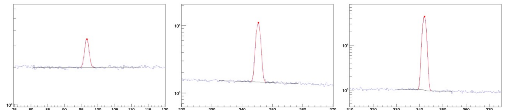
Source placed in gas detector mounted at various distances from face of HPGe detector:

- 151 mm from HPGe cap
- 51 mm from HPGe cap with plastic medium for background suppression




Source spectrum collected at TAMU of γ rays in coincidence with emitted β-particles



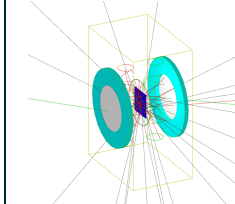
$^{111}$Cd γ-ray peaks and background fitted with Gaussian and step function, respectively

## Efficiency Calculations

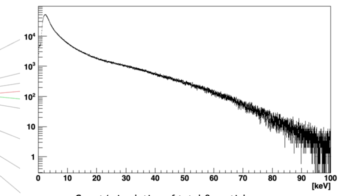
γ-ray detection efficiencies provided by CYLTRAN simulations of the TAMU HPGe detector

β-particle and β-γ coincidence detection efficiencies provided by Geant4 simulations of the 4$\pi$ gas counter

- Close to 100% detection efficiency



Geant4 visualization of gas counter




Geant4 simulation of total β-particle energy deposited in gas detector

## Preliminary Results and Future Work

Using the gamma branching ratio formula where $N_{\beta\gamma}$ is the β-γ coincidence peak area, $N_\beta$ is the total number of β-particles detected, and $\epsilon_\gamma$, $\epsilon_{\beta tot}$, $\epsilon_{\beta\gamma}$ is the γ-ray, β-particle, and β-γ coincidence detection efficiency (respectively):

| γ-ray Energy [keV] | $I_\gamma$ | $I_\gamma$(S. Collins et al. 2013) | $I_\gamma$(NNDC) |
|---|---|---|---|
| 96.75 | 0.0999(22) | 0.1018(14) | 0.1155(60) |
| 245.40 | 1.077(14) | 1.113(14) | 1.235(66) |
| 342.13 | 6.57(7) | 6.68(7) | 6.68(33) |

**Future work**

Multiple experiments to determine $BR_\gamma$ using this method have been carried out for $^{95}$Zr, $^{147}$Nd, $^{144}$Ce, and $^{156}$Eu

- Future experiments will look at $^{161}$Tb, $^{128}$Sb, and $^{115m}$Cd in the interest of reducing uncertainty in medical isotope diagnostics, FPYs, and r-process calculations

Use of nuCARIBU facility for sample implantation

- Replace 252Cf spontaneous fission source in CARIBU with actinide foil source for neutron-induced fission
- More reliable source of fission products

Local experimental setup at LLNL Nuclear Counting Facility with 4$\pi$ gas counter and BeGe detector for γ-ray spectroscopy

## Acknowledgements

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