Energy Dependent Fission Product Yields

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Motivation: Provide High-precision, Self-consistent FPY Data to Support Fission Theory and Evaluation

Goal: Predicting independent and cumulative FPYs data simultaneously and consistently in the energy-dependent manner
Previous Campaign: Cumulative FPYs from Long Irradiation

- Peculiar energy dependency
- There is a positive slope of the $^{147}$Nd FPY from 0.5 to ~4.0 MeV:
  \[ \Delta Y(^{147}\text{Nd})/\Delta E_n = (5.8\pm1.5)\%/\text{MeV} \]
- At higher energies the FPY for $^{147}$Nd turns over and decreases

Fission Product Yield Measurements at TUNL using Monoenergetic Neutron Beams

\[
FPY = \frac{\text{Gamma\_count}}{\text{Fission\_count}} \times \left( \frac{m_{\text{thin}}}{m_{\text{thick}}} \right) \times C_i
\]

Short-lived Fission Product Yields (min – hours)

- Six irradiations on $^{235}\text{U}$, $^{238}\text{U}$, and $^{239}\text{Pu}$ at $E_n = 0.56, 1.5, 4.6, 6.5, 9.0, \text{ and } 14.8 \text{ MeV}$
  - Irradiation time = 1 h
  - Transfer time ~ 4 minutes using the JACK-RABBIT System
  - Counting time = one week of continuous counting

- FPY data for more than 45 fission products with half-live of few minutes to a few days

- Providing time dependent FPY information to the FIER* code

* E. Matthews et al. FIER code. NIMA A 891 (2018) 111–117
Short-lived FPYs from Neutron Induced Fission of $^{235}\text{U}$, $^{238}\text{U}$, and $^{239}\text{Pu}$ at $E_n = 4.6$ MeV

J. Silano et al. Prepared for publication
Short-lived FPYs from Neutron Induced Fission of $^{235}\text{U}$, $^{238}\text{U}$, and $^{239}\text{Pu}$ at $E_n = 9.0$ MeV

![Graph showing cumulative yield of various fission products](image-url)

J. Silano et al. Prepared for publication
Fission Gamma-Ray History of the FPY data

Cumulative fission product yields of $^{235}\text{U}$ and $^{239}\text{Pu}$ as a function of product mass

Fission product gamma-ray ratio as function of incident neutron energy

Time evolution of fission product yield $\gamma$-rays from $^{235}\text{U}$, $^{238}\text{U}$ and $^{239}\text{Pu}$

A. Tonchev et al. LLNL report. Prepared for publication
Fastest Sample-Irradiated Transfer System in the Entire NNSA Complex

RApid
Belt-driven
Irradiated
Target
Transfer
System

**R A B I T T S**

**Completed**
- 1 and 10 m transfer systems
- Transfer time = 400ms/1m or 1s/10m
- Fully synchronized with the DAQ system and beam time structure
- User defined cycles \( t_{\text{irr}}, t_{\text{dec}}, t_{\text{mes}} \) can be repeated many times
- List-mode DAQ based on digital electronics

**Performed**
- Significant background improvement
- Multiple cycles on \(^{235}\text{U}, ^{238}\text{U}, \text{and} ^{239}\text{Pu} \) at \( E_n = 1.5, 2.0, \text{and} 4.6 \text{ MeV} \)
Fastest Sample-Irradiated Transfer System in the Entire NNSA Complex

**RApid**

**Belt-driven**

**Irradiated**

**Target**

**Transfer**

**System**

**RABITTS**

**Completed**
- Complete redesign of the 10 m system
- Obtained state-of-the-art BEGe detectors, combined with digitized based DAQ. Significant (>30%) energy resolution of the fission gamma-ray spectra

**Performed**
- FPY data for FPs with half-live of sub-second to a few minutes
- Developed analytical methods to process complex gamma-ray spectra

December 15, 2018

BEGe detectors, combined with digitized based DAQ. Significant (>30%) energy resolution of the fission gamma-ray spectra

BEGe

CeBr$_3$

Clove

10 m system

021829
RABBITS in Action
Preliminary $^{238}$U FPY Data at $E_n = 2.0$ MeV

- Observed over 300 $\gamma$-rays resulting from fission, representing over 87 fission products
- Preliminary FPY values for 39 fission products

Additional data
- $^{235}$U, $^{238}$U, $^{239}$Pu
- $E_n = 2.0, 4.5$ MeV

Constraining cumulative yields and moving towards independent yields
Fission Fragment Distribution*

Completed: 16 FPYs
(long irradiation)

Fission Product Distribution
Fission Product Distribution

Completed: 16 FPYs (long irradiation)

Obtained: 46 FPYs (JackRabbit)
Demonstrate: 87 FPYs (RABITT)

Obtained: 46 FPYs (JackRabbit)

Completed: 16 FPYs (long irradiation)
Broader Impact of the New Fission Product Yield Data

Fission Product Yields

Basic Physics

Application

Reactor neutrino study

Nuclear astrophysics and cosmochemistry

Radio-isotope production for medical applications

New FPY data base

Nuclear Forensics

Nuclear energy
Summary

- Constructed two (1 and 10 m) fast sample-transfer systems fully synchronized with the TUNL beam structure and DAQ
- Demonstrated unambiguous isotope identification (>87 fragments) using different cycle modes
- Consistent time-dependent FPY information from different symmetric and asymmetric modes of irradiation and counting

Short-lived fission products are in our reach!
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