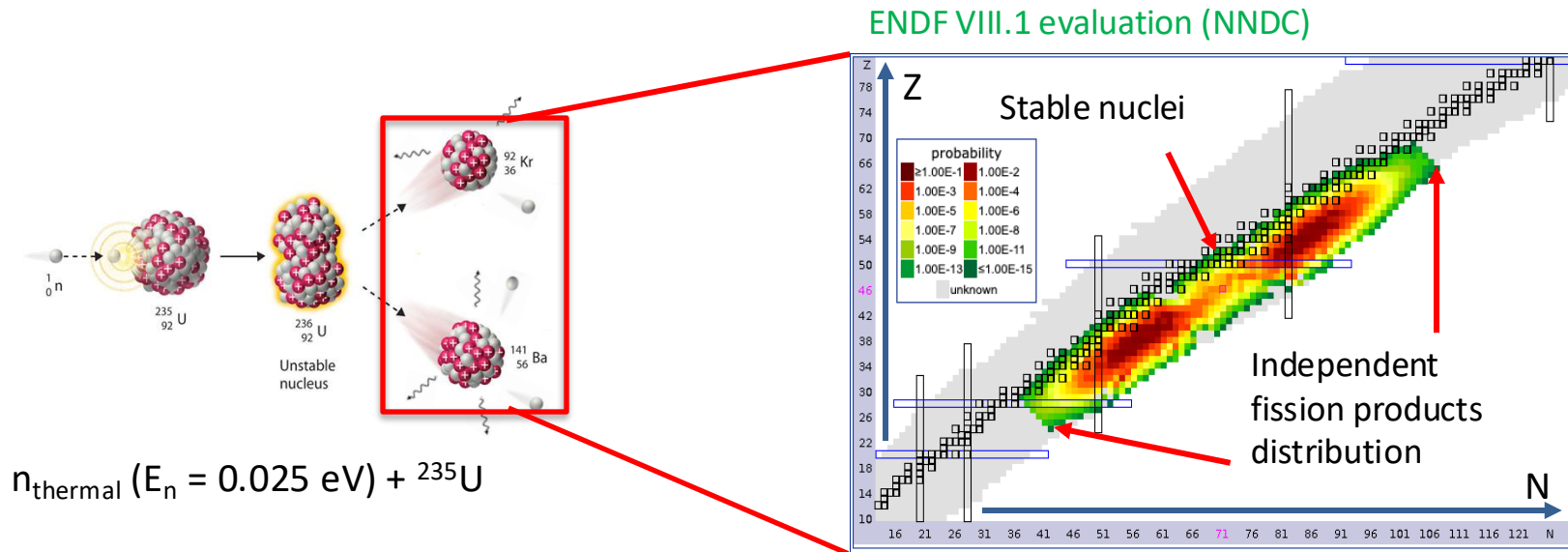# Cumulative fission product yields from neutron-induced fission of ^{235}U and ^{239}Pu at 4.6 MeV

A.P.D. Ramirez, J. Silano, A.P. Tonchev, R. Malone (LLNL)

M. Gooden, T. Bredeweg, V. Linero, D. Viera, J. Wilhelmy (LANL)

S. Finch, C. Howell, Krishichayan, W. Tornow (TUNL)

FIESTA 2024

Lawrence Livermore National Laboratory

Fission Product Yield

ENDF VIII.1 evaluation (NNDC)

$n_{thermal}$ (E_n = 0.025 eV) + ^{235}U

Stable nuclei

Independent fission products distribution

- **Independent fission yields** - probability of specific nuclide produced directly in a fission process (post-neutron emission)

- **Cumulative fission yields** - probability of a specific nuclide produced directly in a fission process and via the decay of precursors
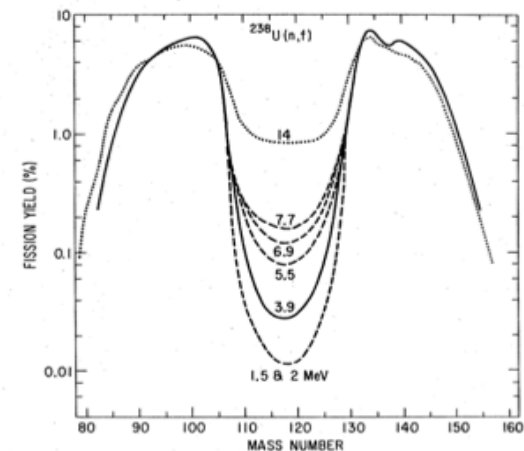
Impact of FPY Data

- ## Reactor applications
  - Decay heat after shutdown of reactors due to β and γ decays of fission products

- ## Nuclear astrophysics
  - FPY required in modeling nucleosynthesis in the cosmos via fission recycling

- ## Nuclear forensics
  - Examination of nuclear and other radioactive materials using analytical techniques to determine the origin and history of the material

- ## Fundamental understanding of the fission process
  - Study nuclear fission in both analytical and numerical ways to understand the mechanisms responsible for fission properties

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- Rely on nuclear data libraries:
  - only three energy regions: 25 meV (thermal), 0.5 MeV (fission), and 14 MeV (high energy)

- Improved precision of FPY including short-lived fission products ($T_{1/2} < 1$ hr) – not a lot of experimental data

- Need of nuclear FPY data for future compilation and evaluation work

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Goal: **Provide high-precision, energy-dependent FPY data to support fission theory and evaluation**

- Fission product yield measurements using neutron activation method and γ-ray spectroscopy
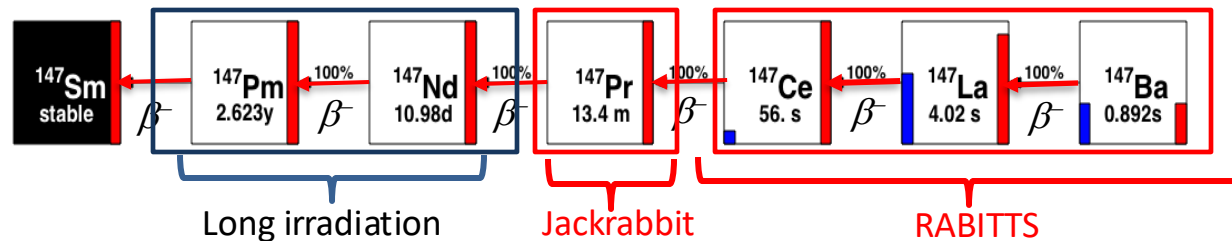
For A = 133:
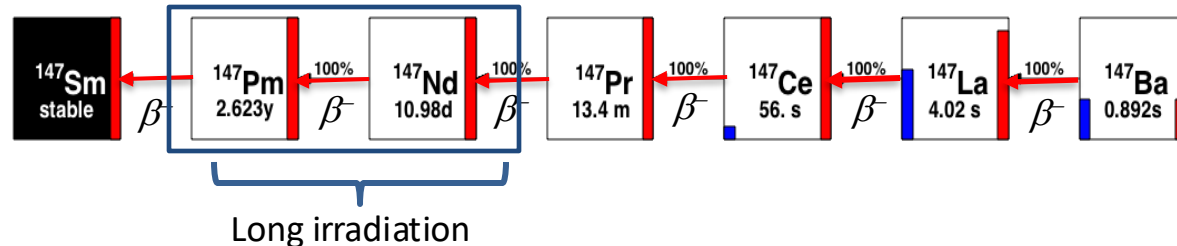
Long irradiation

- Previous campaign on long-lived fission products ($T_{1/2} > 1$ hr) with energy dependence (Long-irradiation activation)

M.E. Gooden et al., NDS 131, 319 (2016) and PRC 109 (4), 044604

LLNL-LANL-TUNL Collaboration

- Extend FPY data to fission products with half-lives of minutes to seconds

For A = 133:

Long irradiation   Jackrabbit   RABITTS

- **Long irradiation** – irradiation for a few days to a week
- **Jackrabbit** – irradiation for 1-2 hours

Conventional Activation Method

- **RABITTS** – cyclic activation

Conventional to Cyclic Activation

Neutron irradiation

Counting facility

+

T_{irr} = 1 hr; T_{count} = 5 m; T_{wait} = 4.5 m
Number of cycles: 1

^{96}Sr (1.07 s)

Single irradiation

Multiple irradiation

$T_{1/2}$ = 5 m
$T_{1/2}$ = 1 m
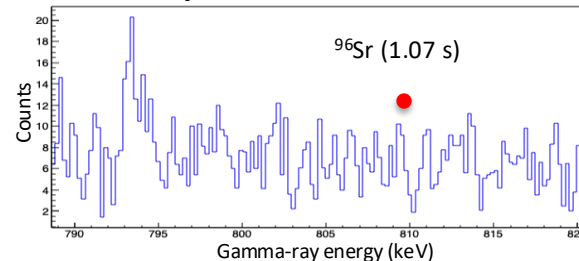
T_{irr} = 1 m; T_{count} = 5 m; T_{wait} = 1 s
Number of cycles: 200 cycles
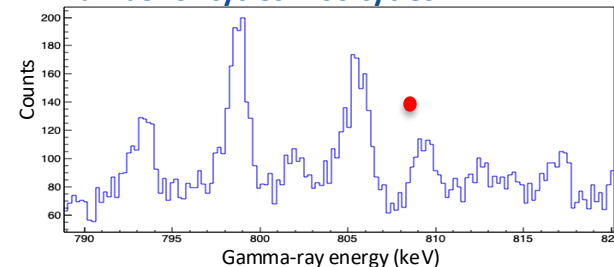
T_{irr} = 4 s; T_{count} = 20 s; T_{wait} = 1 s
Number of cycles: 4000
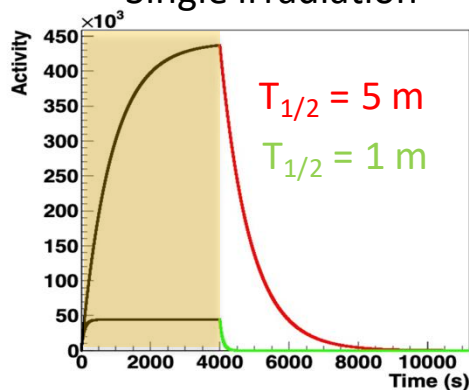
RApid Belt-driven Irradiated Target Transfer System (RABITTS) at TUNL

Counting station

Counting position

Irradiation room

beamline

Irradiation position

1 m

RABITTS track

Neutron detector (TOF)
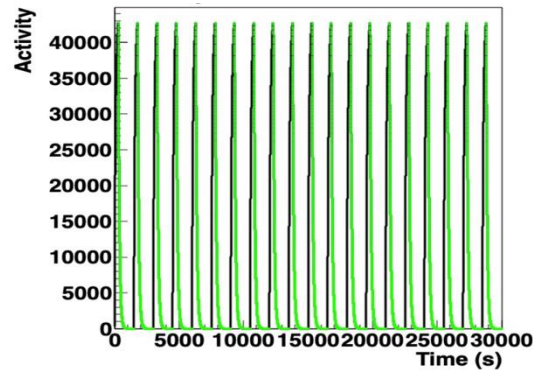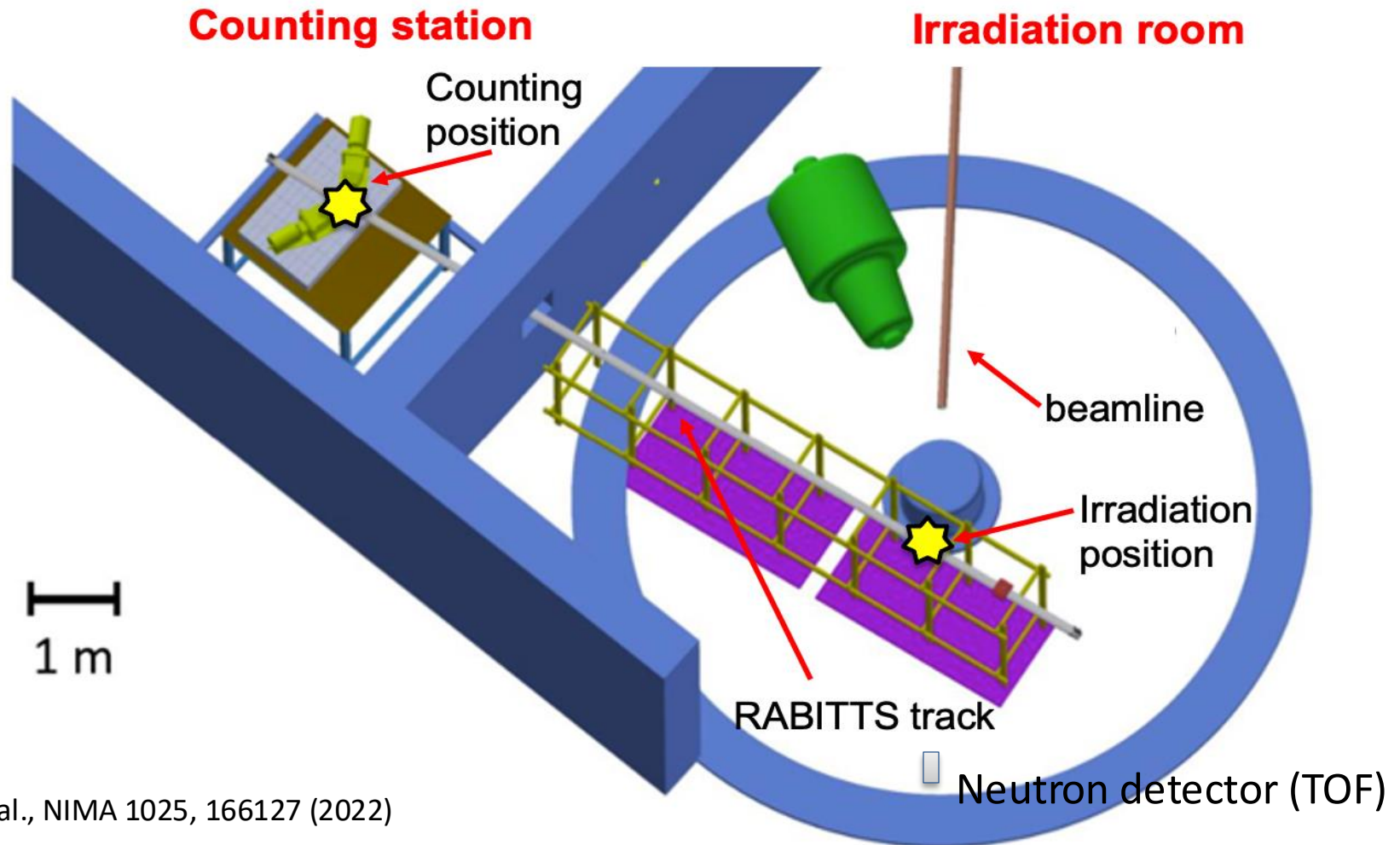
Finch et al., NIMA 1025, 166127 (2022)

RApid Belt-driven Irradiated Target Transfer System (RABITTS) at TUNL

RApid

Belt-driven
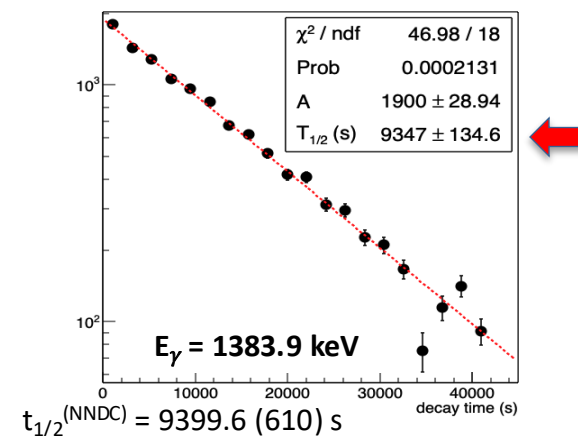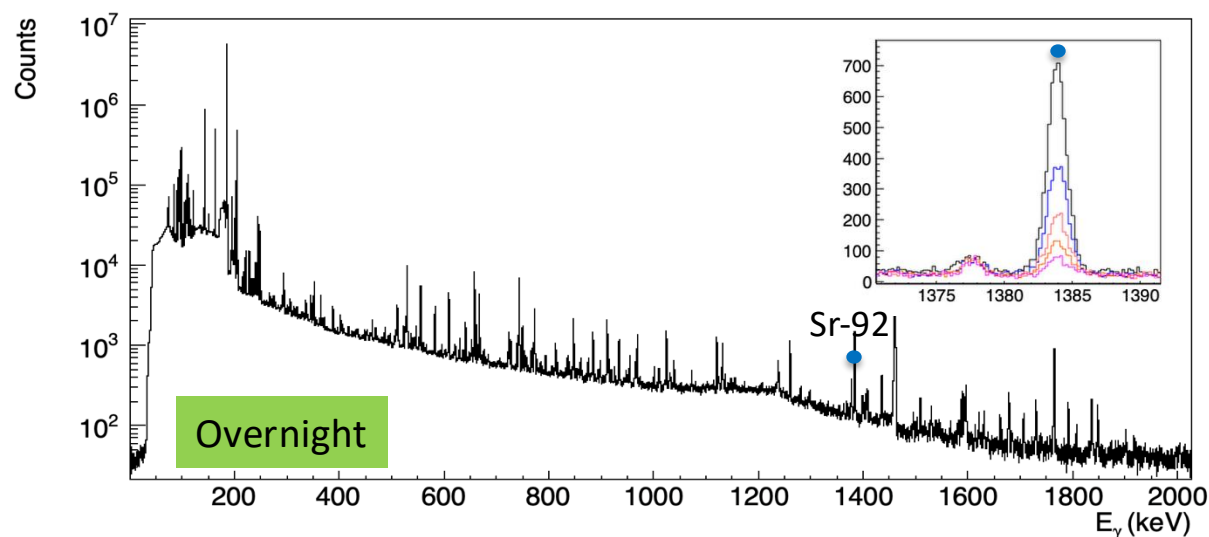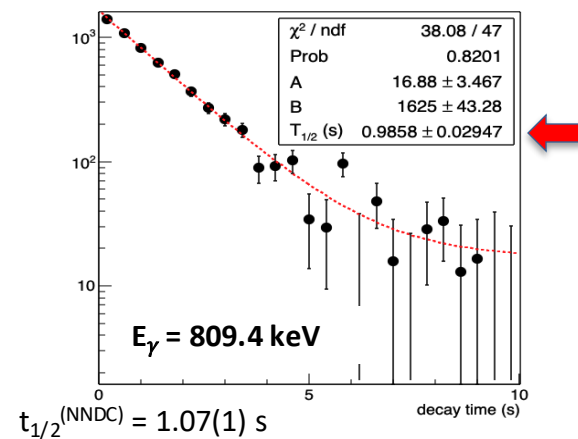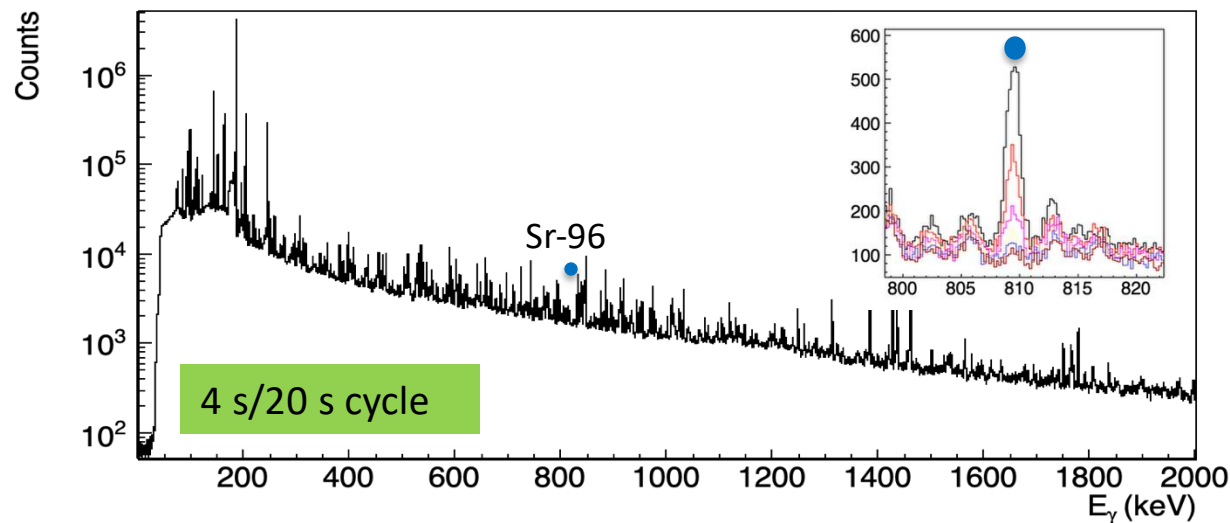
Irradiated

Target

Transfer

System

Counting Area

- Clover HPGe
- CeBr
- BEGe #1
- actinide target
- BEGe #2
- CANBERRA Cryo Pulse 5 plus

Irradiation Area

- Actinide foil
- DFC
- Neutron production gas cell

10 m
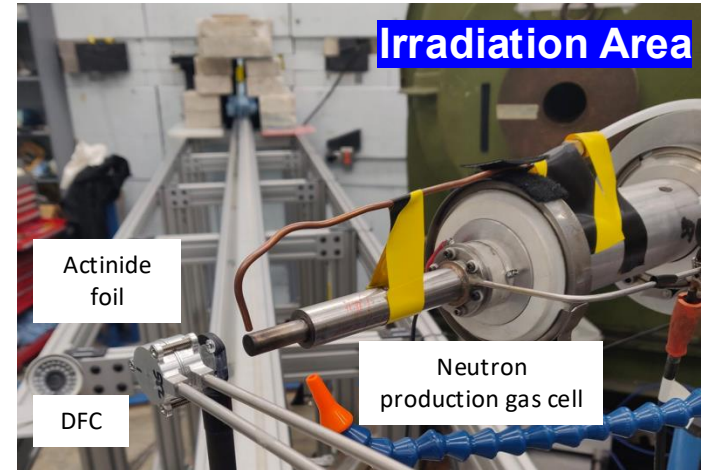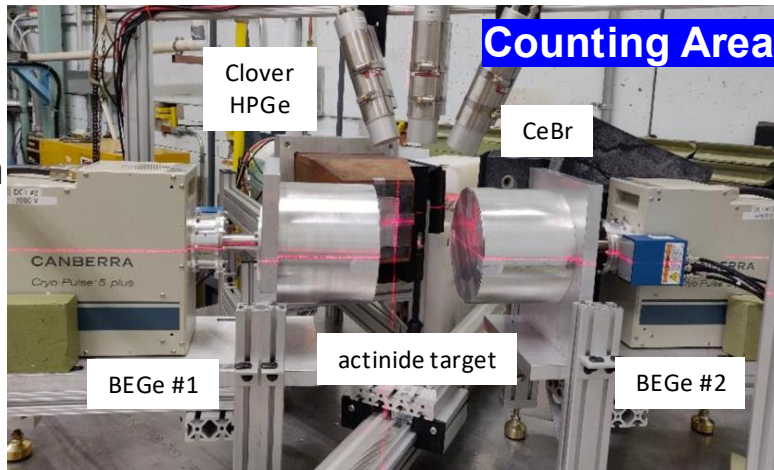
- Cyclic activation with short-time irradiations
  - variable irradiation, transfer, and counting times

- Reduced neutron background
  - 10-m transfer system (t ~ 1 s)
  - Beam deflection system
- Developed analytical methods to process complex gamma-ray spectra

Fission Product Identification

4 s/20 s cycle

E_γ = 809.4 keV

$t_{1/2}^{(NNDC)}$ = 1.07(1) s

Overnight

E_γ = 1383.9 keV

$t_{1/2}^{(NNDC)}$ = 9399.6 (610) s

Fission Rate Determination

- Extrapolate fission rate in thick actinide target using dual fission chamber rates and MCNP calculated flux ratios

- Compare select fission product yields from RABITTS overnight data with Jackrabbit data as reference values
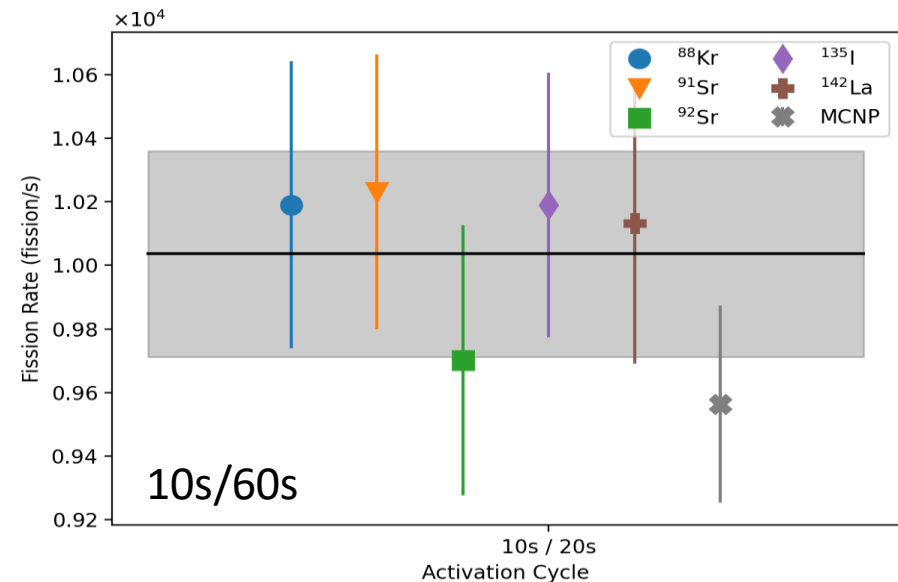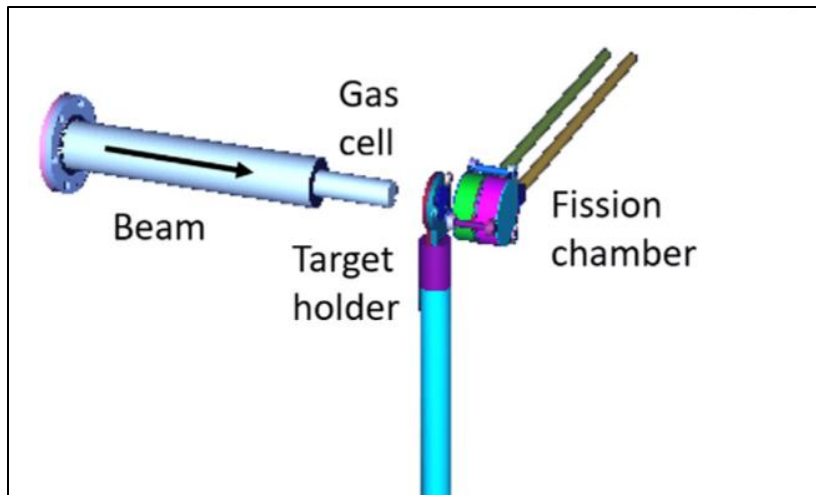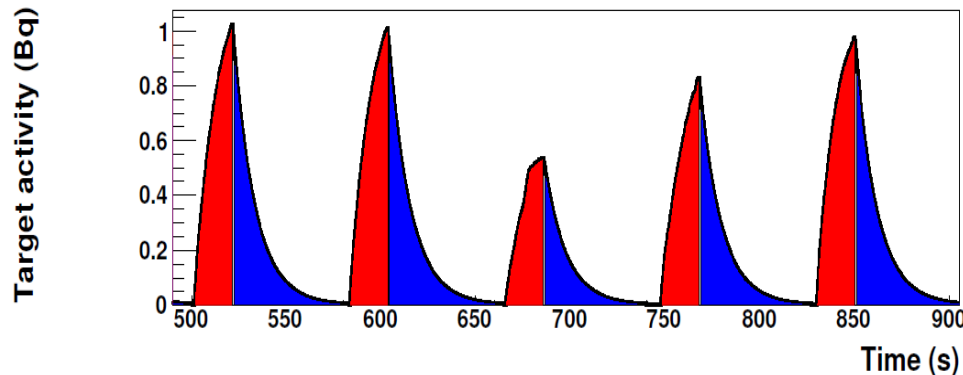
RABITTS Cycles

Irradiation cycle information for ^{239}Pu
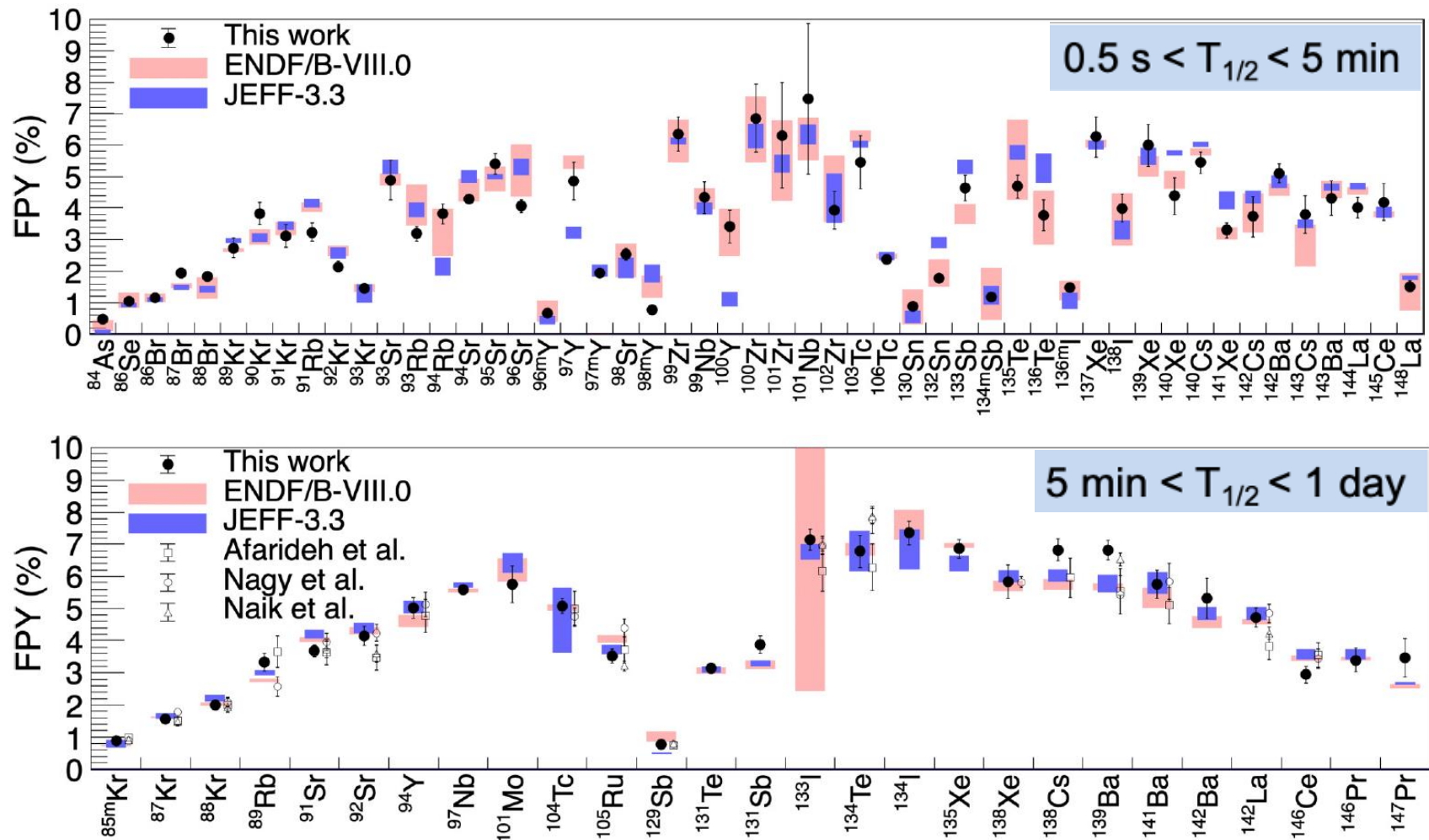

1 | 4 s | 20 s | x 4800

2 | 10 s | 60 s | x 1800

3 | 60 s | 300 s | x 350

Irradiation time   Counting time

- Three irradiation cycles on ^{235}U, ^{238}U, and ^{239}Pu at 0.06, 0.56, 2.0, 4.6, 9.0 and 14.8 MeV

- Measured multiple γ-ray transitions for each fission product

- Obtained unique time-dependent FPY information relevant to fission product yield evaluation project

Short-Lived FPYs from ^{238}U(n,f) at E_n=4.6 MeV
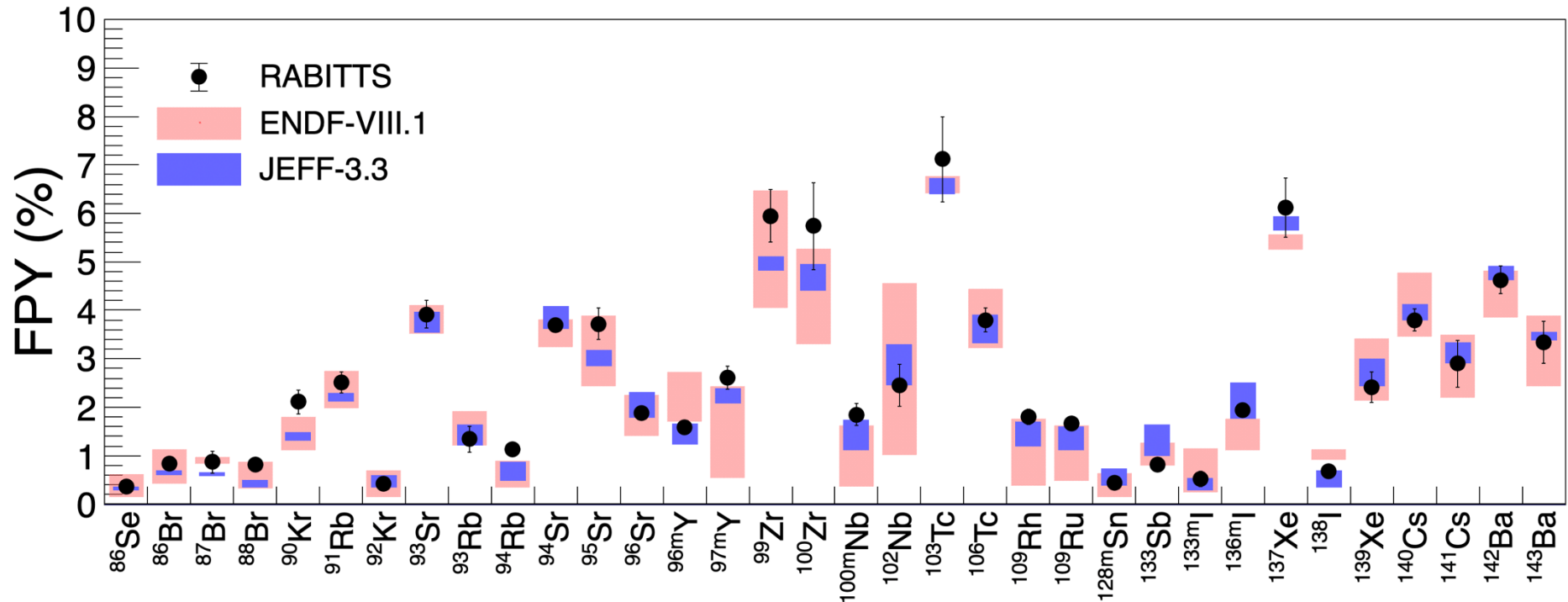

A.P.D. Ramirez et al. **107**, 05408 (2023)

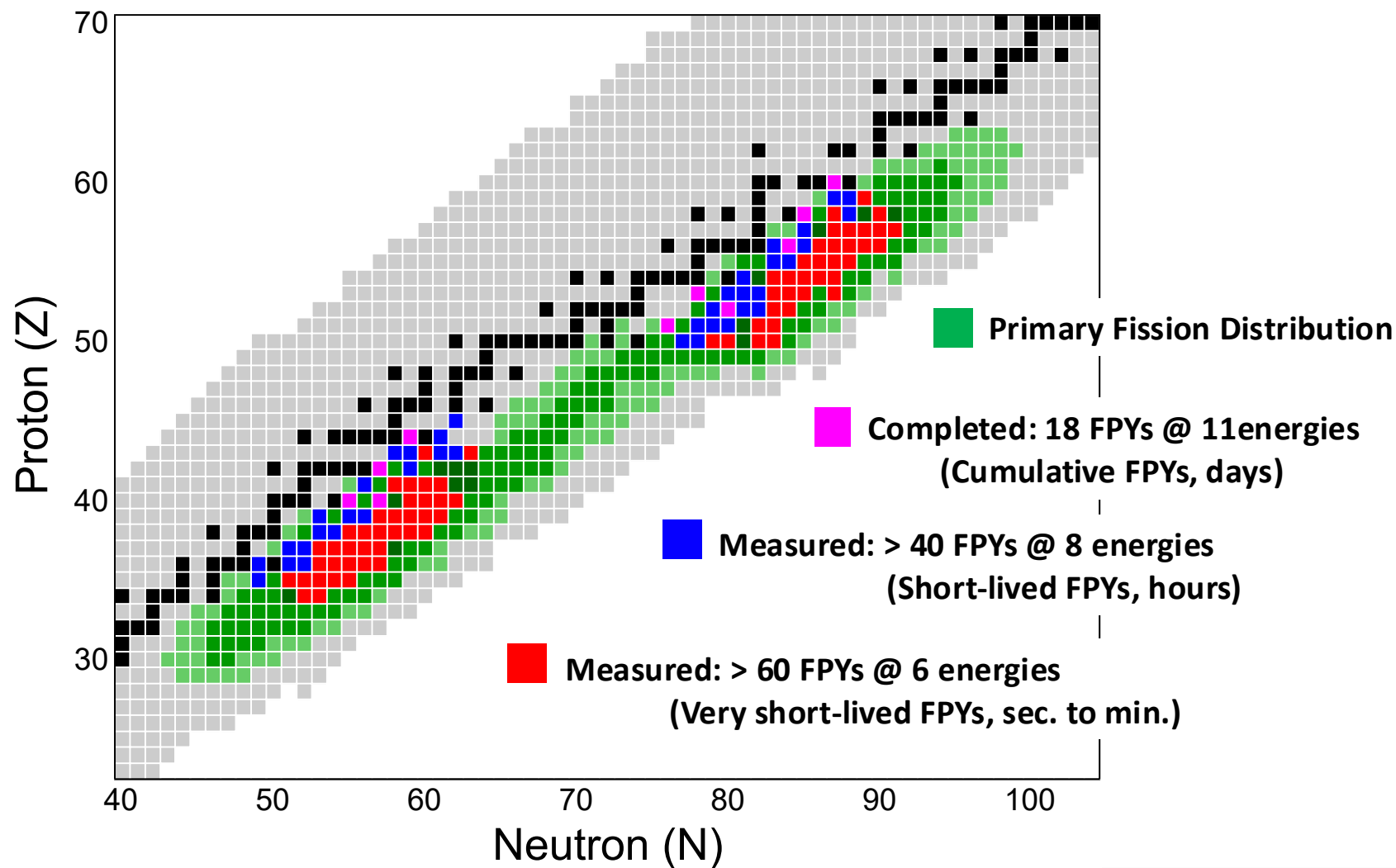# Preliminary FPYs from ^{235}U(n,f) at E_n=4.6 MeV
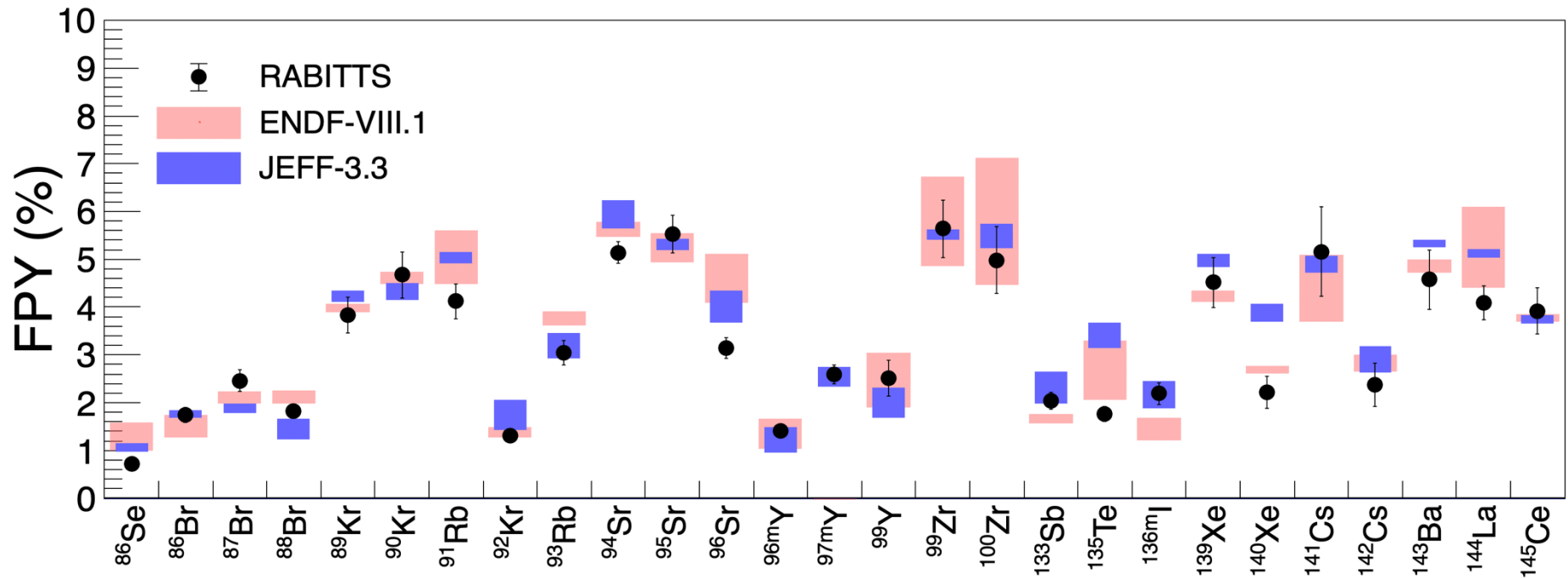
A.P.D. Ramirez et al.

Preliminary FPYs from ^{239}Pu(n,f) at E_n=4.6 MeV

V. Linero (Colorado School of Mines/LANL)

Summary: Fission Product Yield Map

Primary Fission Distribution

Completed: 18 FPYs @ 11energies
(Cumulative FPYs, days)

Measured: > 40 FPYs @ 8 energies
(Short-lived FPYs, hours)

Measured: > 60 FPYs @ 6 energies
(Very short-lived FPYs, sec. to min.)

Acknowledgements

Lawrence Livermore
National Laboratory