Impact and needs of precision decay data for determining fission yields

FPY beta-gamma branching ratios

Workshop for Applied Nuclear Data Activities (WANDA)

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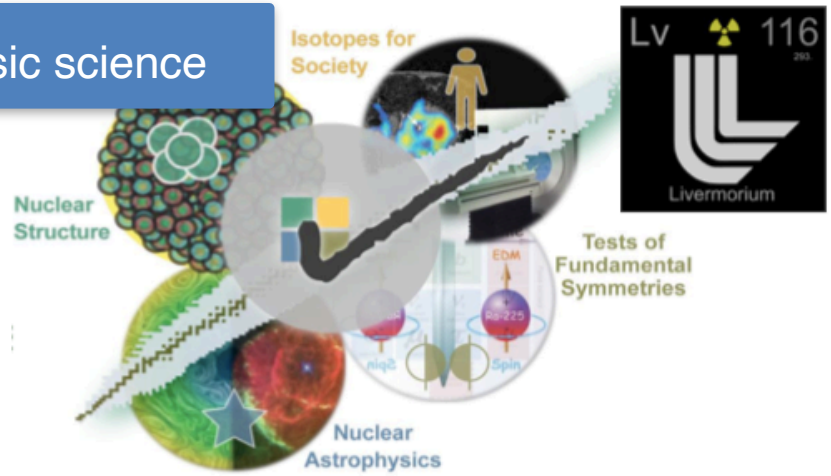
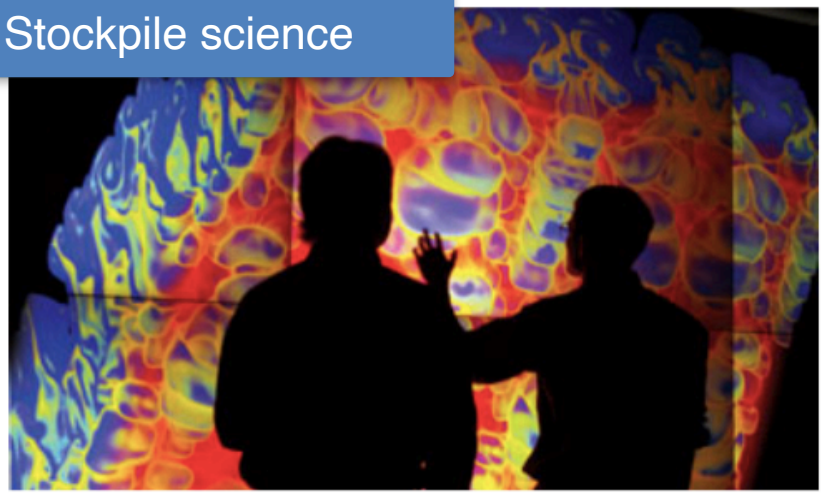
Fission-product decay data is a cross-cutting need for multiple application spaces in nuclear science

Basic science



Nuclear astrophysics

Stockpile science



Nuclear energy

Nuclear fission and β decay

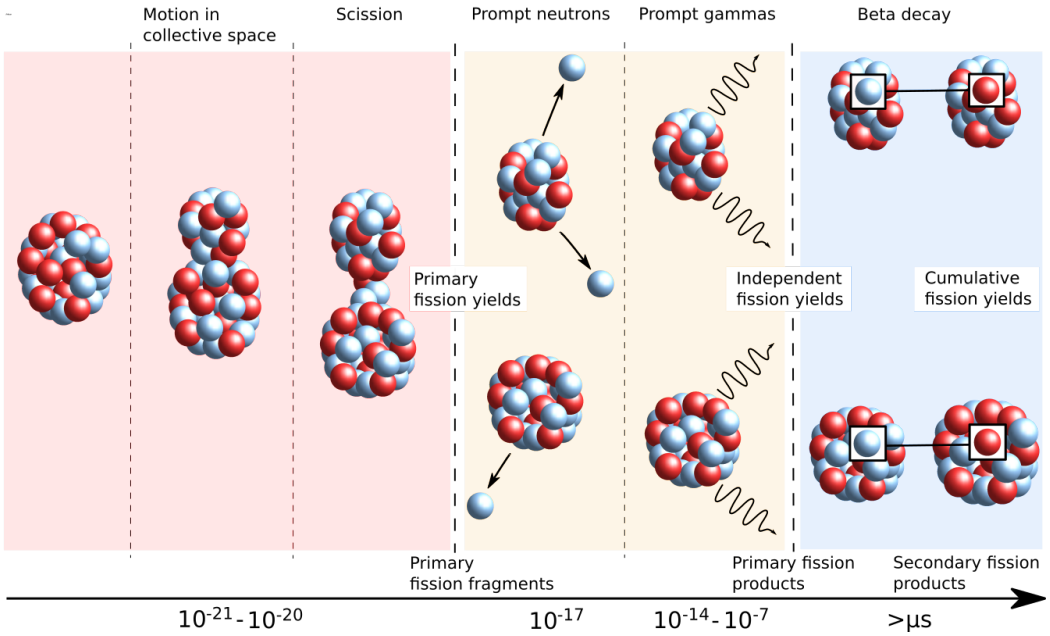
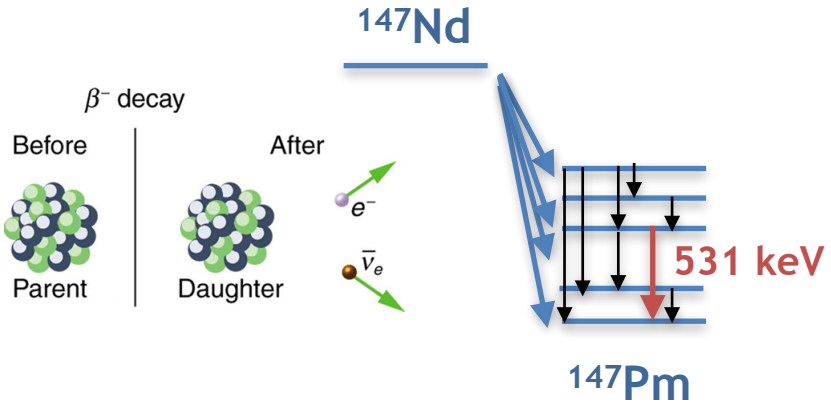
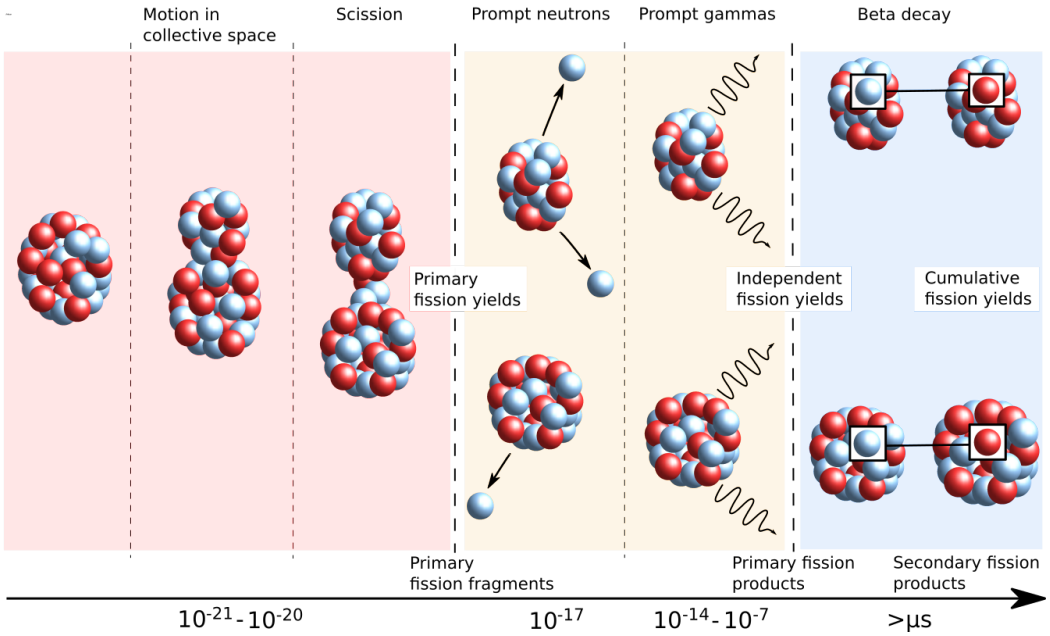


Figure courtesy of N. Schunck



→ γ-ray intensity (I_γ) is the fraction of time a certain γ-ray is emitted per β−decay

Nuclear fission and β decay



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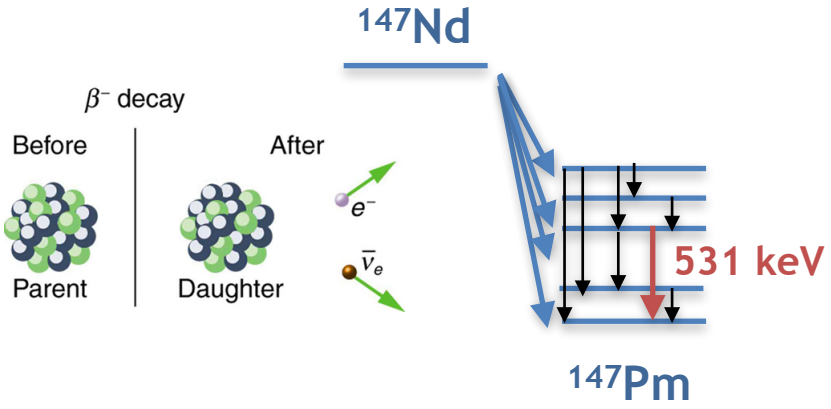
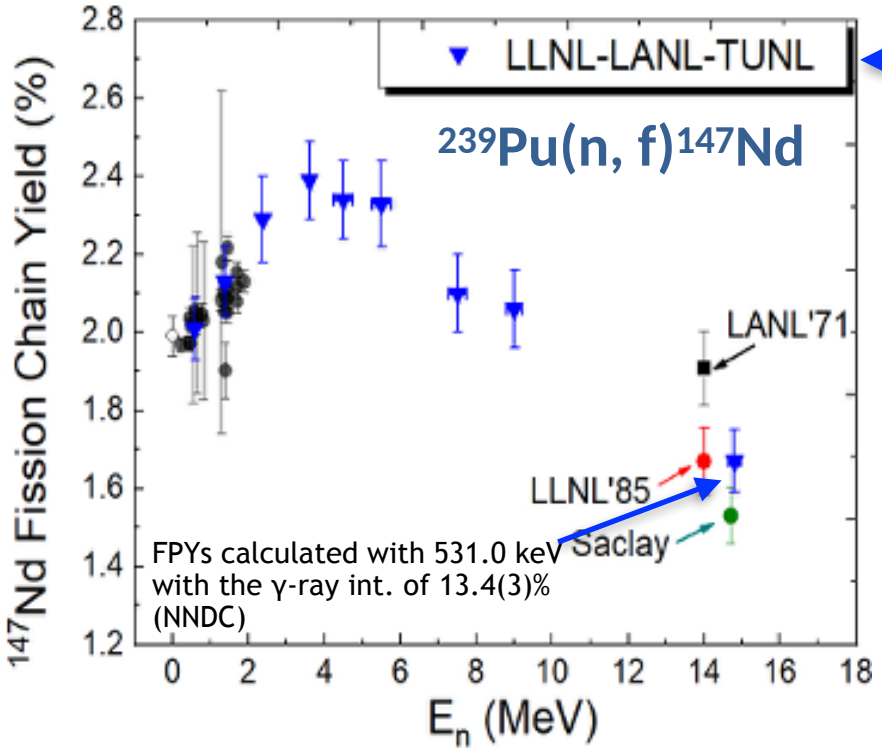


→ γ-ray intensity (I_γ) is the fraction of time a certain γ-ray is emitted per β−decay

Detailed information on the decay properties and **γ-ray intensities** are needed to:

- Test theory predictions - models are tested when compared with **measured** data
- Predict prompt fission gammas since models rely on statistical and **discrete** decay properties
- **Identify and determine** fission product yields (FPYs) - fission decay data is **a proxy for FPY**

Ongoing efforts to improve FPYs evaluations



M. D. Gooden et al. NDS 131 319-356 (2016).
C. Bhatia et al., Phys. Rev. C 91, 064604 (2015).
LLNL POC: A. P. Tonchev

Joint LLNL/LANL/TUNL effort on FPY measurements - multi-institutional effort on providing new FPY evaluation

Detection of characteristic γ-ray is a straightforward and reliable way to determine the number of fissions that occur in a chain reaction.

$$FPY = \frac{\lambda N_\gamma}{F_1 I_\gamma \epsilon_\gamma \left(1 - e^{\lambda t_e}\right)\left(e^{\lambda t_d}\right)\left(1 - e^{\lambda t_m}\right)} \cdot \mathcal{G} \cdot \prod_k C_k$$

→ The γ-ray intensities serve as a **normalization factor** for obtaining FPYs,
→ uncertainties of the γ-ray intensities **directly impact** the quality of FPY determination

Many long-lived isotopes have large (3% to even 30%) uncertainties on their γ-ray intensities and that nuclear data needs to be improved.

Lots of new fission yields measurements, still some suffer from poor beta decay information

→ (LLNL-LANL-TUNL) new results for ^{238}**U(n,f)** at E_n = 4.6MeV with fission yields of short (seconds and minutes) fission products

→ the **γ-ray intensity uncertainty major contributing factor in the total (absolute) uncertainty** of all RABITTS FPYs except for a few, with the γ-ray intensity uncertainties of 10% up to even 30%!

→ several short-lived FPYs including **isomeric** yields discrepant with the evaluated values.

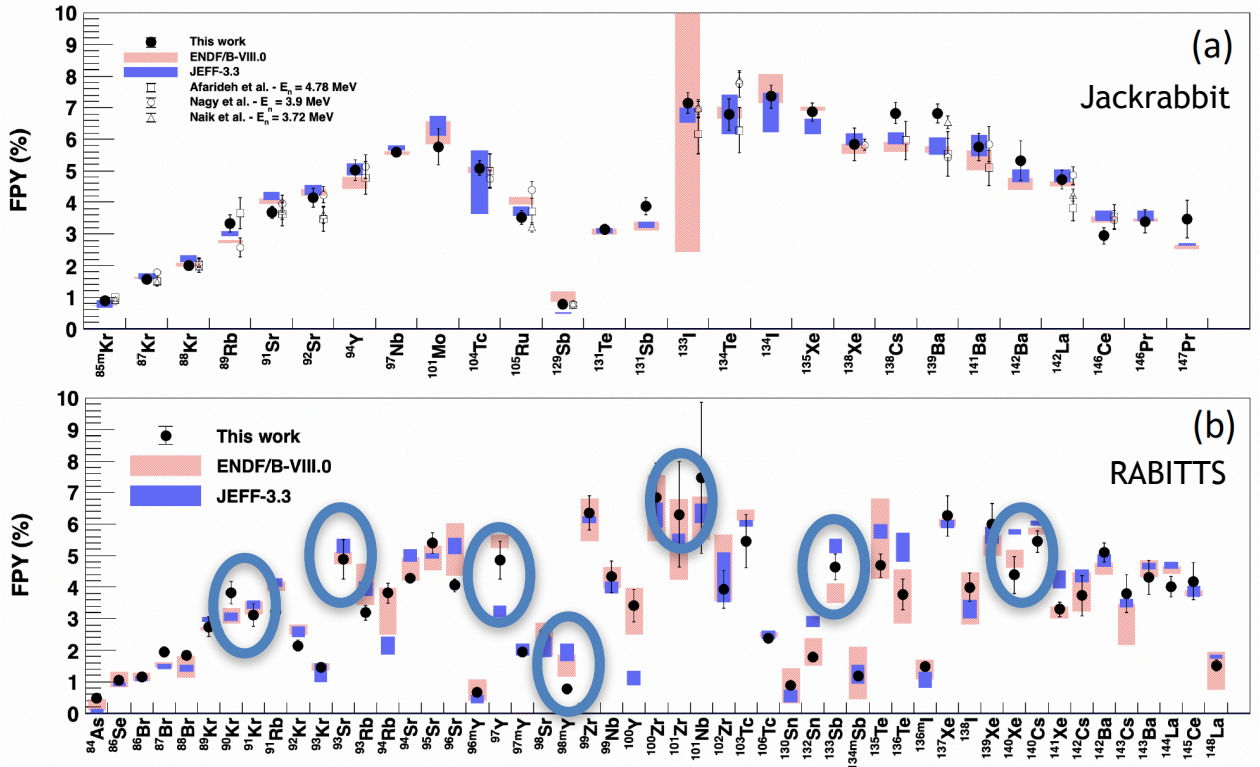
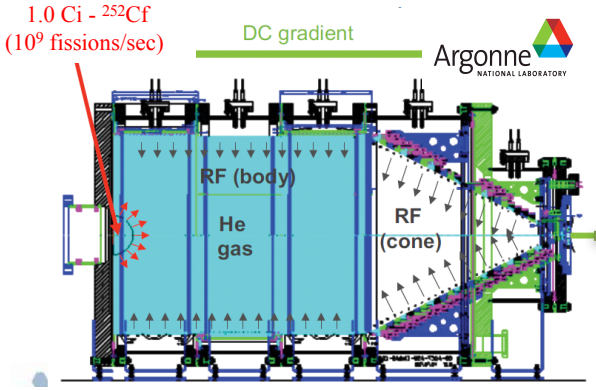


Figure courtesy of A. Ramirez (LLNL), submitted to PRC

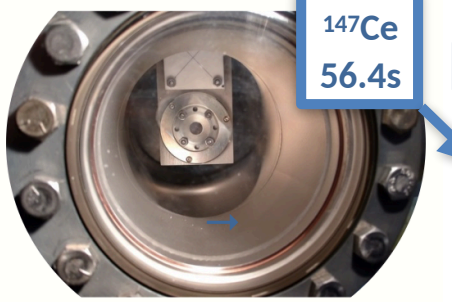
These measurements rely on **accurate** knowledge of the **half life** ,absolute **γ- ray intensities** and **isomers** of these short-lived fission products, more **precise values of these decay parameters are needed** to reduce the systematic uncertainty in these FPYs.

We developed a method for sub-1% precision decay measurements of long-lived fission products

Fission product sample harvested at CARIBU (ANL)



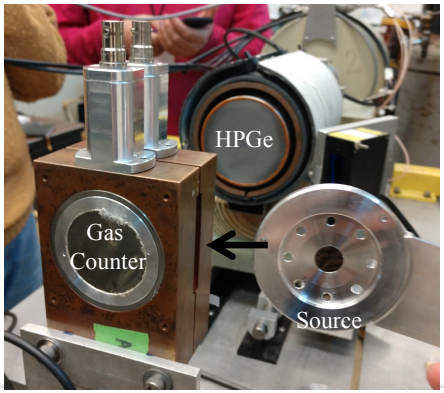
Radioactive ions implanted on a thin carbon foil at CARIBU



Radioactive short-lived ions deposited on a thin carbon foil

^{147}La 4.02s β^- → ^{147}Ce 56.4s β^- → ^{147}Pr 13.4m β^- → ^{147}Nd 10.9d β^- → ^{147}Pm 2.62a β^- → ^{147}Sm stable

Precision decay beta-gamma measurement at Texas A&M



→ ultra-pure sample of fission products of interest

→ beta-gamma detection system with well-calibrated HPGe and almost 100% efficient gas counter

Isotope of interest measured at TAMU

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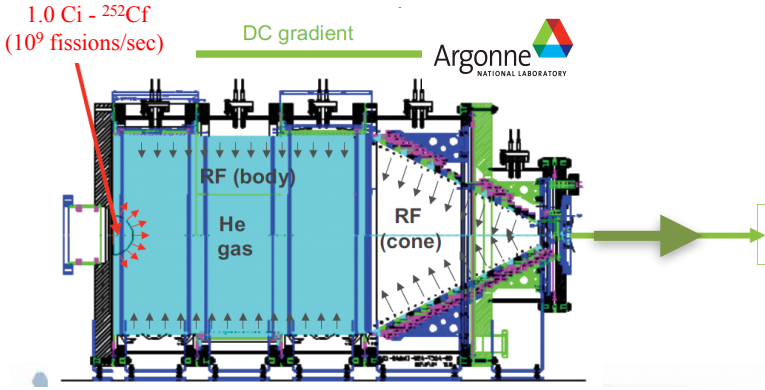

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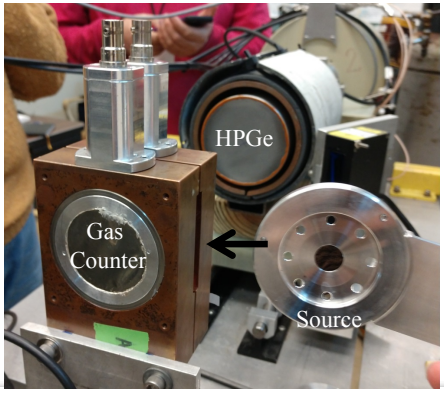
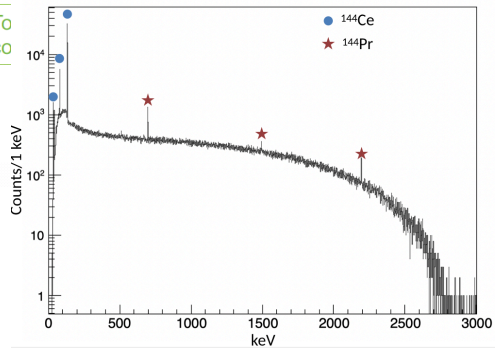
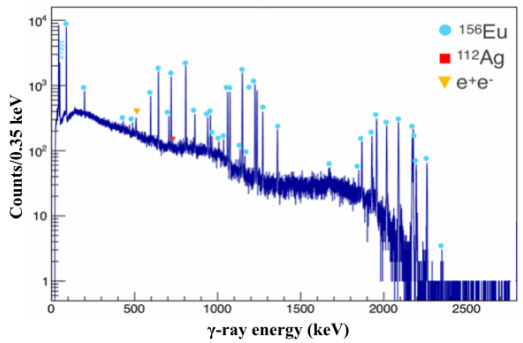


Results for ^{95}Zr and ^{147}Nd:
K. Kolos, N. D. Scielzo LLNL-TR-811617 (2020)
K. Kolos, et. al., Nucl. Instrum. Methods A **1000** 165240 (2021)

We have carried out multiple experiments throughout the last few years and more results to come for ^{144}Ce, ^{156}Eu and ^{111}Ag:





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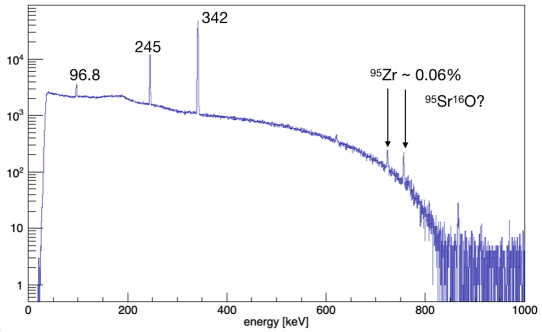
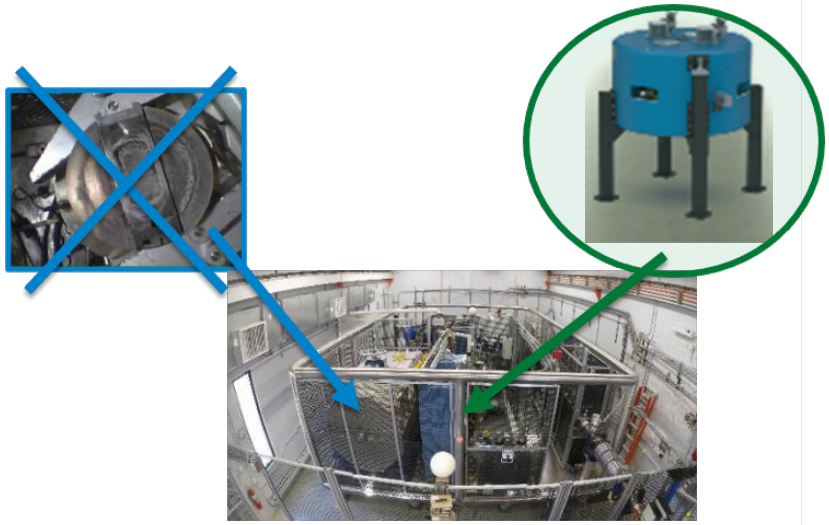


nuCARIBU opens up new opportunities for measuring short-lived fission products from actinides

Replace ^{252}Cf source (CARIBU) by neutron-induced fission on actinide foils (**nuCARIBU**).

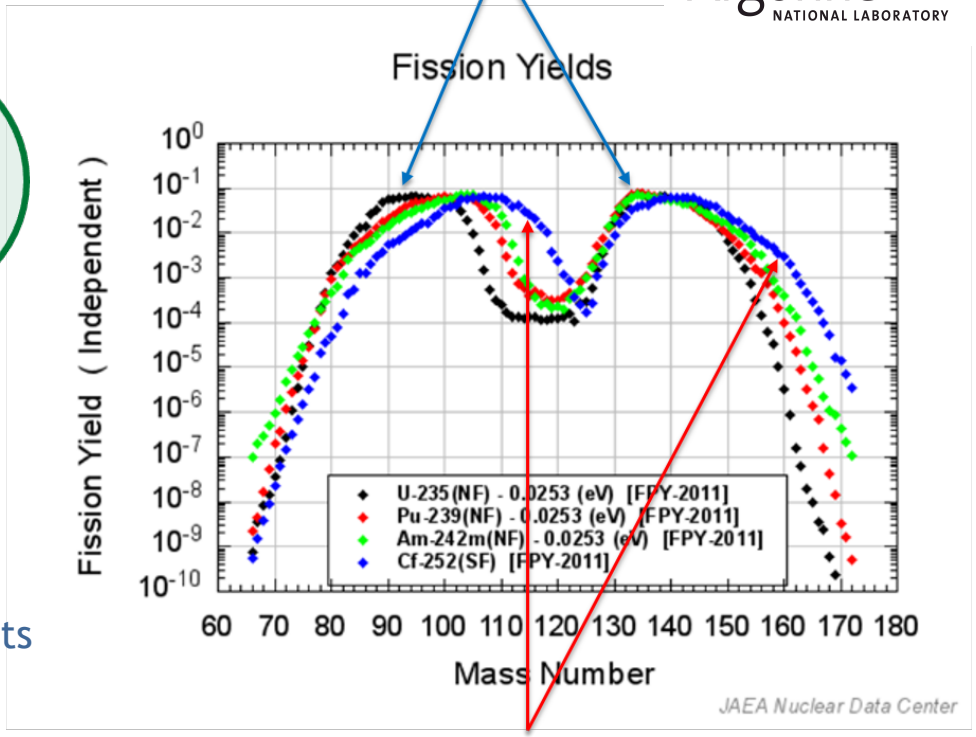


→ more reliable source of fission products
→ higher yields in ^{132}Sn region

→ low-energy and reaccelerated beams of fission products delivered to experimental stations

Slide courtesy of G. Savard (ANL)

Significant gain

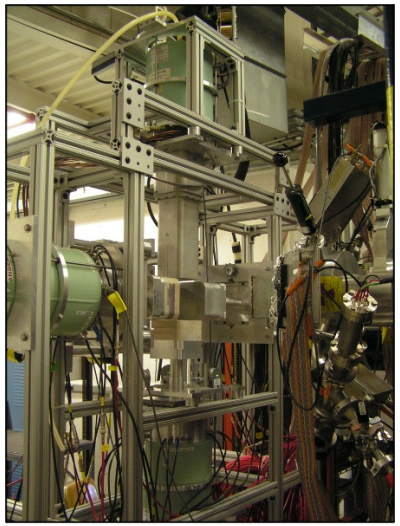


Significant loss

Neutron source installation later this spring!

Improving decay data with the X-Array

***X-Array*: 5 HPGe clover detectors** (4 of 60x60 mm and one 70x70 mm SuperClover **beta plastic detector** (~80%efficiency GEANT4), mylar **tape station,** and **digital electronics**



→ **allows for measurements of half-lives, γ-γ cascades, and isomers of fission products with $T_{1/2}$ as short as ~ ms**

Previously measured: $^{134,\ 134m}$**Sb** half-life and high-to-low spin ratio

K. Siegl, K. Kolos, N. D. Scielzo et al. PRC 98, 054307 (2018)

→ we were able to improve half lives of ground state and isomer in ^{134}Sb

^{134}Sb $T_{1/2}$ = 0.6744(53) s (Previous value 0.78(6) s)

^{134m}Sb $T_{1/2}$ = 9.87(11) s (Previous value 10.07(5) s)

→ high-to-low spin (isomer-to-ground state) ratio obtained from β build-up and decay curves:

$$\sigma_h/\sigma_l = 2.03 \pm 0.05$$

The isomeric yield ratio can be used to understand the initial angular momentum of the fragments from the fissioning system.

Instrument capable of delivering high-quality data and in combination with fission product beams from nuCARIBU will be a great resource for future measurements

First of many measurements of short-lived fission products to improve FPY evaluations

→ 5 days of beamtime at Argonne National Laboratory to investigate the beta-decay of ^{128}Sn

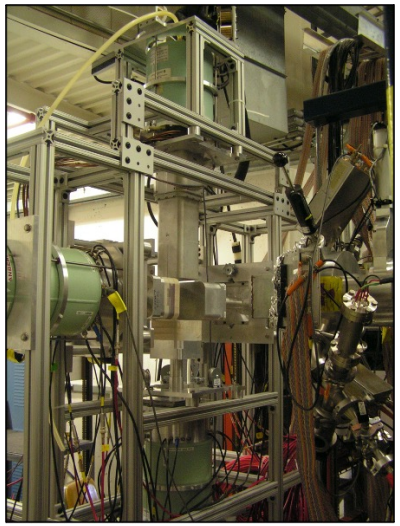
→ this isotope is an important species used in FPY evaluations but the uncertainties in its' γ-ray intensity (12% unc.) currently *contribute 80% of the total error* to FPY.

→ Experiment will use radioactive beam of ^{128}Sn from CARIBU/nuCARIBU and implant on a mylar tape inside the plastic detector in conjunction with the X-Array.

→ with different tape cycles measurements of both isotopes ^{128}Sn and ^{128}Sb and their isomers

→ With this state-of-the art technique we expect to improve the most intense and most relevant to applications **γ-ray intensities** from the beta-decay of ^{128}Sn by **a factor of 4**

→ additionally measurements of **half-lives and isomer-to-gs ratios**



Decay of ground state and isomer of ^{128}Sn/^{128}Sb will be remeasured (X-Array + SATURN + nuCARIBU)

E_n (MeV)	^{235}U *n*-induced FPY	Current Error	Expected improved Error
4.5	0.84	0.11	0.05
9	0.88	0.11	0.04

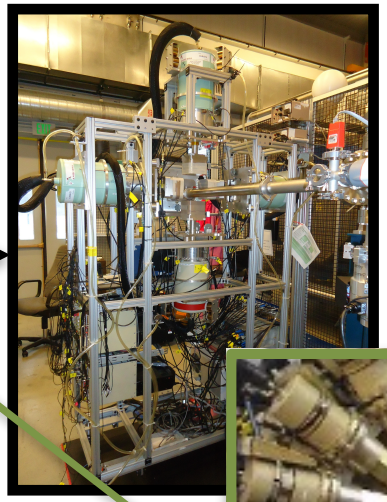
FPY results from J. Silano and A. Tonchev (LLNL)

Experiment will improve precision of neutron-induced cumulative FPY of ^{128}Sn by up to a factor of 3!

Opportunities for addressing nuclear data needs on short-lived fission products

→ **γ-ray intensities** are essential for determining the fission product yields and the quality of that data directly impact quality of the FPY

→ **nuCARIBU** facility at ANL will open up new great opportunity for decay studies of fission products with **the X-Array** and Gammasphere (ideal for high-Q value isotopes and detecting large cascades)

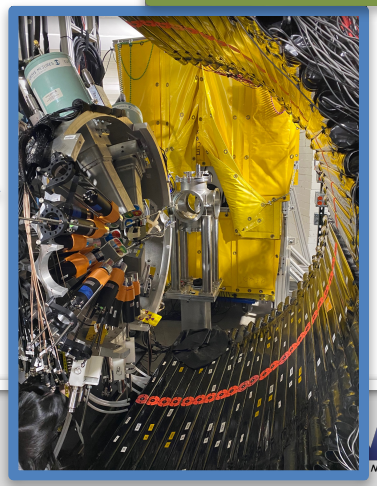


→ **measurements of half lives, γ-intensities, isomers**

→ with multiple-gamma detection capability - with the Gammasphere - we will be able to collect precise data on complex decay schemes and pin down **inconsistent transitions**

(*also see talk of Jeremias Garcia Duarte*)

→ **Measurements of decay properties also at FRIB with FRIB Decay Station** Versatile state-of-the art array of implant, charged particle, gamma-ray and neutron detectors capable of **"complete" decay information**



Thank you!