Improving the Nuclear Data on Fission Product Decays at CARIBU

Project Report at WANDA 2021

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Lawrence Livermore National Laboratory

Joint Proposal of LLNL and ANL

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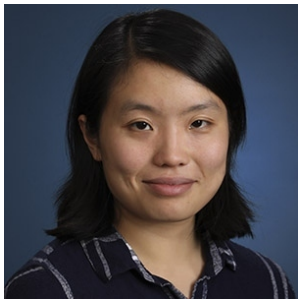

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Funded by DOE Office of Nuclear Physics/ Nuclear Data

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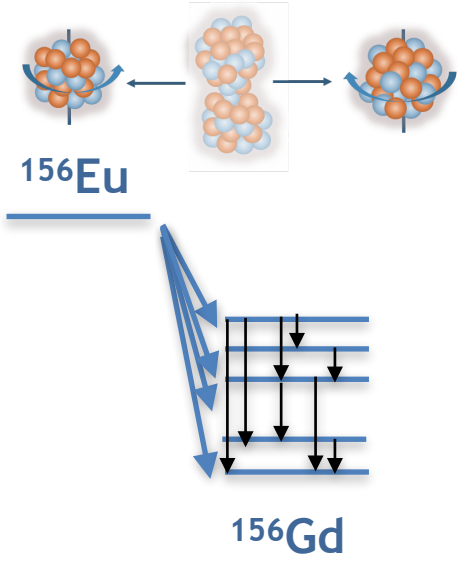
The Goal of this Project is to Perform Detailed Studies of Key Fission-Product Decay Properties

Nuclear Data Impacts Understanding of Nuclear Events:



Fission-product isomer-to-g.s. ratios

Understanding of fission dynamics and angular momentum

Beta-delayed γ-ray branching ratios

Nuclear data for fission yields – impacts nuclear forensics

Measurements of short-lived fission products

- $^{134m/134}$Sb isomeric-to-ground state ratio measurement (X-Array)
- $^{102m/102}$Nb ion counting with Canadian Penning Trap (CPT)

Improved and New ND

Precision branching ratio of long-lived fission products of the importance to nuclear forensics

- ^{156}Eu precision decay measurement

Isotope	Half-life [days]	γ-ray energy [keV]	Current branching ratio [%]
^{156}Eu	15.2	811.8	(9.7±0.8)
^{161}Tb	6.9	74.6	(10.2±0.5)
^{111}Ag	7.5	342.1	(6.68±0.33)
^{127}Sb	3.85	685.5	(36.8±2.0)

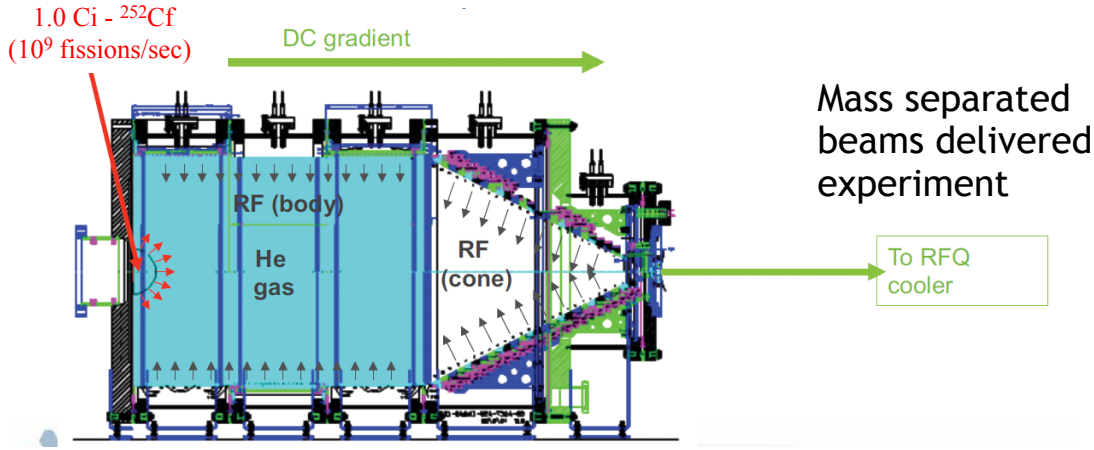
Uncertainties of the order of 5-10% need to be remeasured

CARIBU Opens Up Opportunities to Study Decays of Fission Products

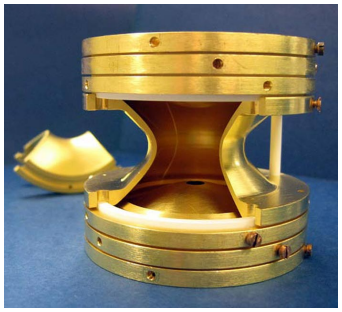
CAlifornium **R**are **I**sotope **B**reeder **U**pgrade

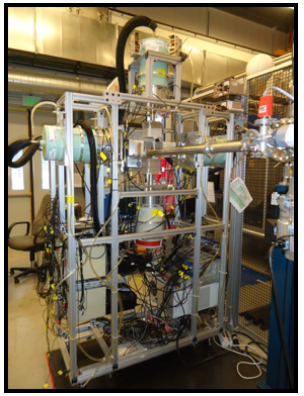
^{252}Cf spontaneous fission source

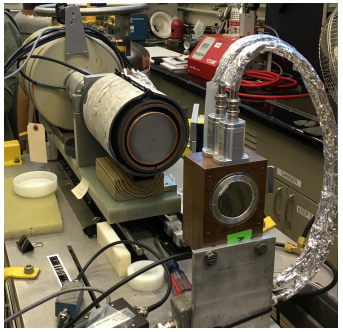
Mass-separated beams of any fission product with $t_{1/2}$ > 25 ms



Mass separated beams delivered to experiment







G. Savard, R. Pardo. Proposal for the ^{252}Cf source upgrade to the ATLAS facility. (2005)

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For more details on the CARIBU facility see Guy Savard's talk today at 1:15 PM (EST)

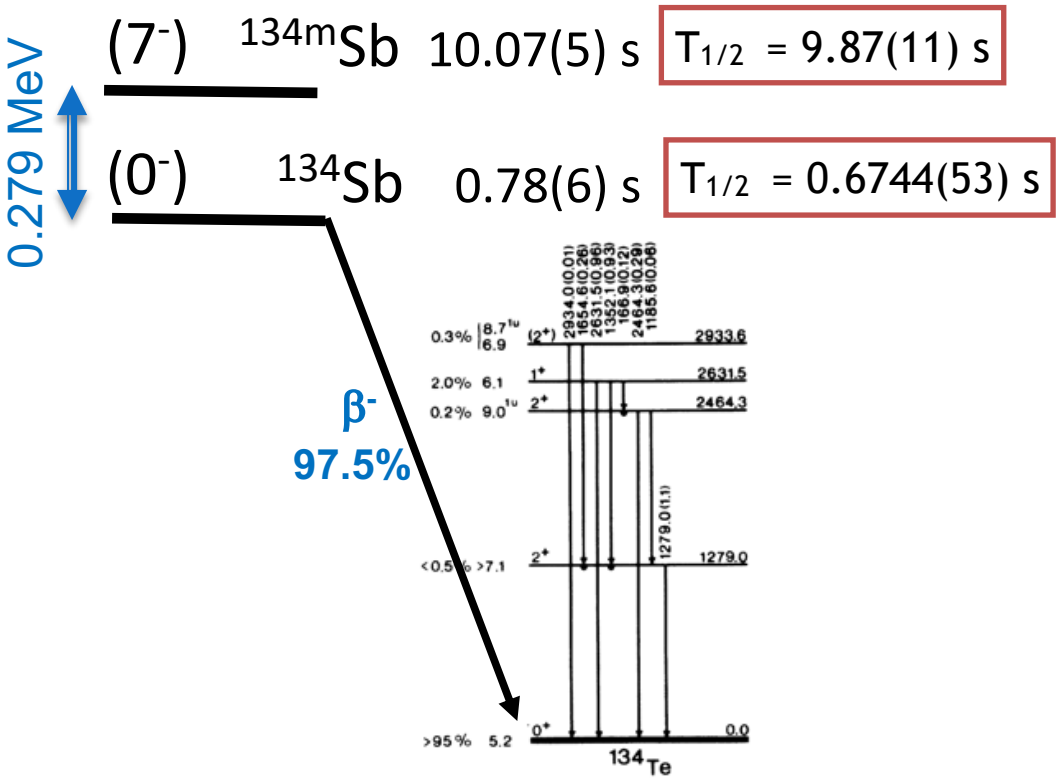
We Measured Beta Decay Properties of $^{134/134m}$Sb: half-lives

→ decay measured with sophisticated detector array (**X-Array/SATURN**)

→ low energy ^{134}Sb beam implanted on a mylar tape

→ two tape cycles optimized to measure g.s. and iso state decays

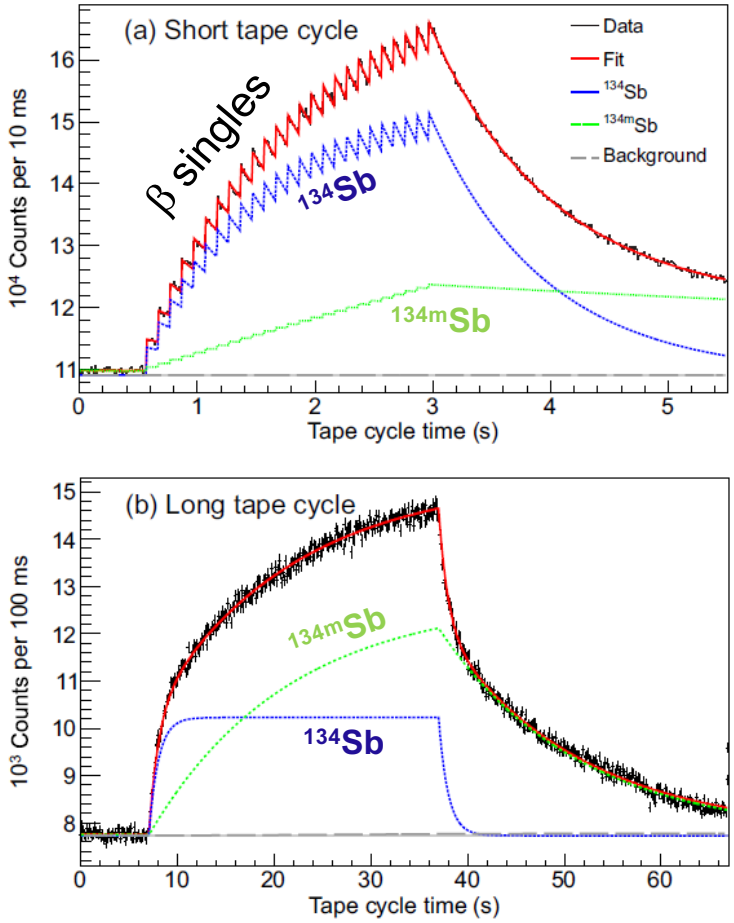
→ improved half-lives from β-γ coincidence and β singles data



B. Fogelberg et al. PRC 41, 5 (1990)

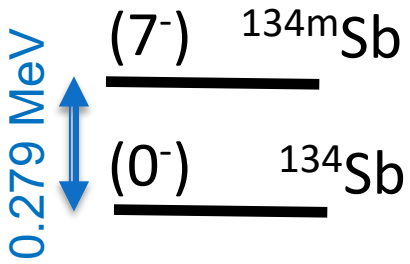
We Measured Beta Decay Properties of $^{134/134m}$Sb: half-lives and isomeric-to-g.s. ratio

→ high-to-low spin ratio obtained from ß build-up and decay for short and long tape cycle



→ Simple relation used for σ_h/σ_l ratio spin of initial fragments

[Madland and England, Nucl. Sci. and Eng. 64, 859 (1977)]



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

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

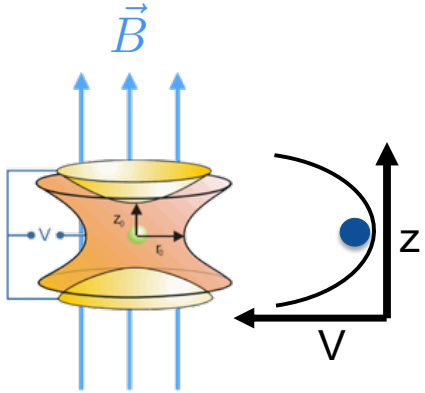
K. Siegl, K. Kolos, N. Scielzo et al. PRC 98, 054307 (2018)

We're Working with ANL to Use An Ion Counting Method for Isomer-to-g.s. Ratio Measurements

→ Identify isomer and ground state by mass, this method is independent on decay properties

Mass and energy: $E = mc^2$

$$E + \Delta E_{isomer} = (m + \Delta m_{isomer})c^2$$



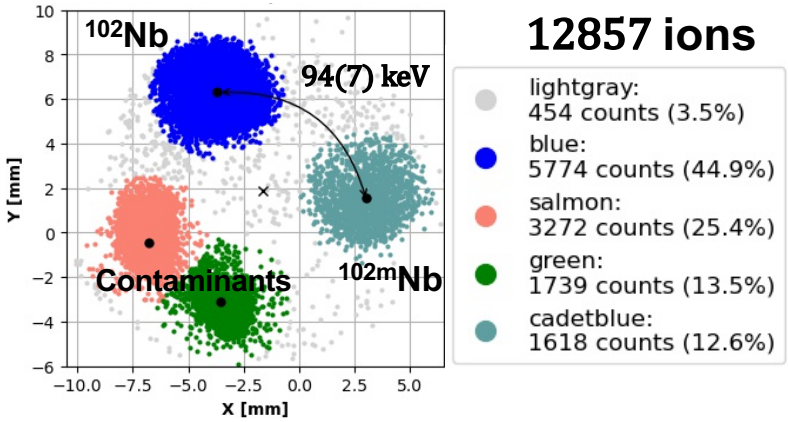
→ ions in the strong magnetic field of a Penning trap, where the frequency of the ion's cyclotron motion depends on the mass of the ion

For more details on the CPT see Guy Savard's talk today at 1:15 PM (EST)

1st measurement of a larger campaign

Isomer-to-g.s. Ratio Measurement of ^{102,102m}Nb

→ ions ejected from the trap and transported to a position-sensitive detector

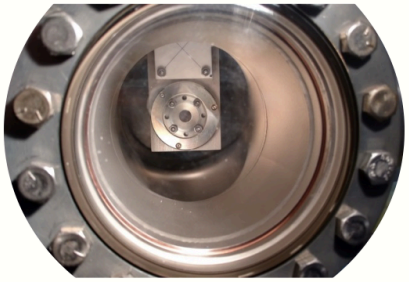


Preliminary result:
g.s.-to-isomer = 3.1(5)

Poised to carry out more measurements when CARIBU is back online

Precision Branching Ratio Measurements of Long-lived Fission Products

→ Many long-lived fission products measured in 60s and 70s have high uncertainties on decay branching ratios



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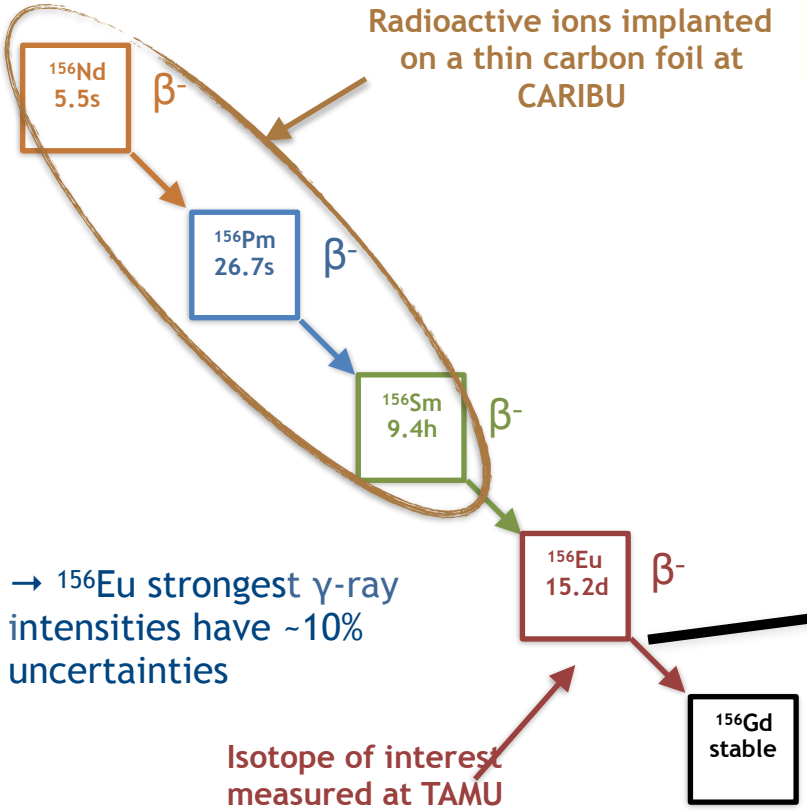
Sample harvesting

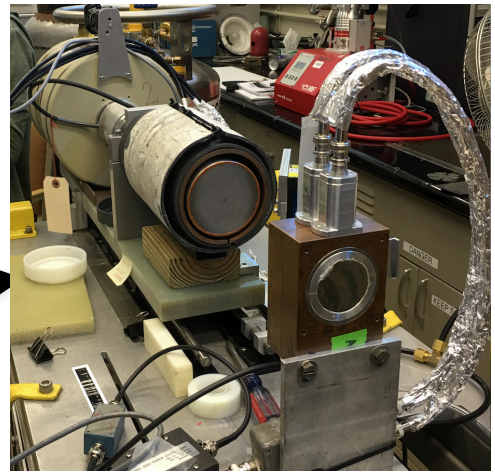
→ Implant mass-separated radioactive ion beam on thin carbon foil at CARIBU (ANL)



Decay measurement

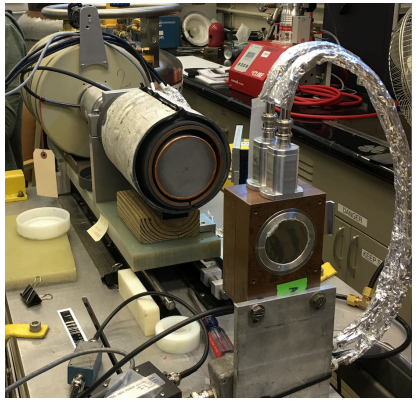
→ ß detection and γ-ray spectroscopy at TAMU

→ ^{156}Eu strongest γ-ray intensities have ~10% uncertainties



Method described in K. Kolos et al. "New approach to precisely measure γ-ray intensities …" submitted to NIM A (2020)

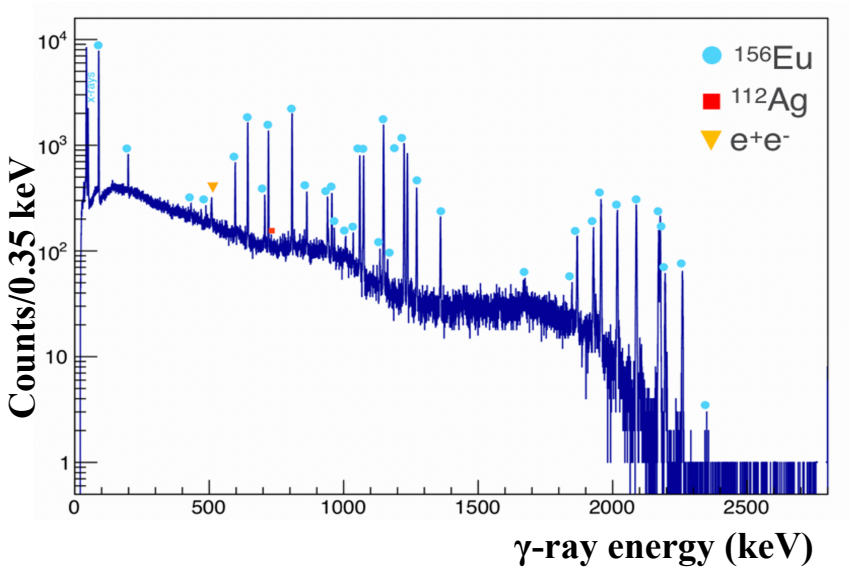
We Collected High-quality Data for ^{156}Eu

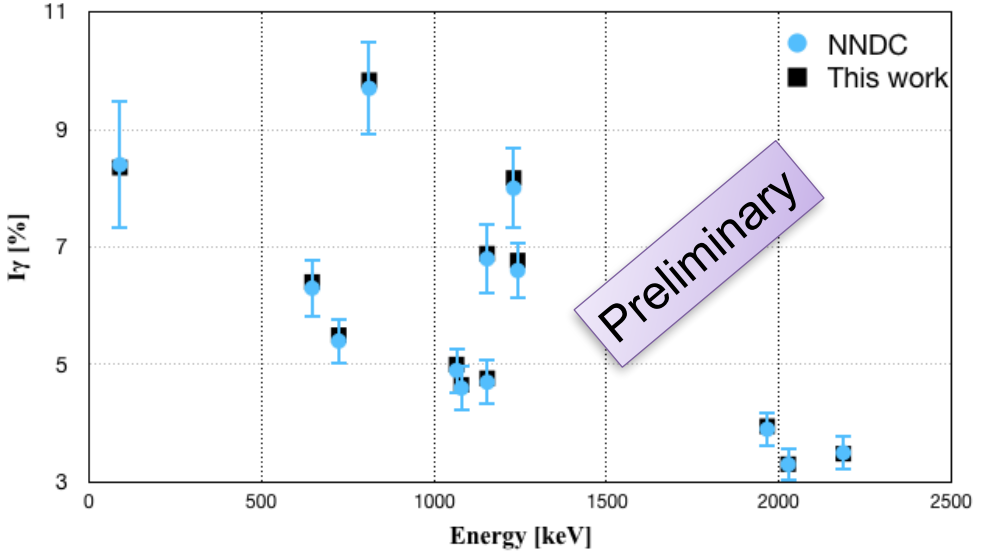


→ Data collected with precisely calibrated ß-γ coincidence detection setup

→ data collected during 7 days

With our technique we were able improve ^{156}Eu decay data and reach sub-1% precision!





→ Comparison of current (NNDC) evaluated data with our results for γ-ray branching ratios

Results Dissemination and Outlook

We publicize our results at workshops, conferences, reviews:

- Independent Review in November 2020

Publications:

K. Siegl, K. Kolos, N. D. Scielzo et al. "Beta-decay half-lives of ^{134,134m}Sb and their isomeric yield ratio produced by the spontaneous fission of ^{252}Cf" PRC 98, 054307 (2018)

K. Kolos, A. M. Hennessy, N. D. Scielzo et al. "New approach to precisely measure γ-ray intensities for long-lived fission products, with results for the decay of ^{95}Zr" submitted to NIM A (2020)

+ Working on publication of ^{156}Eu results (M. Bencomo)
+ More from CPT measurements

Working with graduate students:

- Kevin Siegl (Notre Dame), B. Champine and Tyler Nagel (UC Berkeley), A. Hennessy and E. Heckmaier (UC Irvine), Erin Good (LSU), Benjamin Schroeder (TAMU)

Welcoming new collaborations!

→ More experiments to come: isomeric-to-g.s. with the CPT and precision decay studies of long-lived FP branching ratios

Thank you!