

Measurement of the Isomeric Yield Ratio of Xenon-135m from Neutron Capture on Xenon-134

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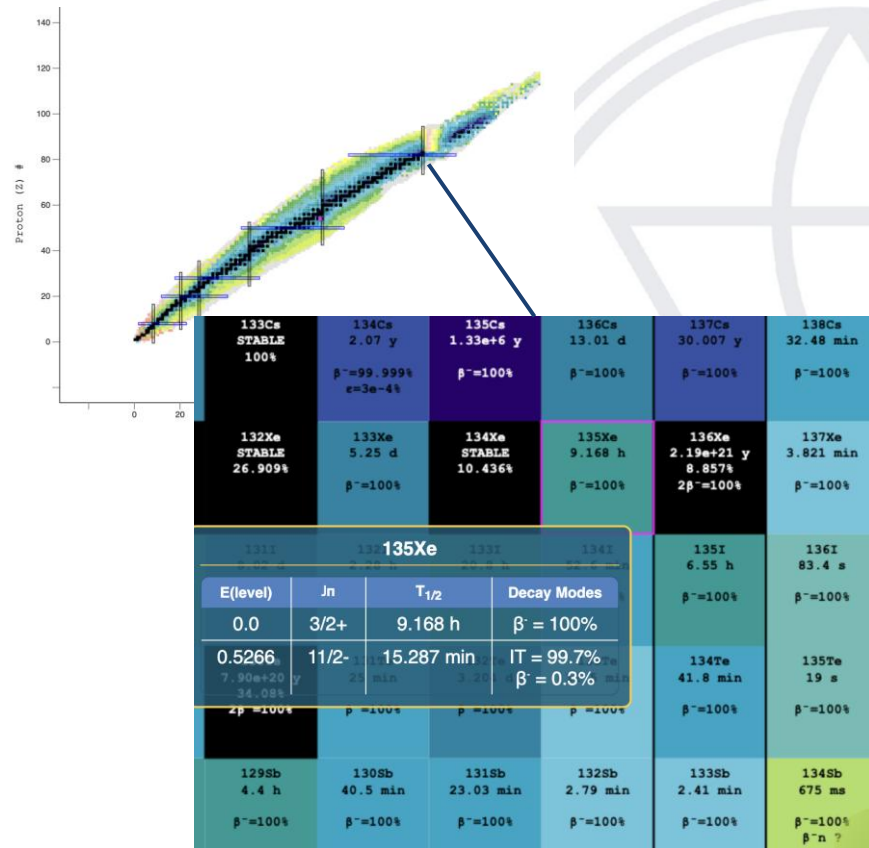
University of Dallas Physics Department · Work performed at the UT
Austin TRIGA Mark II



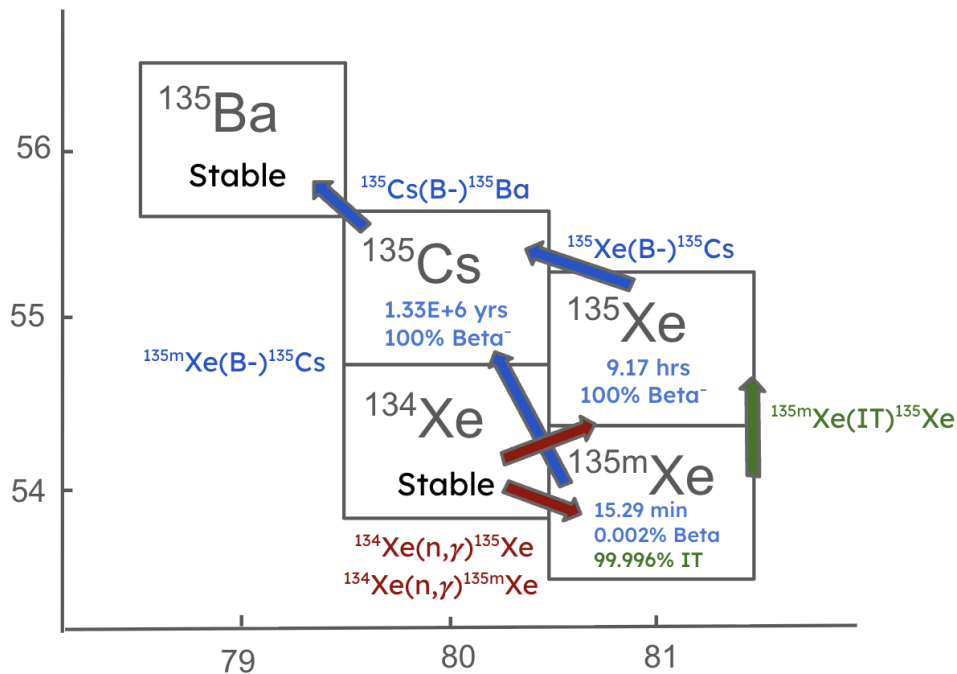
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Introduction: Why Xenon-135?

- ^{135}Xe is the dominant fission-product poison in nuclear reactors, and has one of the largest thermal absorption cross sections known (~ 2.6 million barns).
- It absorbs thermal neutrons without fissioning, competing with the fuel and driving reactor transients (known as the “xenon pit”).
- Yet its isomeric yield ratio has only a few decades-old measurements, and models disagree by 2-3x.



The Complex Xe-135 Decay Scheme:



- Neutron capture on ^{134}Xe produces ^{135}Xe in both its ground and metastable states.
- Red: neutron capture
Green: isomeric transition ($m \rightarrow g$)
Blue: β^- decay.



The Isomeric Yield Ratio

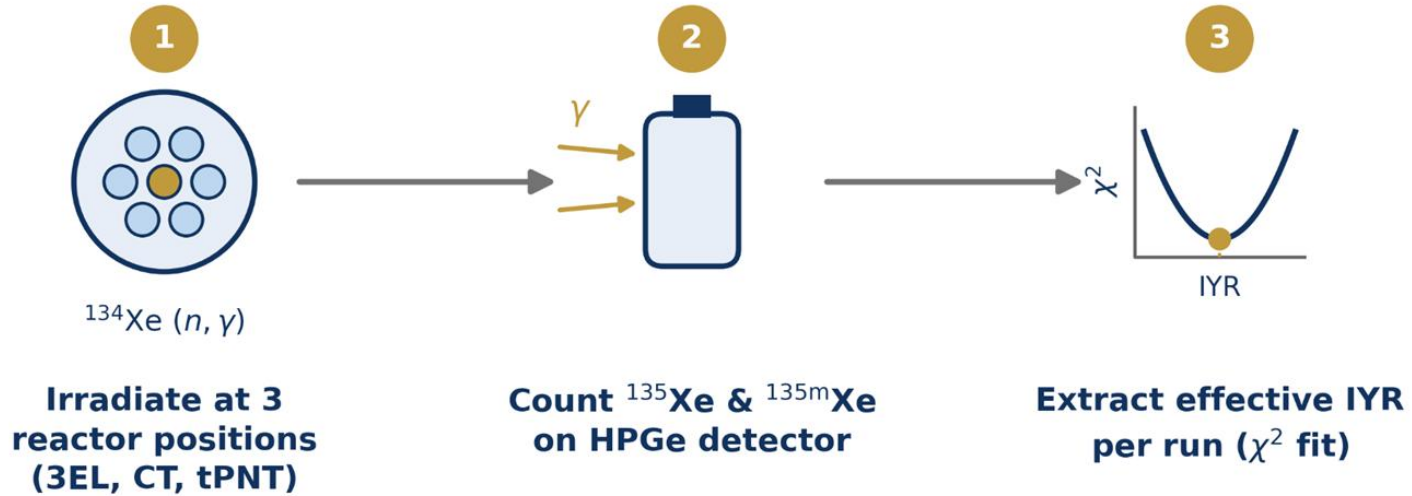
- On formation, ^{135}Xe settles into either the ground state ($3/2^+$) or a metastable state ($11/2^-$).
- The large spin difference makes the metastable decay highly forbidden, so it is long-lived ($T_{1/2} = 15.3 \text{ min}$).
- The fraction formed in the metastable state is the isomeric yield ratio (IYR):

$$\text{IYR} = N_m / (N_m + N_g)$$

where N_m and N_g are the metastable and ground-state abundances



Experiment Outline:



The Reactor and Three Irradiation Positions:

- All three runs were performed at the UT Austin TRIGA Mark II reactor.
- Three positions, each a different neutron spectrum: 3EL, CT (central thimble, in-core), and tPNT (pneumatic transfer).
- Using multiple positions builds in a cross-check across spectra.

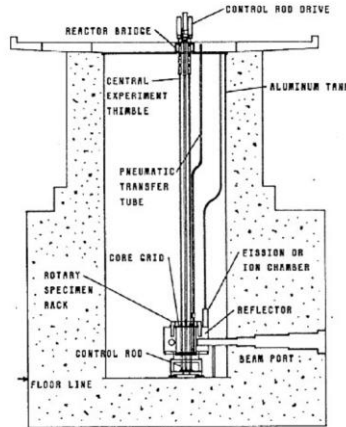


Figure 1.1, UT TRIGA Mark II Nuclear Research Reactor

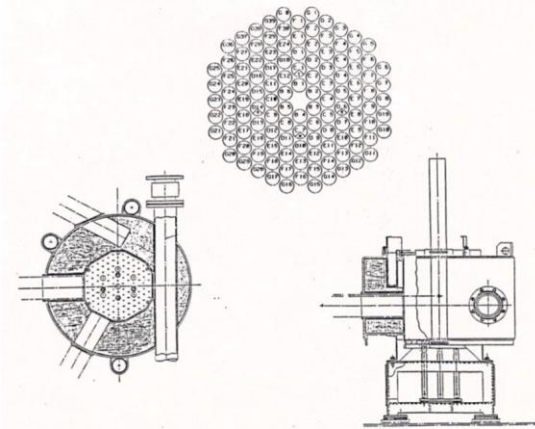


Figure 1.2, Core and Support Structure Details



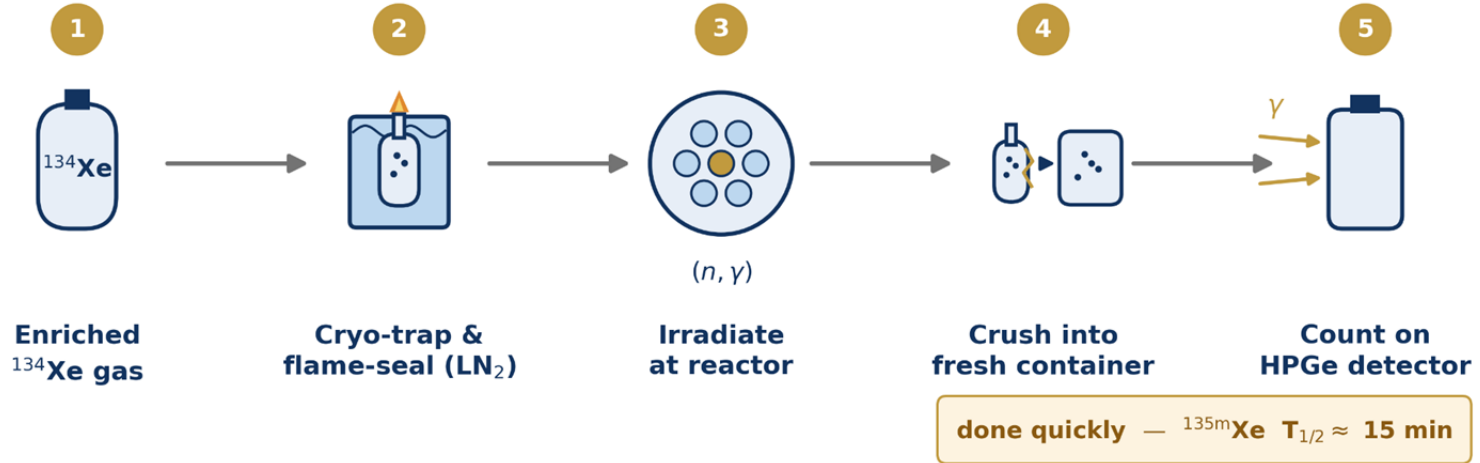
Methods Varied Between the Three Runs:

The three runs differed in irradiation position, timing, power, and container:

	Method 1	Method 2	Method 3
Date	July 3, 2025	August 1, 2025	January 16, 2026
Irradiation facility	3EL	CT	tPNT
Irradiation time (s)	100	3600	10
Nominal reactor power (kW)	100	100	900
Irradiation container	15 mL chamber	Quartz ampule	Quartz ampule
Counting container	150 mL chamber	Quartz ampule (20 cm standoff)	150 mL chamber

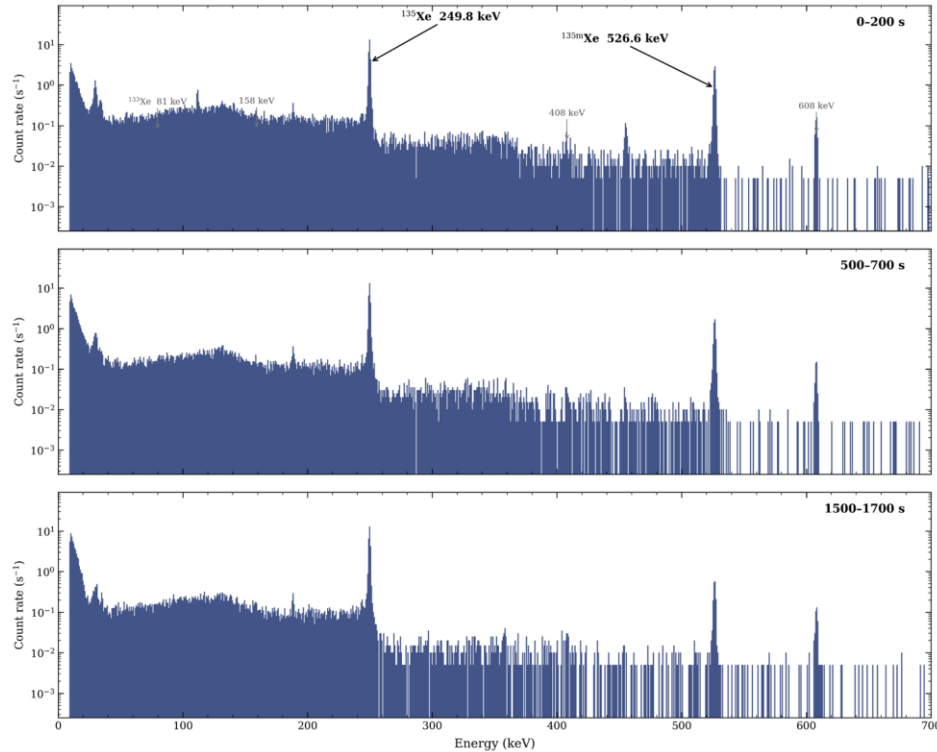


Sample Preparation:



Counting Setup:

Jan 16, 2026
(EOI $\rightarrow$ 1.5 h)

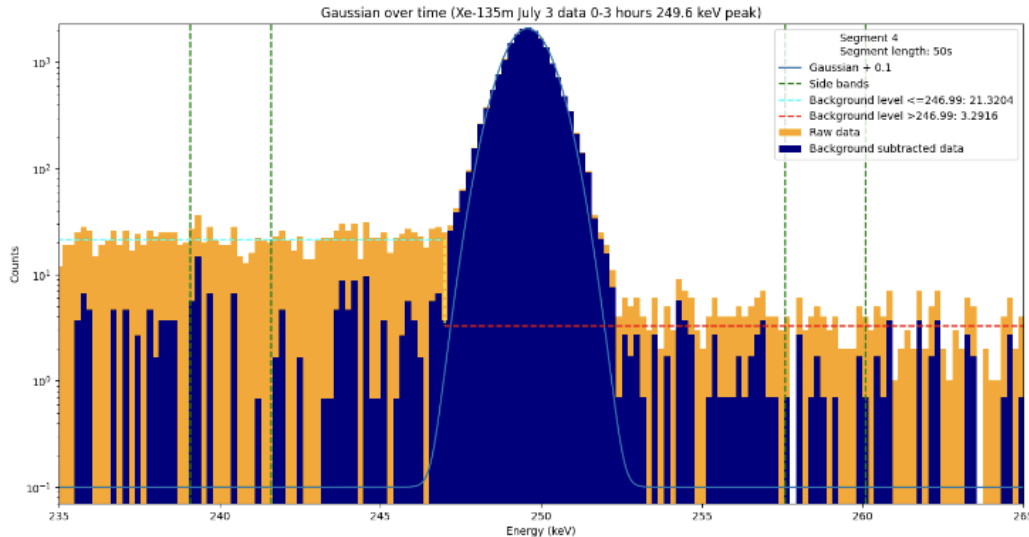


- γ -rays were counted on an ORTEC GMX-series HPGe detector in an ORTEC low-background lead shield, read out by a DSPEC-50 MCA.
- Spectra were collected in time bins, dead-time corrected, and tracked over time.



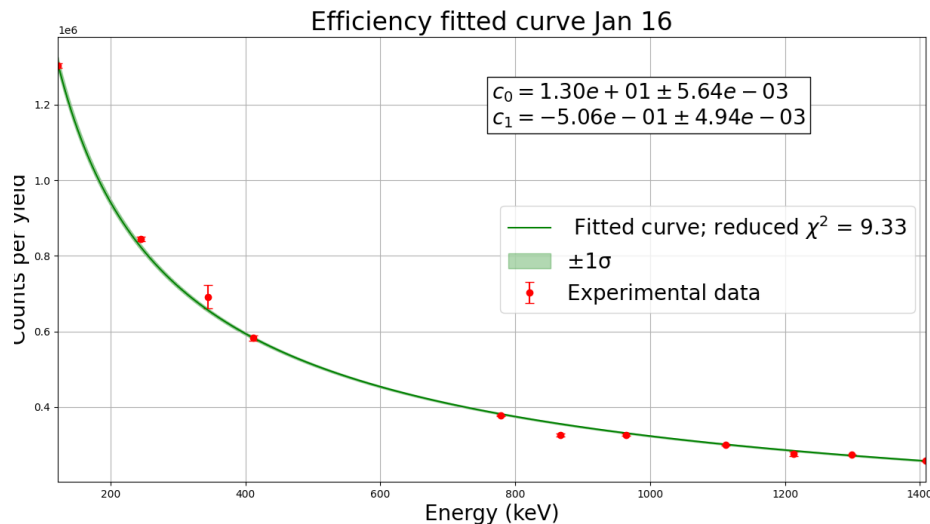
Extracting Counts from Gamma Ray Spectra

- Each run's spectra were split into 50-second bins to resolve the decay in time.
- In every bin, the 526.6 and 249.8 keV peaks were fit with Gaussians to extract their counts.



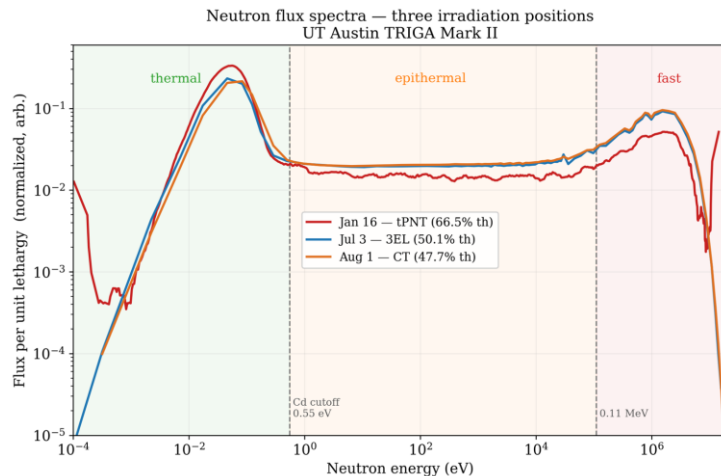
Efficiency Calibrations

- The A_{527}/A_{250} ratio depends on the detector's relative efficiency at the two lines, so it is measured for each counting geometry.
- Calibrated with a ^{152}Eu source (12 γ lines, 122–1408 keV) fit to a log-log efficiency curve; the europium was spread on polystyrene beads to mimic the xenon gas fill, matching the calibration geometry to the count.



Flux characterization:

Position spectra were taken from facility characterizations: a SAND-II spectrum for tPNT (Jan 16), and MCNP simulations for 3EL and CT (Jul 3, Aug 1).



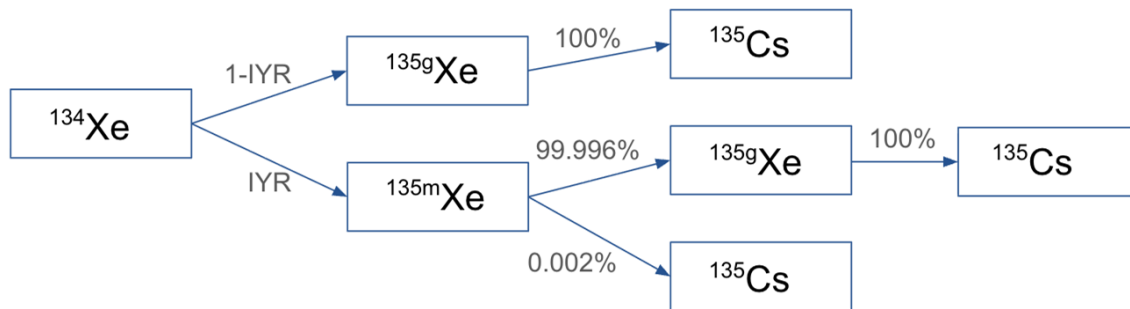
Thermal, epithermal, and fast fractions were then computed for each run:

Irradiation	Thermal (%)	Epithermal (%)	Fast (%)
Jan 16 — tPNT	66.5	19.1	14.4
Jul 3 — 3EL	50.1	25.2	24.7
Aug 1 — CT	47.7	26.1	26.2



Building an Analytical Model:

A model predicts how much ^{135}Xe and $^{135\text{m}}\text{Xe}$ are produced, splitting each capture into a metastable branch (IYR) and a ground branch ($1 - \text{IYR}$)



The coupled abundances were solved analytically with the Bateman equations.



Analysis: From Spectra to a Ratio

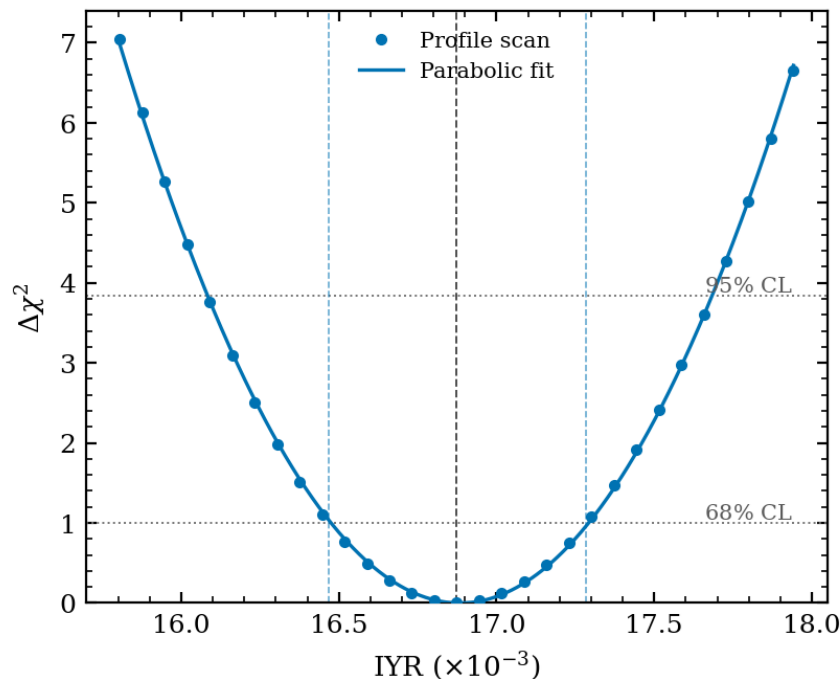
- The 526.6 and 249.8 keV decay rates give the metastable and ground-state activities over time.
- Taking their ratio cancels the flux, capture cross section, and target amount, which isolates the IYR and reduces the uncertainty introduced by the parameters.



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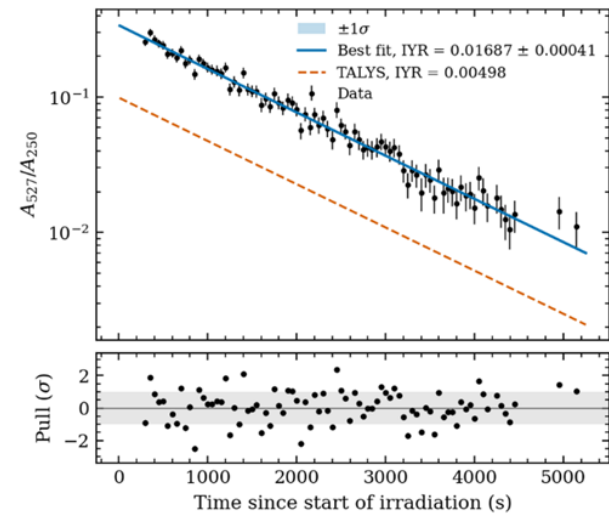
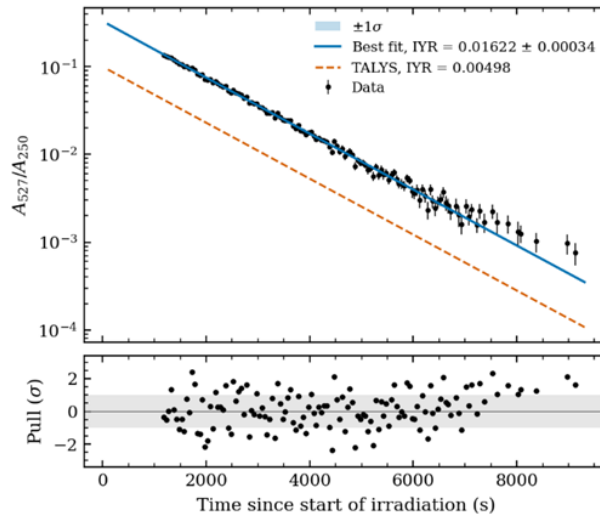
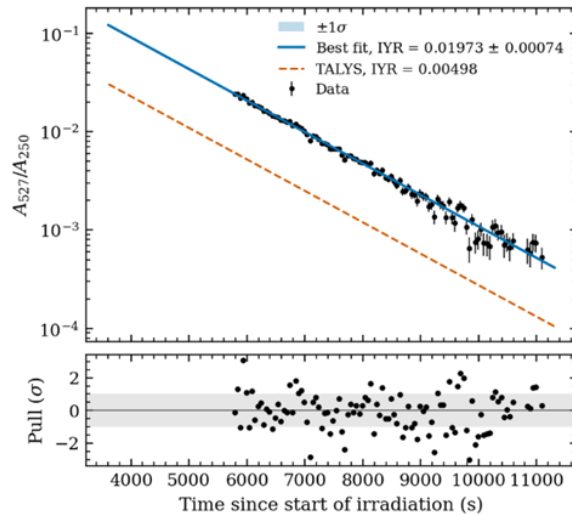
Fitting the Data to the Analytical Model



- The modeled abundances were converted to activity ratios using the efficiency calibration, isolating the IYR.
- A χ^2 minimization (MINUIT) fit the IYR, letting detector and nuclear inputs float as constrained nuisance parameters.
- Left: the χ^2 profile for one run. The minimum gives the best-fit IYR and its 68% / 95% intervals.



Fitting the Data to the Analytical Model



Each run's activity ratio is well described by the best-fit model ($\chi^2/\text{ndof} \approx 1$), and sits far above the TALYS default prediction (dashed).

Results:

The measured effective IYR for the three runs:

Irradiation	Facility	Thermal (%)	IYR _{eff}	χ^2/ndof
Jan 16, 2026	tPNT	66.5	0.01687 ± 0.00041	0.97
Jul 3, 2025	3EL	50.1	0.01622 ± 0.00034	1.20
Aug 1, 2025	CT	47.7	0.01973 ± 0.00074	1.30



Discussion:

- The values all sit at or above the prior measurement (Belov 2001, 0.013 ± 0.002).
- the range of values are due to the different fractions of thermal neutrons each sample experienced.
- Caveat: the Aug 1 (CT) run sits $\sim 3\sigma$ high. Because 3EL and CT have nearly identical spectra, this is a run-level systematic, and most likely due to Aug 1's counting geometry and efficiency ratio, but is under investigation.



Conclusions/Next Steps

- Measured the $^{134}\text{Xe}(n,\gamma)^{135\text{m}}\text{Xe}$ isomeric yield ratio across three neutron spectra at the UT Austin TRIGA Mark II, obtaining $\text{IYR}_{\text{eff}} \approx 0.016\text{--}0.020$.
- Demonstrated the reactor's multi-position capability for precision nuclear-data measurements.
- Next: extend the analysis to recently acquired data, incorporating rigorous flux unfolding and cadmium-covered irradiations.



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