

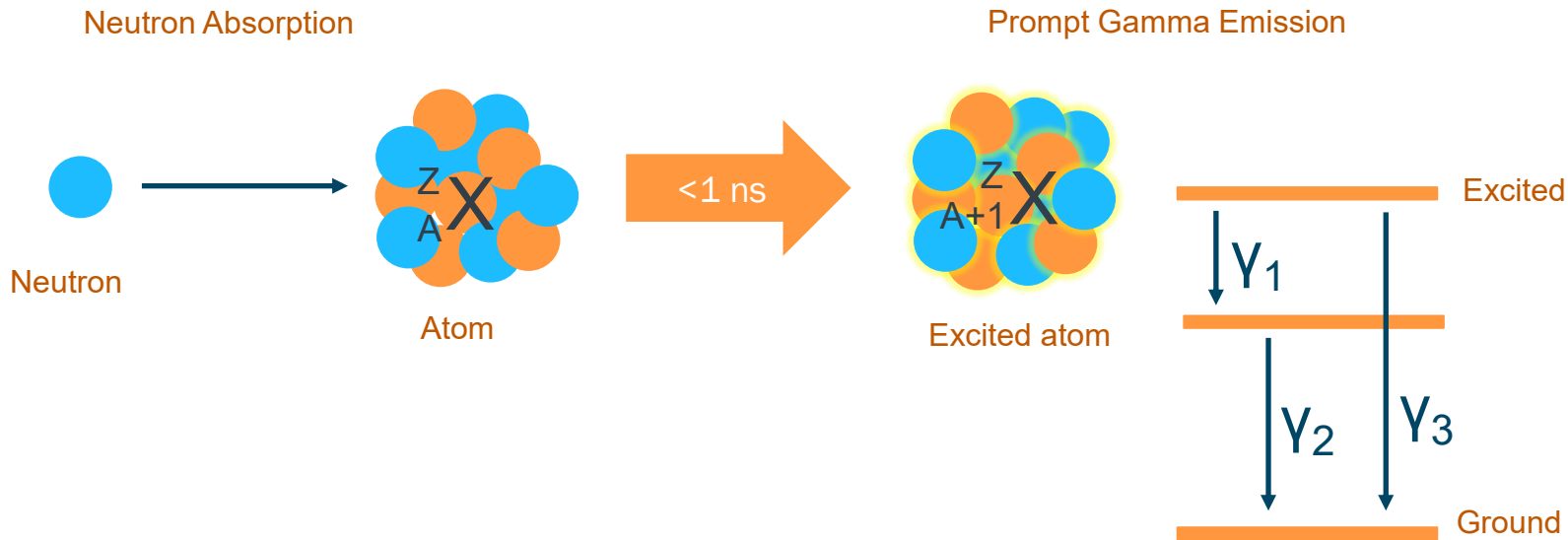
SEP 2026

XENON-135 PRODUCTION AND PGAA FOR FUNDAMENTAL DATA

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What is a “prompt” gamma?



The goal

- Irradiate Xe134 to produce unstable isotope Xe135
- Move sample to thermal neutron beam + detector system to count gammas produced in $^{135}\text{Xe}(n,\gamma)^{136}\text{Xe}$ reaction
- Determine new ^{136}Xe energy levels

The motivation

- Despite its relevance to nuclear reactors, the behavior of $^{135}\text{Xe}(n,\gamma)^{136}\text{Xe}$ is not well known

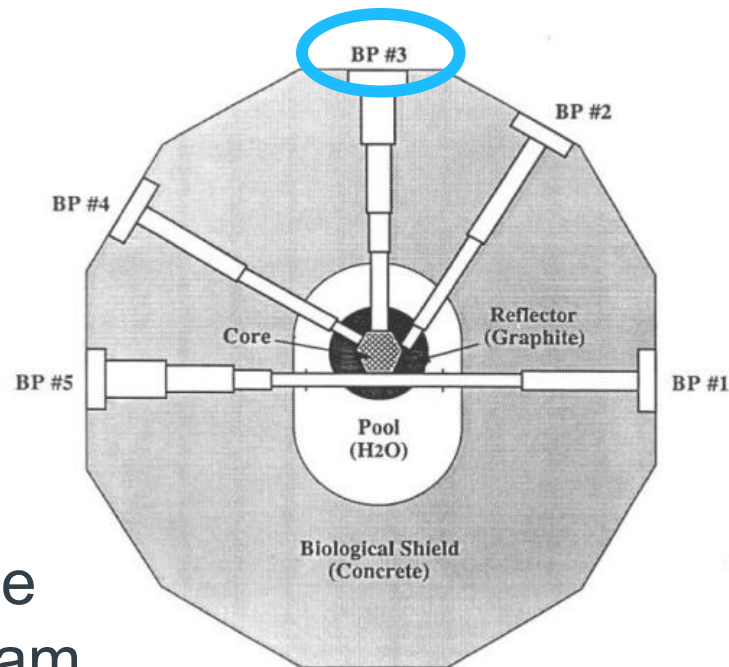
- Xe135 is an unstable isotope, making it hard to procure a sample

(other Xenon measurements ongoing at ILL FIPPS)

Isotope	Target Half-life	Cross Section (b)	Known Prompt Gammas
$\text{Xe}^{124}(n,\gamma)\text{Xe}^{125}$	$1 \times 10^{22} \text{ y}$	150.2	2
$\text{Xe}^{126}(n,\gamma)\text{Xe}^{127}$	Stable	3.487	0
$\text{Xe}^{130}(n,\gamma)\text{Xe}^{131}$	Stable	4.778	98
$\text{Xe}^{132}(n,\gamma)\text{Xe}^{133}$	Stable	0.4506	0
$\text{Xe}^{134}(n,\gamma)\text{Xe}^{135}$	Stable	0.2649	0
$\text{Xe}^{135}(n,\gamma)\text{Xe}^{136}$	9.168 h	2,665,000	0
$\text{Xe}^{136}(n,\gamma)\text{Xe}^{137}$	Stable	0.2607	37

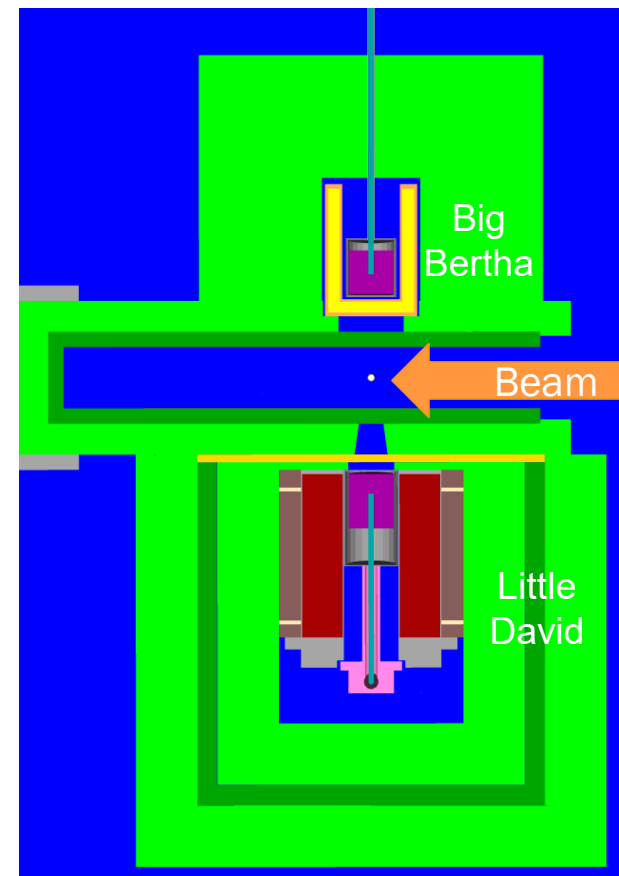
The system

- A cold neutron beam line with thermal flux of 1.56×10^6 n/cm²/s
- NETL's Beam Port 3 (BP3)
- Two HPGe detectors pointed at the sample area shielded from the beam line.



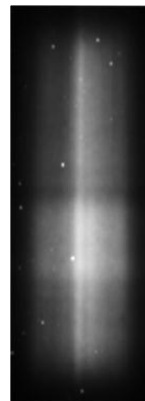
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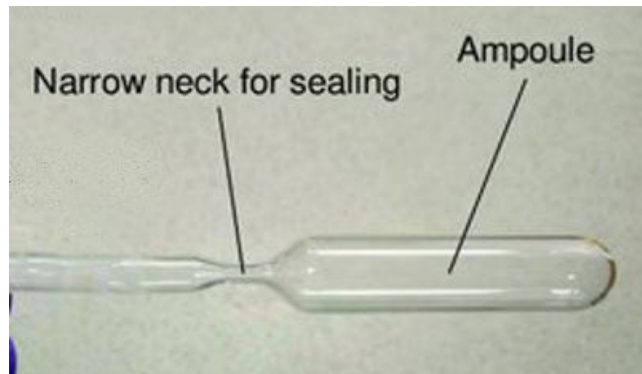


The sample

- Quartz ampoule (SiO_2)
- 1 bar
- 10 mm inner diameter
- 2.3 mL volume



Radiograph of BP3 beam.



The challenge

- Maximizing our target material maximizing primary background contributor, the decay of ^{135}Xe
- Needed to determine the highest possible activity acceptable in the detector area.
 - This will be driven by acceptable dead time values with a hard ceiling at ~80% dead time to prevent damaging the detector.

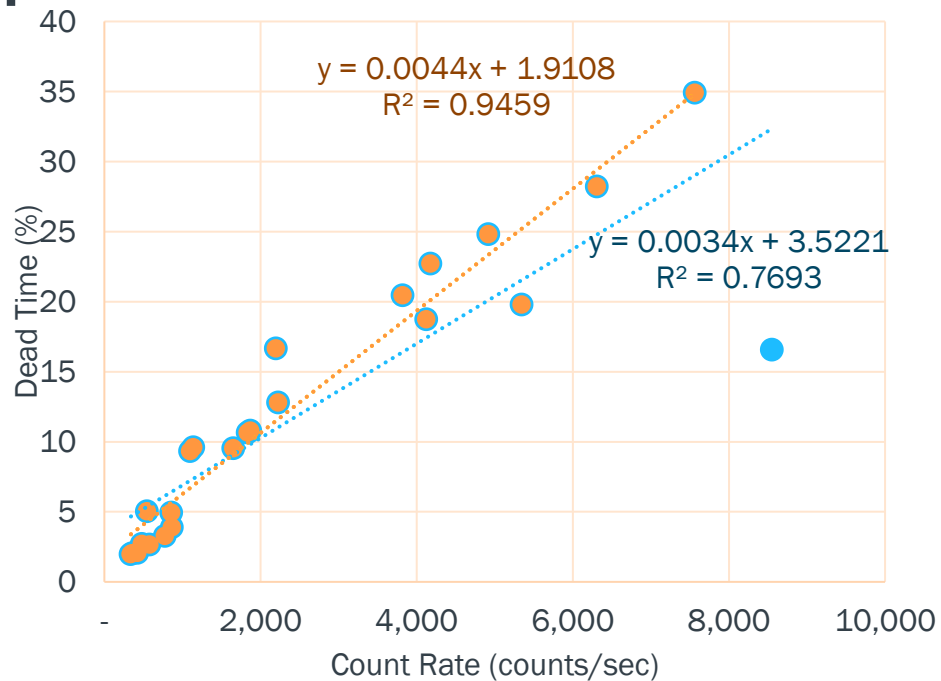
^{135}Xe
9.168 h

$\beta^- = 100\%$

Pulse Ht. Analysis	
Start:	9:47:12 AM 4/18/2025
Real:	1,185.20
Live:	988.88
Dead:	16.56 %

Dead time prediction

- Gathered historical count rate vs deadtime data for each HPGe
 - Deadtime for HPGe comes from post processing, not particle energy discharge.
 - Did not have to weight the deadtime contribution by particle energy
 - Used most conservative dead time estimate
- 8,250 cps gives a 40% deadtime on Big Bertha



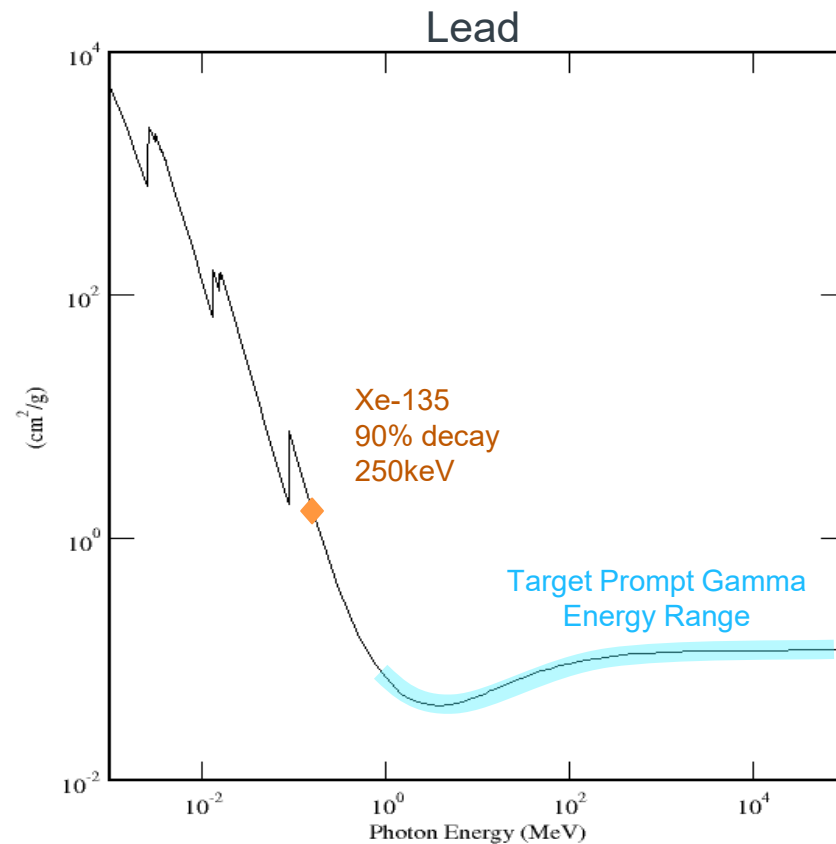
Targeting sample activity

- Deadtime trendline allowed us to acquire target number of counts per second: 8,250 cps
- How does that translate to activity?
 - Incorporate detector efficiency, geometric efficiency, and shielding.

$$A = \frac{CR}{\epsilon_{\text{det}} \epsilon_{\text{geo}}} e^{\mu x}$$

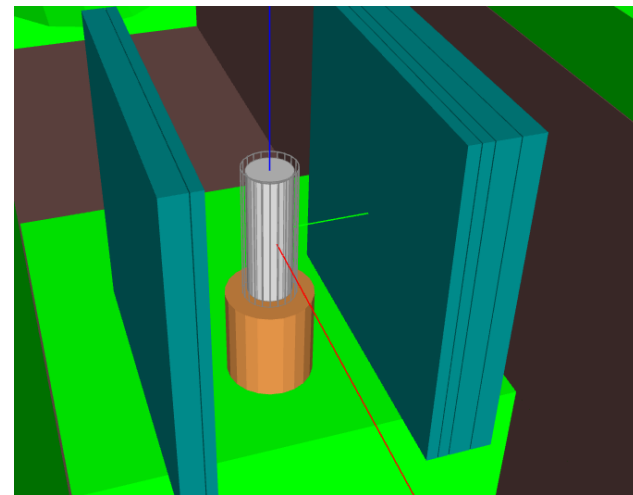
Shielding

- High Z materials shield low energy gammas more efficiently.
- Prompt gammas discovered are likely to be 1+ MeV.



Modeling Detector Counts

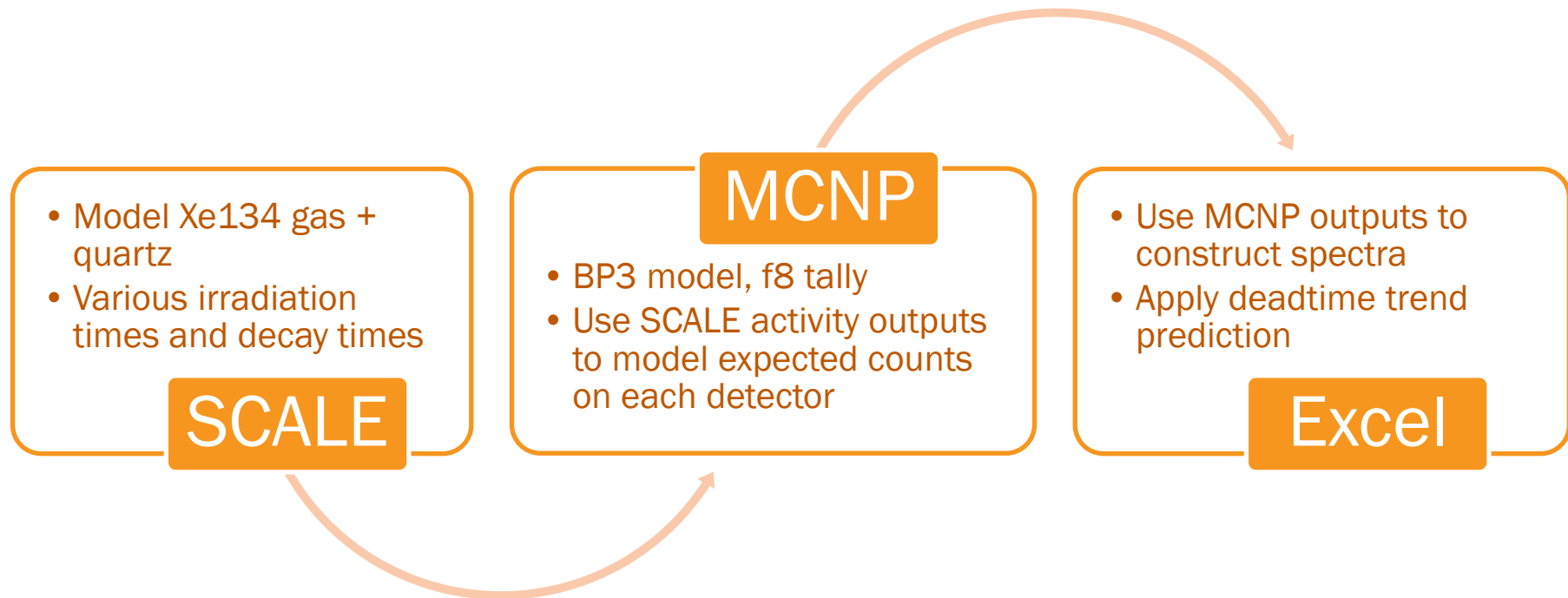
- Model a gamma source in sample area of BP3
 - Decay source term modeled separately from prompt gamma production source term
- Modeling effectiveness of low-energy gamma shielding with Lead.



Geometry of sample + shielding design model. Lead shown in teal, quartz and Xe gas in gray.

```
sdef cell=14 par=p erg=d1
si1 L 0.25 0.608 $ 250keV 96%, 608 keV 4%
sp1 0.96 0.04
```

```
sdef cell=14 par=p erg=d1
si1 L 1.313 2.414 $ equal % 1.313 & 2.414 MeV
sp1 1 1
```



Targeting sample activity

- Tried different shielding options and thicknesses to land on best balance of sample activity and shield

- Result:

1.2 x 10⁷ Bq Xe-135

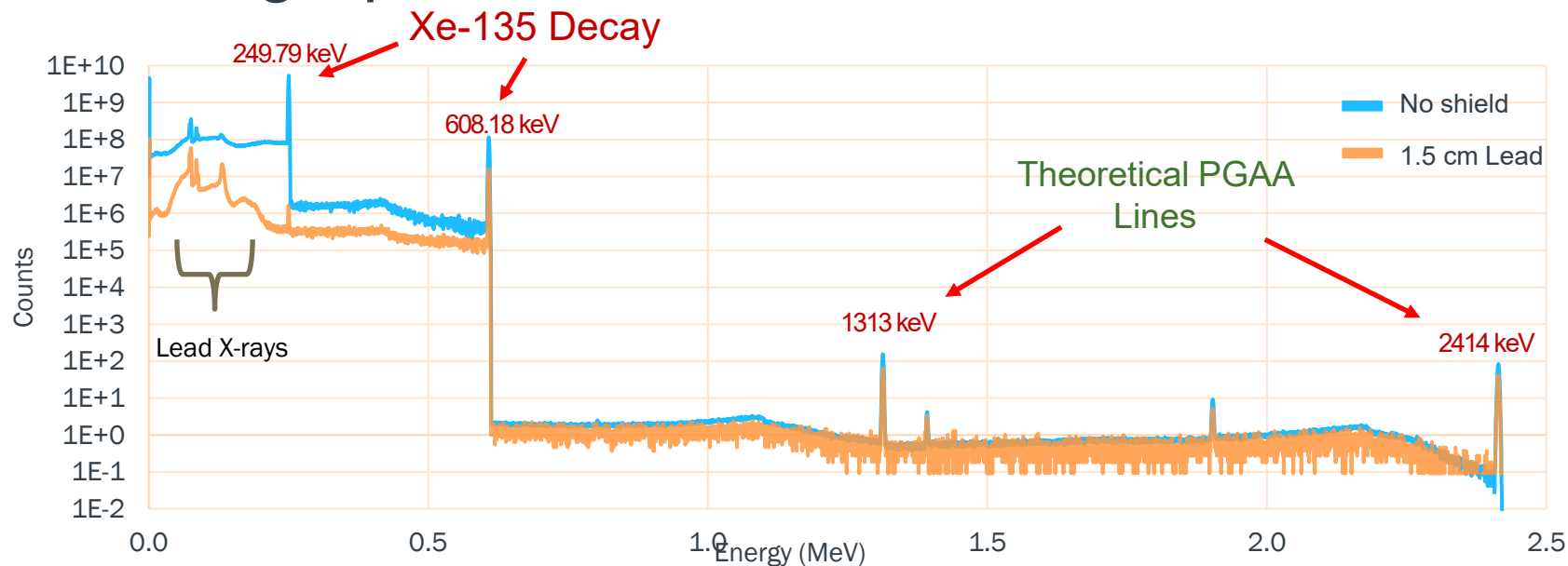
0.324 mCi Xe-135

1.5 cm thickness

3 cm radius

Material	Thickness (cm)	Radius (cm)	counts/sec/ source particle	counts / sec	Dead Time (%)	total counts
Lead	0	0	1.63E-02	2.30E+05	1015.1	8.90E+10
Lead	0.5	2.25	1.92E-03	2.70E+04	123.0	1.05E+10
Lead	0.5	3	1.51E-03	2.13E+04	97.9	8.26E+09
Lead	1	3	7.22E-04	1.02E+04	48.9	3.94E+09
Lead	1.5	3	5.85E-04	8.25E+03	40.5	3.20E+09
Tungsten	1.5	3	4.92E-04	6.94E+03	34.7	2.69E+09
Lead Shot	2	3.2	6.77E-04	9.54E+03	46.2	3.70E+09
Lead	2.3	3.2	5.84E-04	8.23E+03	40.4	3.19E+09
Lead	1.54	2.25	9.55E-04	1.35E+04	63.4	5.22E+09
Lead/Shot	1.54 / 0.75	2.25 / 3.2	5.15E-04	7.26E+03	36.1	2.81E+09

Predicting Spectra



- Modeled contribution from Xe-135 decay and theoretical prompt gamma lines
- Modeling continuous counting for 80 hours
- Theoretical lines taken from states known via other exploration methods

Final Experiment design

Produce Xe-135 from Xe-134

2.3 mL quartz ampoule
15 minutes
900 kW
Central Thimble

Count Xe-135 PGAA

8.75 hrs
1.5 cm BB Lead Shield
0.75 cm LD Lead Shield
900 kW

Repeat
x16

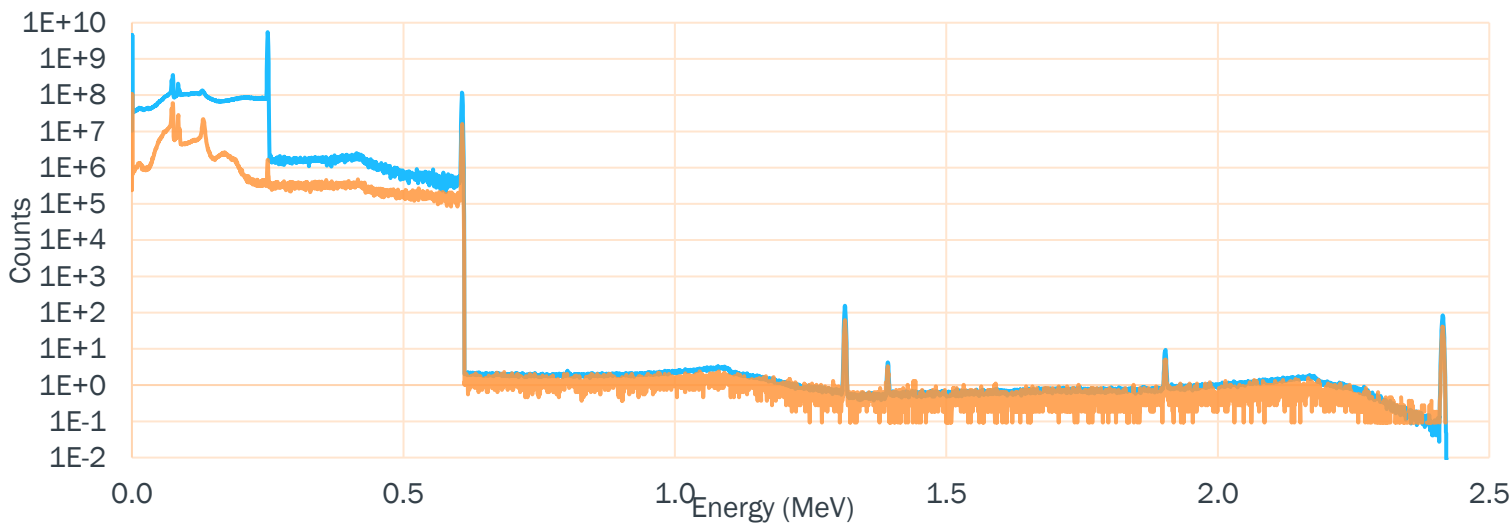
Decay

1 hour
Allows for decay of short lived isotopes

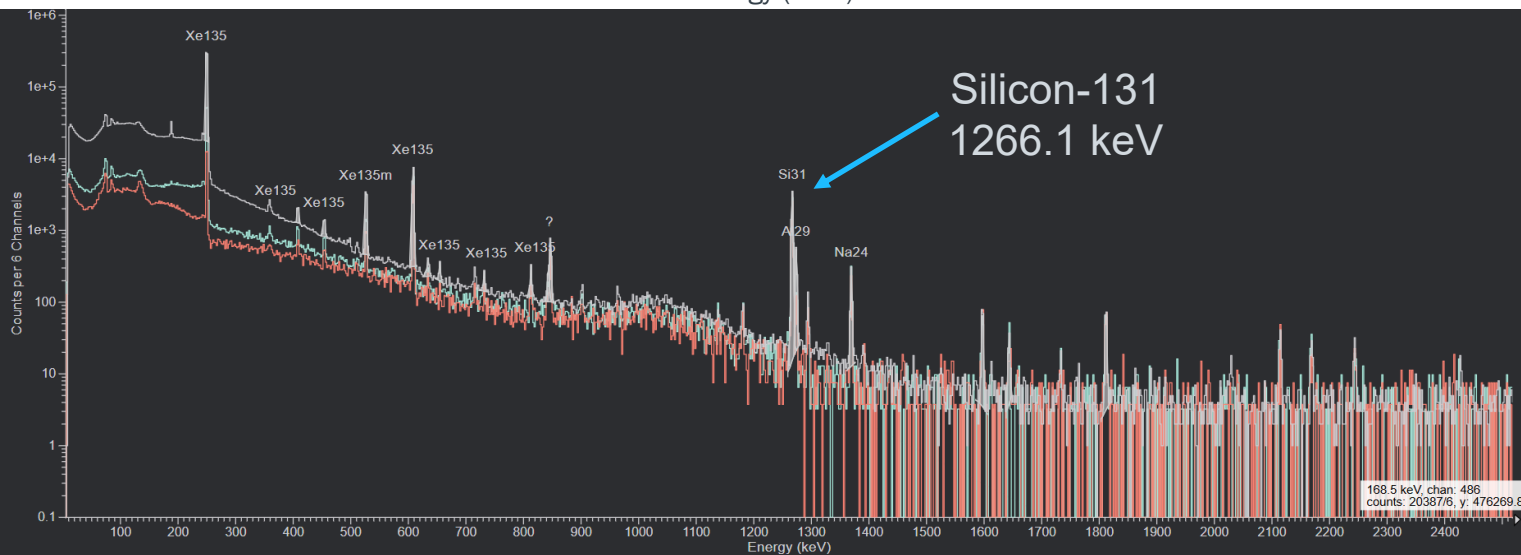
Feasibility Test - Aug 21



- Scaled down version of final experiment
- 1 mL of enriched ^{134}Xe in a quartz vial, loaded into the central thimble experimental area
 - 30 minutes of irradiation
 - $1.57\text{E}13$ neutrons/cm²/s
 - Dilute gold and nickel flux monitor wires



MCNP model
does not
accurately
represent
background



Silicon Peak and
Compton edge
may bury our
Xe-135(n, γ) lines

Feasibility Test – Aug 21

- Produced 4.24×10^5 (0.05) Bq of ^{135}Xe
 - Expected $6.31\text{E}5$ Bq
- Discovered detector enclosure sufficiently shielded Si-131 betas.
 - Transferring irradiated sample to fresh container may be desirable anyway.
- Expected 40% deadtime with no additional shielding, got **10%**
- Good news! More ^{135}Xe can be produced

Conclusions

- Increase irradiation time in CT for more ^{135}Xe
- Activated silicon may bury important counts

Next Steps

- Another trial run
 - Find the acceptable upper limit of Xe-135 activity
 - Use 2.3 mL ampoules
 - Transfer sample before counting

