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Compton Suppressed Gamma Spectroscopy of Spent Fuel Inventories

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NIST Center for Neutron Research

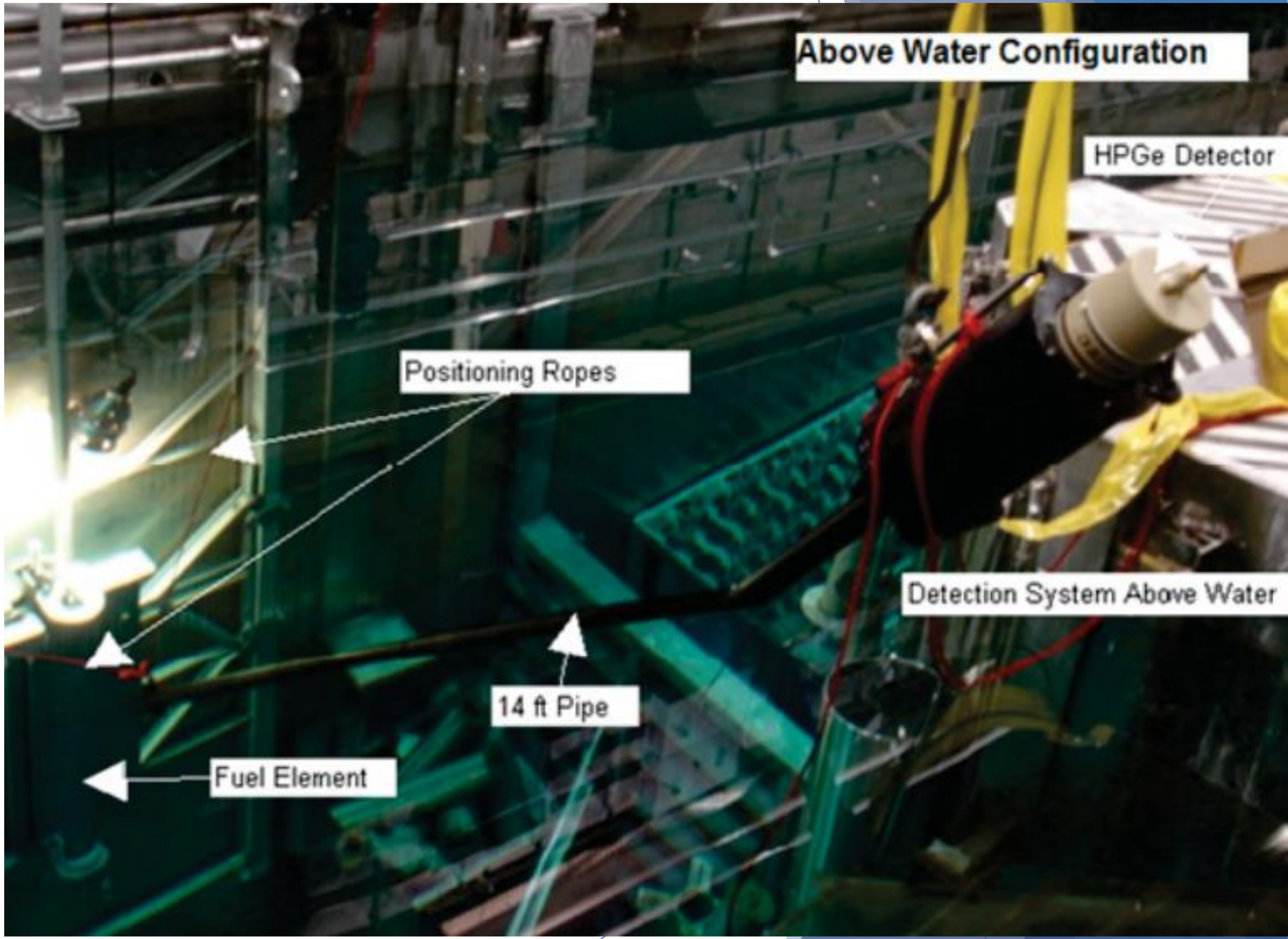
Background

- A little about me:
  - Texas A&M University-Kingsville (Junior Fall 2016)
  - Mechanical Engineering major, and Nuclear Engineering minor
- Project Origins:
  - Idaho National Laboratory (ATR)
  - Penn State University
- Motivation of Project:
  - To successfully determine the burnup of highly enriched uranium (HEU) fuel in the Neutron Beam Split-core Reactor (NBSR) at the NCNR.
  - Benchmark the power and burnup of the NBSR.

INL Study (2013)

A Feasibility and Optimization Study to Determine Cooling Time and Burnup of Advanced Test Reactor Fuels Using a Nondestructive Technique by **Jorge Navarro**

- Determined **burnup and cooling time** of fuel using isotopic γ ray peak area, and **peak area ratios**.
- Relationship was found between burnup and isotopes including ^{137}Cs, and the ratios of other isotopes correlated with the cooling time (such as $^{144}Ce/\,^{137}Cs$).
- Isotope ratios were correlated to **cancel out the geometry** of the measurement.

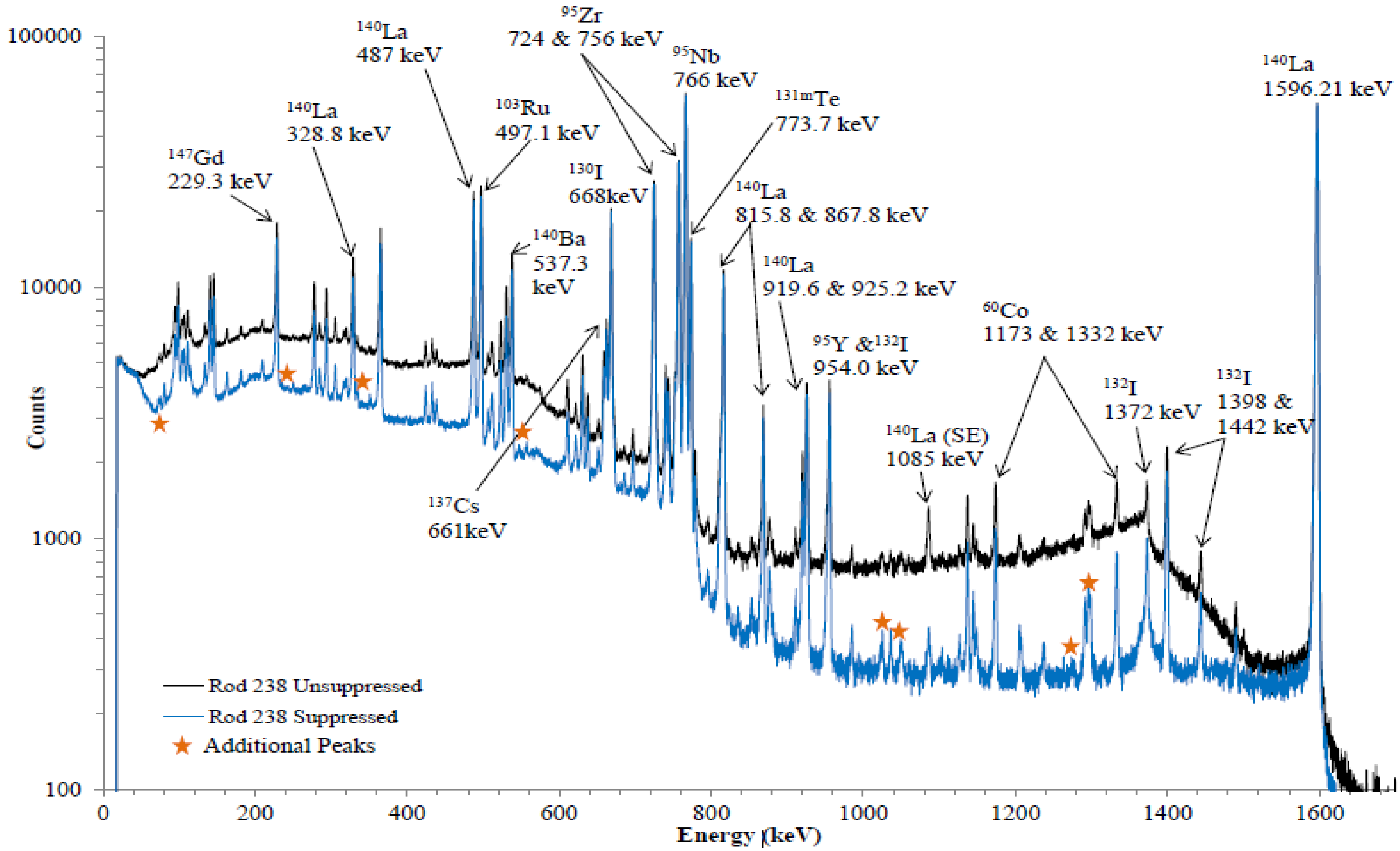


Penn State Study (2014)

Study of Compton Suppression for Use in Spent Nuclear Fuel Assay by **Sarah Bender**

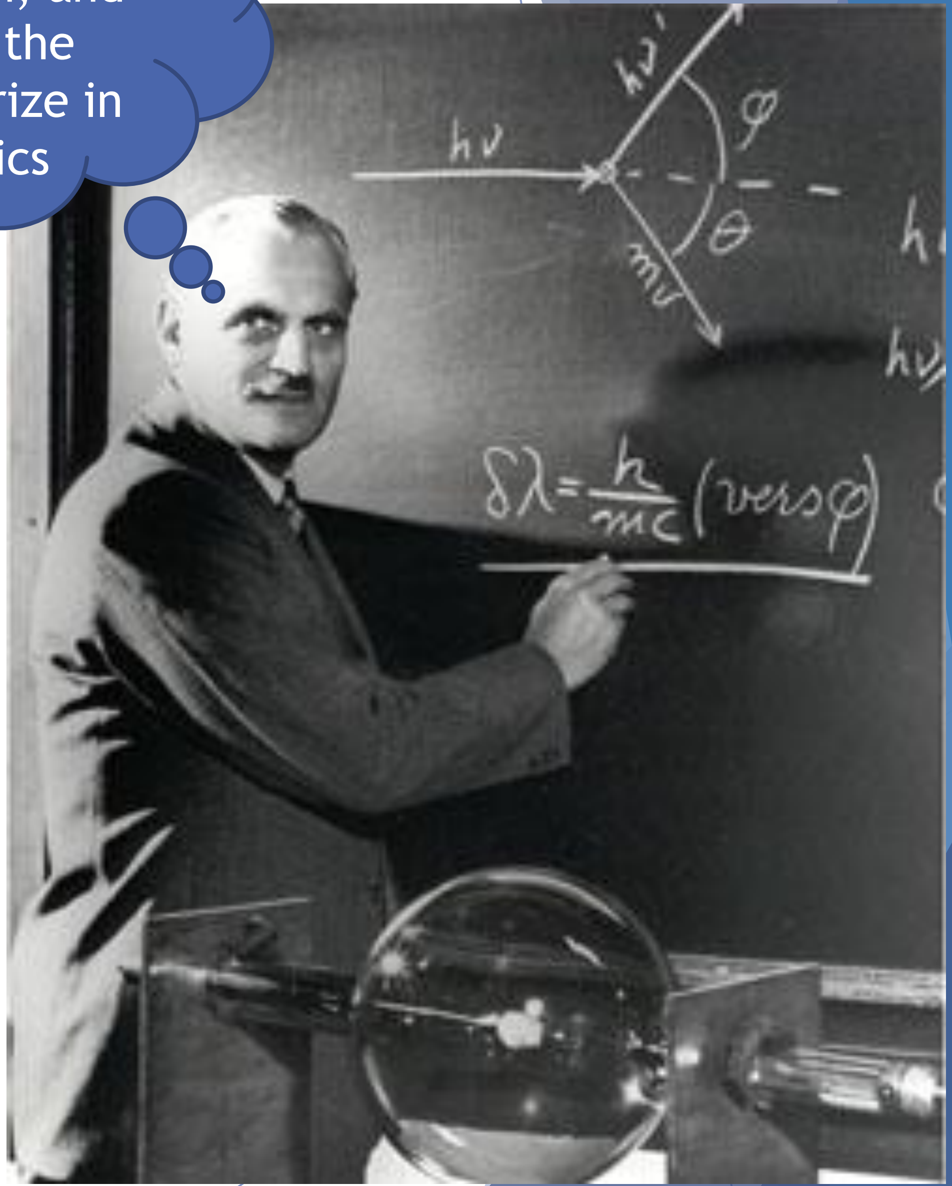
- A fuel sample from the Penn State Breazeale Reactor was measured using **Compton Suppression**.
- Used concrete collimator built into the fuel pool to study aged LEU fuel.
- Eight additional photopeaks were unmasked, allowing for **identification of more isotopes** in the fuel sample.

Penn State Study (2014)

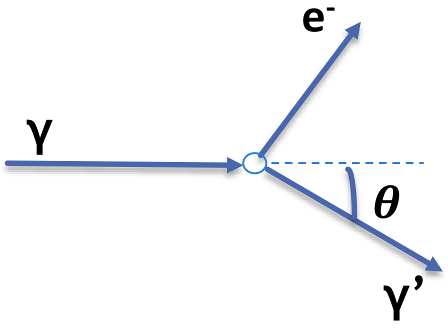


Compton Suppression

I am Arthur H. Compton, and I won the Nobel Prize in Physics

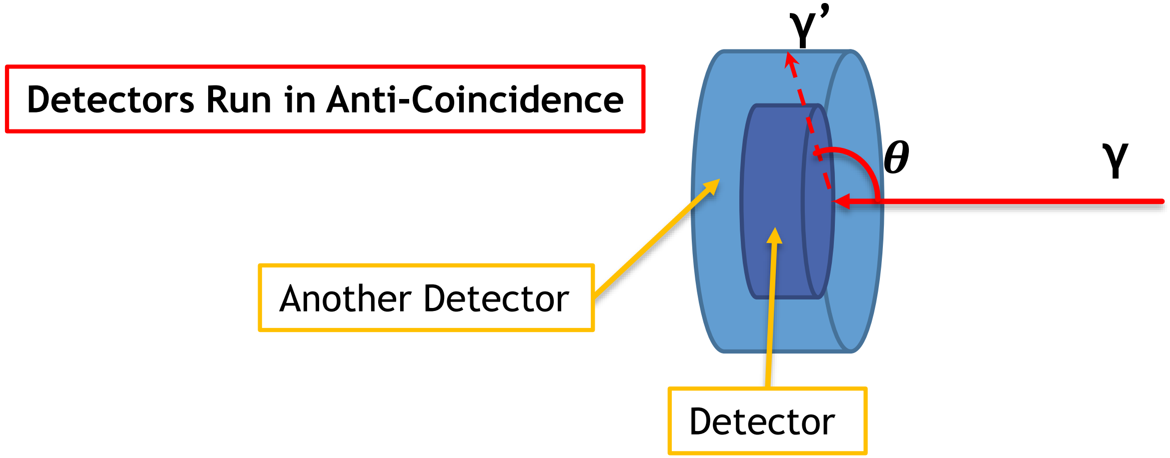


- Compton Scattering



$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

- How do we apply Compton Suppression?



NBSR Fuel

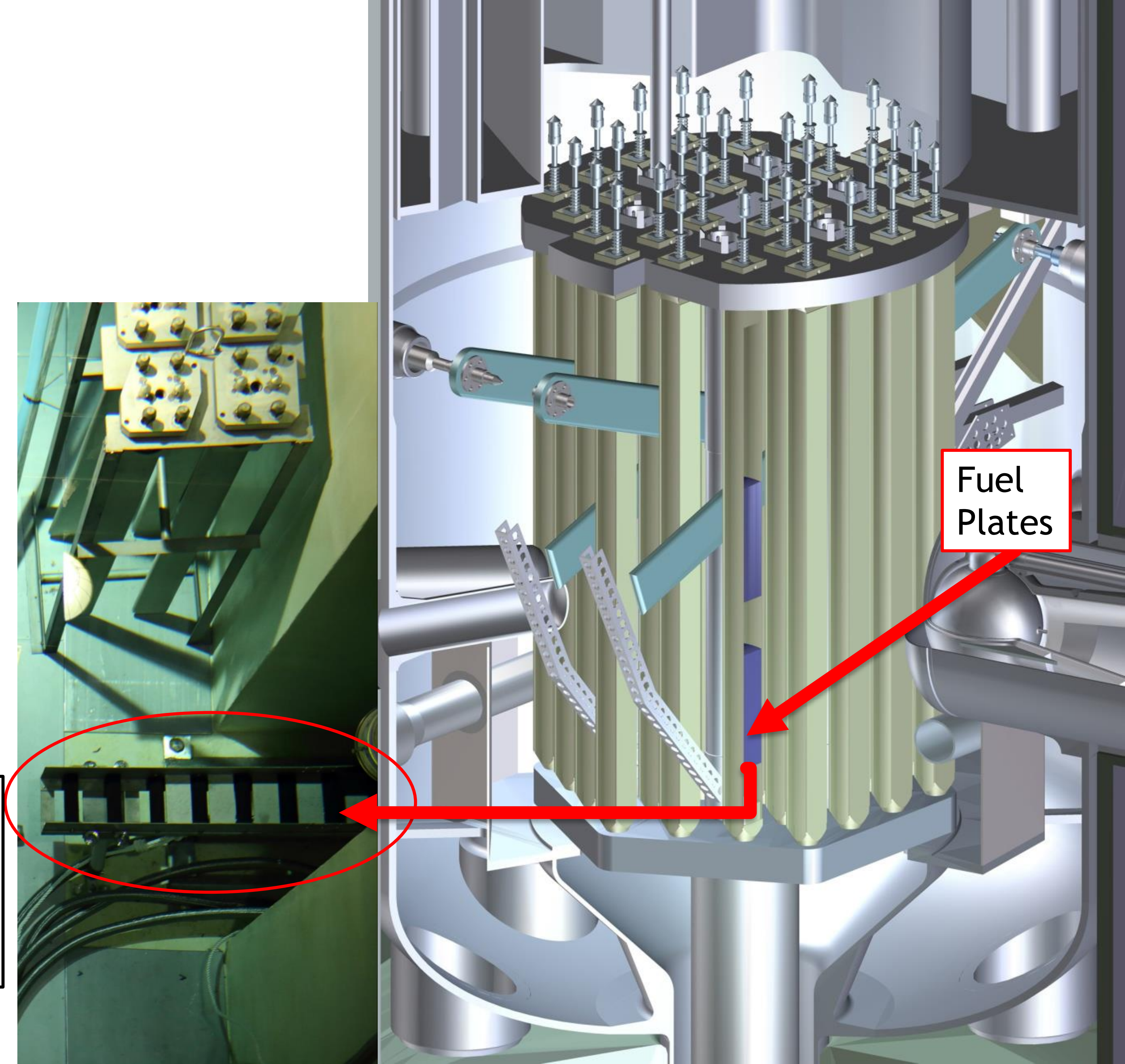
The Reactor:

- D_2O Coolant, moderator, and reflector
- **30 fuel elements with 38.5 day fuel cycles**
- **~20 MW Thermal Power**

The Fuel:

- **93%** U_3O_8 + Al
- **17 fuel plates per region**
- **2 regions per fuel element**

Burnup:
If 10% of an initial isotope underwent fission, the burnup is 10%.
In general: $\frac{MW\cdot d}{Metric\ Tonne} = \frac{Power\times Time\ Spent}{Initial\ Mass\ of\ Fuel}$

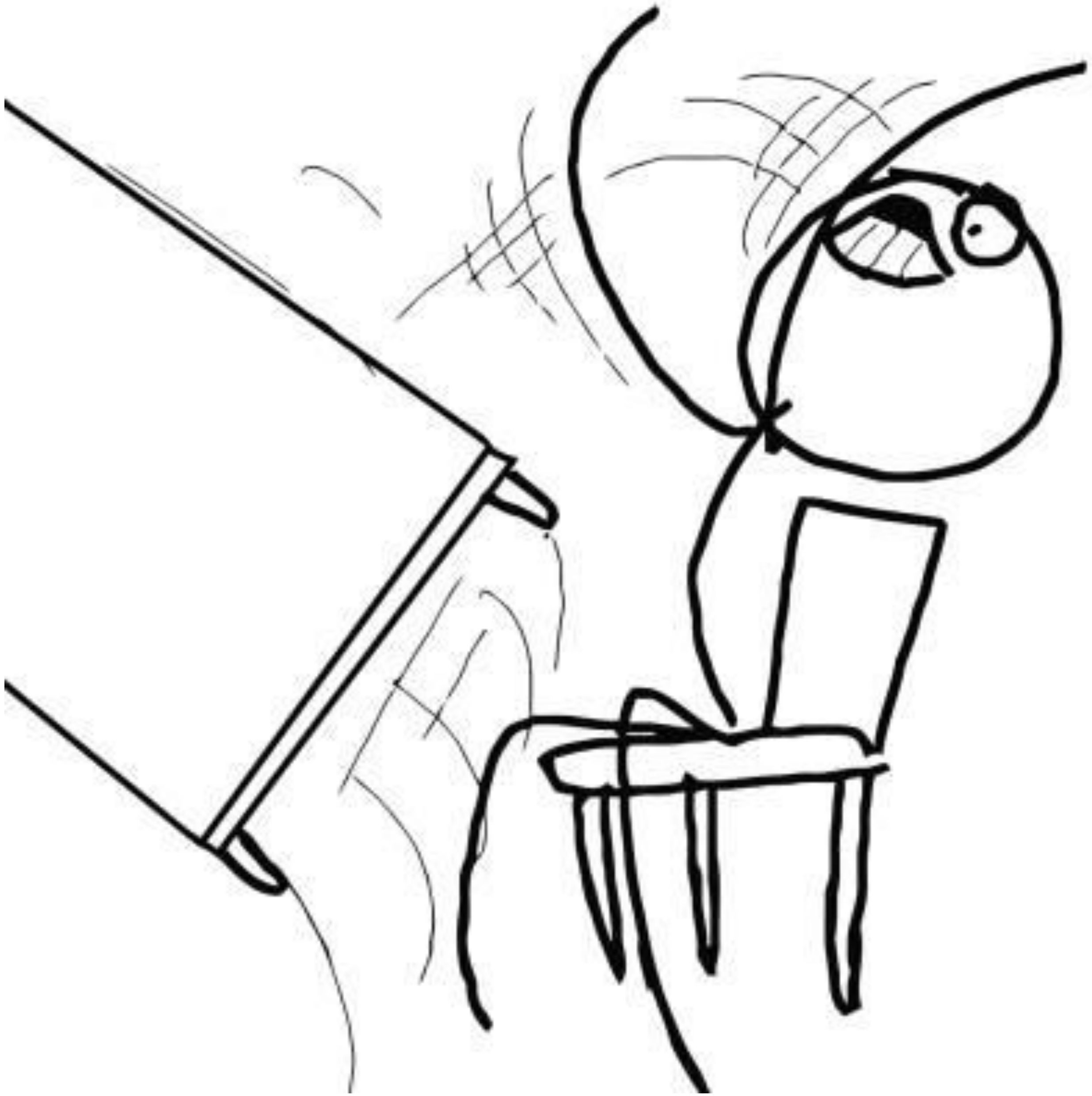


Challenges

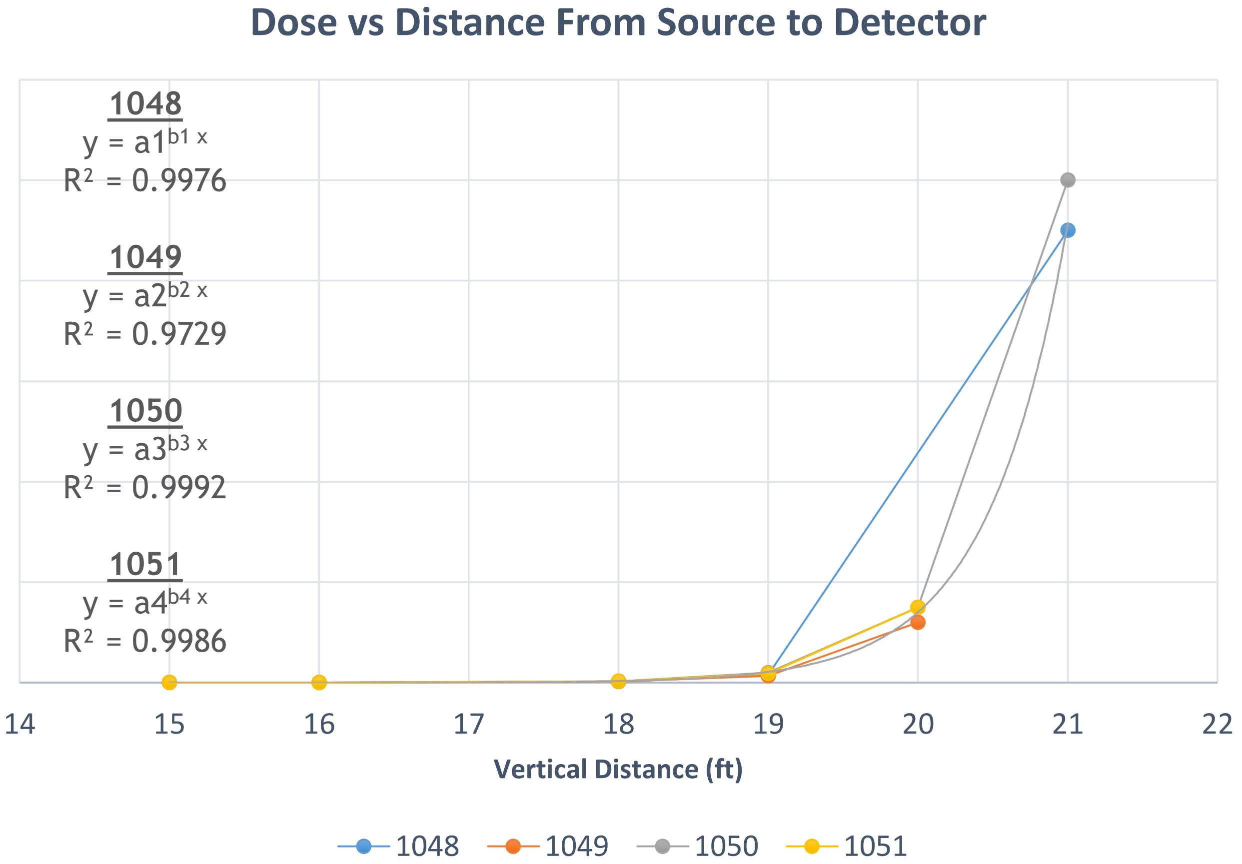
We wanted to measure spectra from different spent fuel elements using a HPGe detector and a BGO detector.

- We had to channel a γ beam from the fuel elements to the detectors.
- The detectors had to be setup in a way that accommodates Compton suppression.
- It had to be safe: health physics, crane lift, and γ beam control.
- Not a single thing besides the collimator and its peripherals was to touch the water.
- Had to be easy to assemble and disassemble for multiple uses for different γ beam sizes.
- Mechanical issues to be addressed: structure, buoyancy, material selection, manufacturing
- Cost Effectiveness
- Detectors Setup and Calibration
- EVERYTHING MUST WORK!!!!

Results?

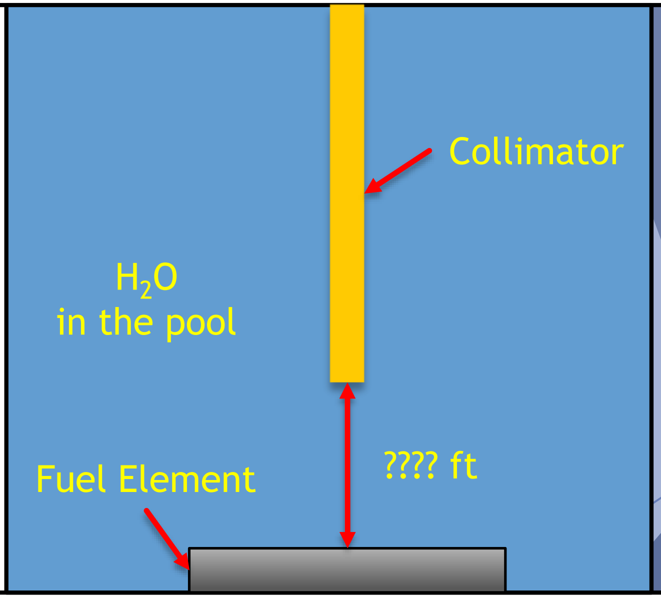


Radiation Safety



Questions:

1. How far down should we initially measure?



Necessities:

1. Attenuation Coefficients (μ)
2. Average Attenuation Coefficient (μ_{avg})
3. Average Tenth Value Layer (TVL)

Measured by Timothy Barvitskie

Radiation Safety

Attenuation Coefficient (μ):

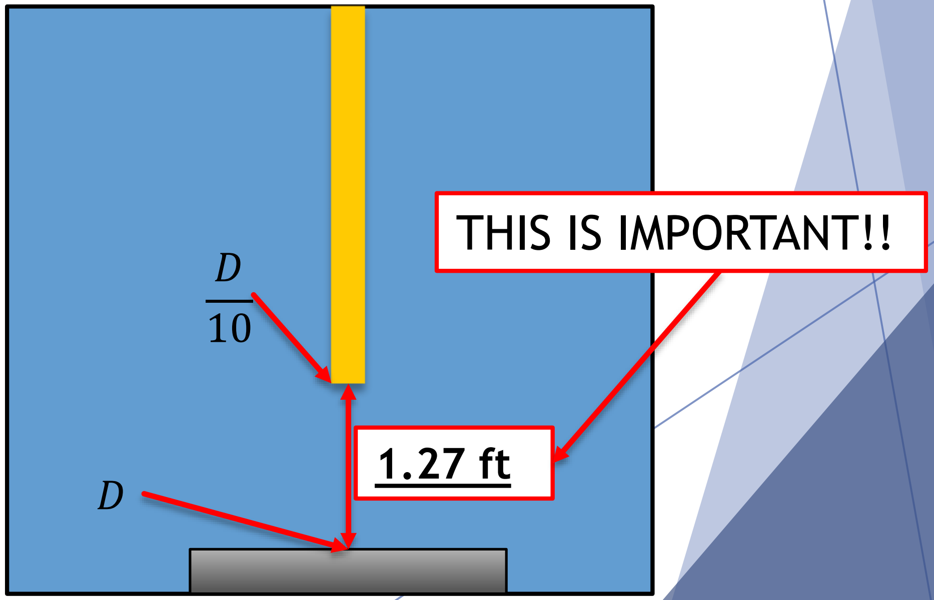
$$D = D_0 e^{-\mu x} \qquad \mu = \frac{-ln(\frac{D}{D_0})}{x}$$

Tenth Value Layer (TVL):

$$TVL = \frac{ln(10)}{\mu}$$

Calculated Results:

	μ (1/ft)	TVL (ft)
1048	1.8697	1.23
1049	1.6869	1.36
1050	1.8735	1.23
1051	1.8437	1.25
AVG	1.81845	1.27



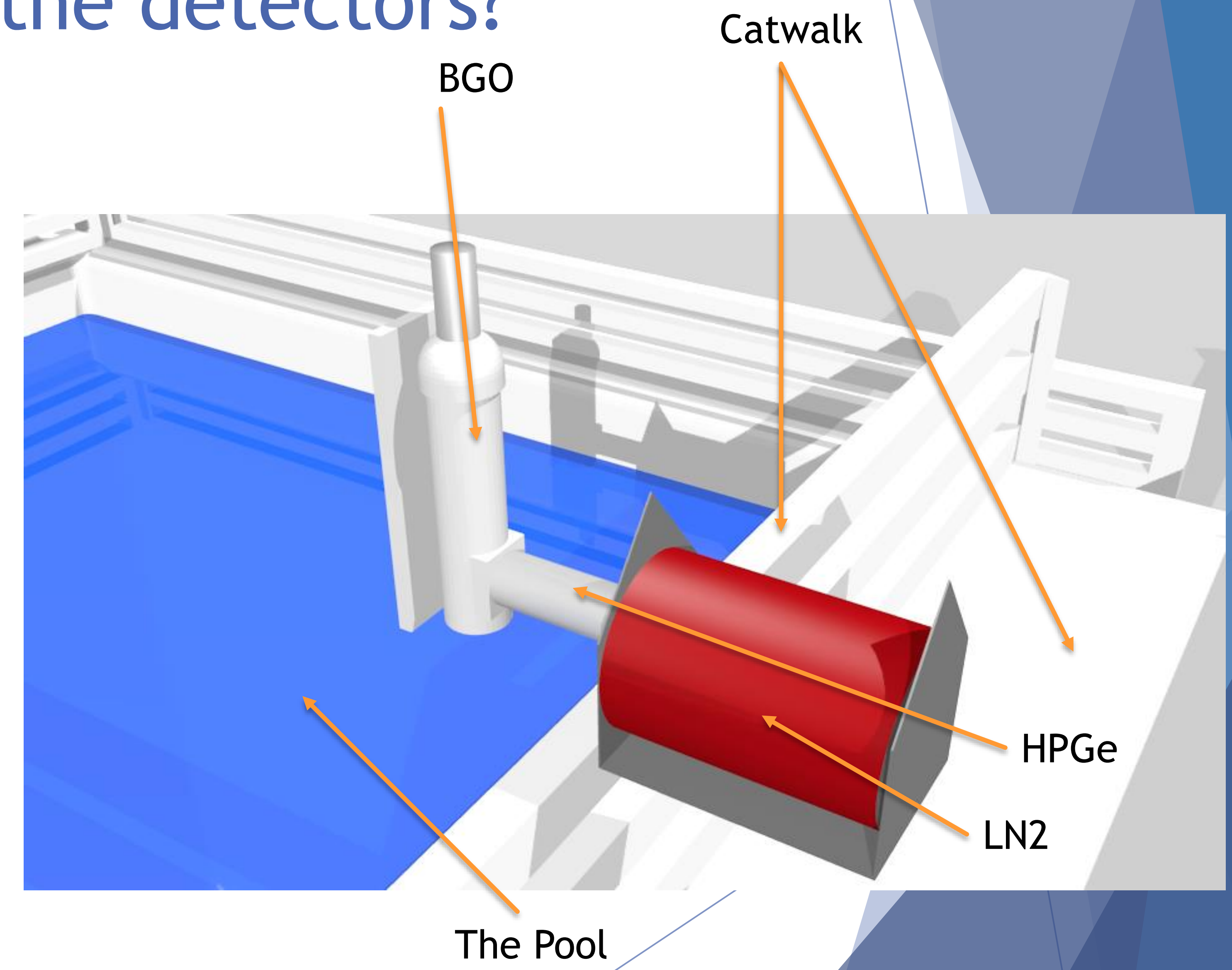
Where do we put the detectors?

Apparatus Requirements:

- Easy to assemble/disassemble
- Mobile
- Stable

Other places that were considered:

- On the side of the pool
- In the pool (under the lid)



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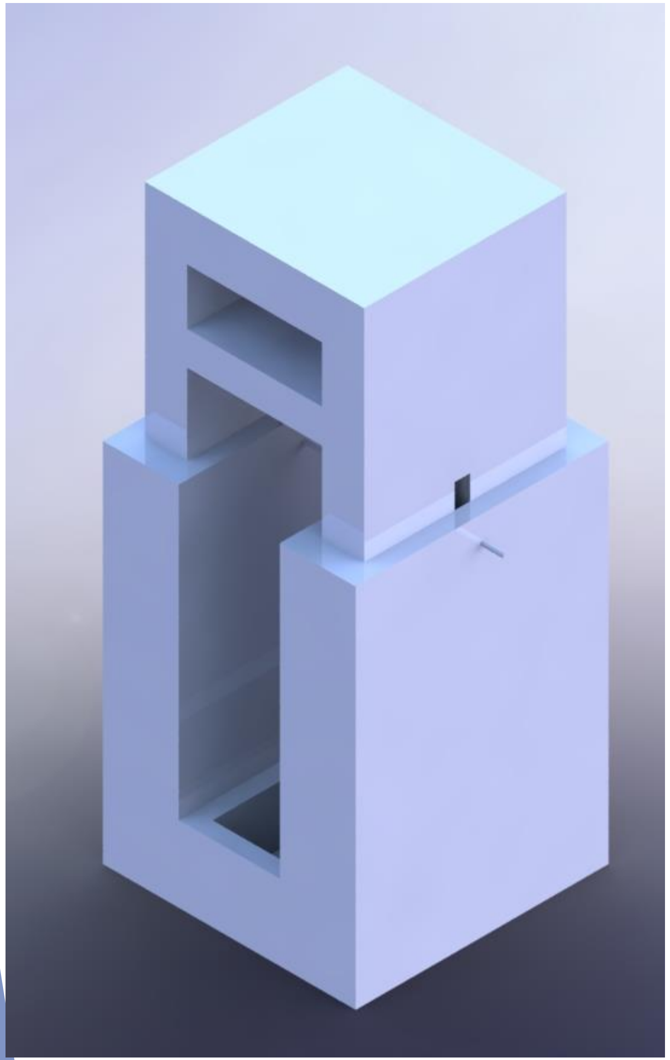

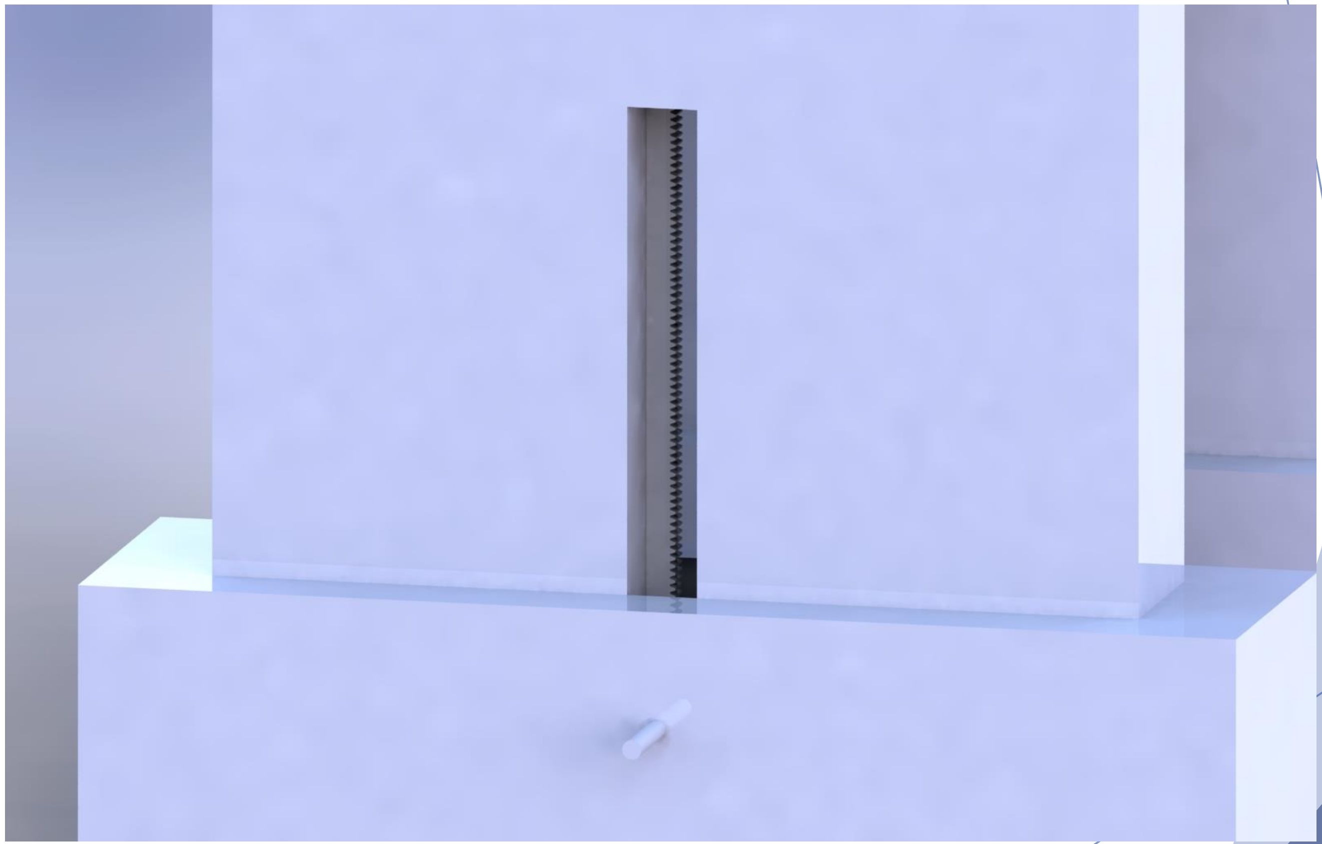

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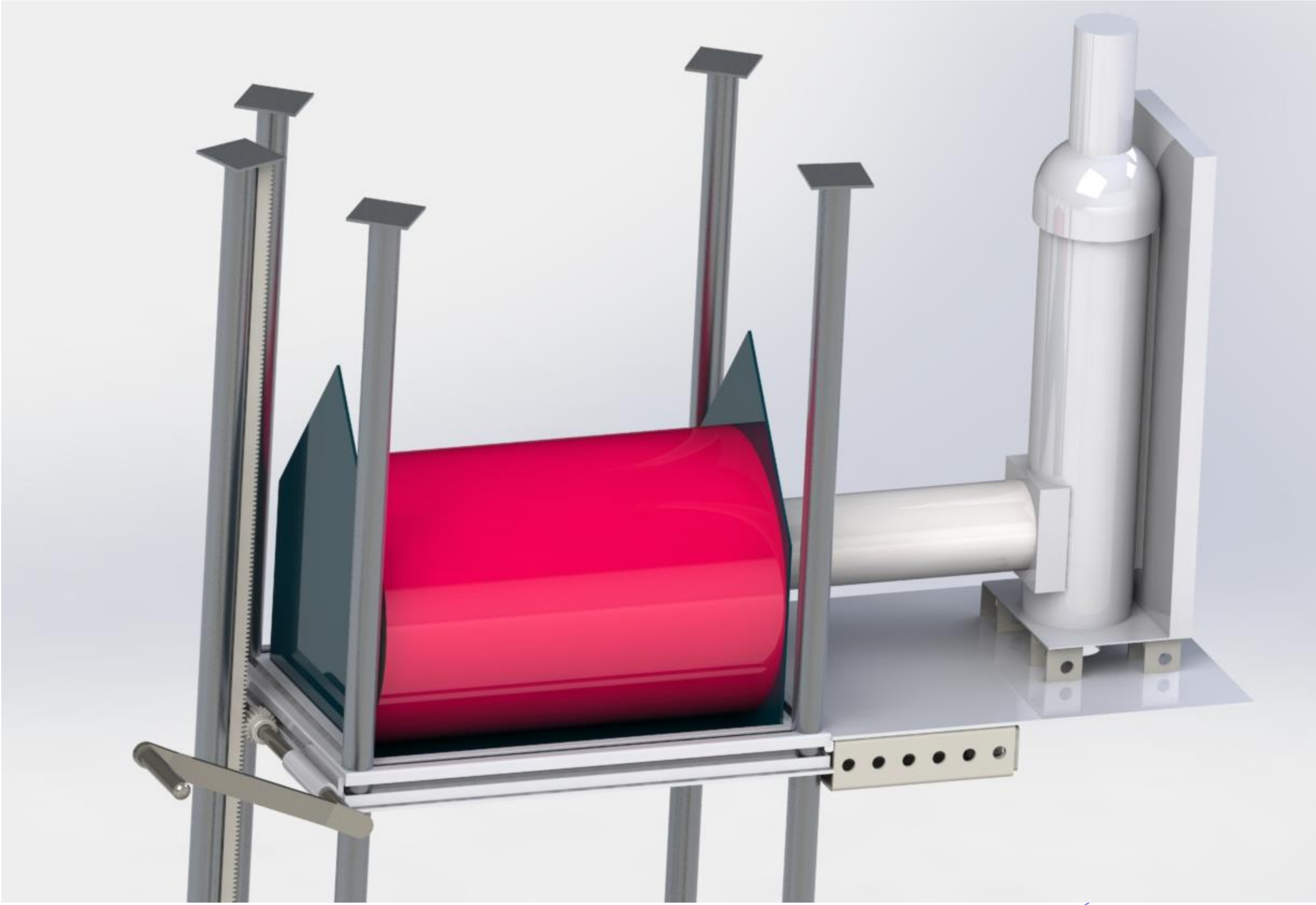

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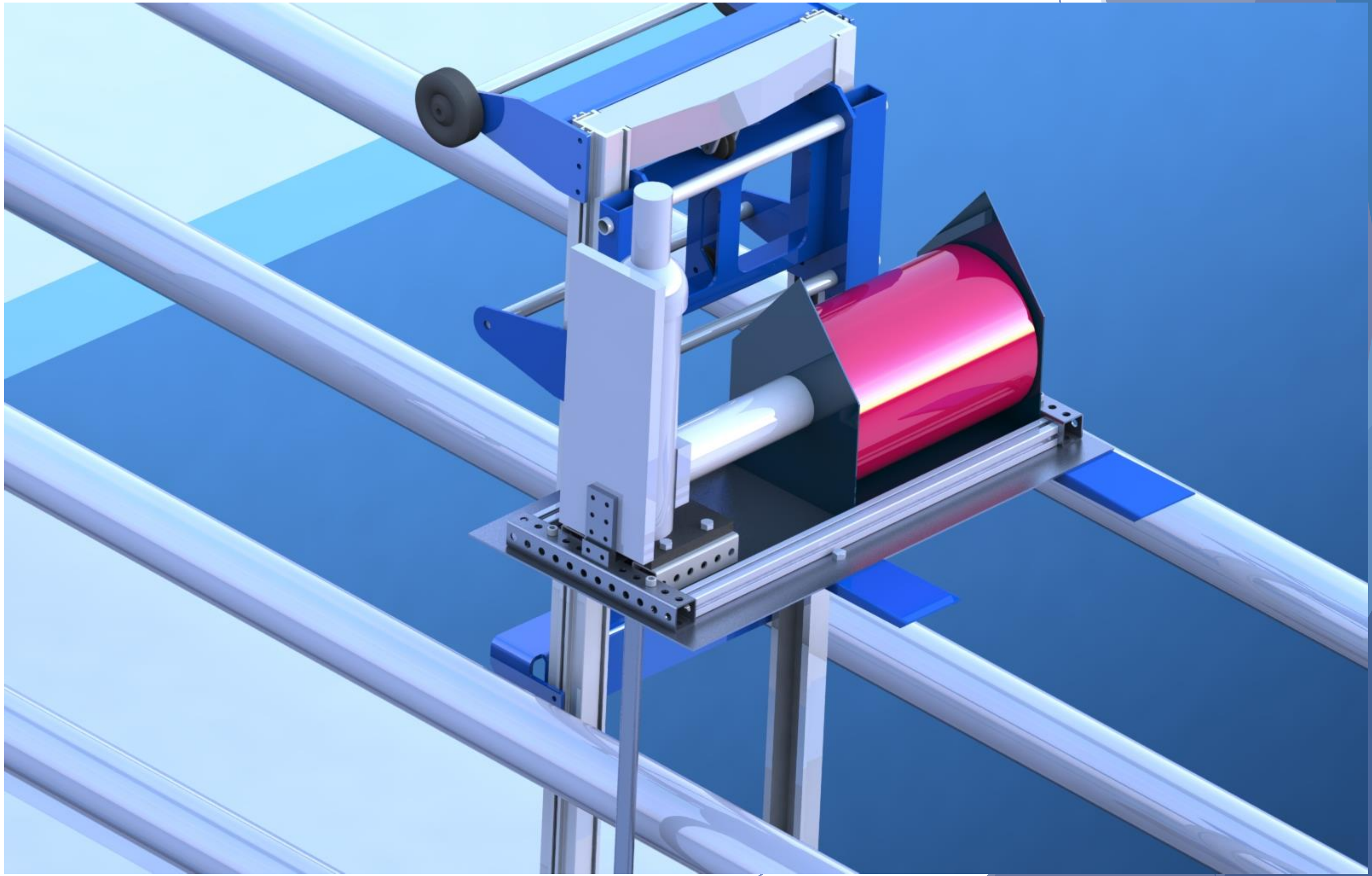
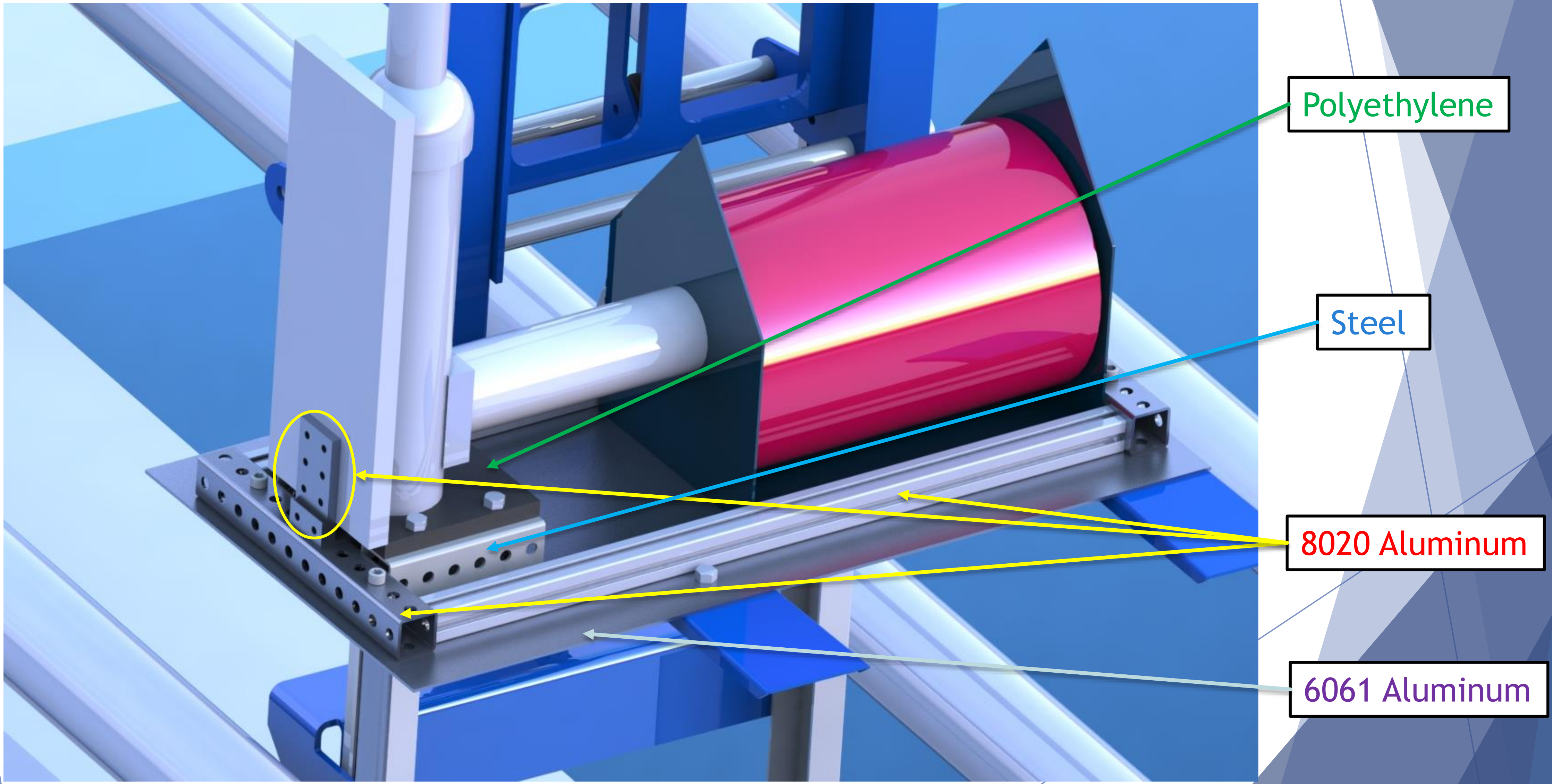
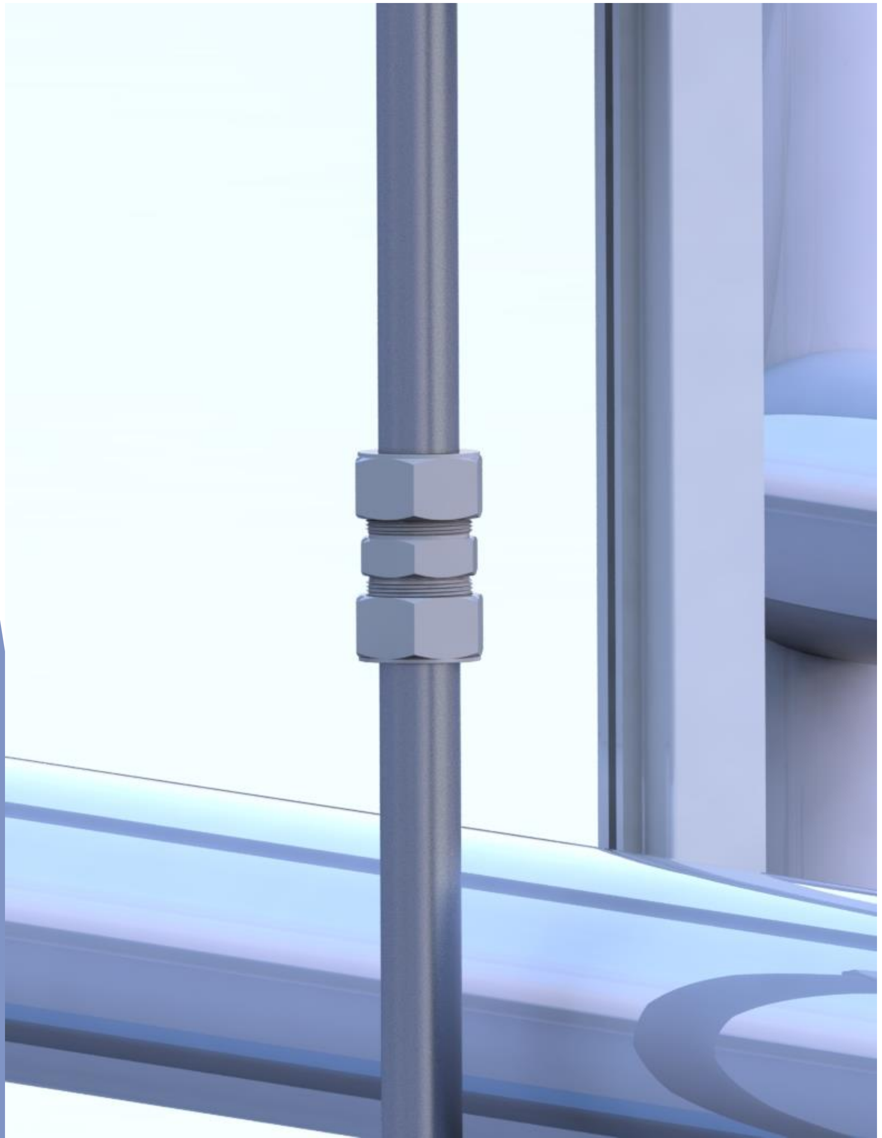
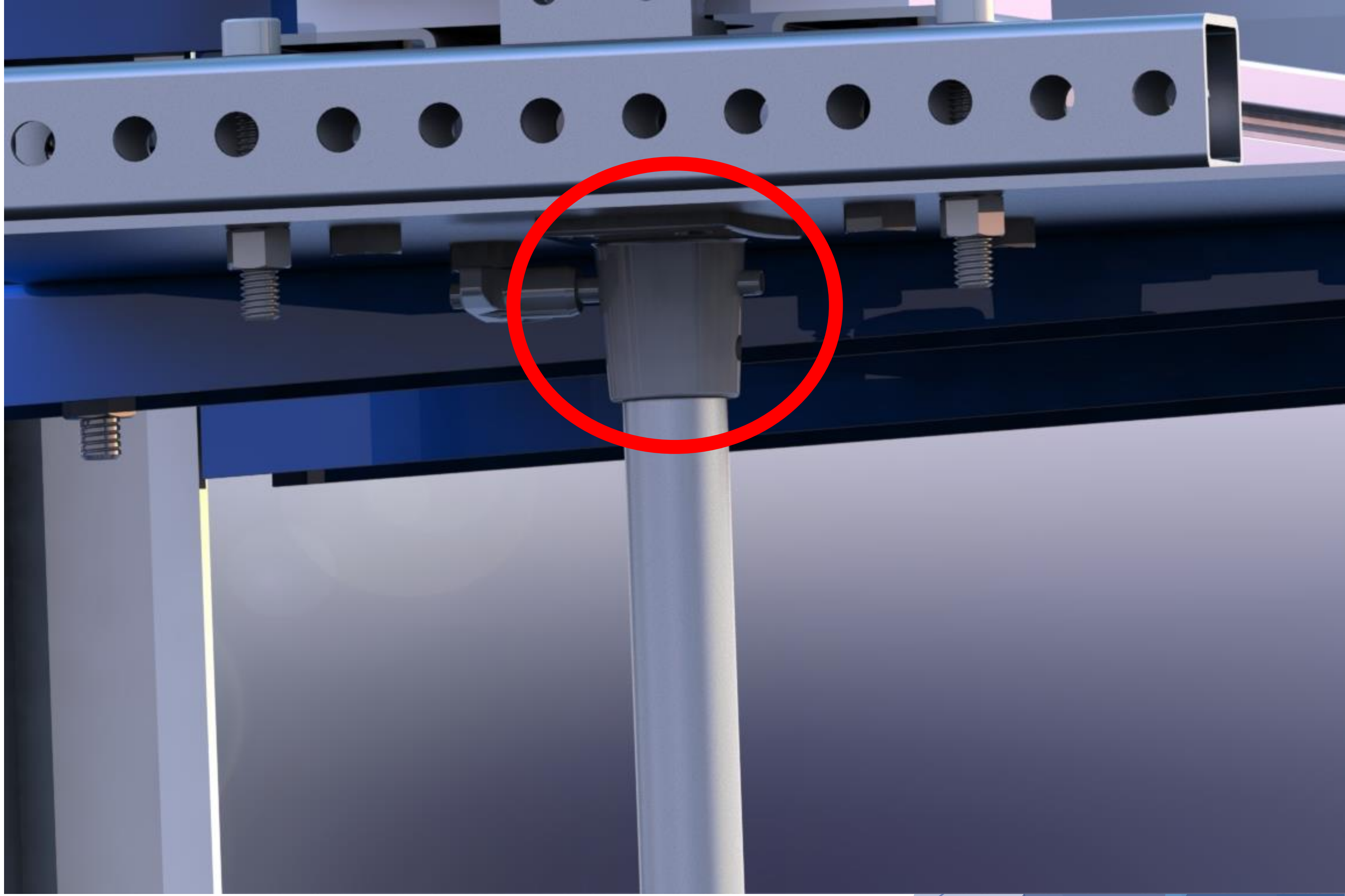


The Apparatus



The Collimator

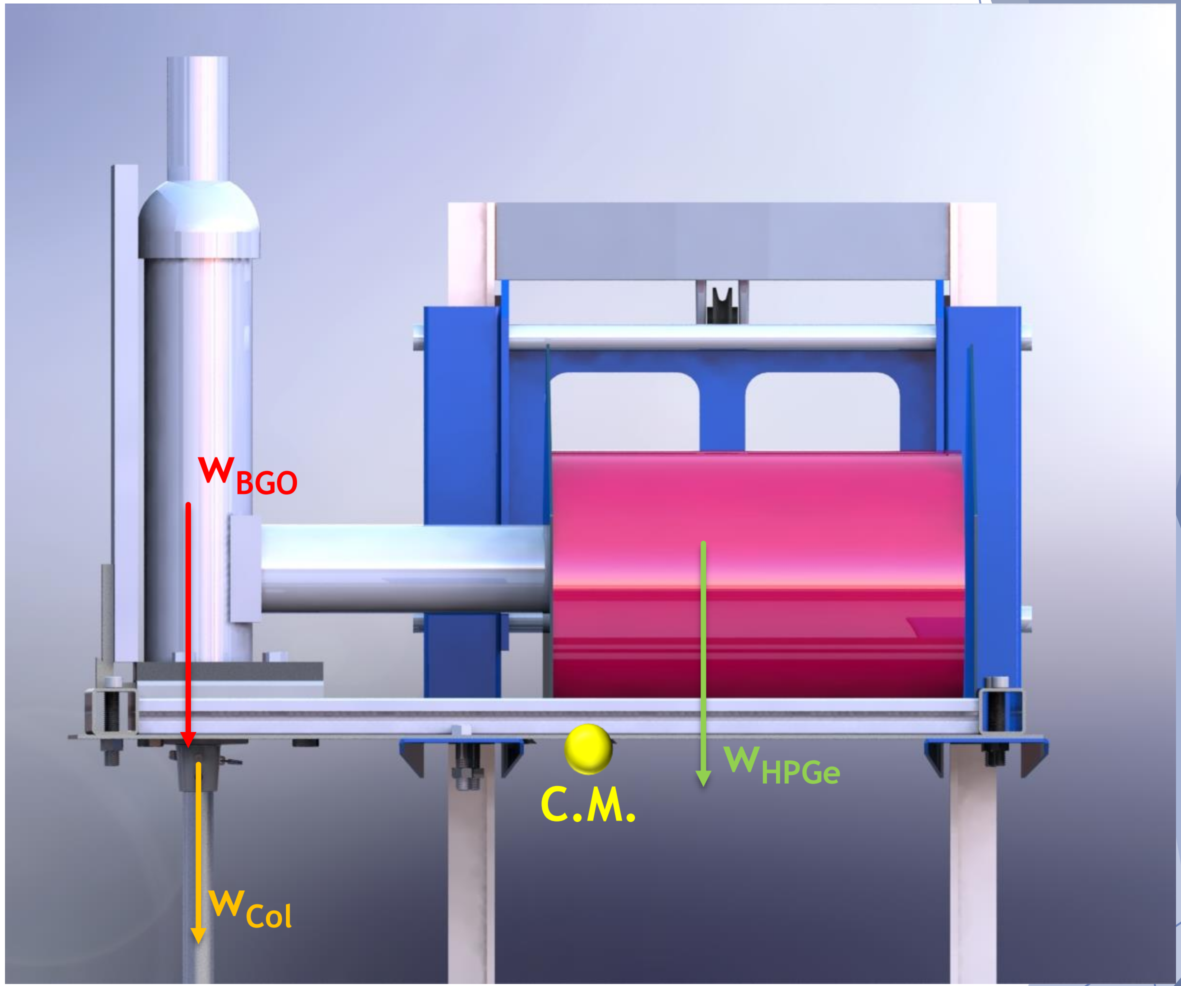




- 6’(x4)
- 1” OD – 0.93” ID
- Connected via Tube Locking Fittings

Structural Analysis

- There is a risk of dropping detectors in the pool.
- Treat system as a structural beam, and find the center of mass for the platform.
- Center of mass was within the safety zone.



$$\Sigma w = 115\ lb$$

$$\boldsymbol{\Sigma w < 400\ lb}$$

Buoyancy Analysis

In order for the collimator to work properly, it must sink in.

Original thought:

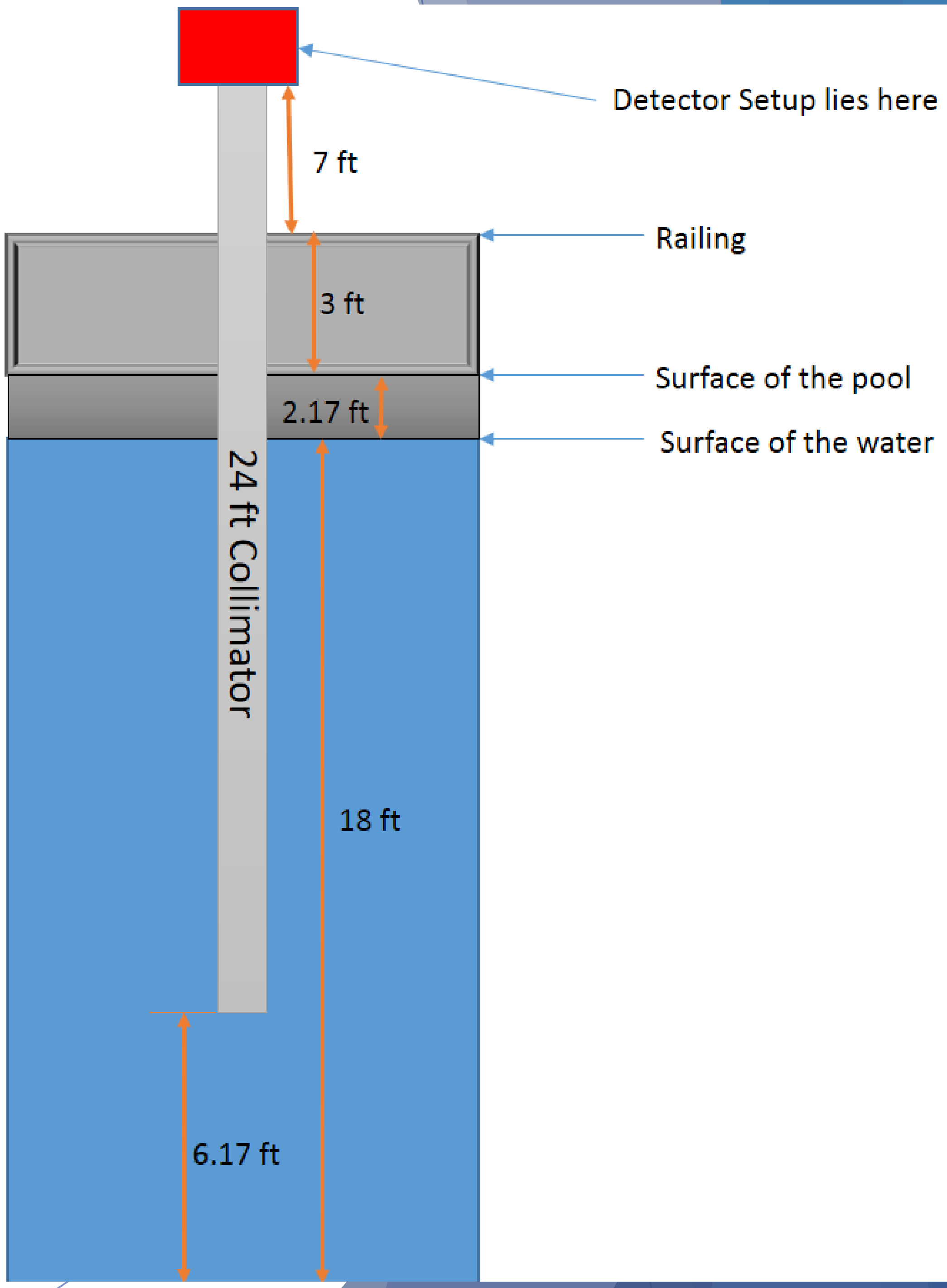
2”OD 1.65”ID tubes for collimator

Health Physics Concerns→ make Collimator smaller (1”OD, 0.93”ID)

$$F_{B,applied} = \rho_{H_2O} \times g \times V_{df,max} - w_{Col} \approx 5\ lb$$

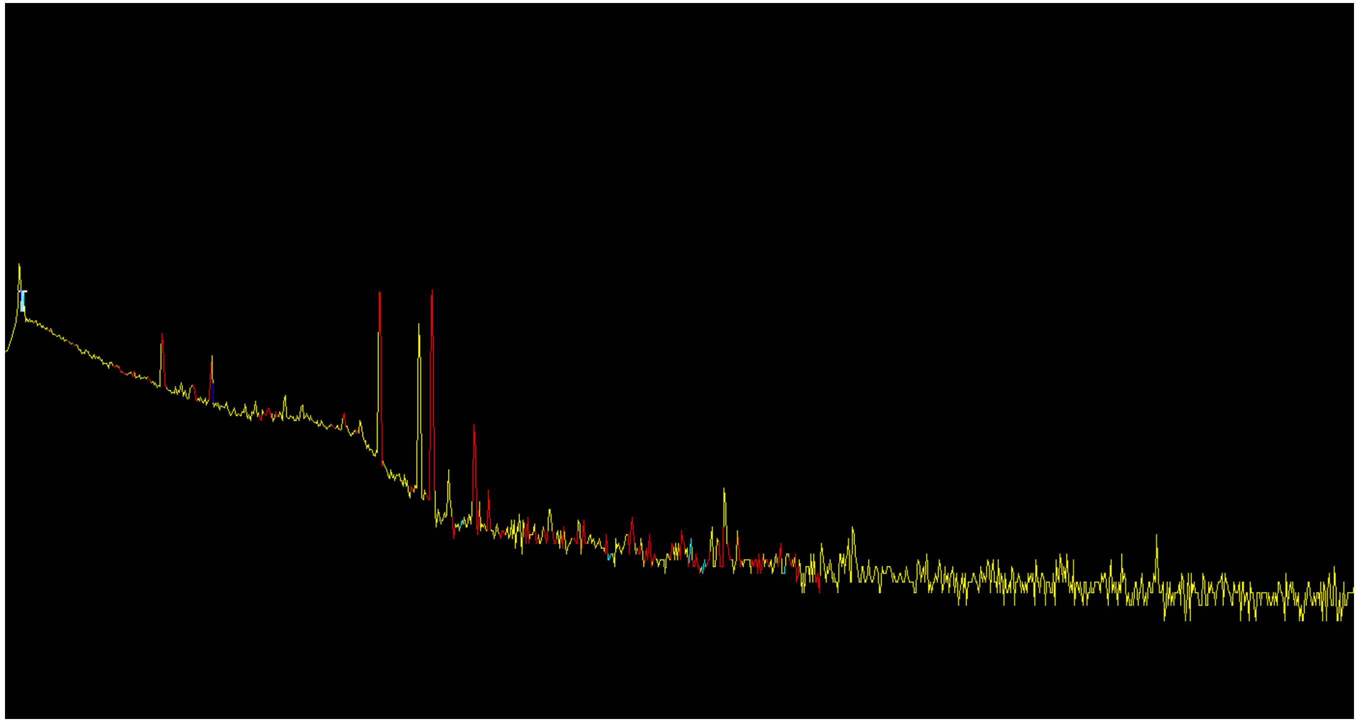
5 lb deficit

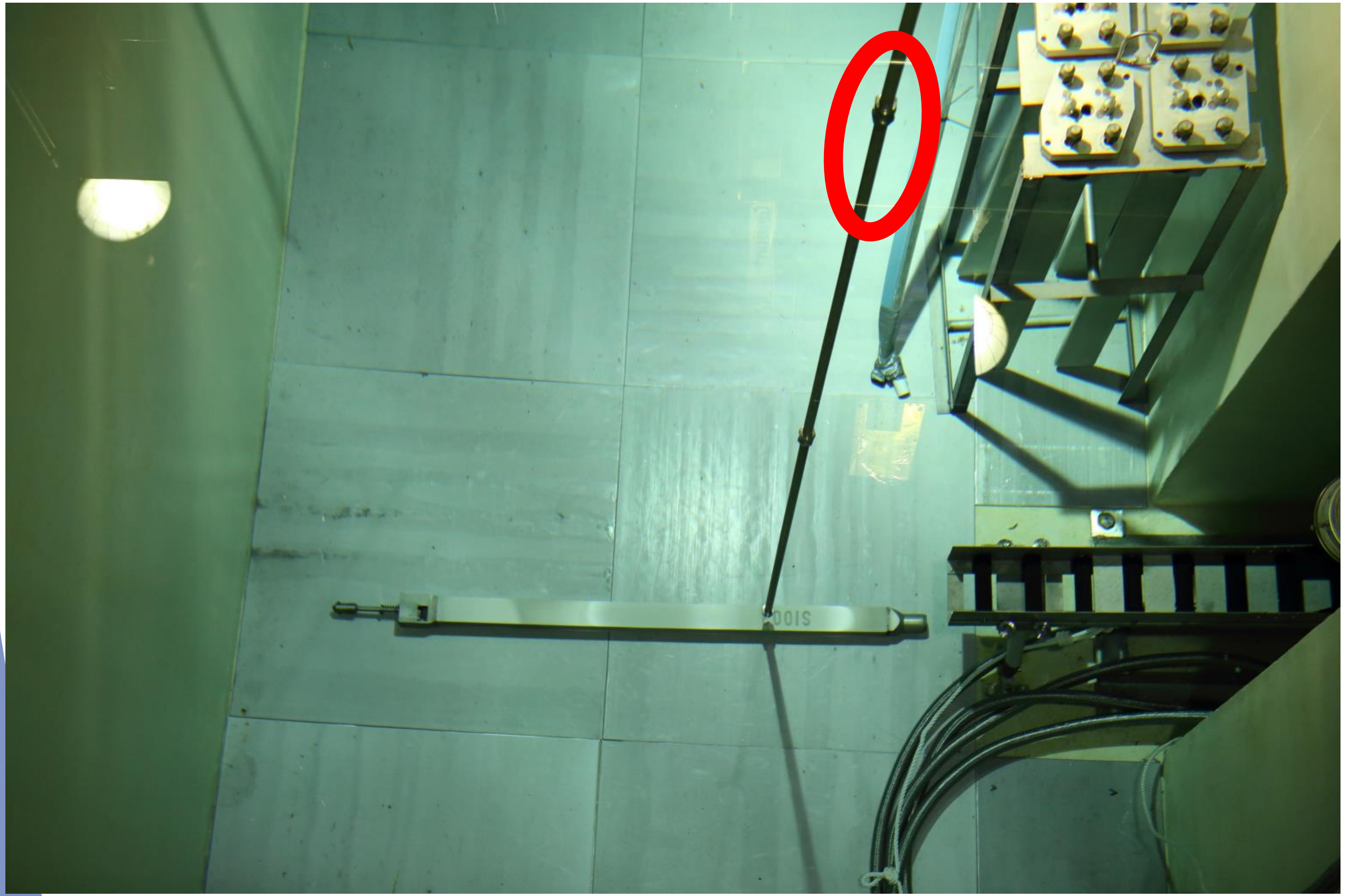
But since it’s held in place, would it REALLY bend too much?



Detector Calibration

- Done using GENIE-2000
- Energy Calibration using Co-60 and Eu-154 Sources



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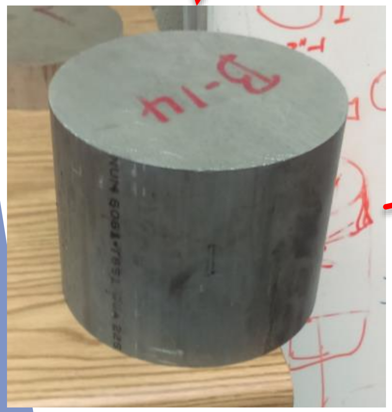
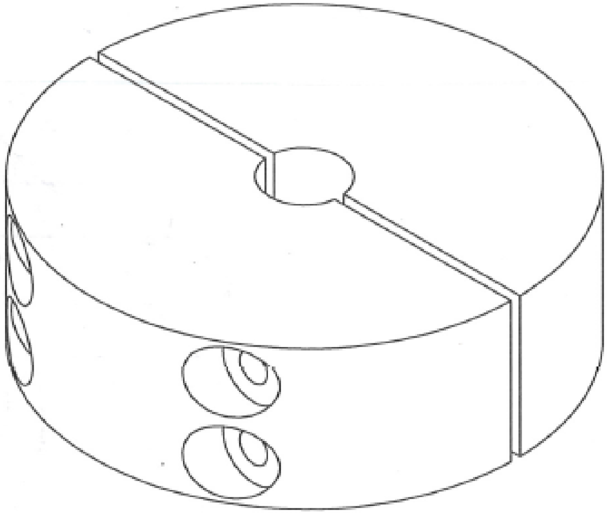
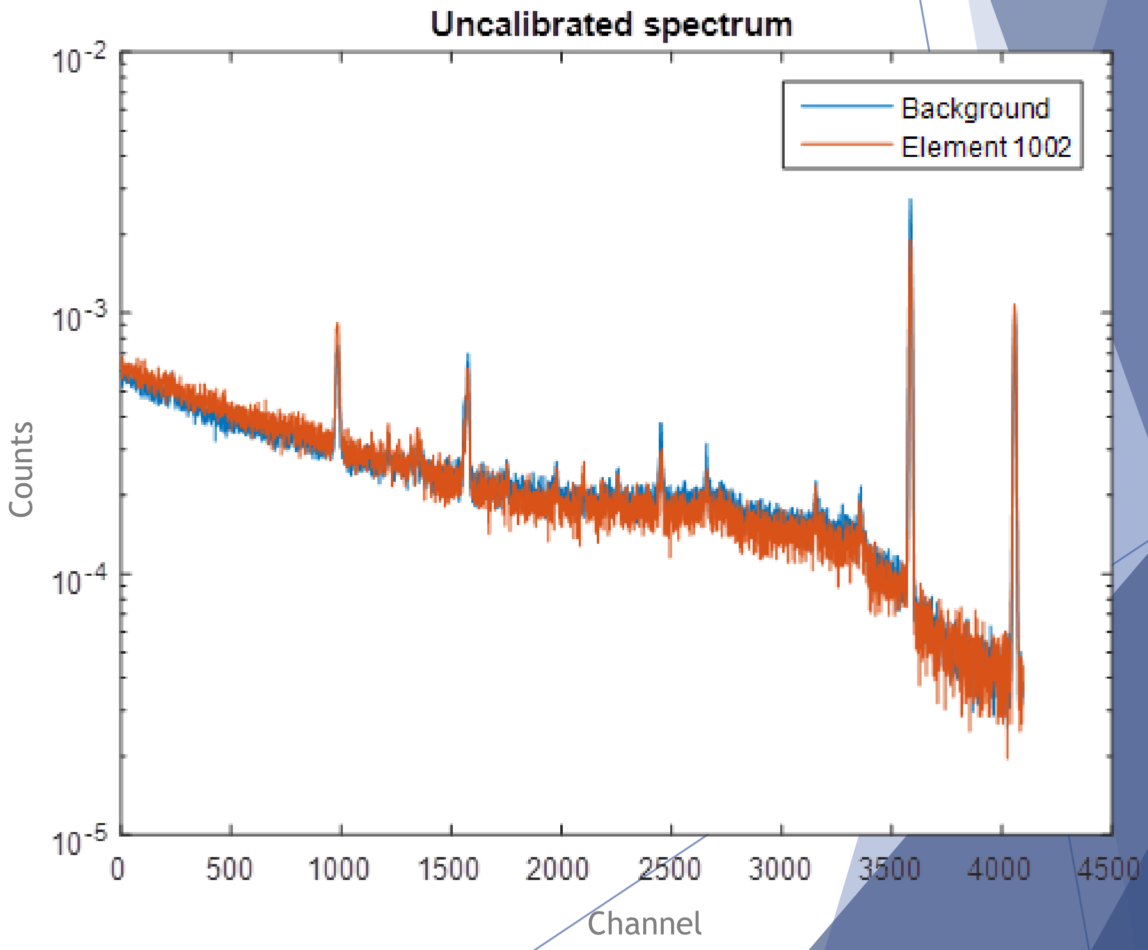
Initial Results

- Collimator was bending in the water.
- Background spectrum was not very different from fuel spectrum.
- Needed a solution







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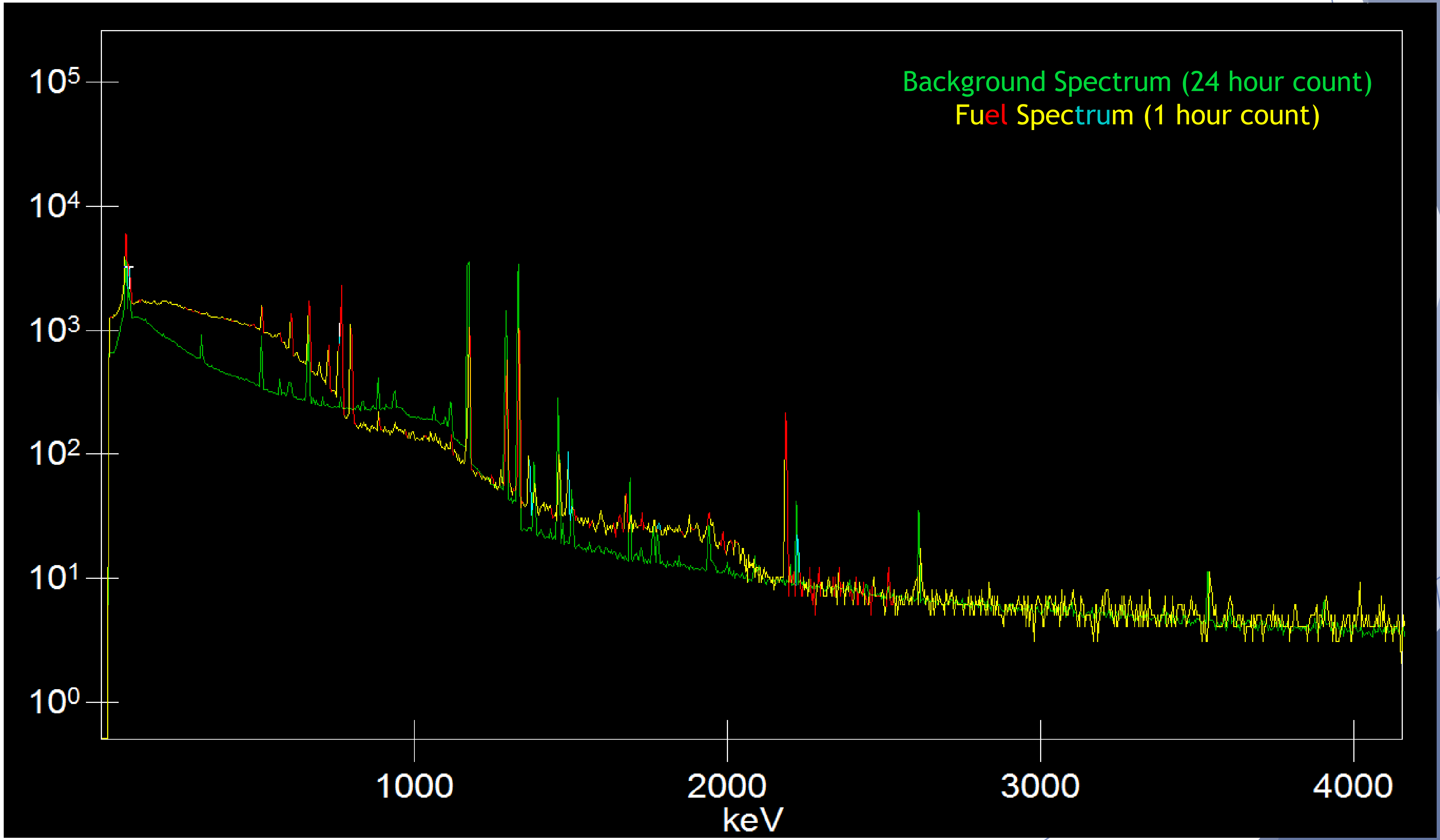

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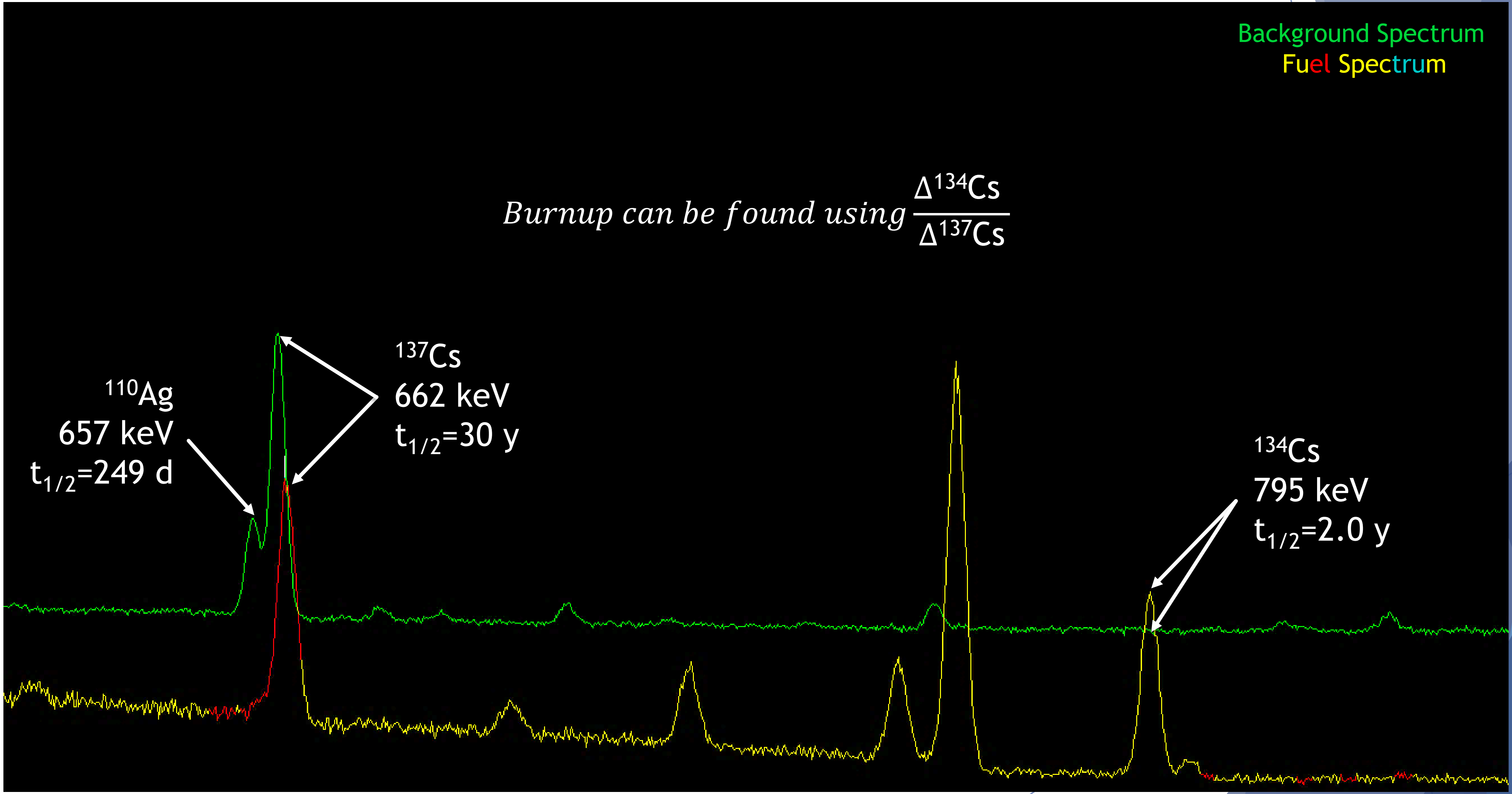
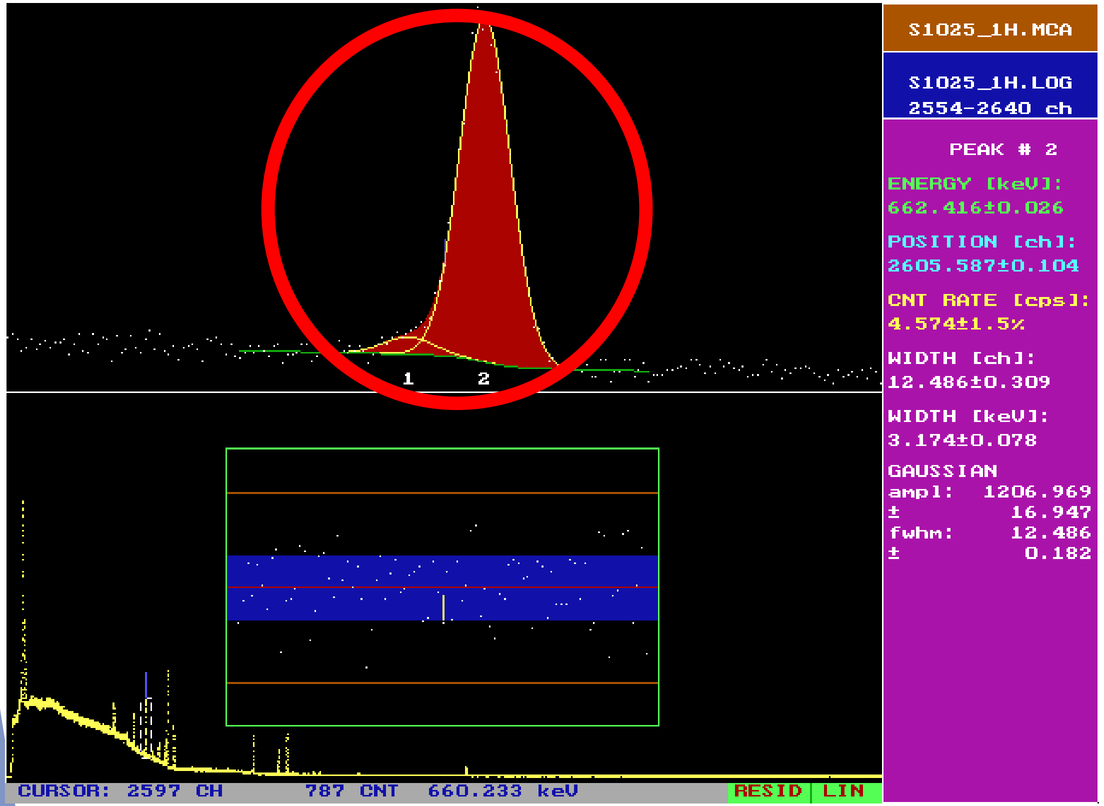
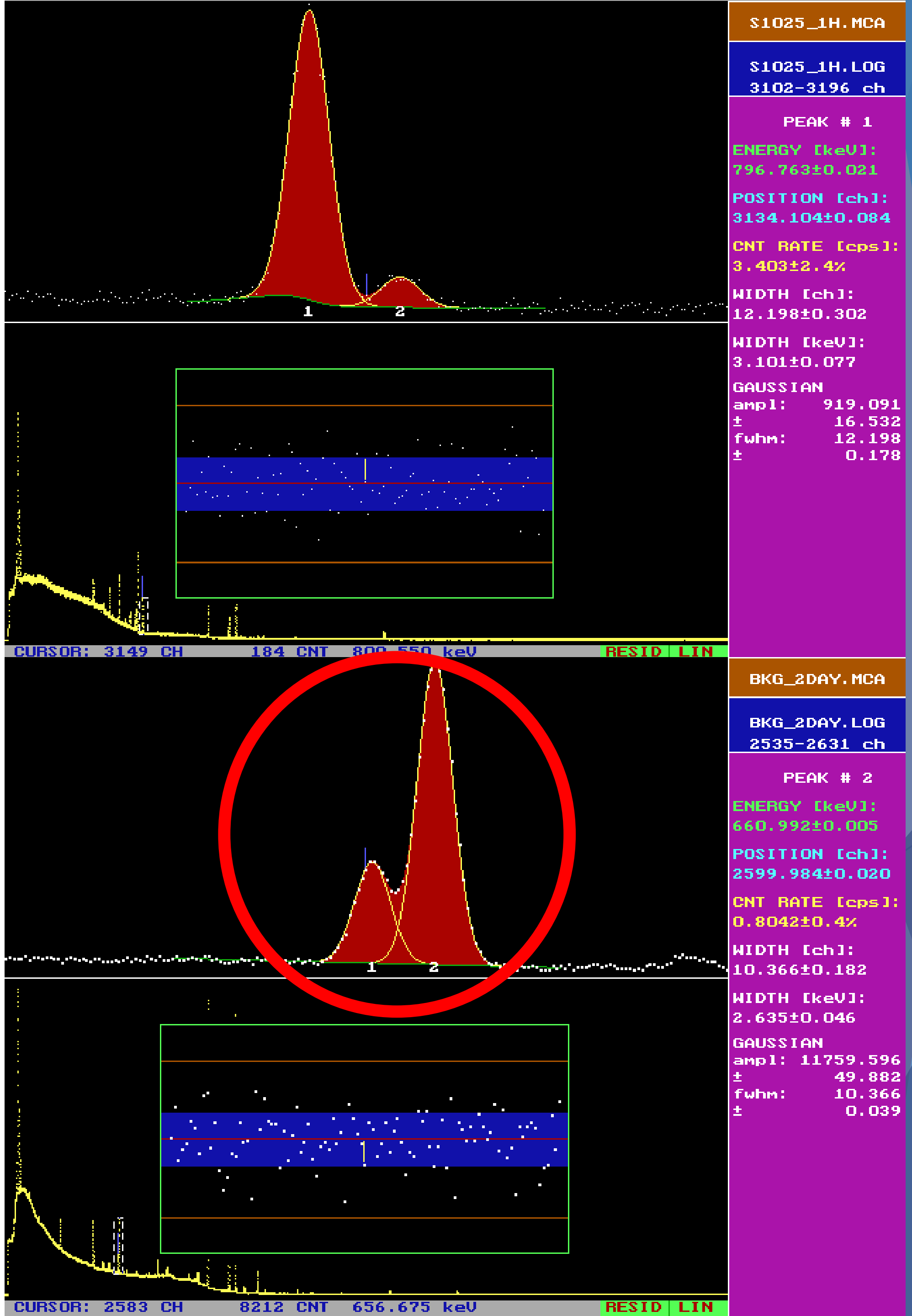


Peak Fitting

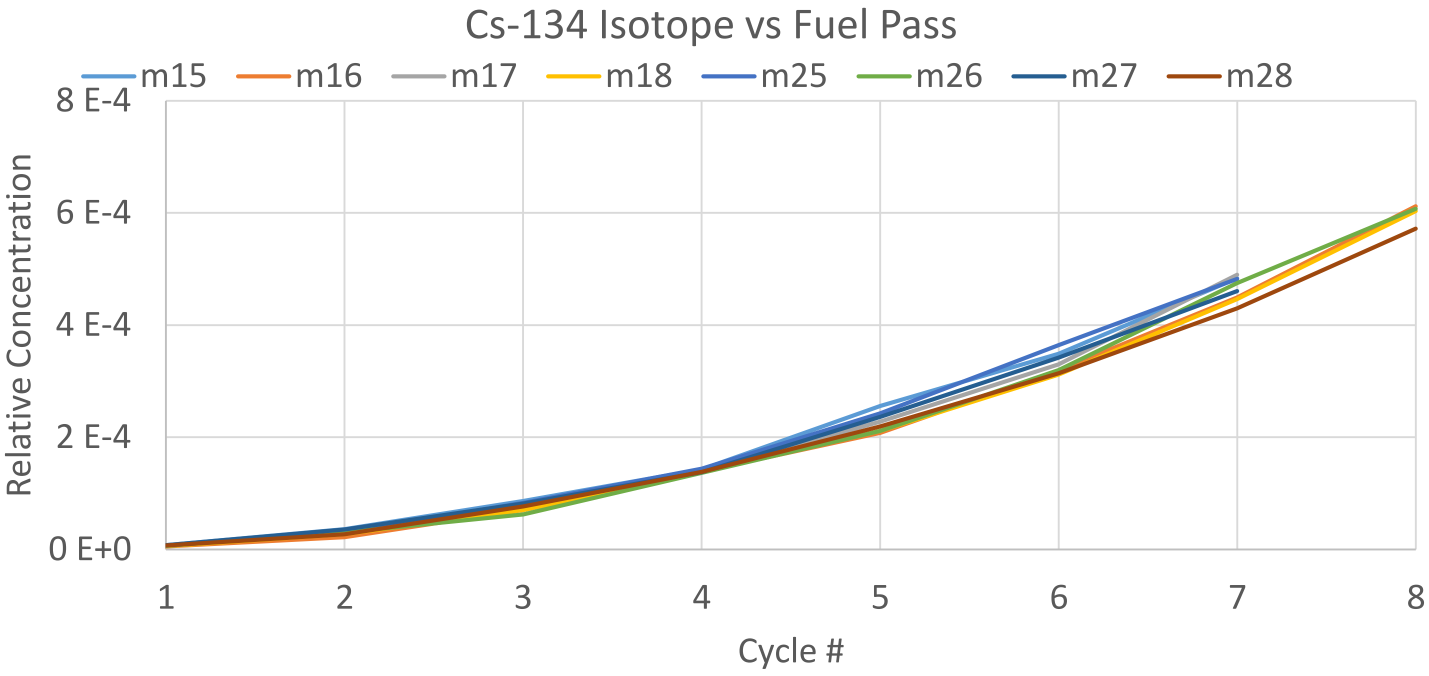


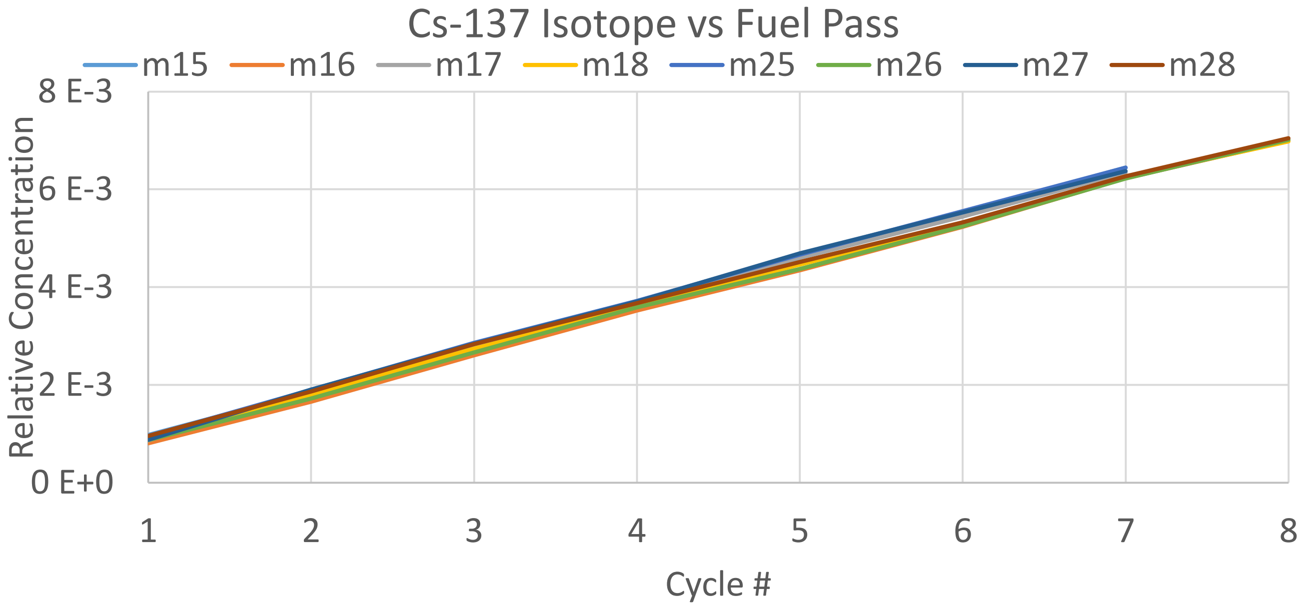


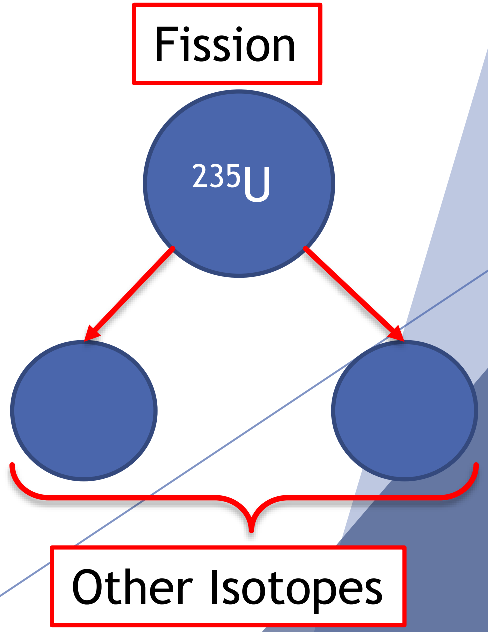
- Peaks were refitted in Hypermet-PC
- $\frac{\Delta{}^{134}\mathrm{Cs}}{\Delta{}^{137}\mathrm{Cs}}$ ratio was calculated with the refitted peaks

Pictures Courtesy of Danyal Turkoglu

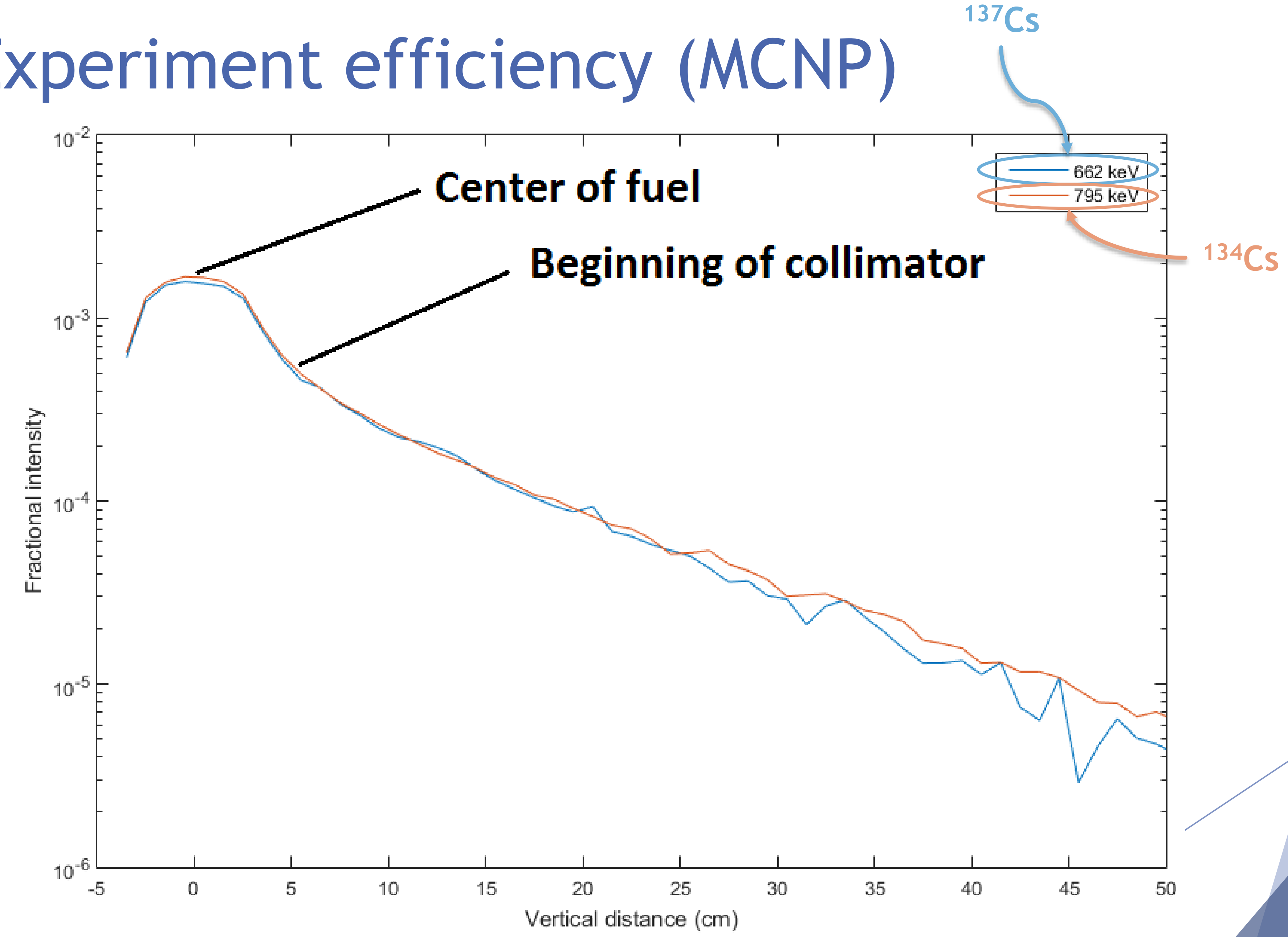
Isotope Buildup over fuel life (MCNP)



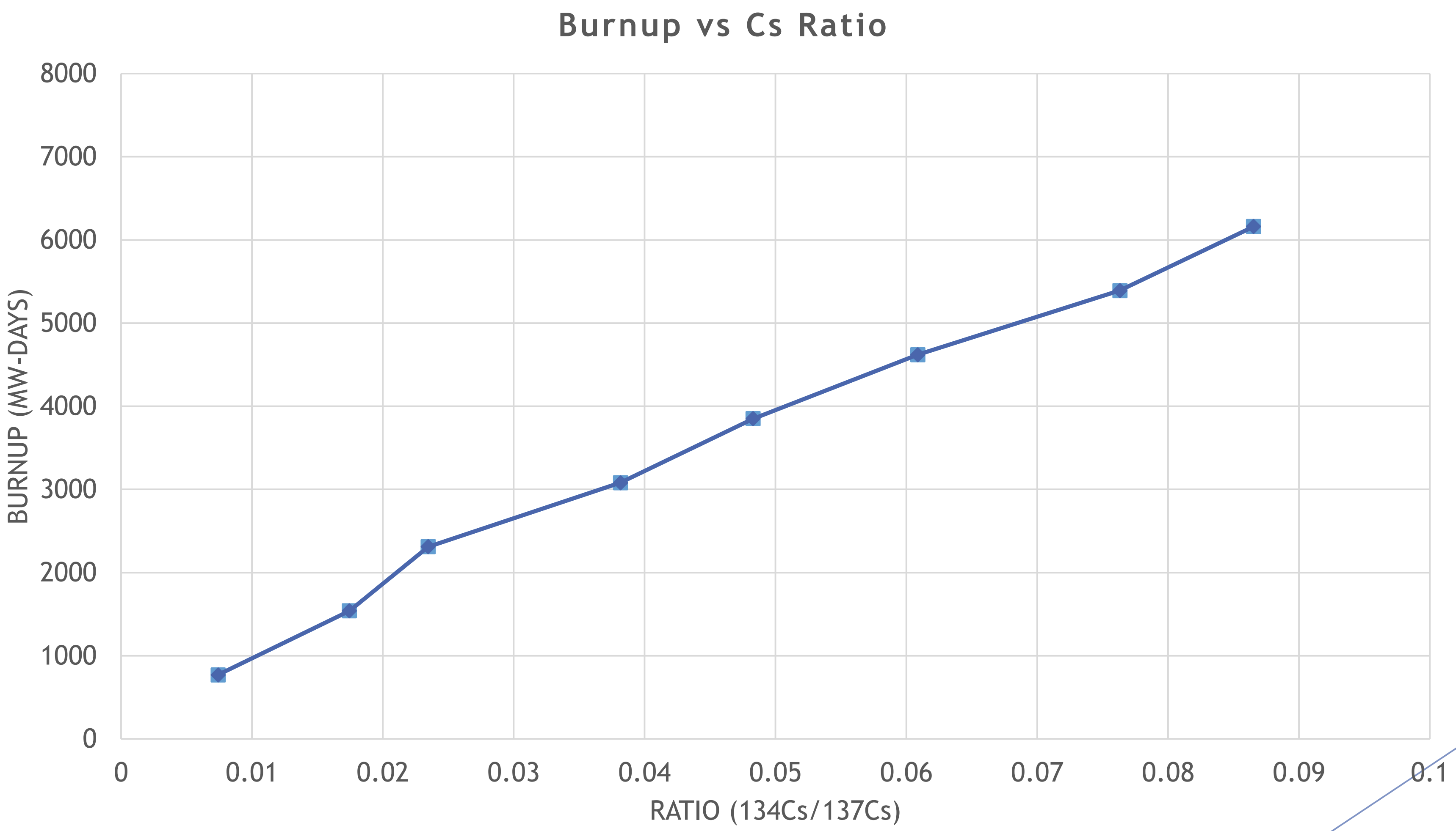




Experiment efficiency (MCNP)



Burnup of fuel (MCNP depletion study)



BURNUP!!

$$\frac{\Delta^{134}Cs}{\Delta^{137}Cs} = \frac{\varepsilon_{134}}{\varepsilon_{137}} \times \frac{CR_{134}}{CR_{137}} \times \frac{\lambda_{137} I_{662}}{\lambda_{134} I_{795}} \times \frac{e^{\lambda_{134} t_{cool}}}{e^{\lambda_{137} t_{cool}}}$$

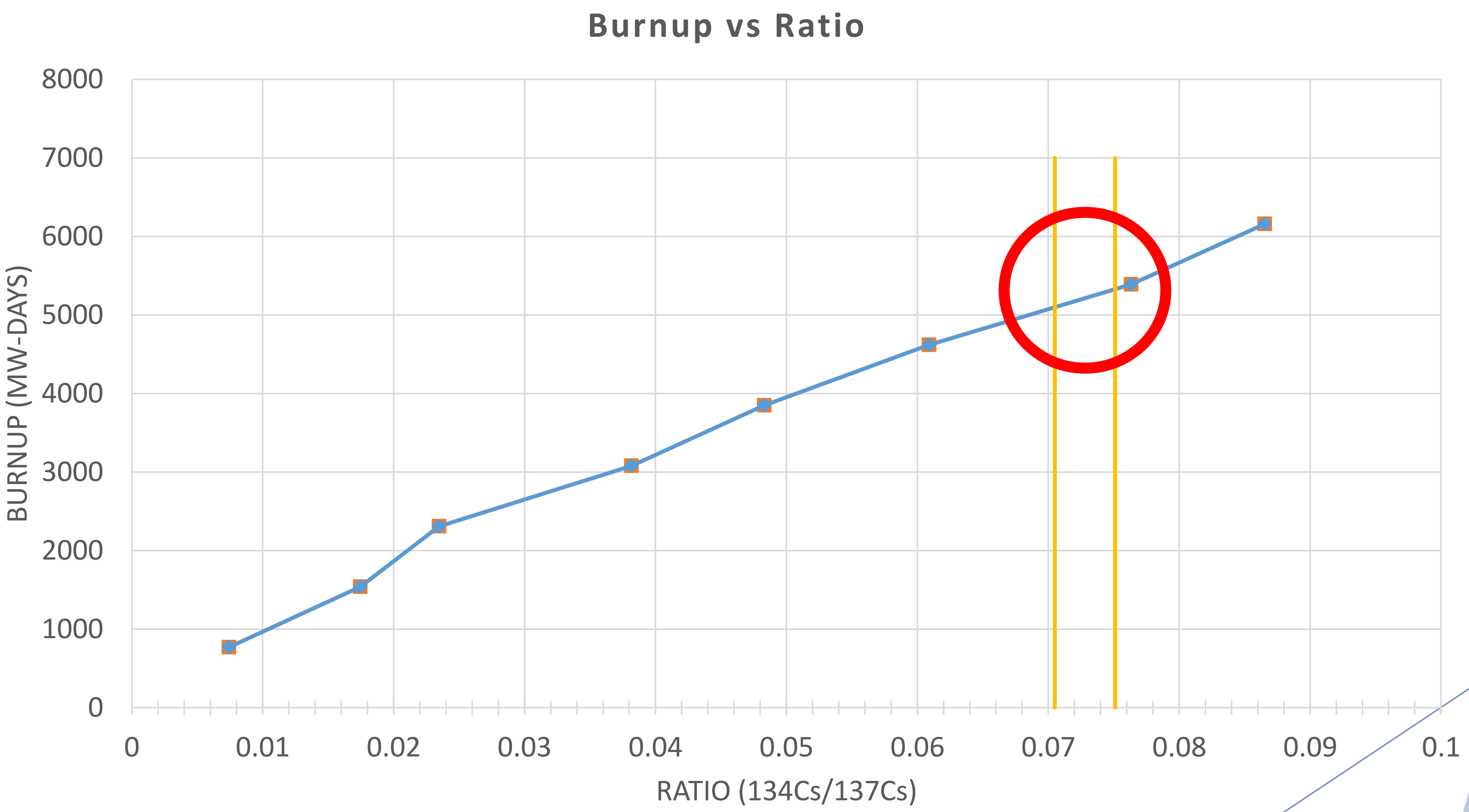
Experiment Efficiency — Count Rate — Specific γ emission rate — Cooling Time

Fuel Element	Isotope Ratio	Burnup (MW-day)	Power* (MW)
S1025 (July 2015)	0.0751	5329	19.8
S1036 (Jan 2016)	0.0705	5100	18.9

*38.5 d cycles assumed (7-cycle fuel)

Calculated error due to background corrected gamma peaks area is +/-0.04 MW

Burnup Results



Conclusion

- Assembled the entire experiment and proved that it works
- Addressed health physics concerns and completed safety evaluation
- Observed several isotopes from fuel, and was able to determine burnup
- **This is the first time this is ever been done**

Future Work

- Make a collimator that works better
- Improve stability of apparatus
- Longer count times (overnight)
- Measuring additional elements
- Evolve this experiment into a gamma spectroscopy scanning apparatus

Acknowledgements

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Acknowledgements

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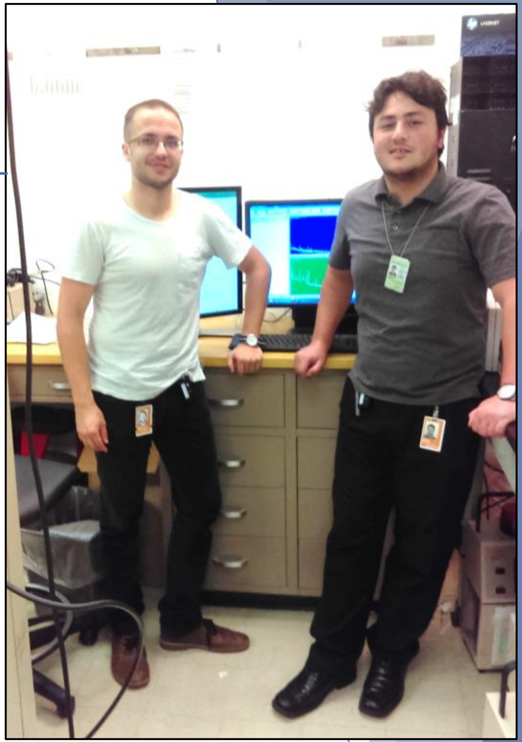
He’s a Mechanical Engineer.
It automatically makes him awesome

Timothy Barvitskie



Guided me through μ and TVL calculations (and helped out with Genie…and helped out with other details of the project)

Danyal Turkoglu

Taught me almost everything I know about detectors

Ryan Fangmeyer

HE’S A SURF STUDENT TOO!!

Acknowledgments

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Bryan Eyers

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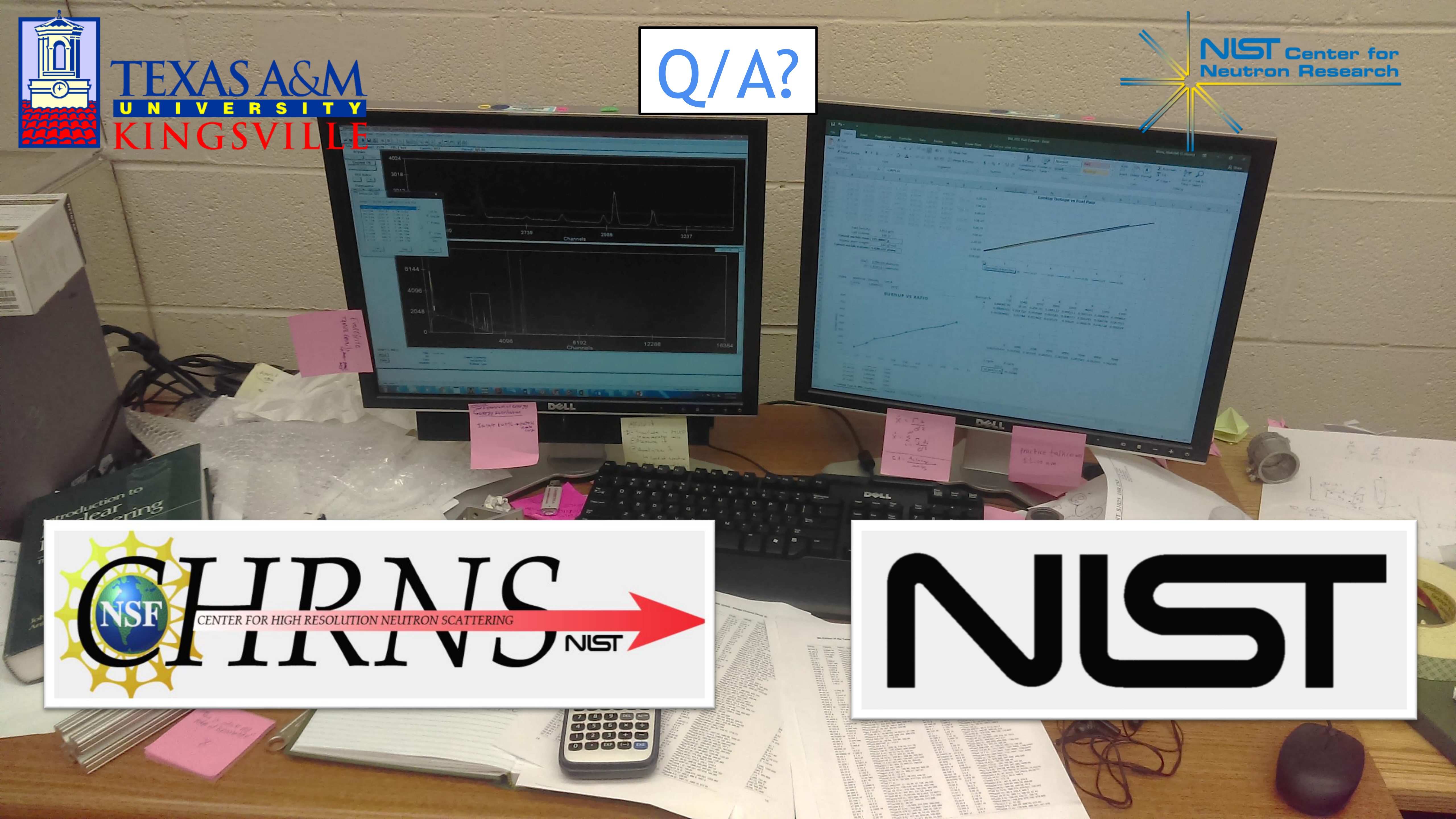
Q/A?

TEXAS A&M UNIVERSITY KINGSVILLE

NIST Center for Neutron Research



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