IER-499 Final Design of a TEX Variant:

Chlorine to Support NNSA Operations

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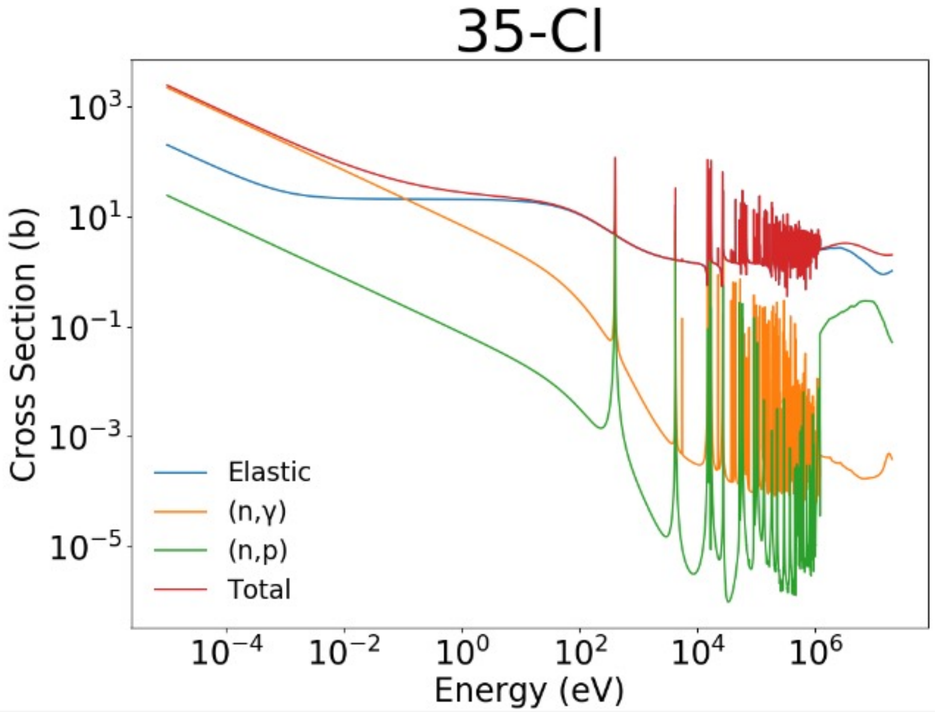
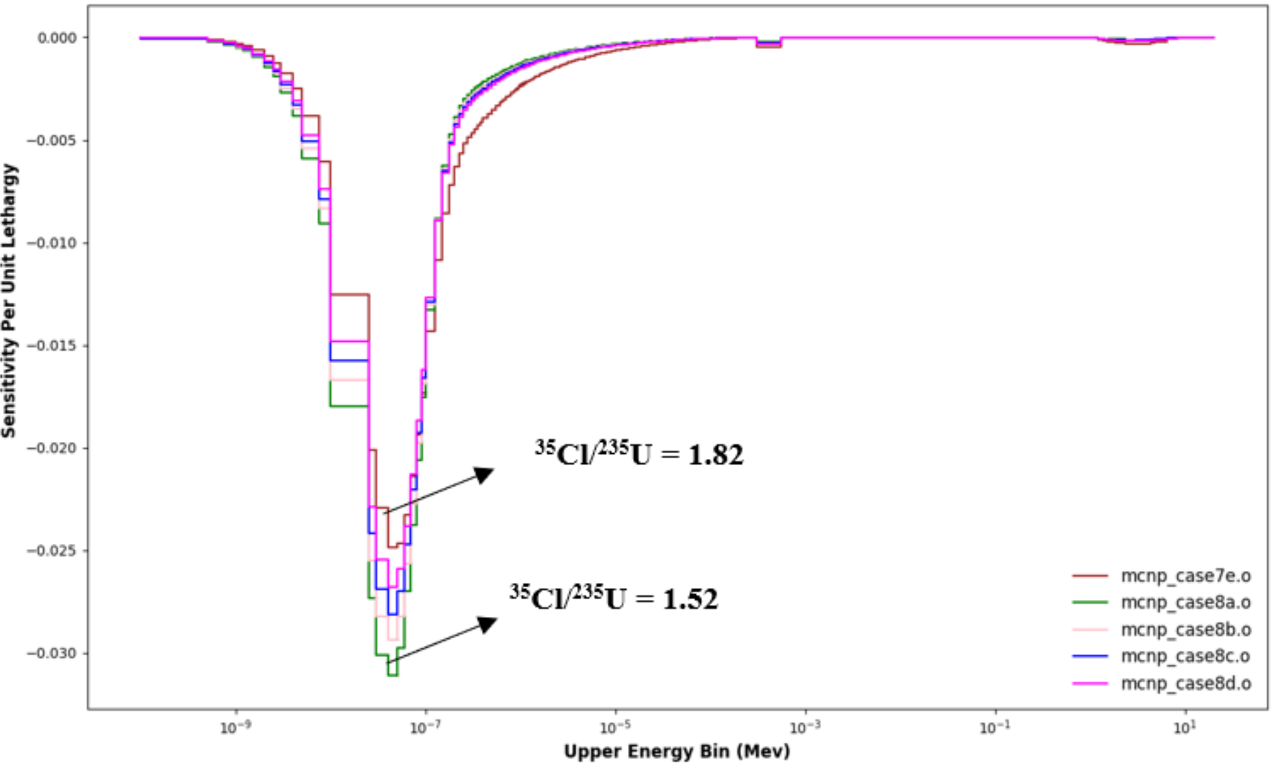
Need for Chlorine Experiments

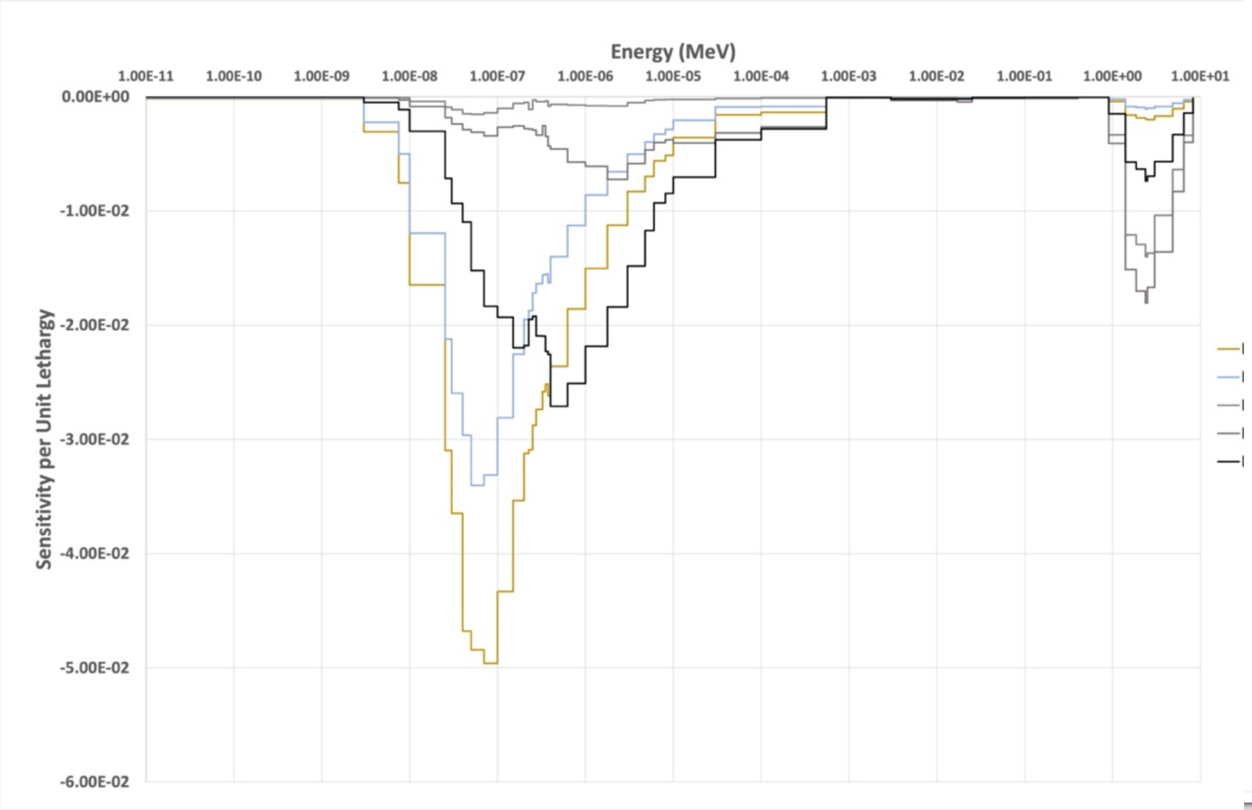
- What are the needs for a chlorine benchmark?
  - Y-12 electrorefining operations which credit ^{35}Cl as a neutron absorber
  - Idaho National Lab / Terrapower for Molten Chlorine Reactor Experiments (MCRE) fuel fabrication
  - Los Alamos National Laboratory for their aqueous plutonium chloride systems
  - $^{35}Cl(n,p)$ for nuclear data needs
    - The cross section is believed to have a significant uncertainty
    - Interest has been expressed by both domestic and foreign entities
  - IRSN and SRNS has also expressed interest in this benchmark



Sensitivity Profiles from Applications

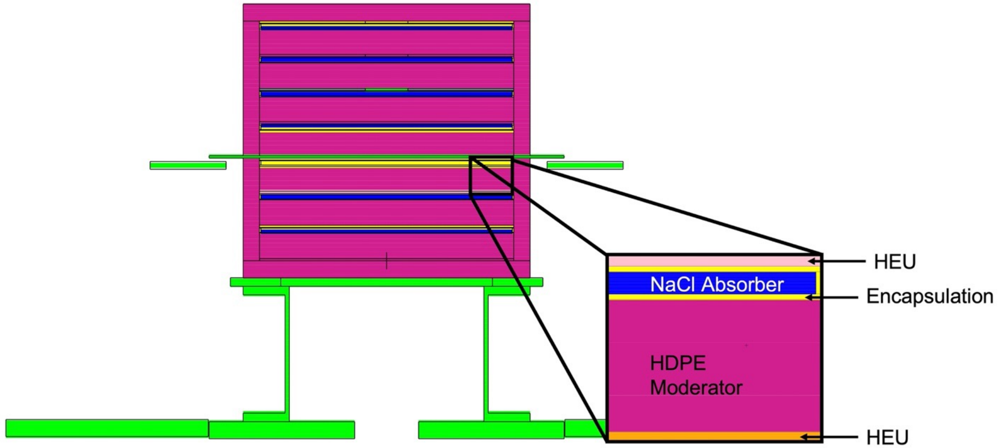
- Sensitivity profiles from Y-12 and INL (MCRE) were used to optimize to and compare
  - Y-12 (left) sensitivity profiles for varying 35Cl/235U ratios (SCALE 238-Group)
  - INL (right) sensitivity profiles for various crit safety upset cases (SCALE 44-Group)

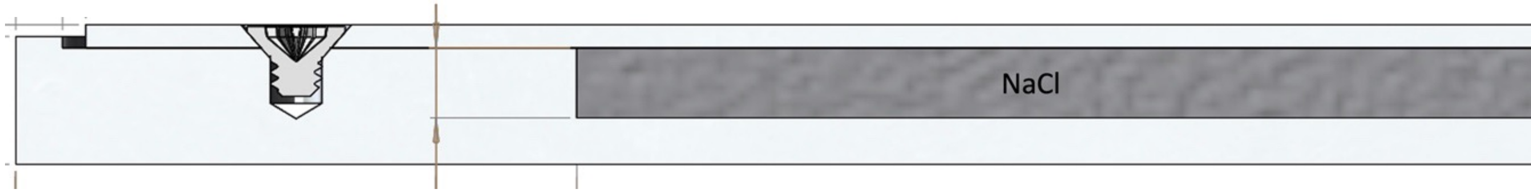




Chlorine Absorber Design

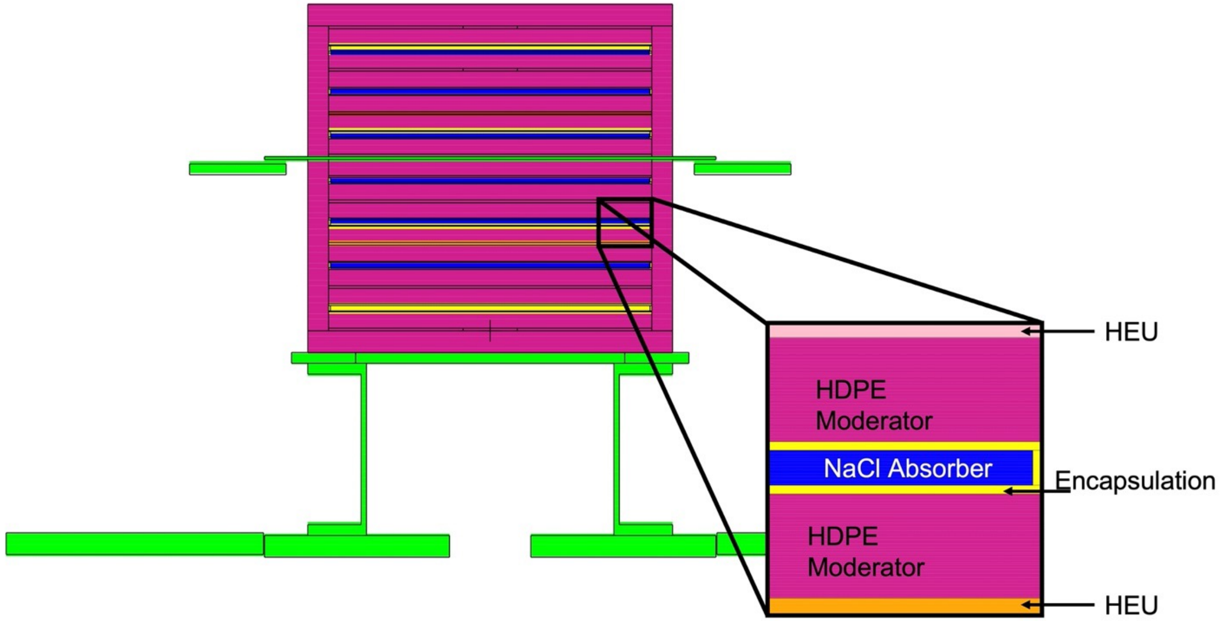
- Many materials and designs were scoped including the use of CPVC and $CaCl_2$, but ultimately NaCl salts were chosen
- Namely, ≥99.5% pure lab grade sodium chloride salt
- Salt is encapsulated in aluminum and placed like any other solid absorber

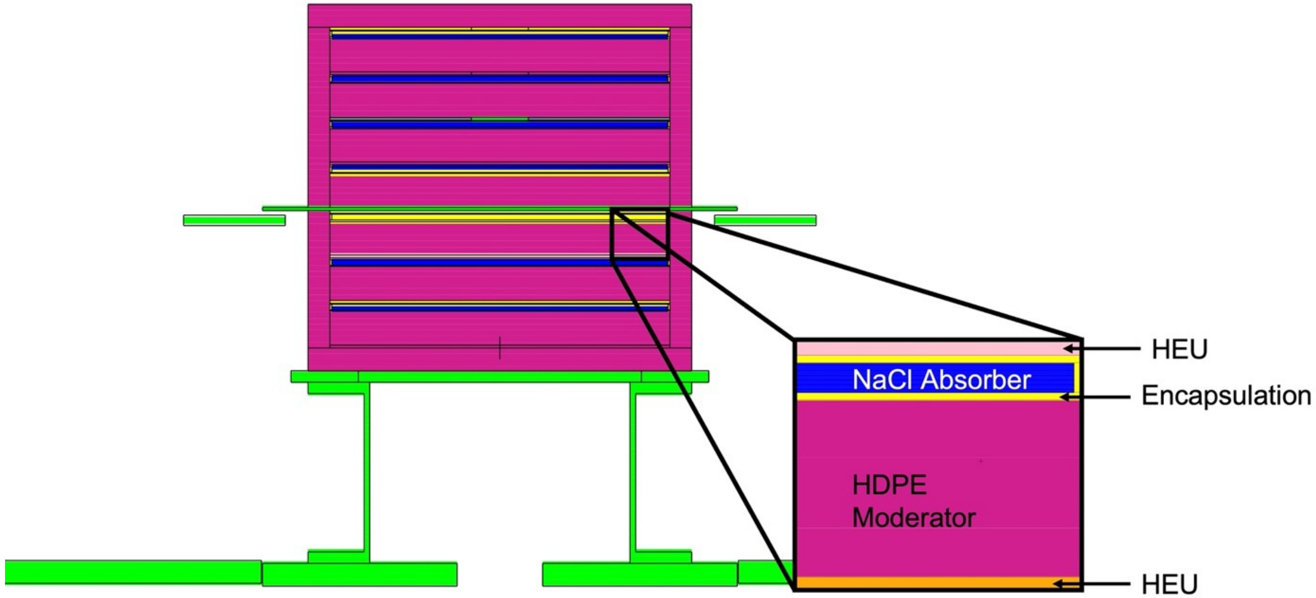




Configurations

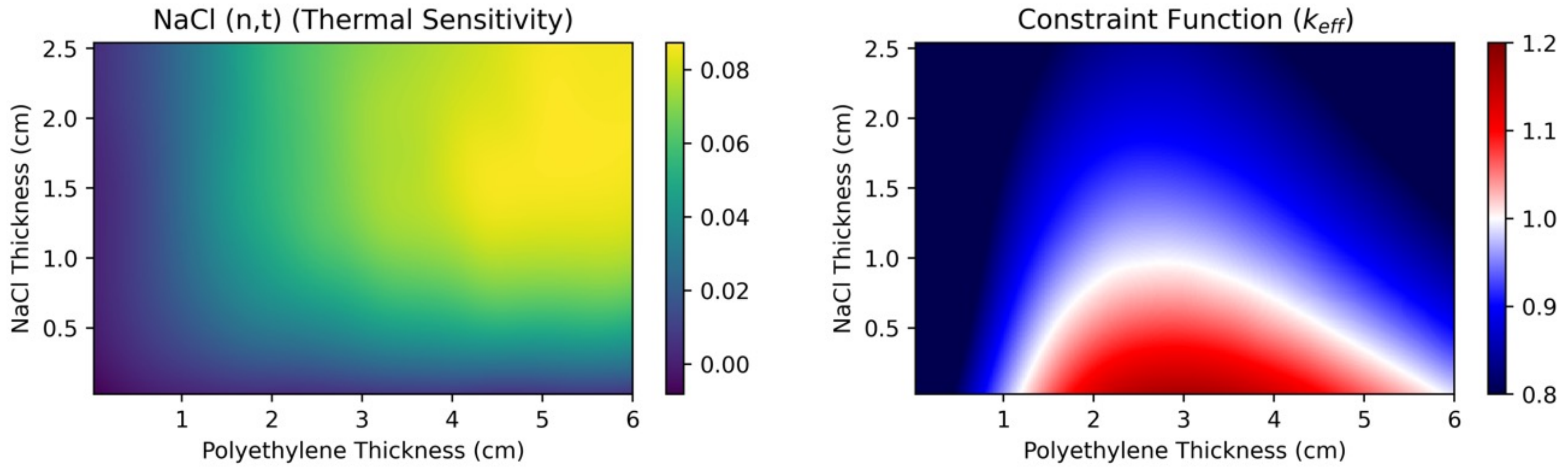
- Two types of configurations: Sandwich (left) and Standard (right)





Bayesian Optimization

- Bayesian optimization was used to find critical configurations that matched the sensitivity profiles from Y-12 and INL well



- The G parameter was used as a similarity metric where G=0 is maximally similar

$$G = 1 - \frac{\mathbf{S}_1^T \mathbf{S}_2}{0.5(|\mathbf{S}_1|^2 + |\mathbf{S}_2|^2)}$$

Critical Configurations

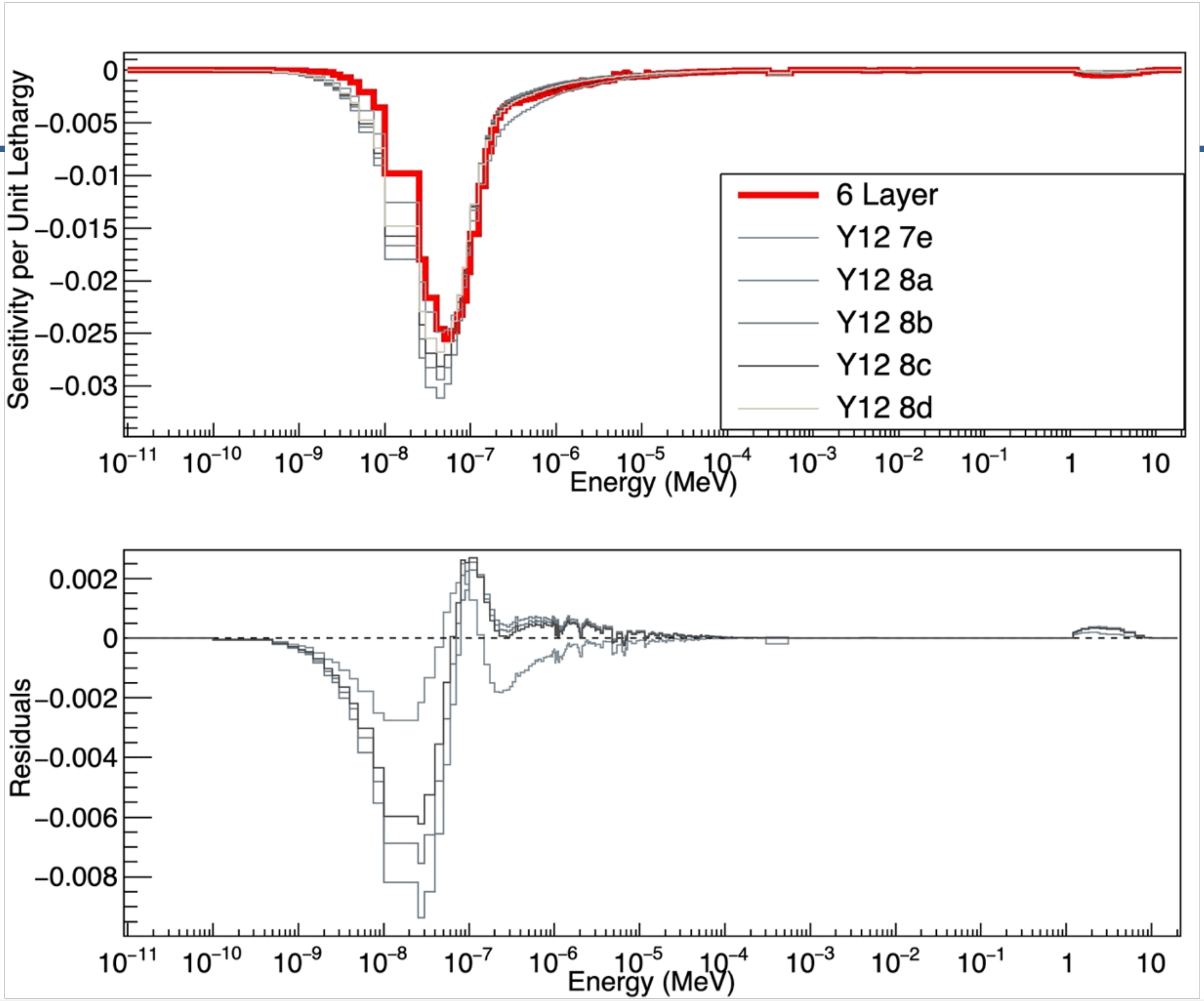
- 3 Standard Configurations:

Number of Layers	HDPE Moderator Thickness (in)	NaCl Absorber Thickness (in)	HEU Mass (g)	HDPE Top Reflector Thickness (in)	H/D Ratio
6	27/16	3/16	37,831	1	0.743
8	7/4	1/4	51,222	1	1.0921
18	1/8	3/16	109,331	1	0.7178

Number of Layers	k_{eff}	k_{eff} of Half Stack	Maximum Thermal Capture Sensitivity Amplitude	Minimum G Parameter for Y-12 (case)	Minimum G Parameter for INL	Thermal Fission Fraction (%)	Intermediate Fission Fraction (%)	Fast Fission Fraction (%)
6	1.00025	0.84995	-0.0255	0.009 (7e)	0.211	62.68	25.78	11.55
8	1.00057	0.86737	-0.0327	0.036 (8a)	0.134	62.93	25.50	11.58
18	1.00129	0.73972	-0.0023	0.754 (7e)	0.722	13.66	51.78	34.56

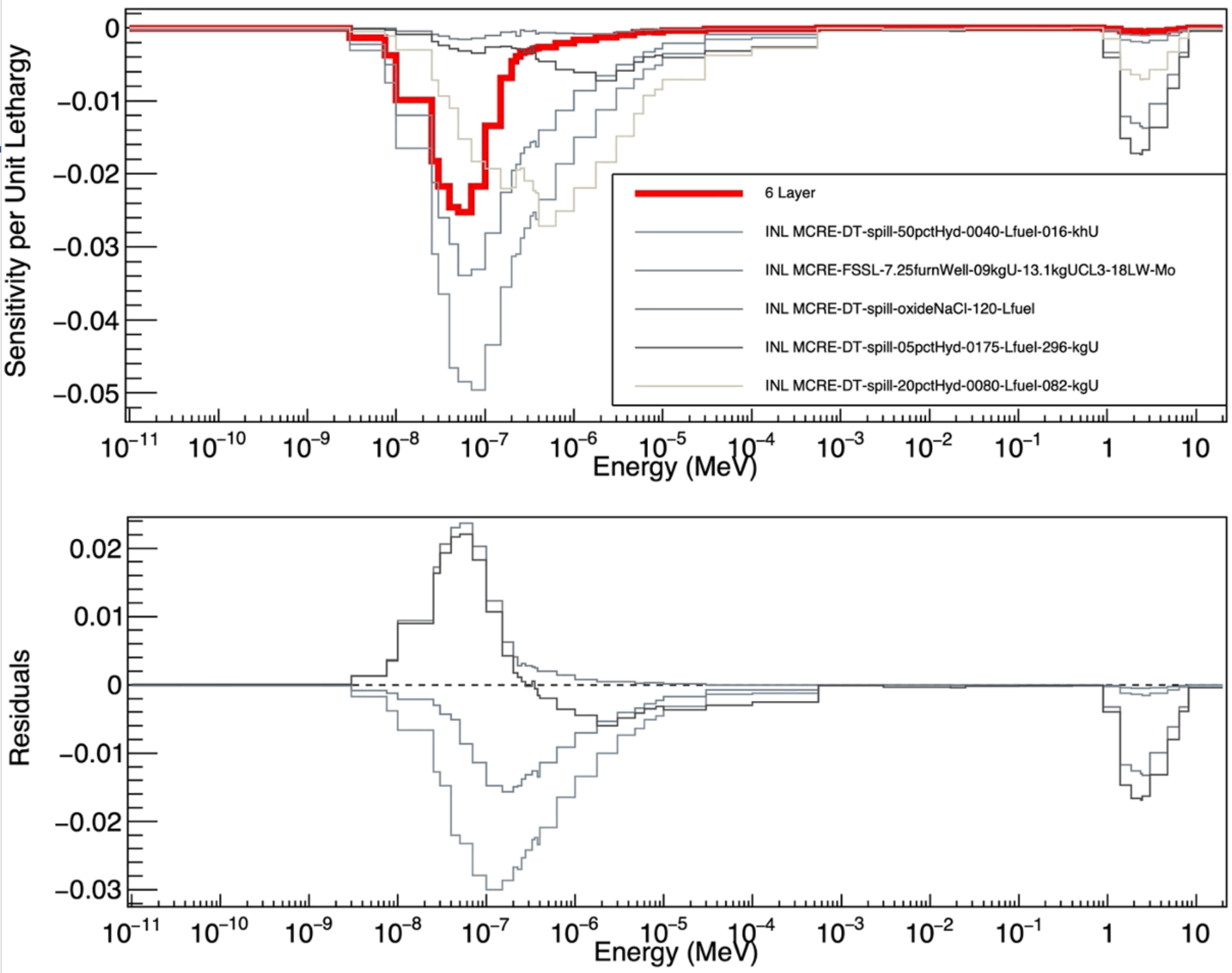
Critical Configurations

- Compared to Y-12:
- Top is a direct comparison to the sensitivity profiles
- Bottom are ‘residuals’ that show the difference between the sensitivity profile of the critical configuration and the application case sensitivity profiles



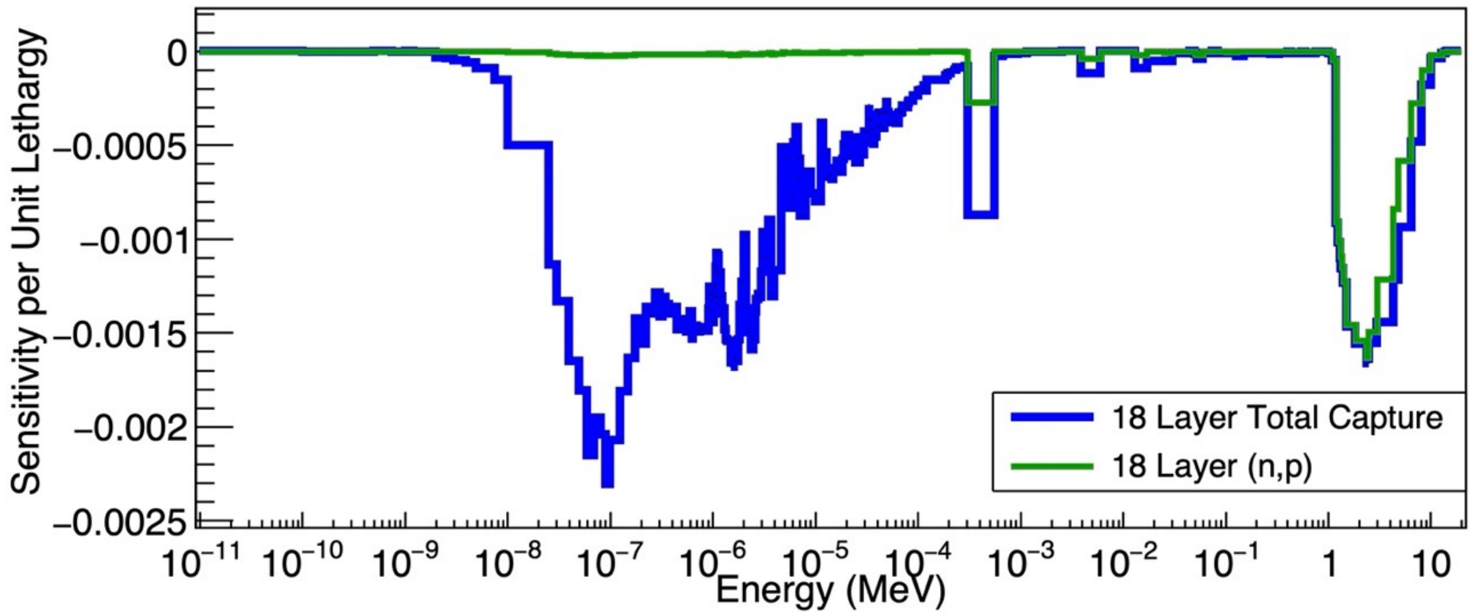
Critical Configurations

- Compared to INL (MCRE):
- Top is a direct comparison to the sensitivity profiles
- Bottom are 'residuals' that show the difference between the sensitivity profile of the critical configuration and the upset case sensitivity profiles



Critical Configurations

- How much of the total capture sensitivity profile for the fastest configuration comes from (n,p)?



Critical Configurations

- 2 Sandwich Configurations:

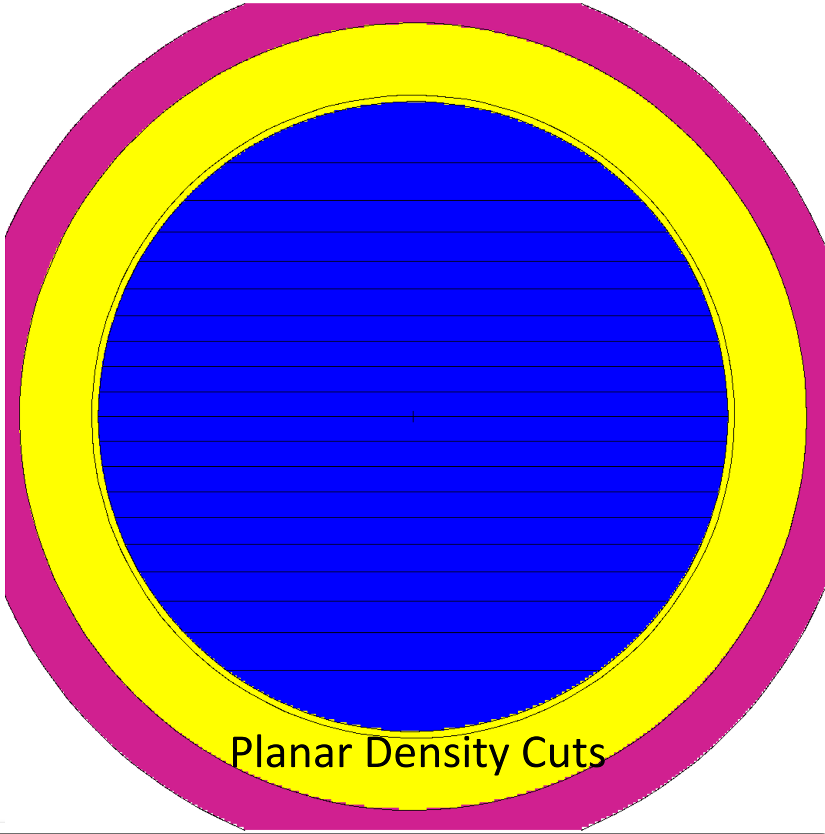
Number of Layers	HDPE Moderator Thickness (in)	NaCl Absorber Thickness (in)	HEU Mass (g)	HDPE Top Reflector Thickness (in)	H/D Ratio
6	11/16	3/16	38,594	17/16	0.6388
8	3/4	1/4	49,552	1	0.9754

Number of Layers	k_{eff}	k_{eff} of Half Stack	Maximum Thermal Capture Sensitivity Amplitude	Minimum G Parameter for Y-12 (case)	Minimum G Parameter for INL	Thermal Fission Fraction (%)	Intermediate Fission Fraction (%)	Fast Fission Fraction (%)
6	1.00094	0.81436	-0.0236	0.009 (7e)	0.206	56.74	31.22	12.04
8	1.00011	0.86381	-0.0246	0.013 (7e)	0.180	58.05	30.19	11.76

Density Studies

- Design relies on pouring salt into an encapsulation, so we need to know how density variations affect the reactivity of the system
- Total density and planar density were studied:
  - Planar density studies show no large change to multiplication factor
  - Total:

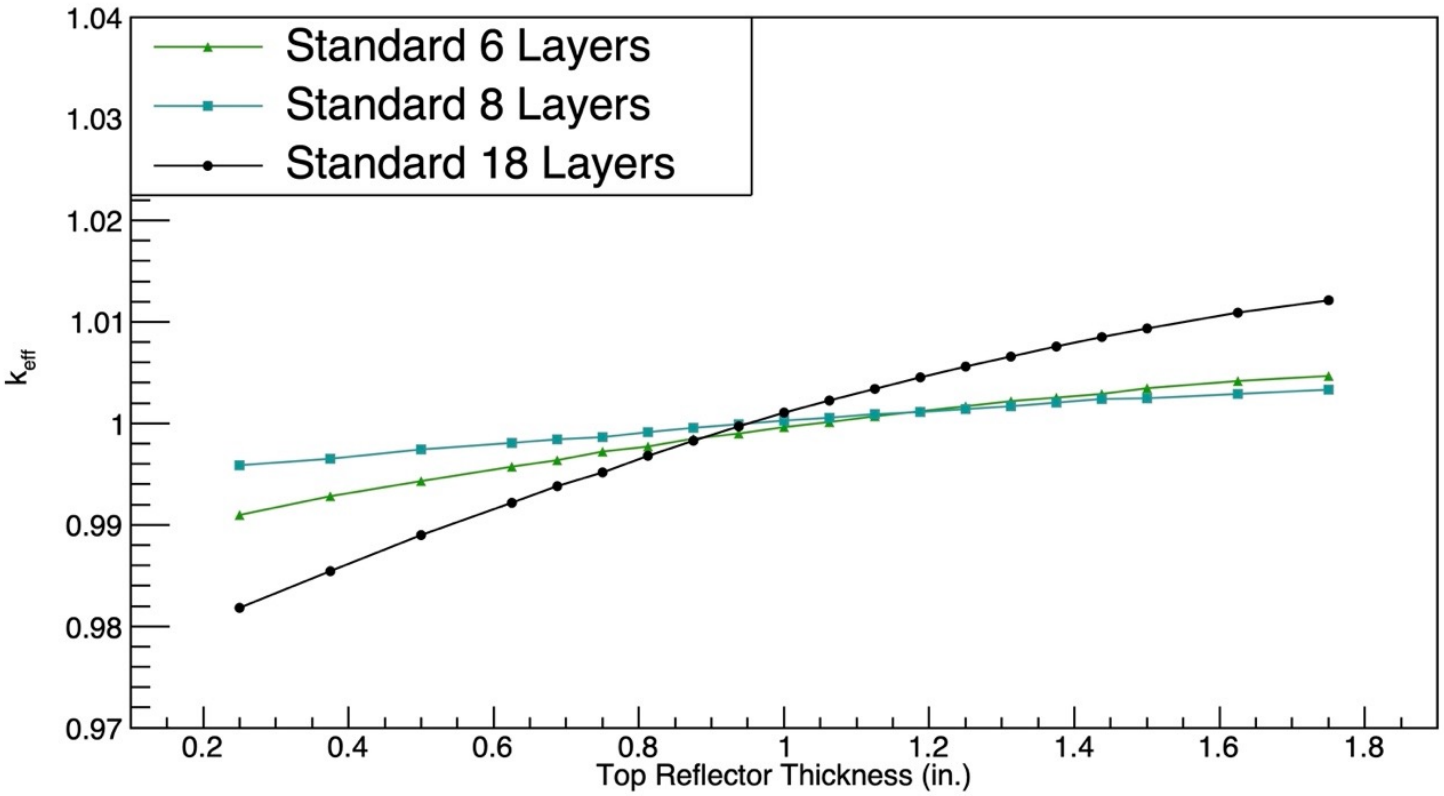
Densities (g/cc)	Standard	
	6 Layer	
	keff	dkeff
1.217	1.01044	0.00156
1.25	1.00888	0.00239
1.3	1.00649	0.00242
1.35	1.00407	0.00100
1.375	1.00307	0.00118
1.4	1.00189	0.00119
1.425	1.00070	0.00056
1.4375	1.00014	0.00049
1.45	0.99965	0.00070
1.4625	0.99895	0.00045
1.475	0.99850	0.00116
1.5	0.99734	0.00439
1.6	0.99295	0.00635
1.75	0.98660	0.01038
2	0.97622	0.00634
2.16	0.96988	-

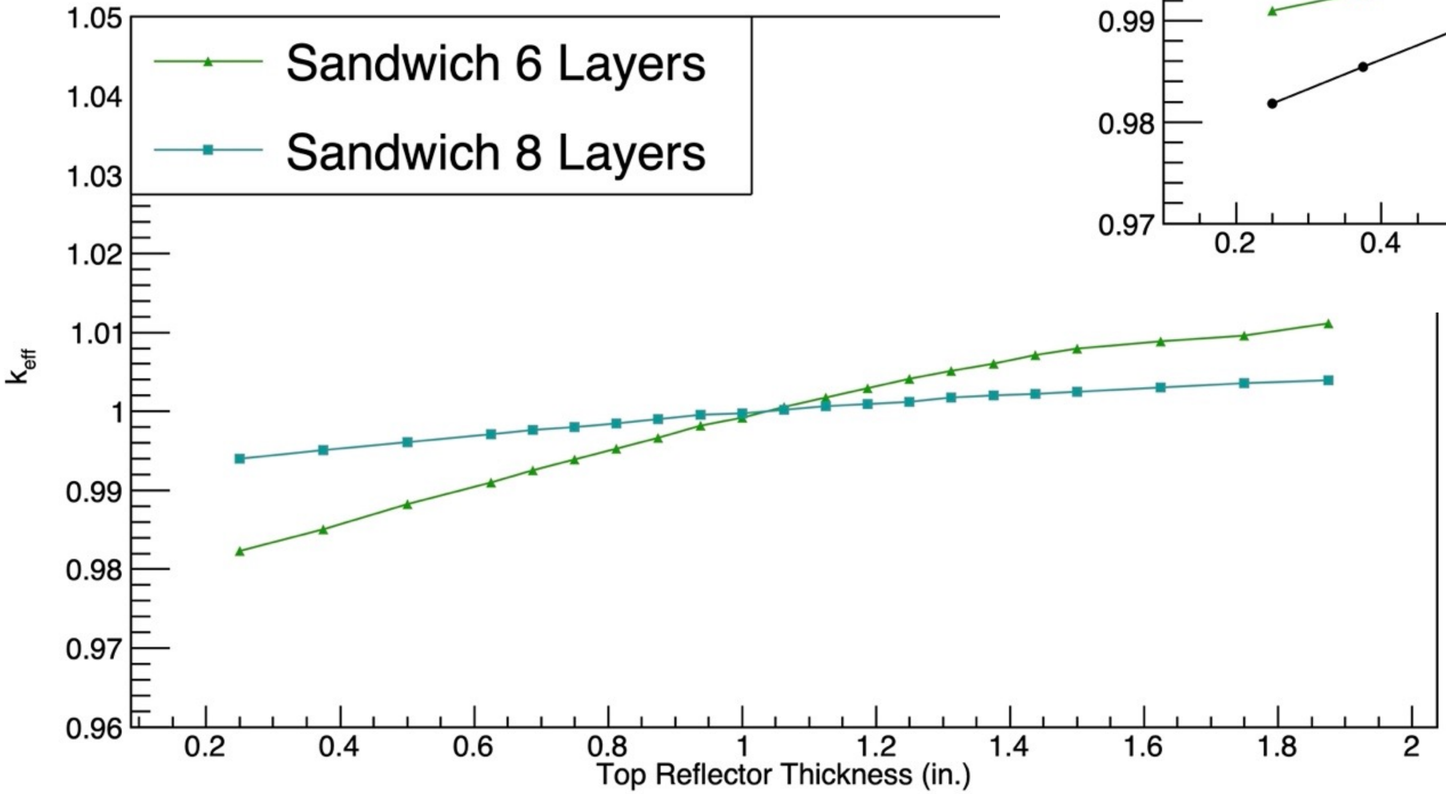


Reactivity Studies

Upper Reflector Thickness

- Upper reflector thickness study:

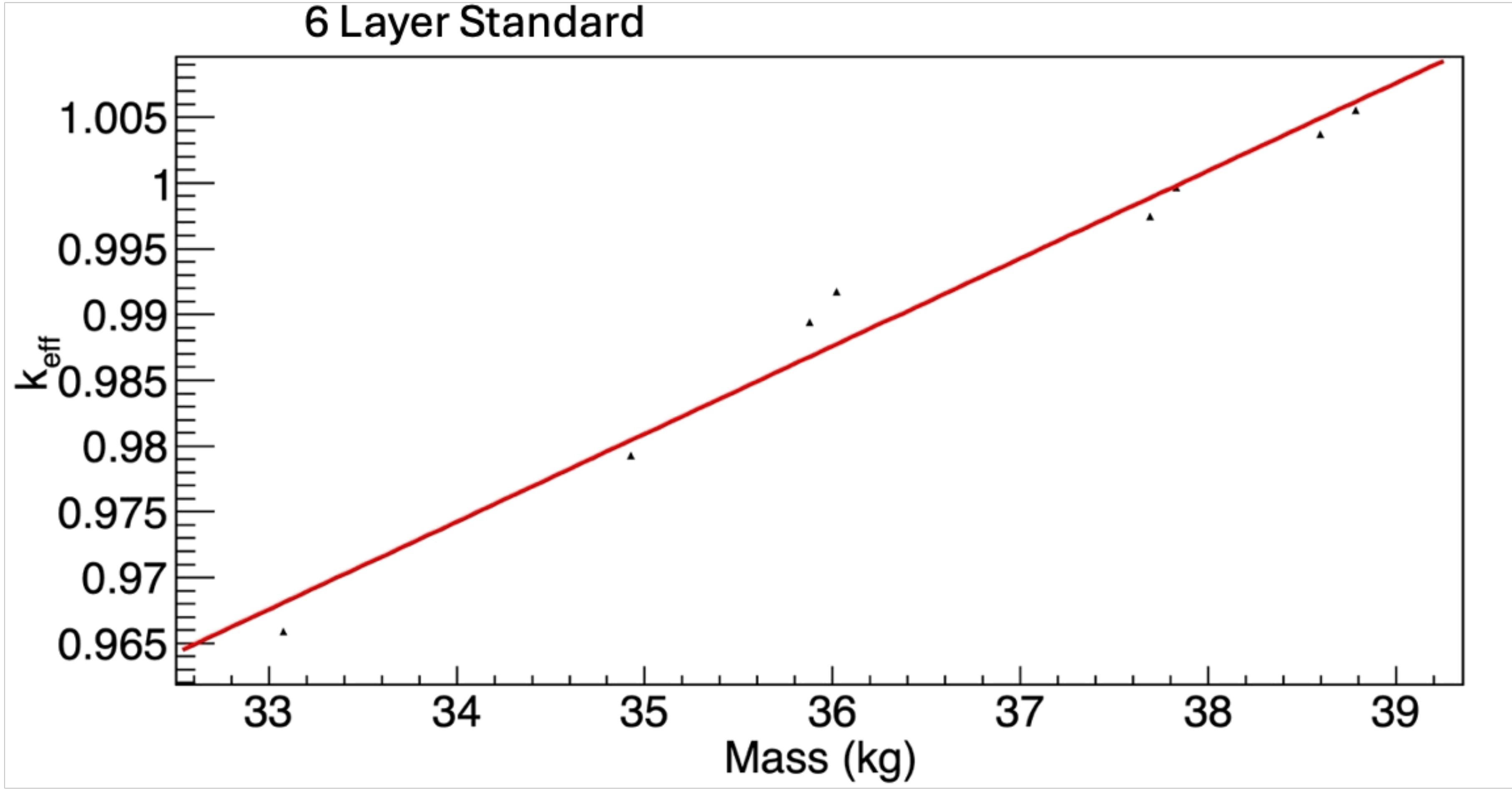




Reactivity Studies

HEU Plate Swaps

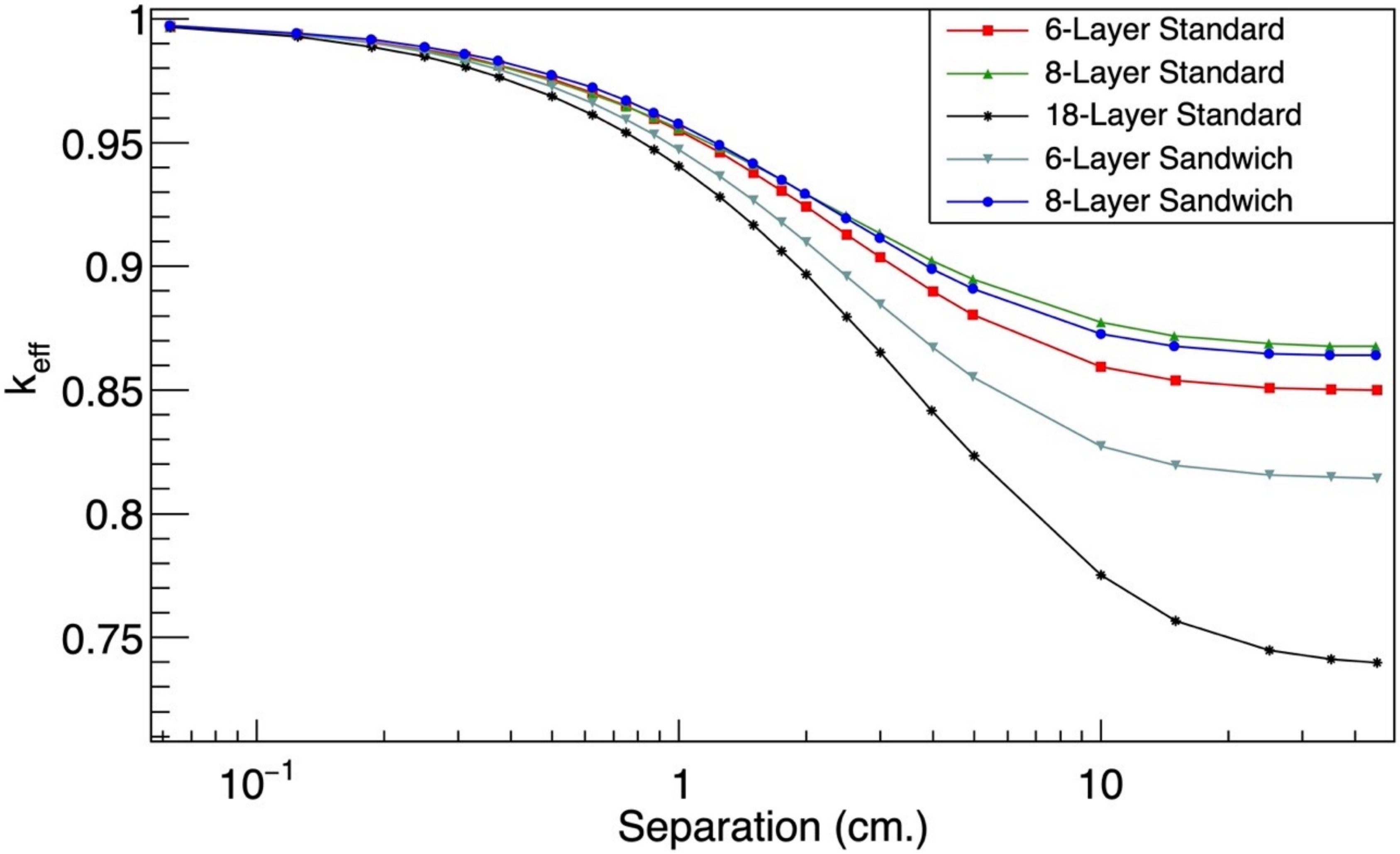
- Reactivity as a function of mass via HEU plate swaps
- Standard configurations
- Similar performed for sandwich configurations



Reactivity Studies

Separation

- Reactivity as a function of separation:



Conclusions

- Final design of TEX with chlorine absorbers was complete
  - 5 configurations were identified, expected to down select to three experimental configurations
  - Great comparison to Y-12 and good comparison to INL sensitivities
  - Fastest configuration touches on the ^{35}Cl(n,p) cross section (continuing to work with Terrapower for faster configurations)
  - Extensive density studies performed to ensure understanding of the salt in the plates
  - Reactivity studies performed to assist with experiment
- Fabrication of the chlorine absorbers is ongoing (with LANL)
- Experiment scheduled to be completed this year

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