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Title: Impact of Higher Fidelity Design Iterations on Critical System Criteria

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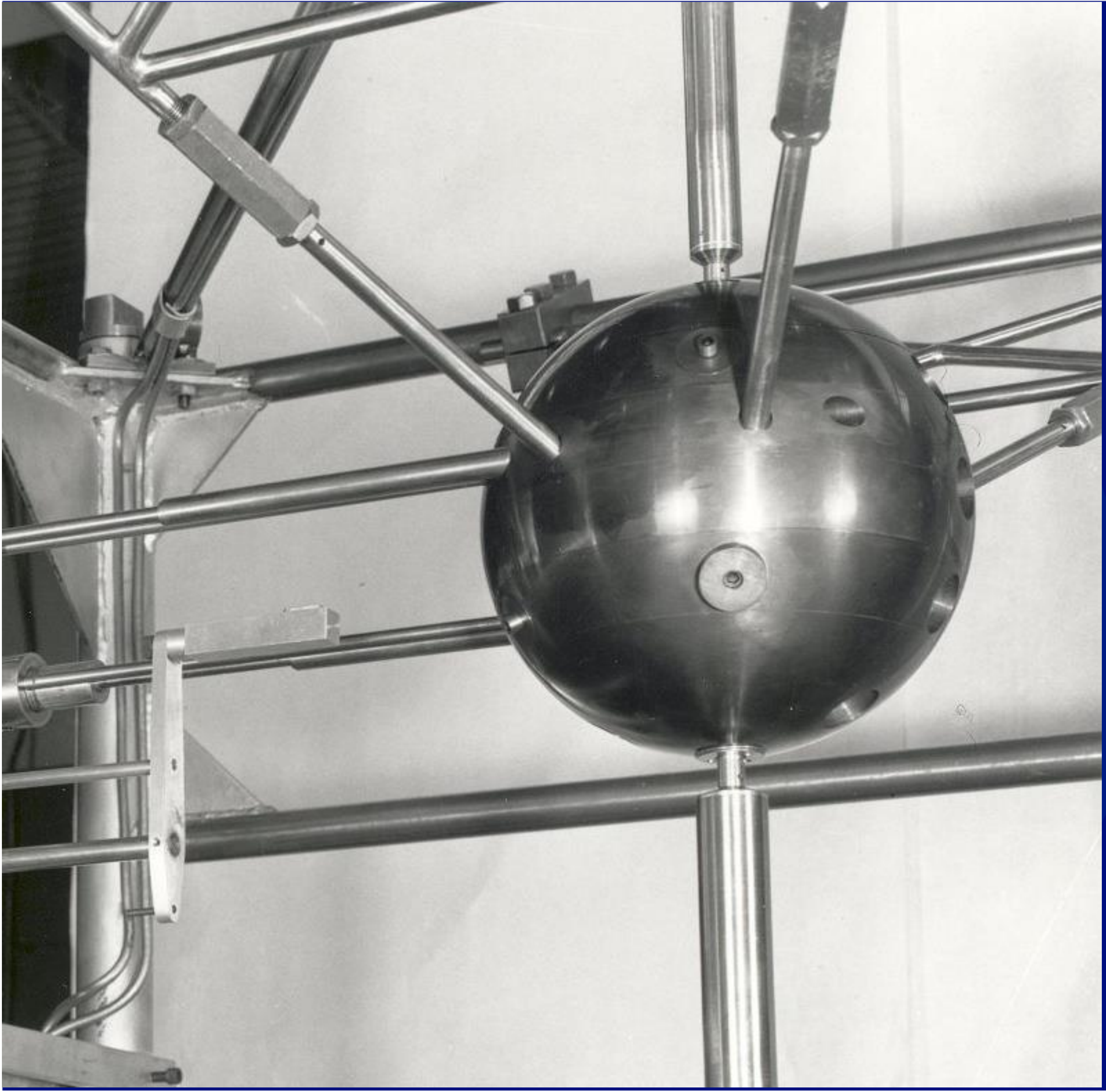

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Impact of Higher Fidelity Design Iterations on Critical System Criteria

MCNP 2024 User Symposium

Peter Brain

08/20/2024

Outline

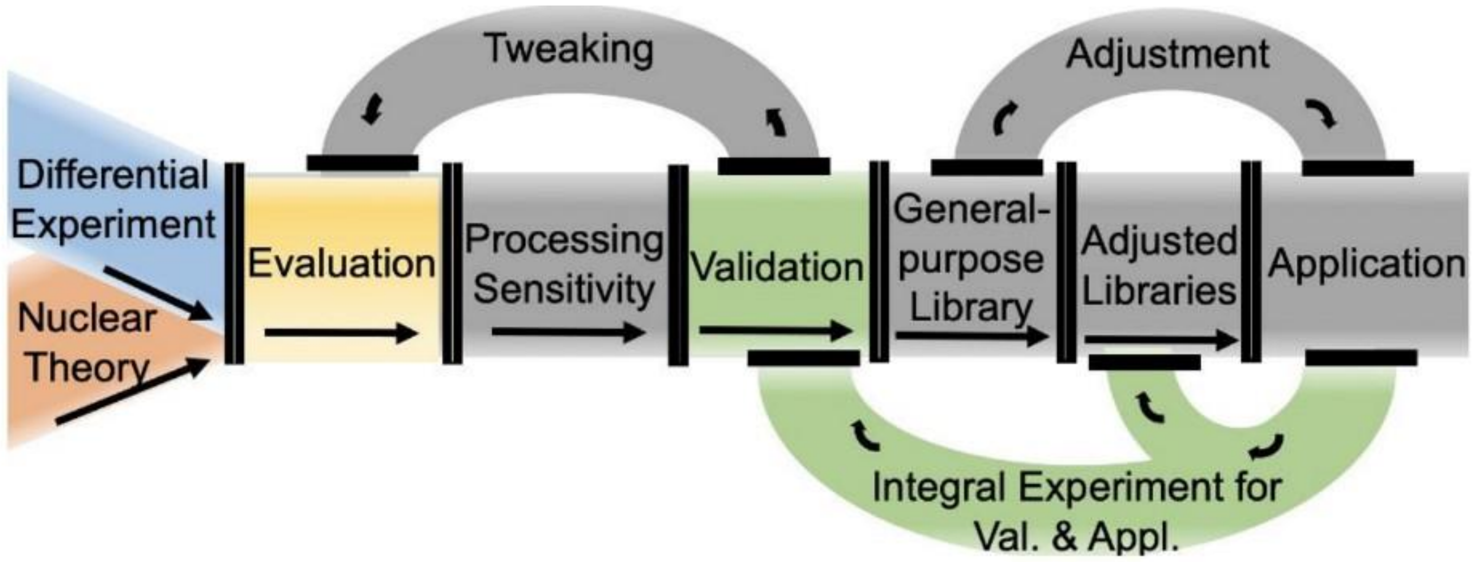
Supporting Pu operations

- Motivation for projects
- Initial Designs
- Progression Methodology
- Results and Comparison
- Concluding Remarks

Motivation

Nuclear Data and Transport Codes need Validation

- MCNP is one of the main codes for nuclear criticality and nuclear data validation
- Integral critical experiments, theorists, and MCNP developers share a unique symbiotic relationship where each provides feedback to the others



Motivation

Nuclear Data and Transport Codes need Validation

- MCNP used in the design, benchmarking, and validation of critical assemblies
- Experiments Underpinned by Computational Learning for Improvements in Nuclear Data (EUCLID) was a collaboration combining many elements of nuclear data pipeline built partially around MCNP

Building Upon EUCLID's Success

PARADIGM

- Validating intermediate regions of Pu (En :1 -30 and 30 – 600 keV)
- Preliminary designed with genetic algorithm to maximize fission sensitivity in energy bins
- See "*Low-fidelity MCNP Integral Experiment Model Optimization* " by N. Kleedtke

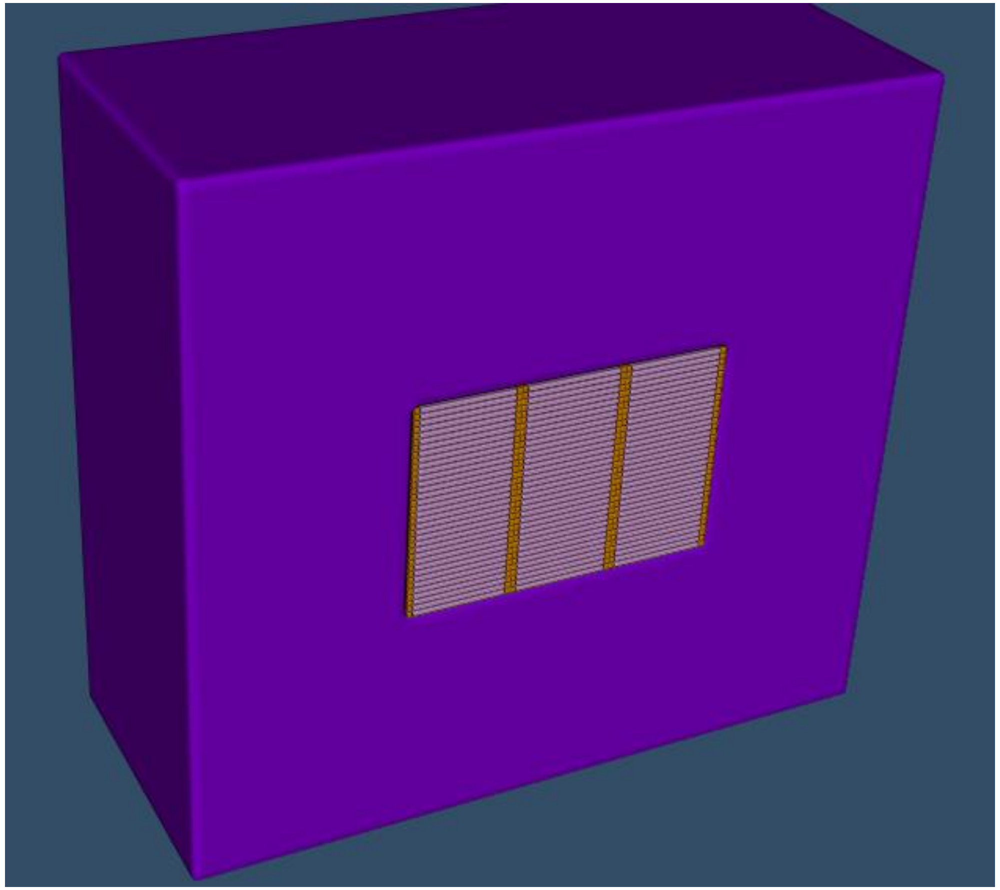
Thales

- Validating Pu reflected by Ta (En > 0.5 MeV)
- Preliminarily designed with D-Opt and broad parameter sweep for ND uncertainty reduction
- See "*Thales: Designing a New Fast Tantalum Benchmark Experiment for Criticality Safety* " by I. Michaud

Initial Designs

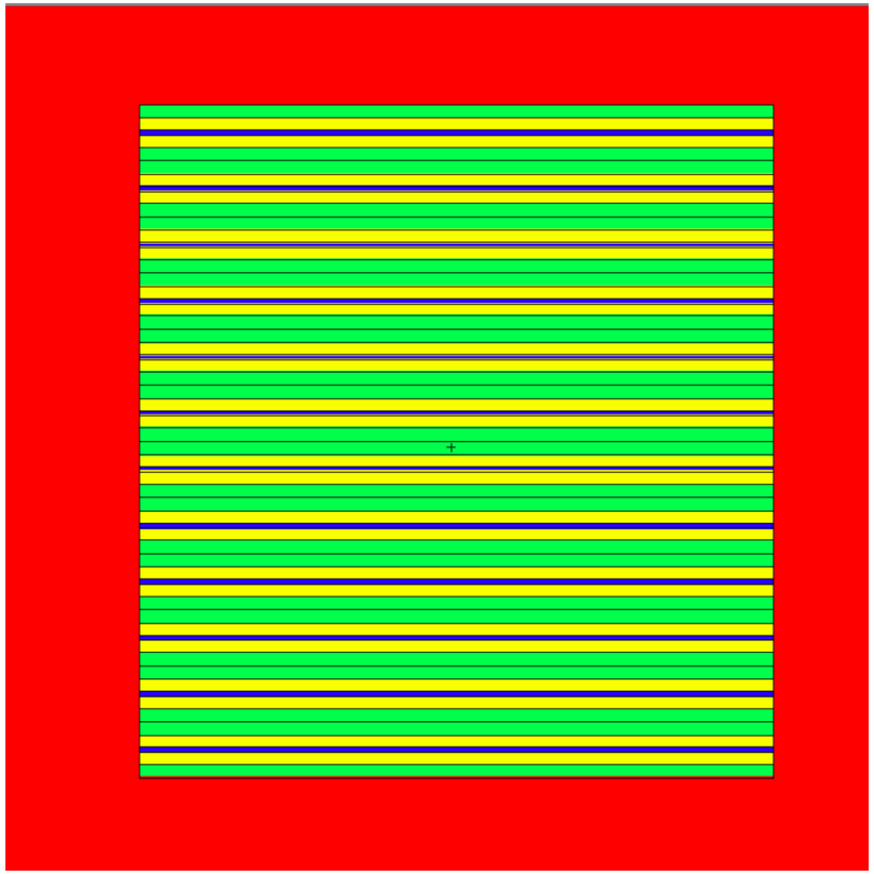
Purpose of Low Fidelity Models

- Simplistic geometry to get an idea of which materials and reflectors need for spectrum
- Computationally cheap
- Easily interface with modification scripts (e.g., MCNP P-Study)

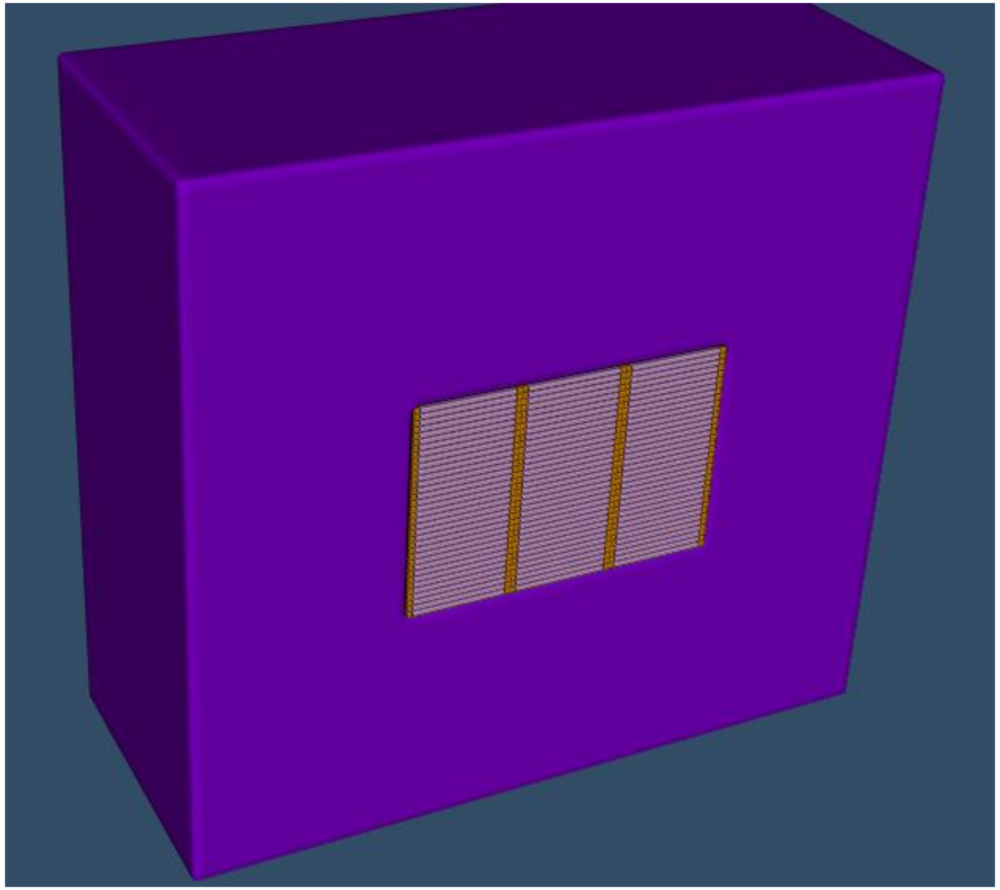


Initial Designs

PARADIGM



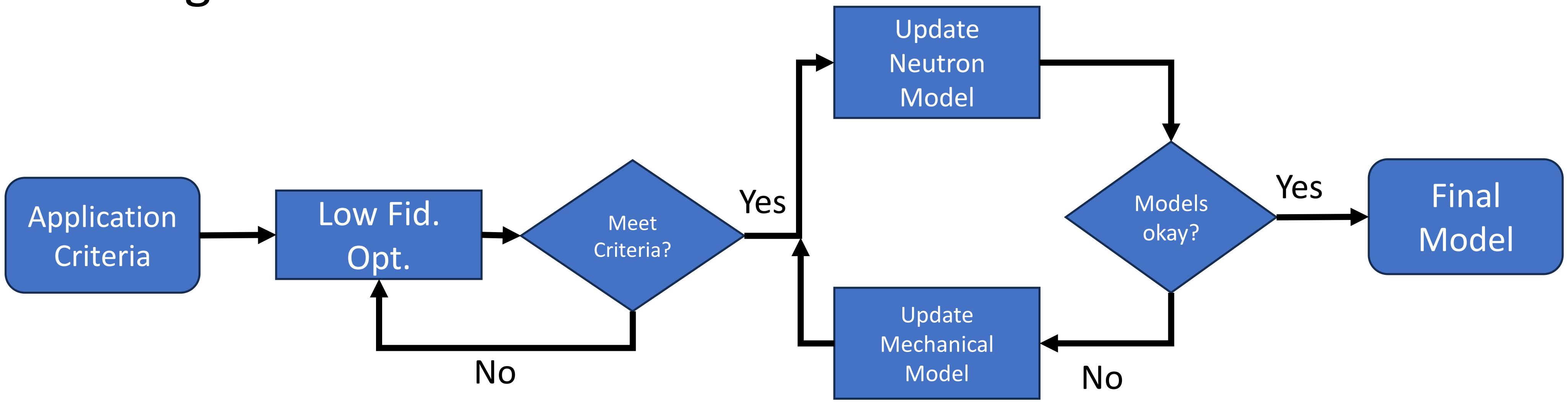
Thales



Low → High Fidelity Model

Neutronic idea → Engineering approved design

- Need to update for higher fidelity fuel form
- Fuel trays/stacking components
- Membrane to split the assembly
- Reflector geometries



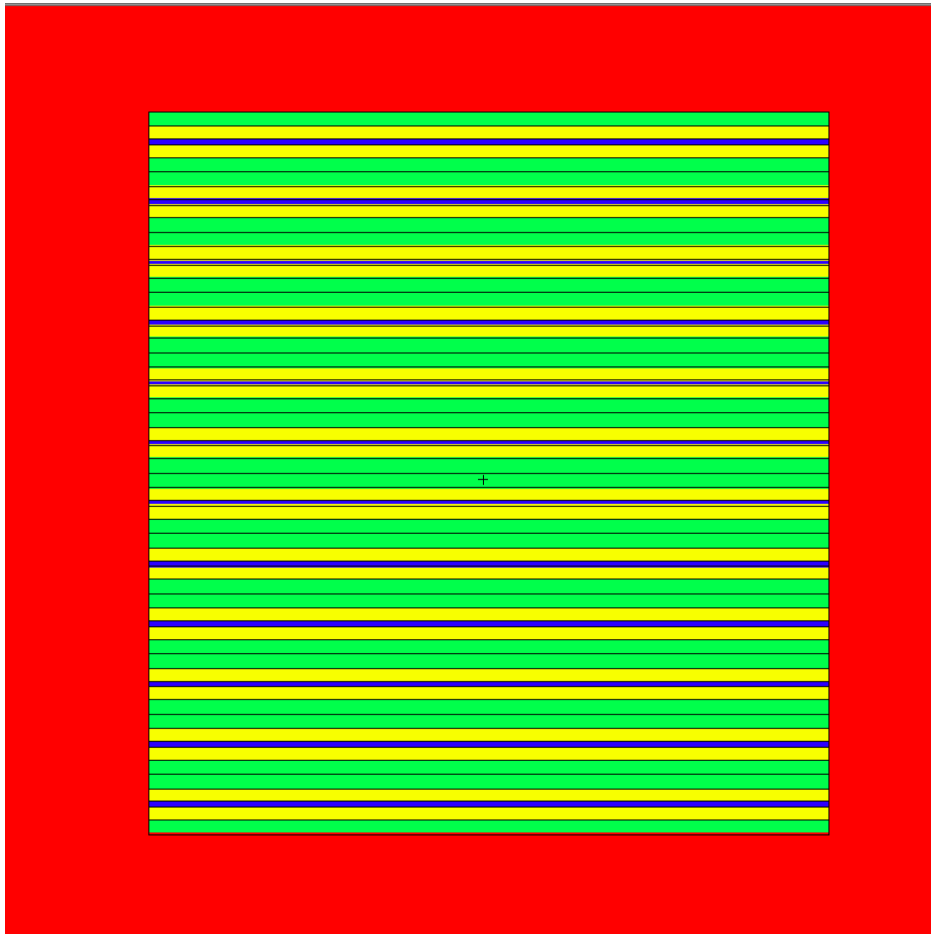
Progression Methodology

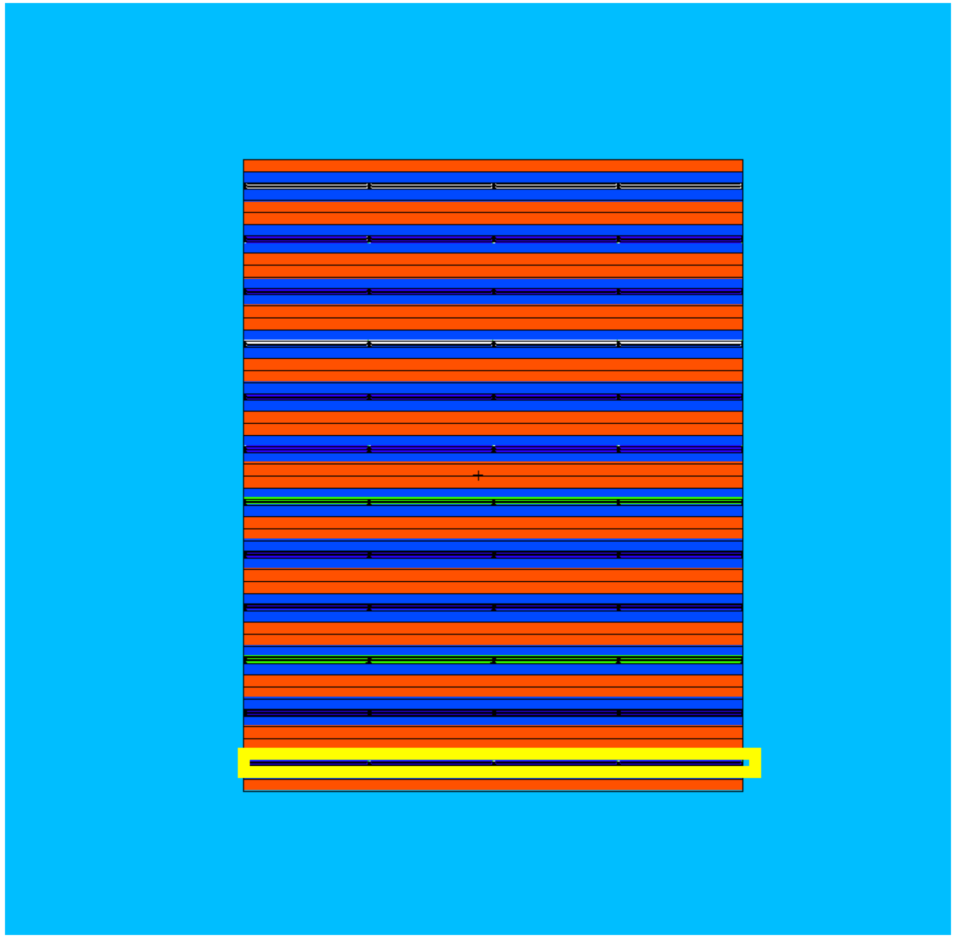
Repetitive tasks lead to scripting

- Adding all those updates results in the design deviating from a critical assembly
- Since both projects utilized the same fuel, it was easy to build fuel, interstitial, reflector classes in Python and go from there.
- Eventually since the two experiments are so different, two separate programs were created to address specific engineering designs

Recreating Simulations

- Each fuel layer now turned into individual fuel plates in a lattice





Recreating Simulations

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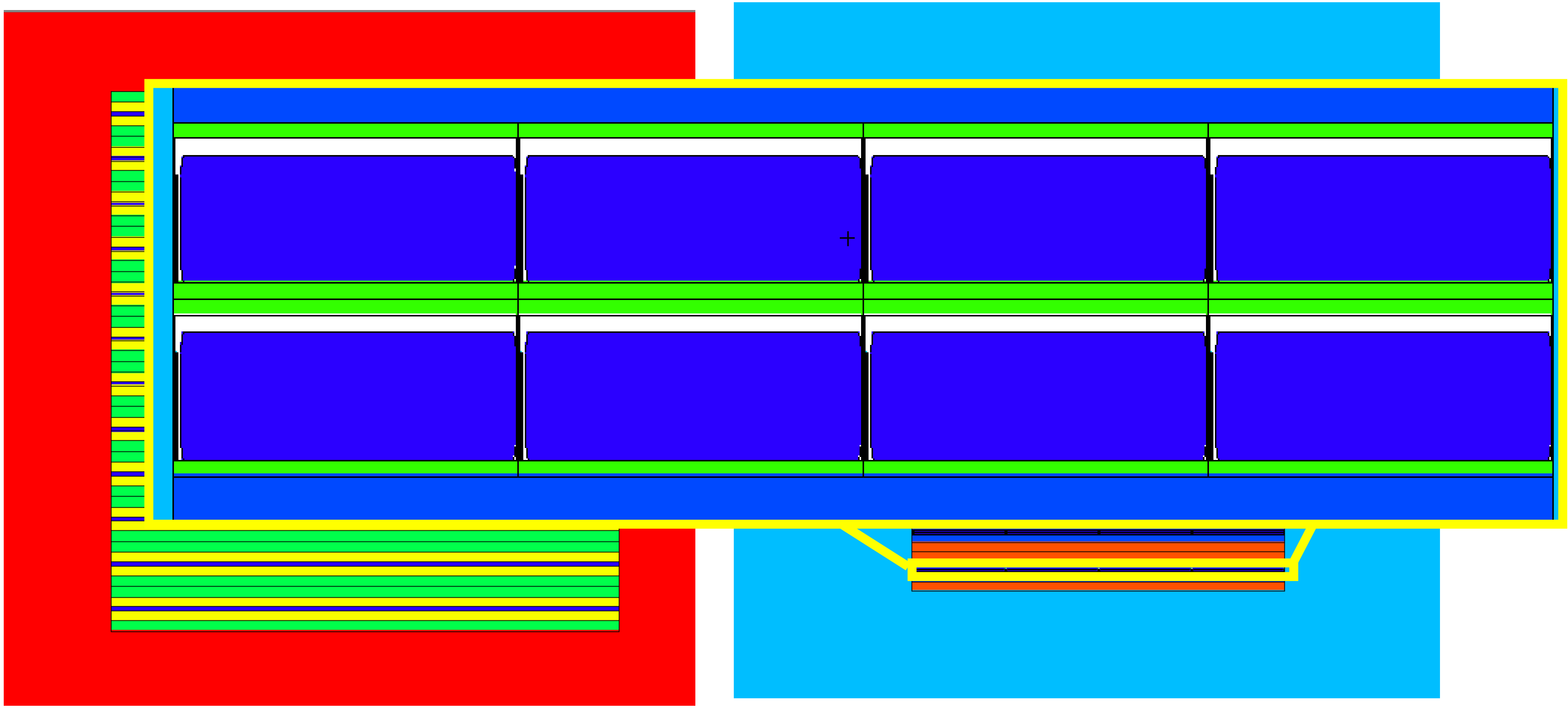


Results

Adding the new fuel, greatly reduces the reactivity of the system by over 10k pcm in most cases

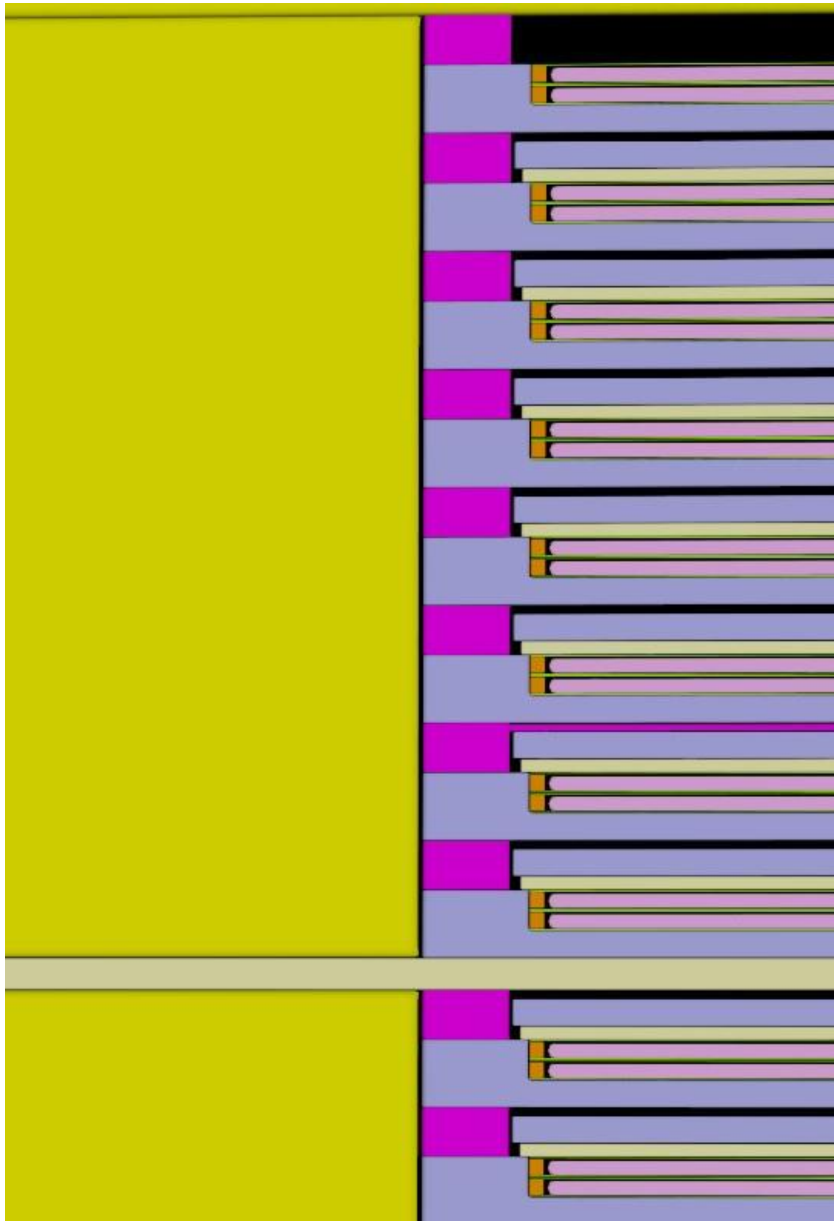
Number of Layers	Mat 1	Thickness 1	Mat 2	Thickness 2	Keff	Sensitivity (1-30 keV)
Low Fidelity (12)	Graphite	1.12 cm	Alumina	1.17 cm	1.00935	0.13246
High Fidelity (12)	Graphite	1.12 cm	Alumina	1.17 cm	0.89719	0.14000
14	Graphite	0.8 cm	Alumina	0.8 cm	1.01290	0.13980

Number of Layers	Mat 1	Thickness 1	Mat 2	Thickness 2	Keff	Sensitivity
Low Fidelity (12)	Boron	0.1 cm	Alumina	2.64 cm	0.77270	0.13246
High Fidelity (12)	Boron	0.1 cm	Alumina	2.64 cm	0.77270	0.14000
14	Boron	0.1 cm	Alumina	2.64 cm	0.66245	0.13980

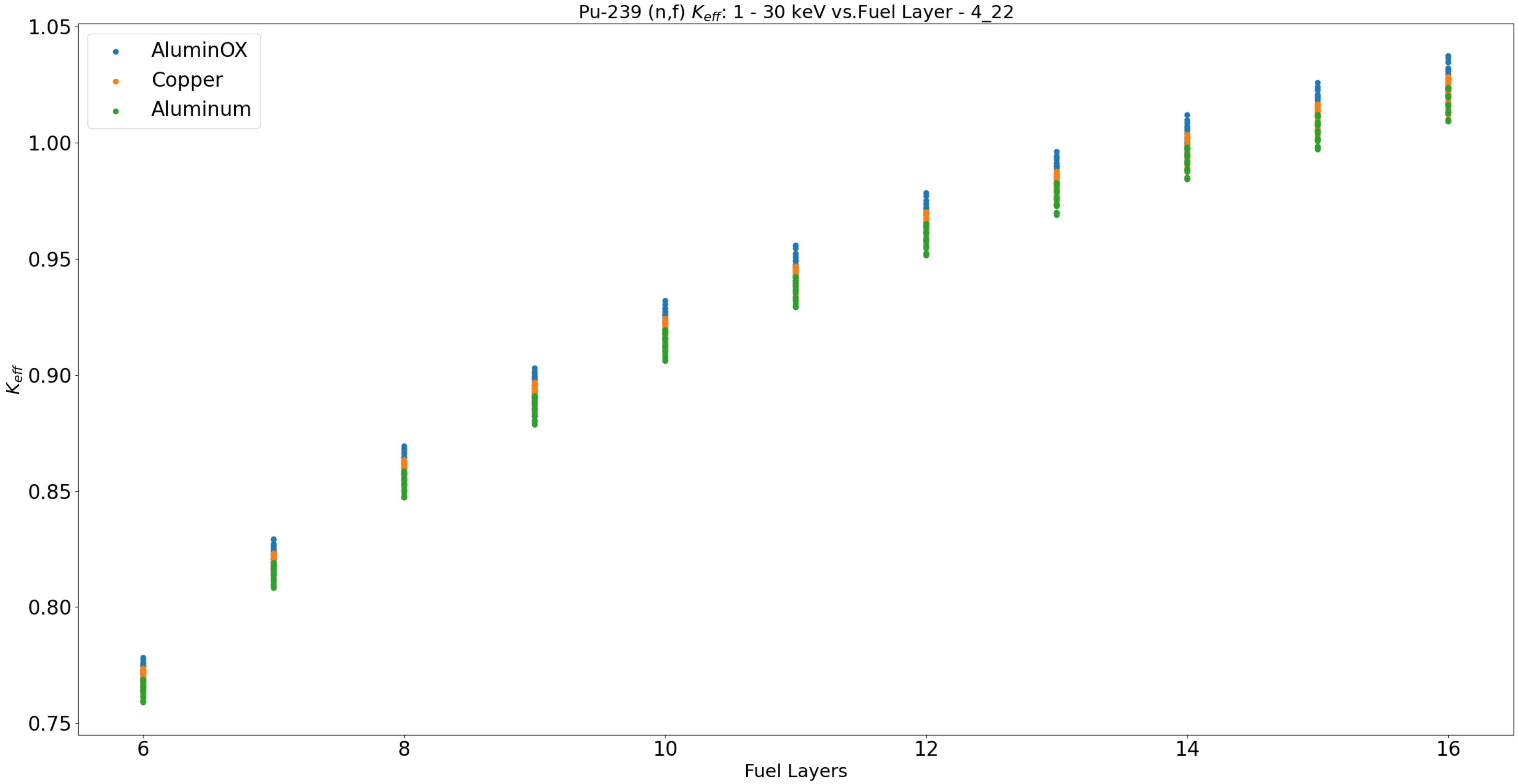
Engineering Tolerance Studies

Sensitivities to volume perturbations

- Tray materials
- Tray thickness
- Air Gaps
- Interstitial material tolerances
- Cost



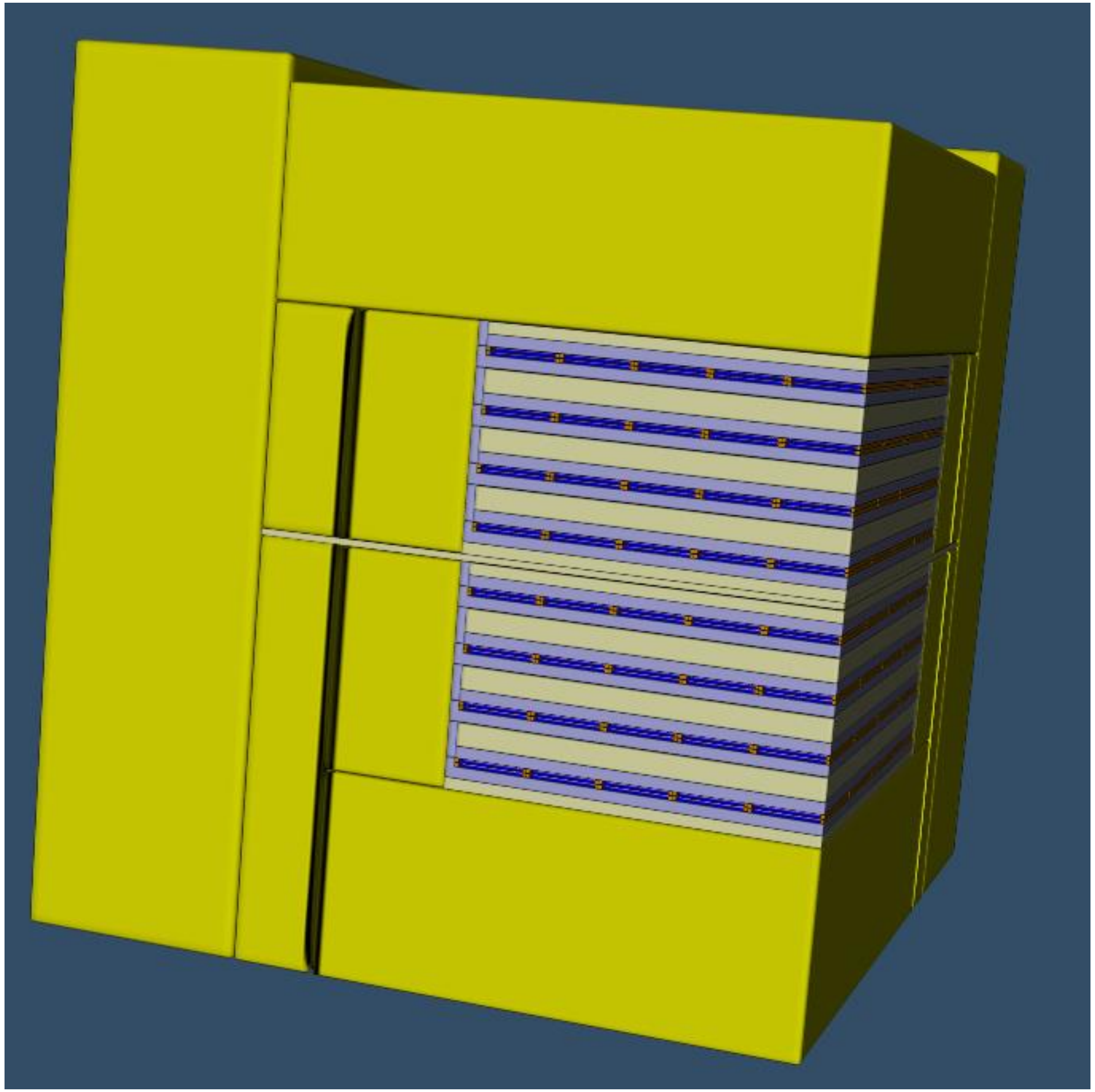
Keff vs. Fuel Layer Study with Changing Wall Materials



PARADIGM Updates

Low to High Fidelity Changes

- Use full ZPPR fuel plate model
- Zeus copper reflector
- Interstitial trays and walls
- Copper upper membrane



Comparison of Low and High Fidelity: 1 - 30 keV Config

Number of [Layers]	Mat 1	Thickness 1 [cm]	Mat 2	Thickness 2 [cm]	Keff	Sensitivity [1-30 keV]	Fluence [1-30 keV]
Low Fidelity [12]	Graphite	1.12	Alumina	1.17	1.00935	0.13246	21.0%
High Fidelity [12]	Graphite	1.12	Alumina	1.17	0.89719	0.14000	22.2%
Critical Config [14]	Graphite	0.8	Alumina	0.8	1.01290	0.13980	21.0%
Add Zeus Reflector [16]	Graphite	0.8	Alumina	0.8	1.011407	0.13587	23.5%
Add Tray and Air Gap [16]	Graphite	0.8	Alumina	0.8	1.012896	0.13299	23.4%

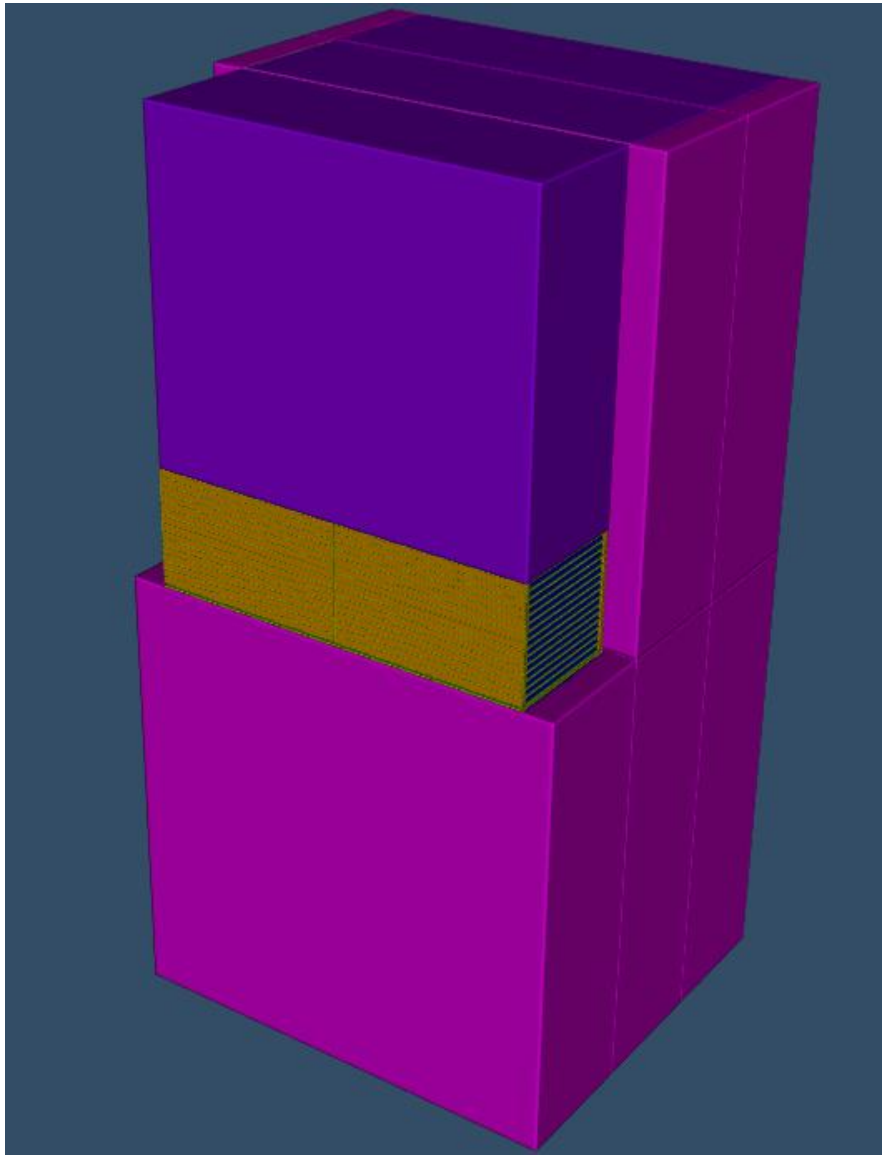
Comparison of Low and High Fidelity: 30 – 600 keV Config

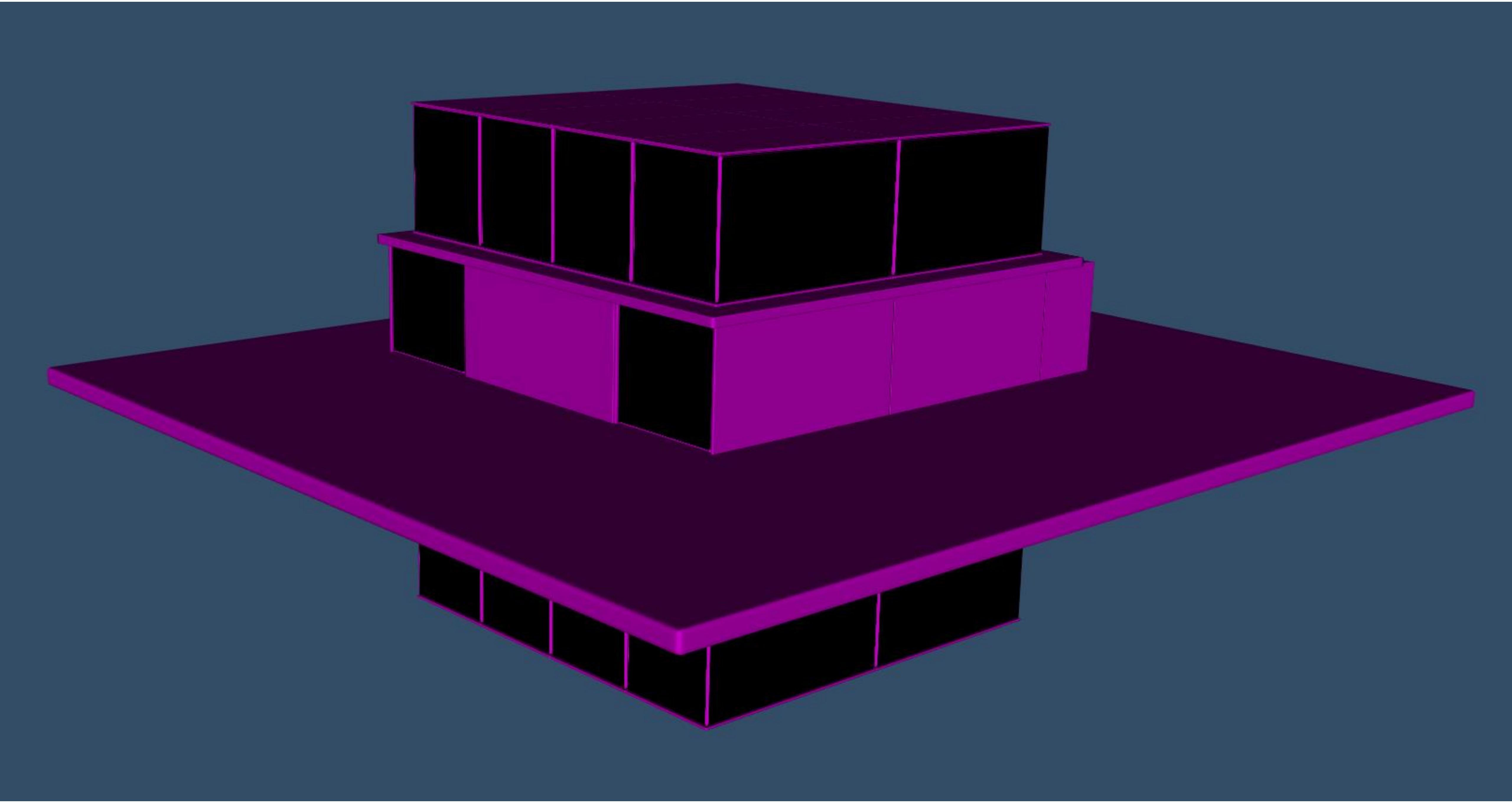
Number of [Layers]	Mat 1	Thickness 1 [cm]	Mat 2	Thickness 2 [cm]	Keff	Sensitivity [30-600 keV]	Fluence [30-600 keV]
Low Fidelity [12]	Alumina	0.4	Boron	0.1	0.77852	0.26631	43.4%
High Fidelity [12]	Alumina	0.4	Boron	0.1	0.66805	0.27362	43.7%
Move to 1 boron layer [12]	Alumina	0.4	Boron	0.2	1.00141	0.27855	48.0%
Add Zeus Reflector [11]	Alumina	0.4	Boron	0.2	1.00700	0.28069	58.5%
Add trays and air gaps [12]	Alumina	0.4	Boron	0.2	1.018206	0.27764	57.8%

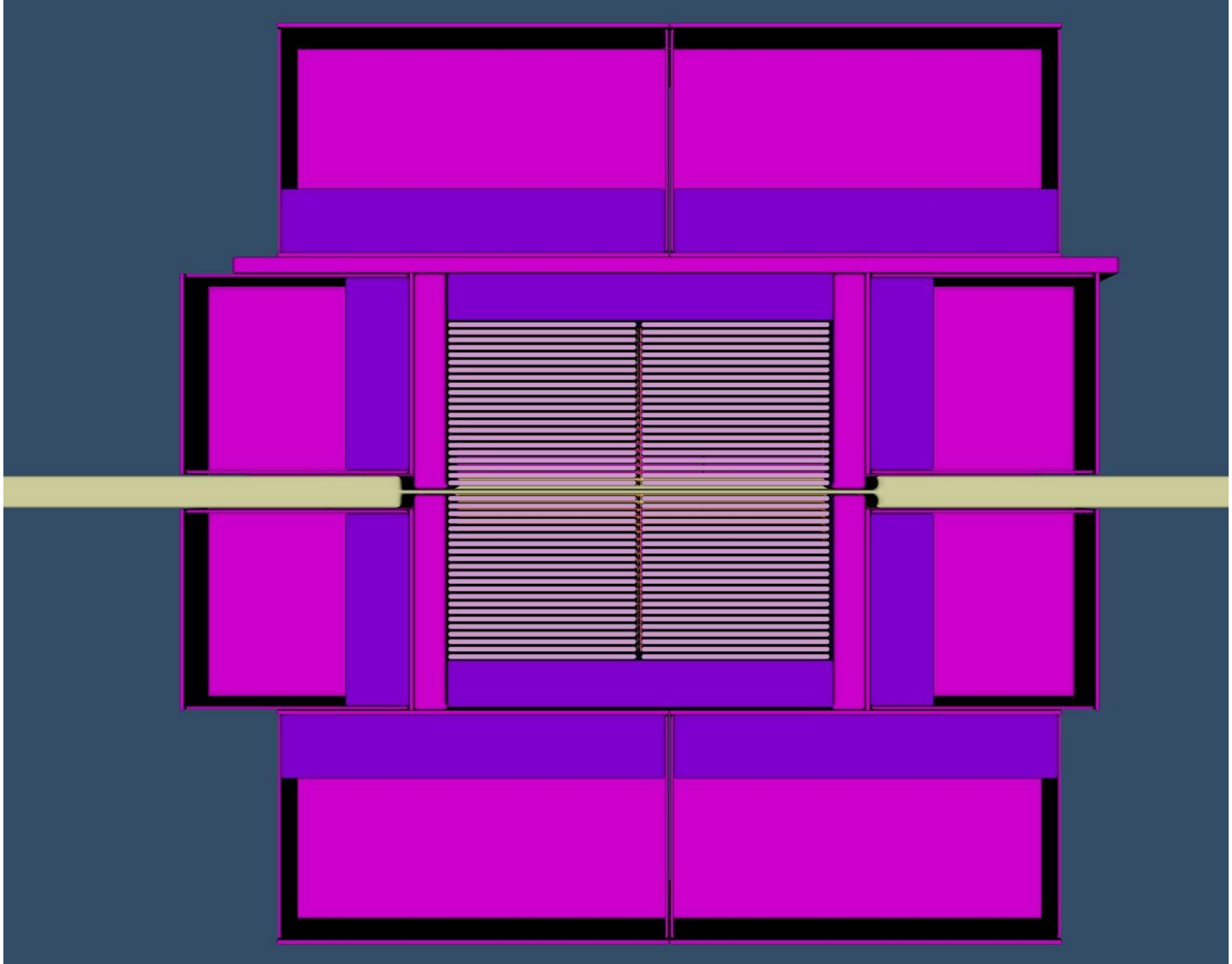
Thales Updates

High Fidelity Considerations

- Containerized the fuel into boxes similar to EUCLID design
- Created containers for the reflector so a square reflector could be constructed
  - Due to the containerization maximum Ta thickness is 8.9 cm
- Performed engineering studies for materials, thickness, air tolerances, etc.







Summary of Keff and Sensitivities

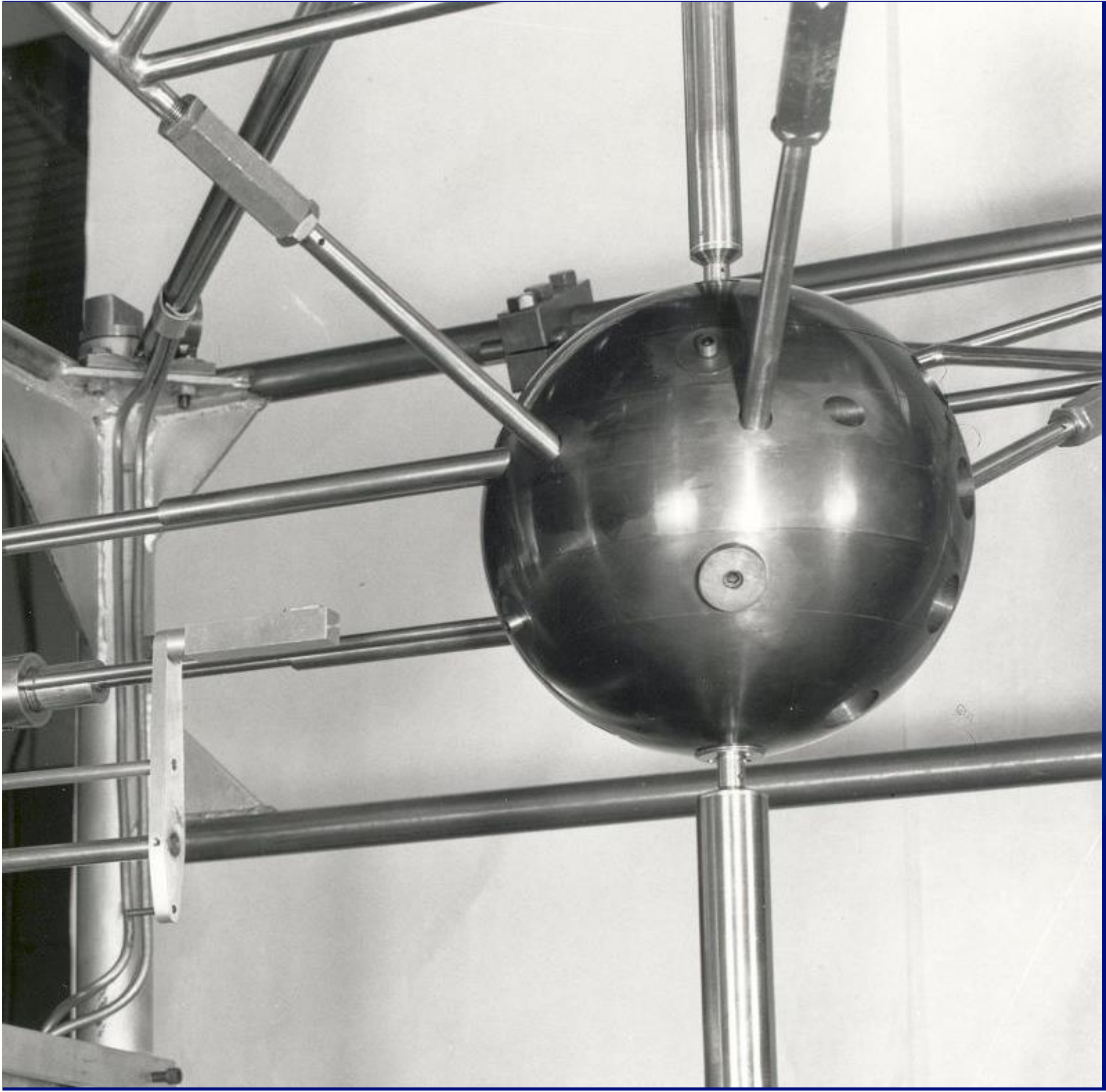
Condense all the inputs into a single table

Configs	Original w/ RPP Reflector Keff	Original w/ RPP Reflector Sens	Euclid w/ RPP Reflector Keff	Euclid w/ RPP Reflector Sens	New Least Keff (Al box)	New Least Sens (Al box)	New Most Keff (Ta box)	New Most Sens (Ta box)
32 Layers 8.90 cm reflector	1.090946	0.114 (El) 0.095 (Inel)	1.066311	0.105 (El) 0.086 (Inel)	1.010248	0.0979 (El) 0.0834 (Inel)	1.014625	0.105 (El) 0.0876 (Inel)
36 Layers 5.08 cm reflector	1.072730	0.105 (El) 0.097 (Inel)	1.052834	0.097 (El) 0.088 (Inel)	1.046267	0.0906 (El) 0.0804 (Inel)	1.050325	0.093(El) 0.085 (Inel)
44 Layers 2.54 cm reflector	1.04377	0.0743 (El) 0.0767(Inel)	1.05829	0.0710 (El) 0.0684 (Inel)	1.043921	0.0701 (El) 0.0676 (Inel)	1.052596	0.078 (El) 0.076 (Inel)
55 Layers 1.27 cm reflector	1.006921	0.060 (El) 0.062 (Inel)	0.999840	0.057 (El) 0.058 (Inel)	1.029687	0.0432 (El) 0.0467 (Inel)	1.039995	0.055 (El) 0.057 (Inel)

Conclusions

If iterating, build for variation

- Recommendation is to construct python script/notebook to handle most of the input deck generation
  - Level of functions and classes can vary based on application
- Low → High Fidelity
  - Fuel form has largest impact on criticality
  - Reflector/Interstitial will dominate the sensitivities



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