Jupiter: A Benchmark Experiment for Lead Void Worth with Plutonium

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  - Results
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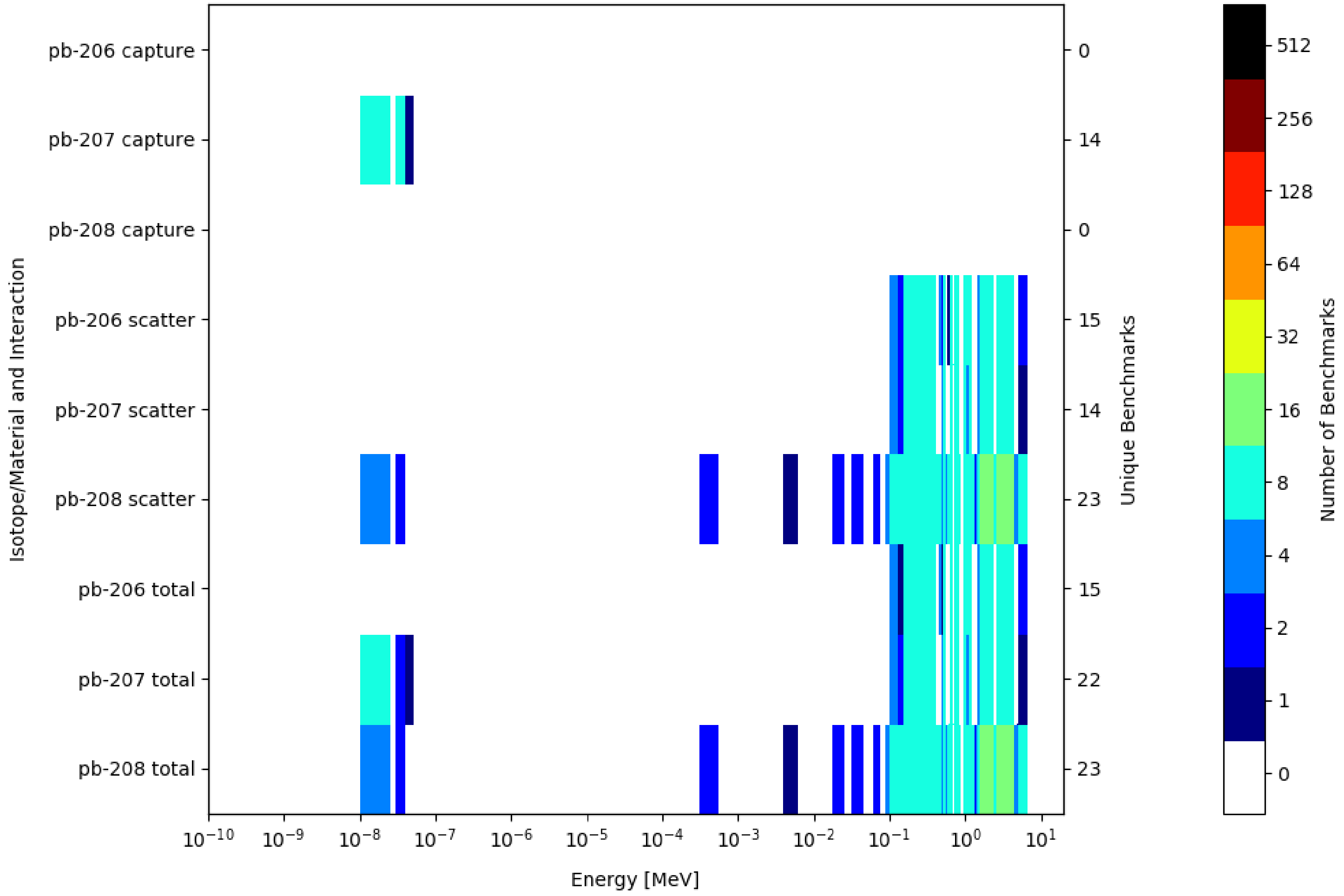
Background

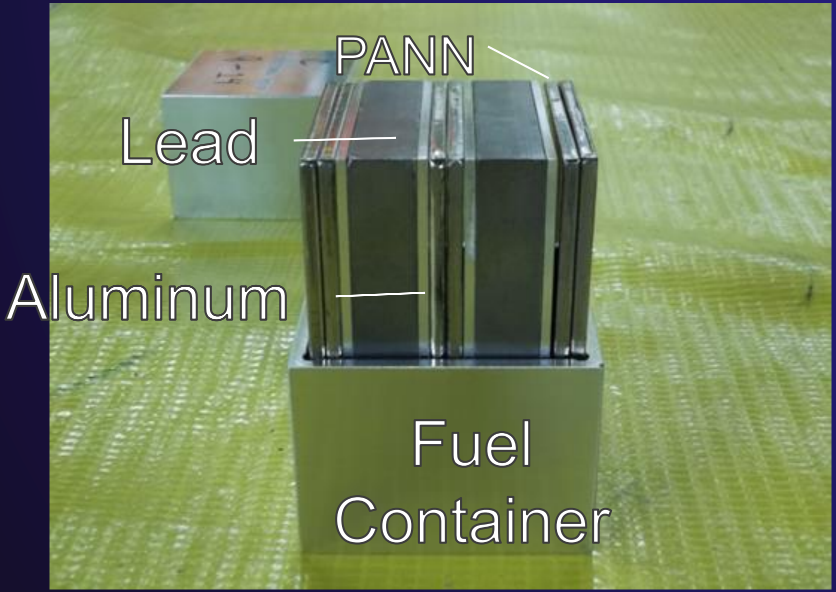
- Collaboration between Los Alamos National Laboratory (LANL) and the Japanese Atomic Energy Agency (JAEA)
  - Goal is to provide useful data for a potential lead-bismuth cooled accelerator driven system in Japan
  - Desired to measure the lead-void reactivity worth for a variety of systems
    - Highly Enriched Uranium (HEU)
    - “Intermediate” Enriched Uranium (mix of HEU and natural uranium plates)
    - Plutonium
    - See papers by K. Tsujimoto et al. and M. Fukushima et al.
- Lead is a very widely used material for shielding

Background – Benchmark Heat Maps

- Less than two dozen International Criticality Safety Benchmark Evaluation Project handbook entries (up to 2016) sensitive to lead



Jupiter – Experiment Description

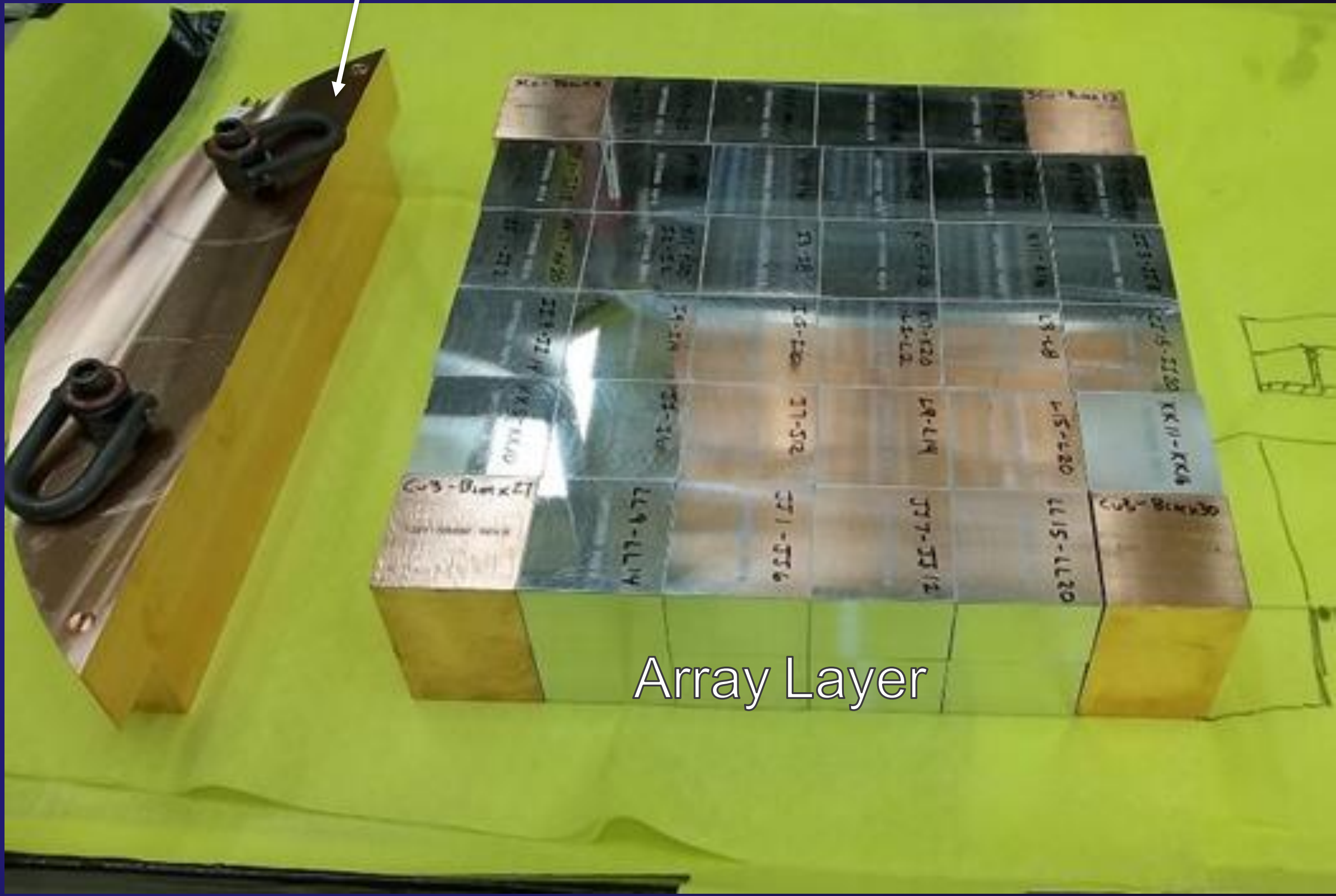


- Array is made of PANN (plutonium aluminum no-nickel) plates from Idaho National Laboratory's Zero Power Physics Reactor experiments
  - Each contains average of ~105g nuclear material, 94% of which is ^{239}Pu
  - Alloyed with aluminum, clad in stainless steel
- Plates are put in "sandwiches" of lead and PANN plates, with aluminum in between
  - 6 plutonium, 2 lead in each box

Nuclide	As-Built Average Wt. % (1960)
^{239}Pu	93.971
^{240}Pu	4.483
^{241}Pu	0.437
^{242}Pu	0.005
Al	1.099

Jupiter – Experiment Description

- Series of boxes and copper blocks put into an array
- Surrounded by copper inner reflector blocks to make cylindrical top and bottom stack for Comet



Jupiter

Cu	Cu	6 Pu 2 Pb	6 Pu 2 Pb	Cu	Cu
Cu	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	Cu
6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb
6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb
Cu	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	Cu
Cu	Cu	6 Pu 2 Pb	6 Pu 2 Pb	Cu	Cu

Top Layer

Cu	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	Cu	.032" Al springs
6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	
6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	
6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	
6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	
Cu	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	Cu	
.032" Al springs						

Middle Layer

Cu blocks

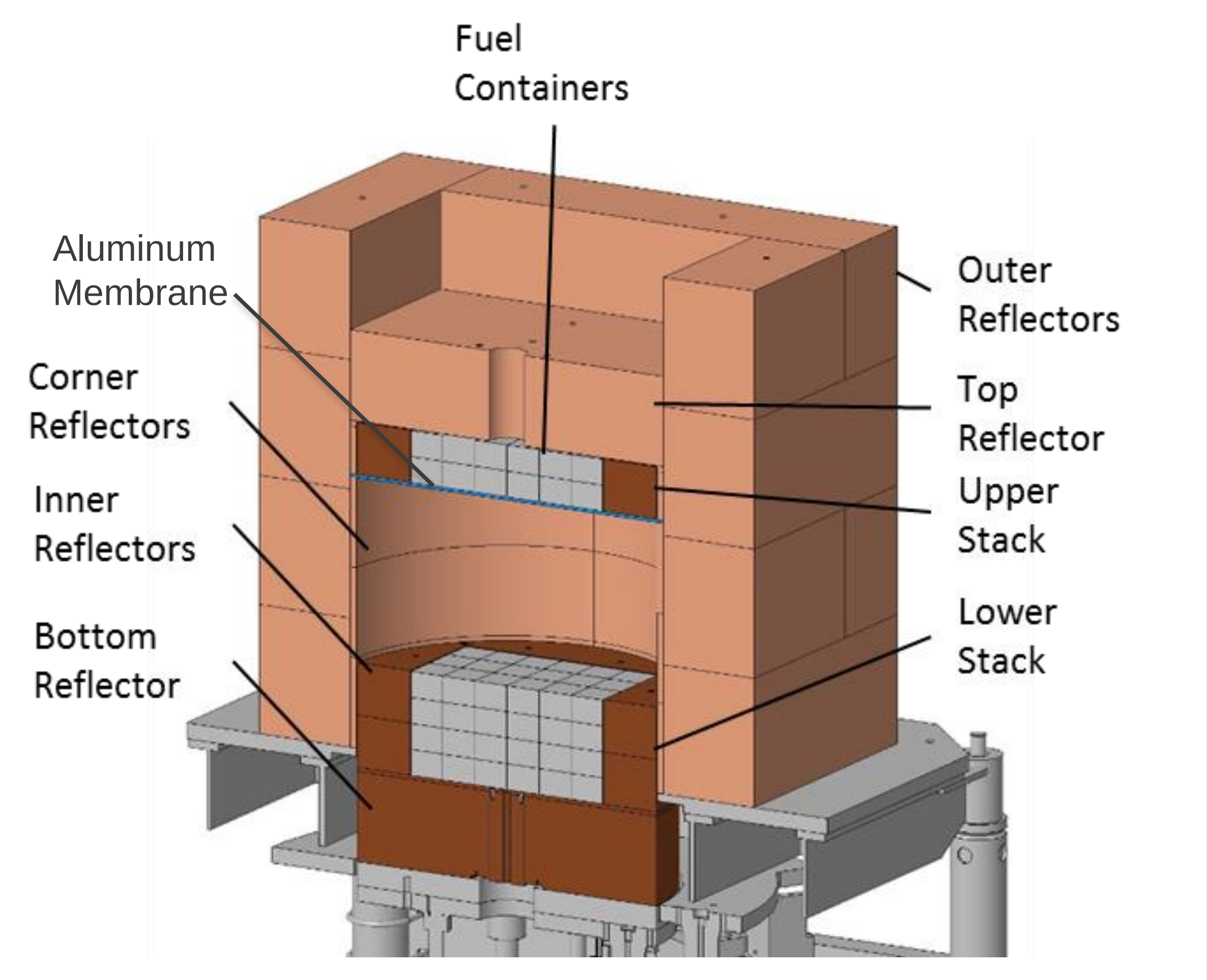
Fuel Boxes

Al Springs

Cu	Cu	6 Pu 2 Pb	6 Pu 2 Pb	Cu	Cu	.032" Al shim
Cu	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	Cu	
5 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	4 Pu 2 Pb	.040" Al shim
4 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	4 Pu 2 Pb	
Cu	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	6 Pu 2 Pb	Cu	.032" Al shim
Cu	Cu	6 Pu 2 Pb	6 Pu 2 Pb	Cu	Cu	
.032" Al shim		.040" Al shim		.040" Al shim		

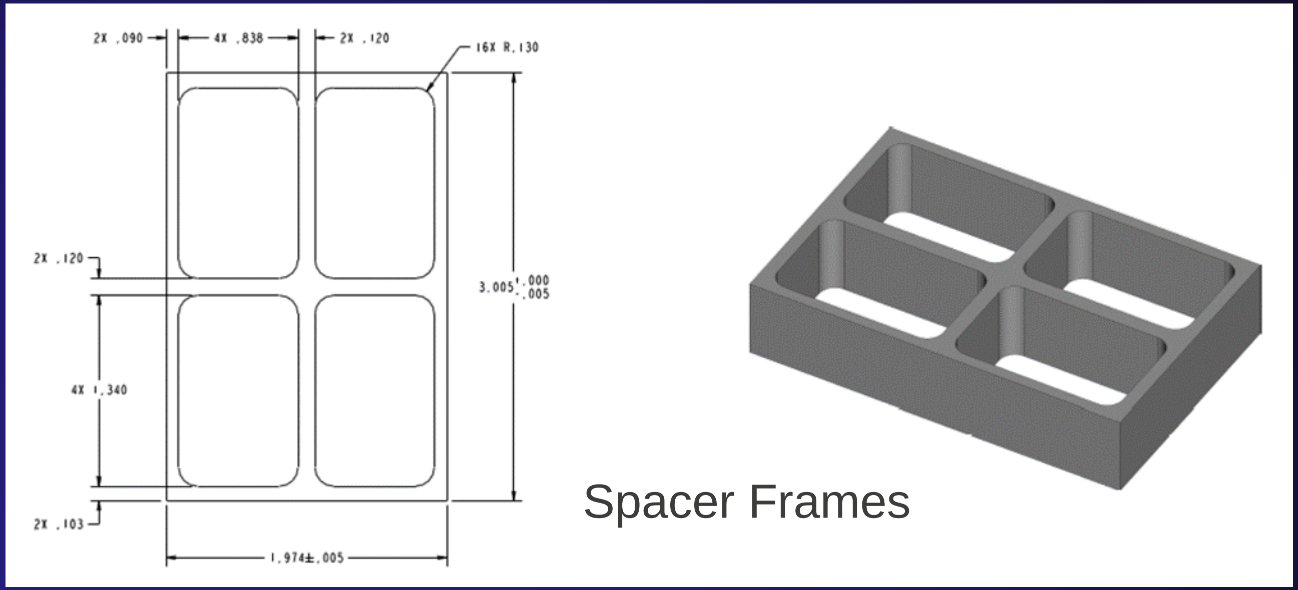
Bottom Layer

Al Shims

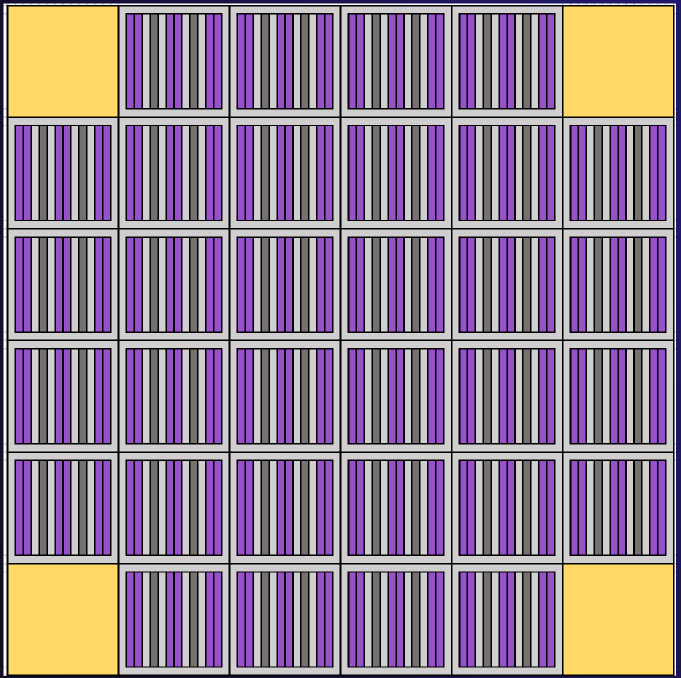


Lead-Void Configurations

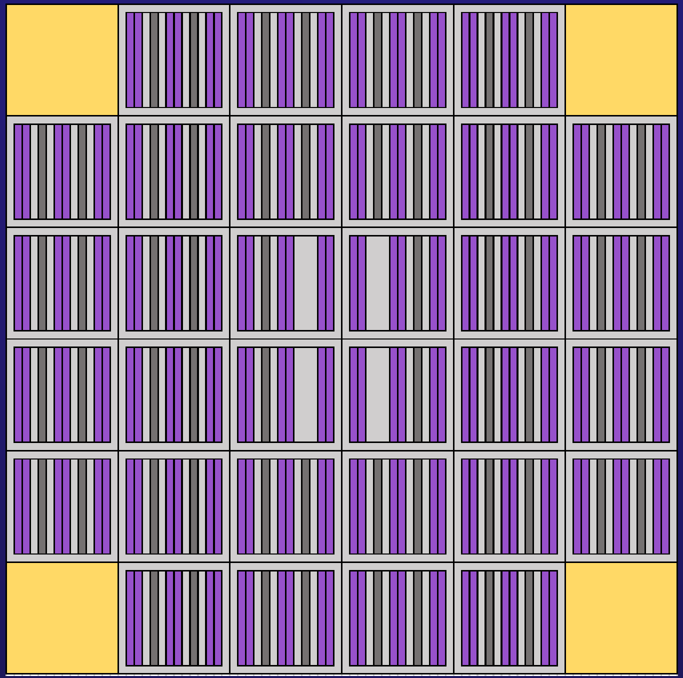
- Aluminum spacer frames to replace the lead and aluminum in most central boxes of middle layer
    - Mass of aluminum is preserved



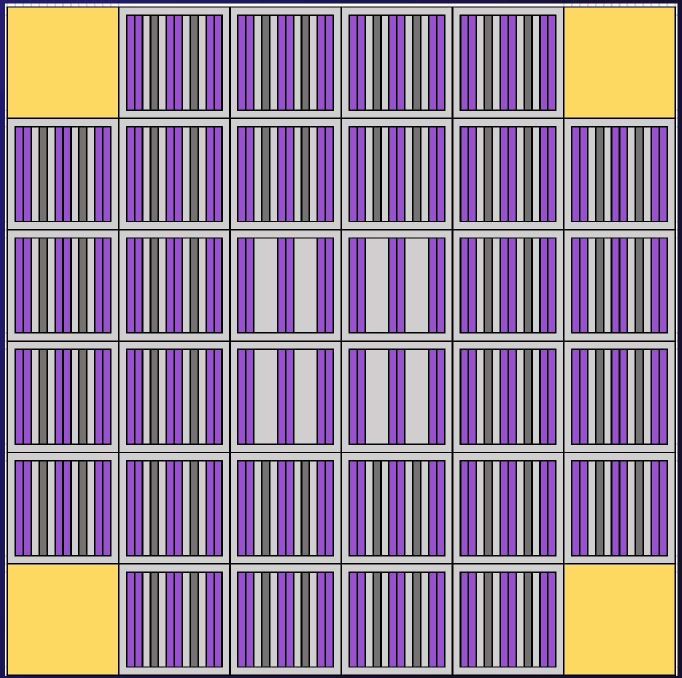
Reference



A1



A12



Experimental Results

Preliminary

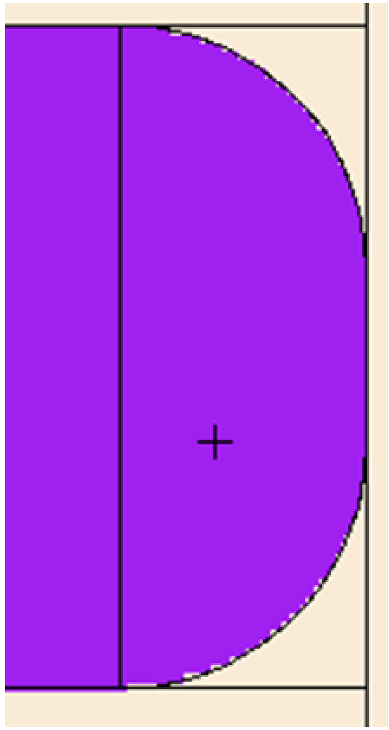
Configuration	Average Excess Reactivity (cents)	Inferred k_{eff}^{*}	σ
Reference	34.5	1.00072	± 0.00002
A1	23.7	1.00050	± 0.00002
A12	11.2	1.00024	± 0.00002

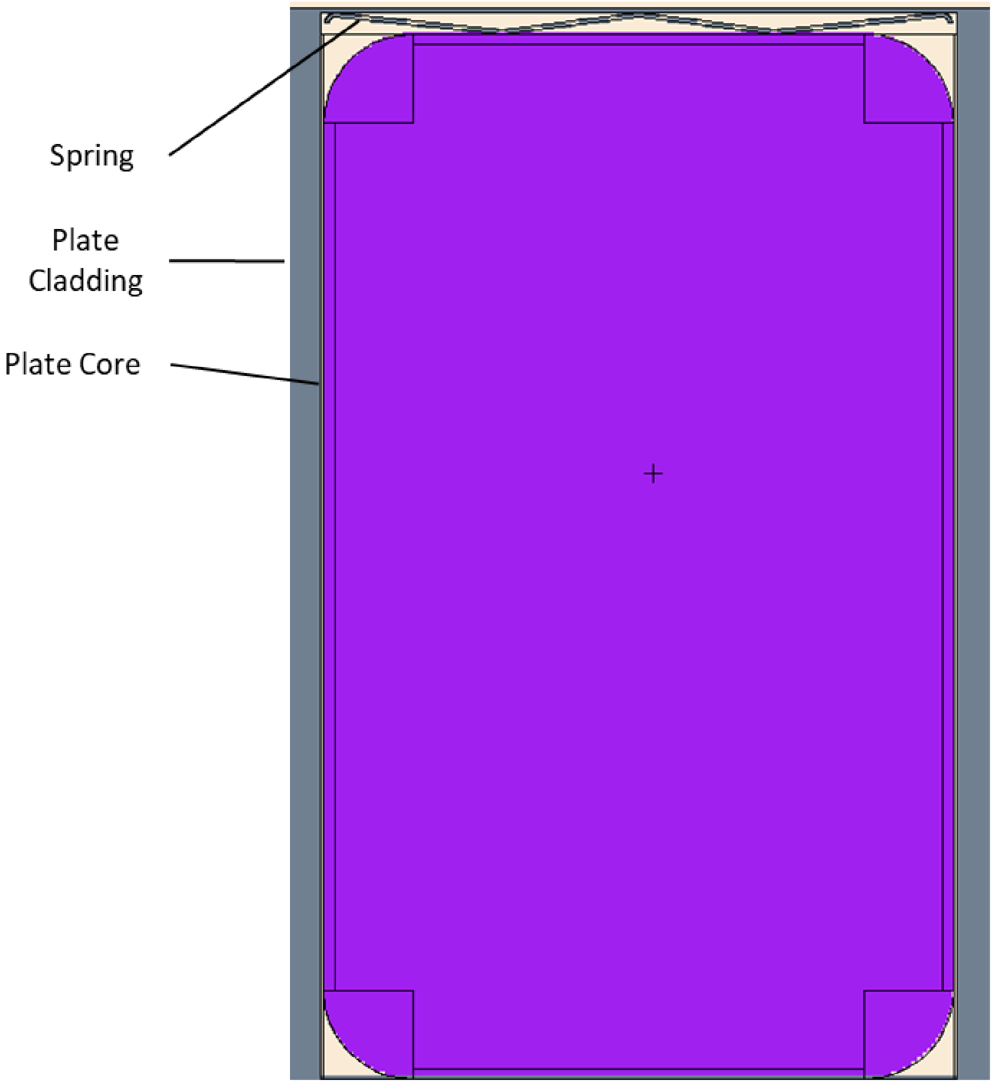
*Based on Keepin's $\beta_{eff} = 0.00210$

G.R. Keepin, *Physics of Nuclear Kinetics*, Addison-Wesley Pub. Co., 1965.

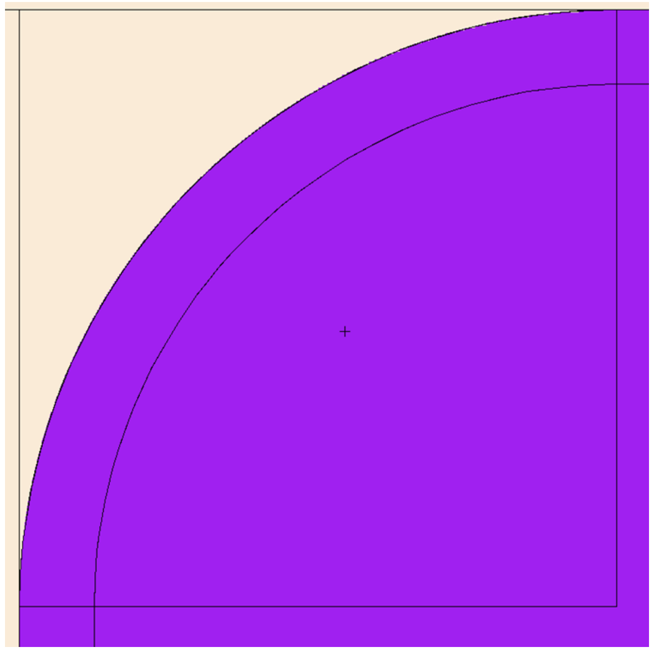
Detailed Model – PANN Plate

Edge Rounding

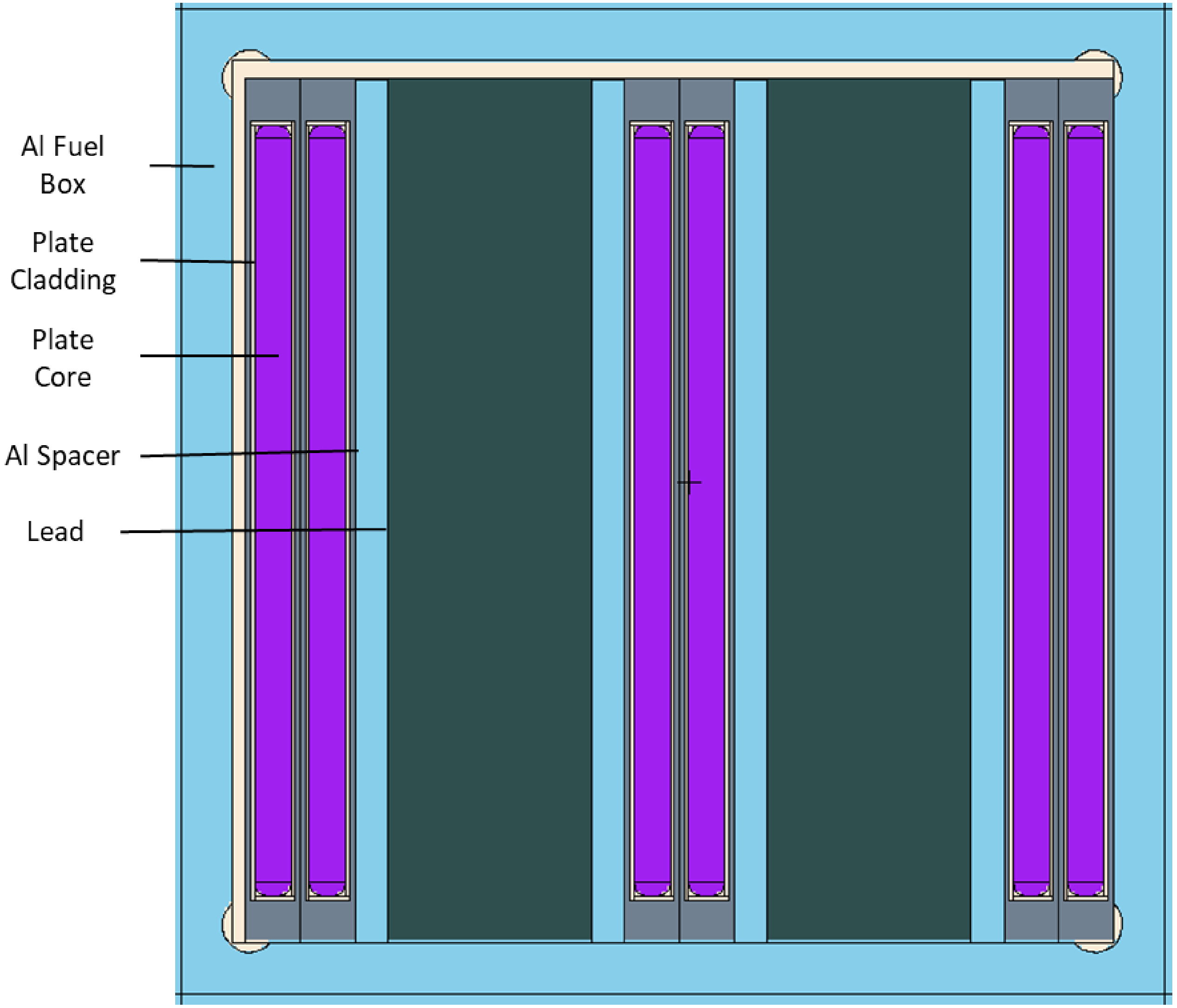




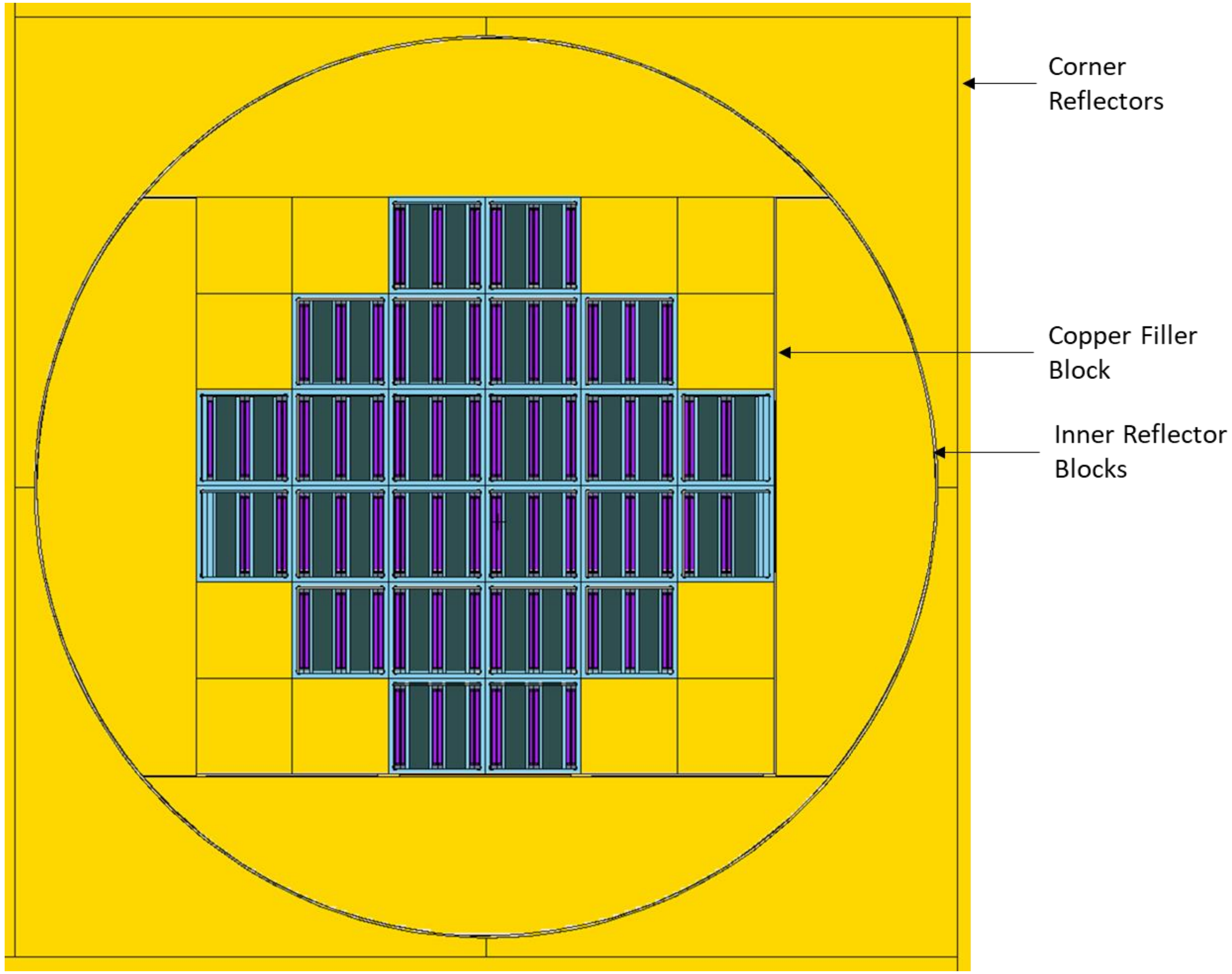
Corner Rounding

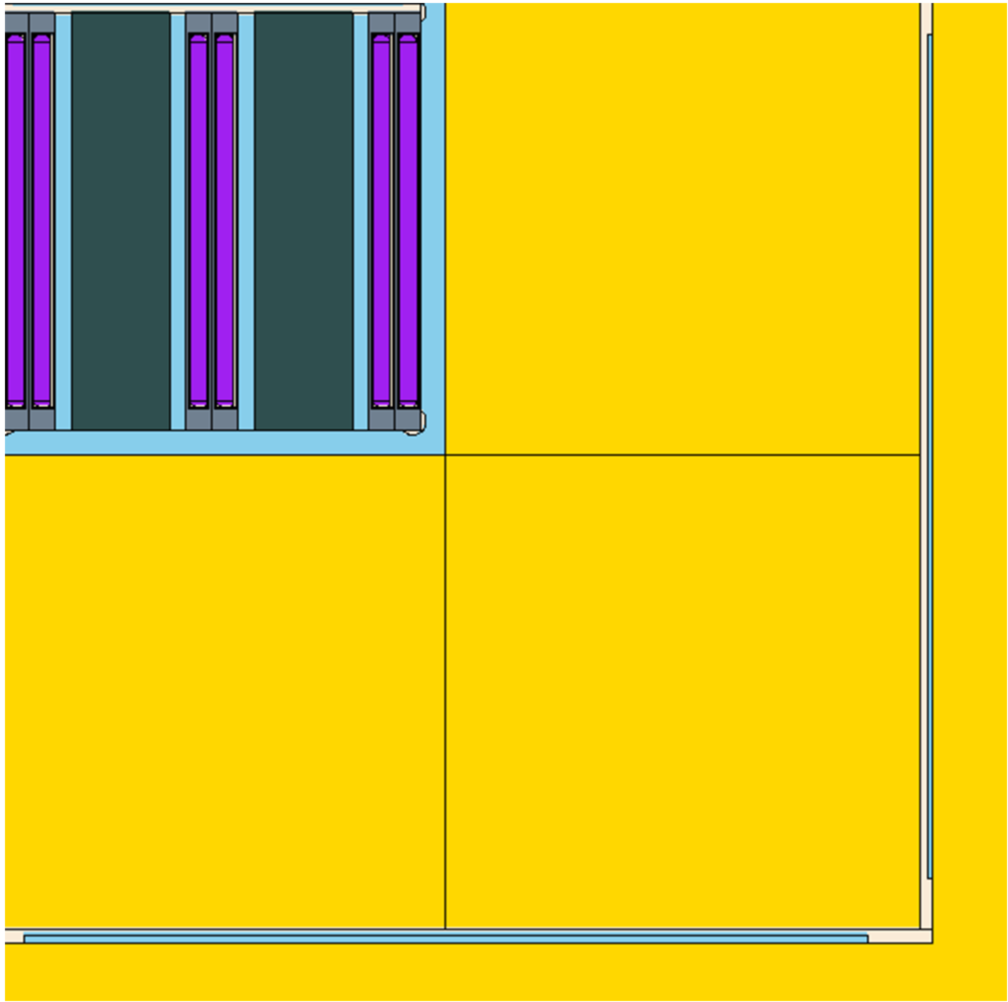


Detailed Model – Fuel Container

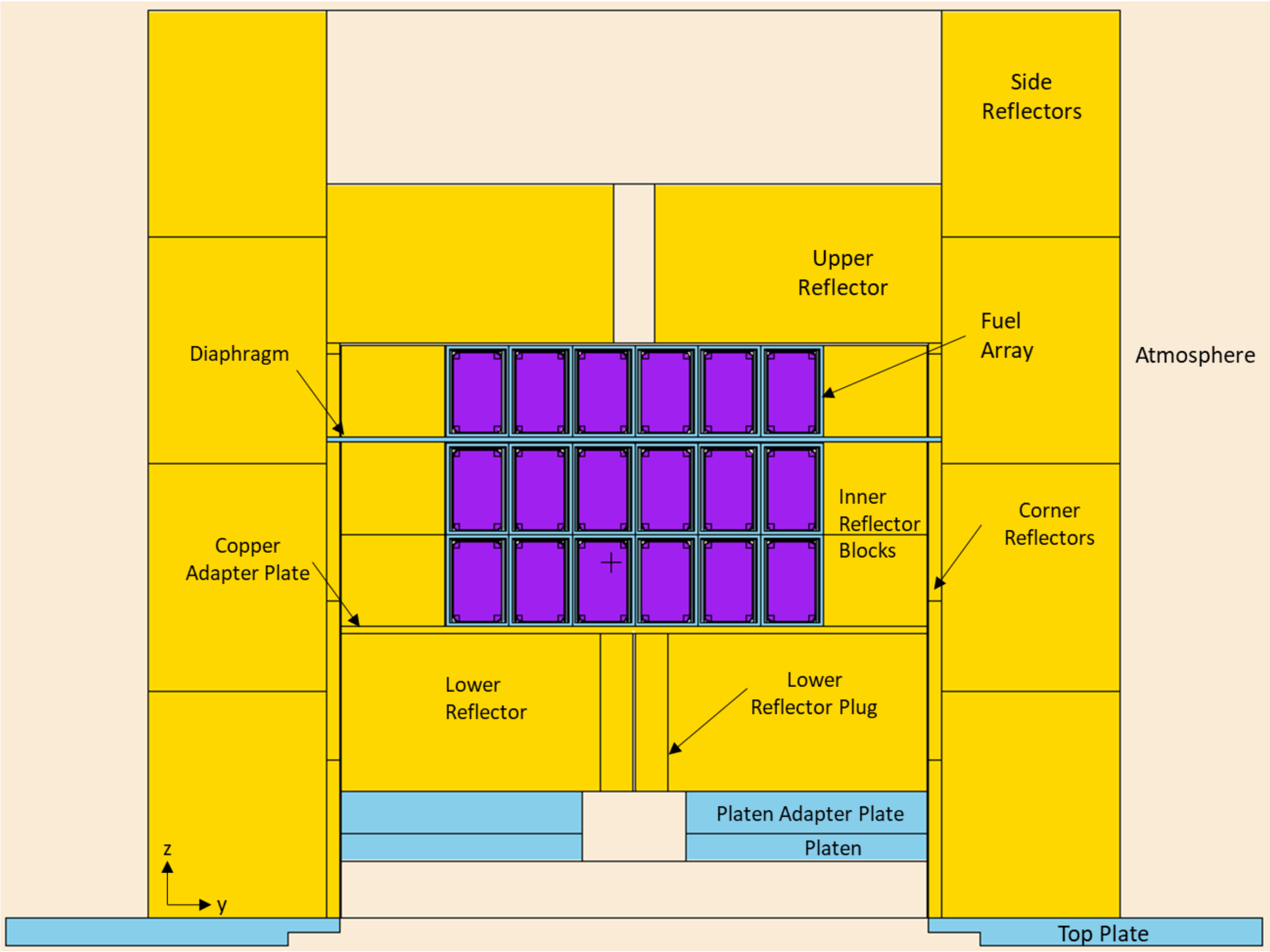


Detailed Model – Array





Detailed Model – Full Assembly



Current Progress

- Some sections under review
  - Experiment Description, Description of Model
- Others in progress
  - Sensitivity and Uncertainty Analysis, Results of Sample Calculation
- Benchmark will also have JENDL, JEFF results

Preliminary

Code (Cross Section Set) →	MCNP6.2 (Continuous-Energy ENDF/B-VIII.0)			MCNP6.2 (Continuous-Energy ENDF/B-VII.1)		
Case ↓	K_{eff}	σ	C-E (pcm)	k_{eff}	σ	C-E (pcm)
Reference	0.99717	± 0.00001	-355	1.00300	± 0.00001	228
A1	0.99690	± 0.00001	-360	1.00273	± 0.00001	223
A12	0.99659	± 0.00001	-365	1.00239	± 0.00001	215

Sensitivity and Uncertainty Analysis

- Partially complete
- Preliminary sample of calculations follow
  - Not an exhaustive list
- Except for mass and composition, calculated through perturbations
  - Mass and composition calculations used KSEN adjoint-based sensitivity
    - Gives sensitivity coefficients S_{k,N_j} of k_{eff} to atom density N_j of nuclide j
    - Used to calculate the sensitivity and uncertainty of the system k_{eff} to the mass or composition of certain components
    - Based on the paper by Jeff Favorite et al.

Parameter	Parameter Uncertainty	$S_{k,\rho}$	Δk_{eff}
Lead Mass	28.09 g (~0.03%)	0.04013	0.00001
Aluminum Fuel Box Mass	13.94 g (~0.19%)	0.02561	0.00005
Aluminum Spacer Mas	55.47 g (~0.86%)	1.895E-4	<0.00001

Conclusion

- The Jupiter experiment has already provided useful data regarding lead void reactivity worth, and a benchmark would help address nuclear data validation deficiencies for this material
- Benchmark is well underway, and will be ready for 2020 ICSBEP meeting
  - Same time as HEU (HMF-102) and IEU (MMF-016) experiment benchmarks

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