IER-523: Design of a UO$_2$-BeO Critical Experiment at Sandia

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Hosted by Sandia National Laboratories

Sandia National Laboratories

Background


Annular Core Research Reactor (ACRR)

- Water-moderated pool-type research reactor

- Uranium dioxide-beryllium oxide (UO_2-BeO) fuel

- Enrichment: 35 wt%

- 21.5 wt% UO_2 – 78.5 wt% BeO

- Density (UO_2-BeO) ~3.4 g/cm^3

- Significant amounts of unused fuel
  - Elements (~25 elements and 2.8 kg ^{235}U total)*
  - Loose pellets (~2 kg ^{235}U)

- Data from historical records (fuel composition and geometry)

Background

Fuel element

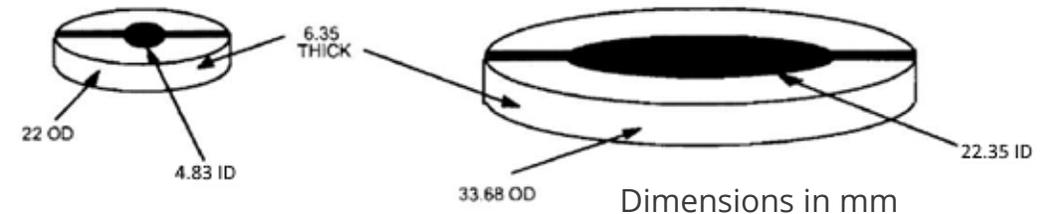
UO$_2$BeO fuel pellets
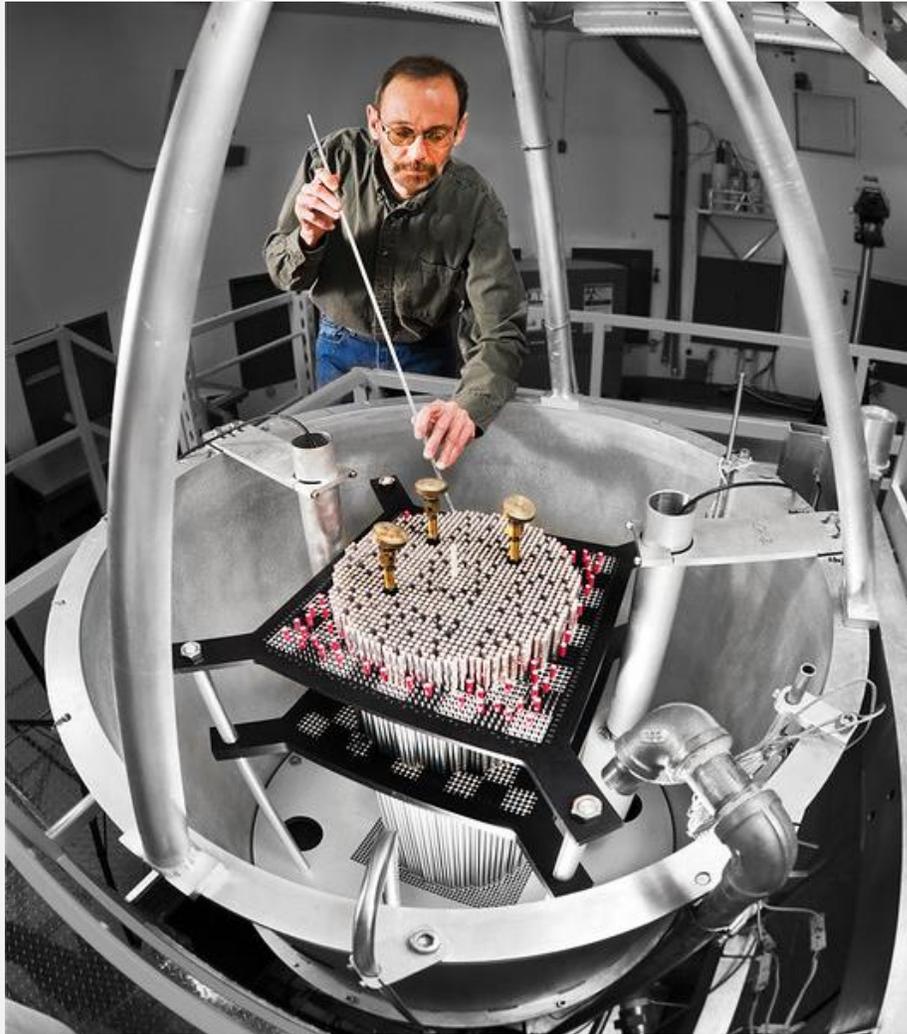
Niobium Cups
Stacked Fuel
Cladding

Outer   Inner
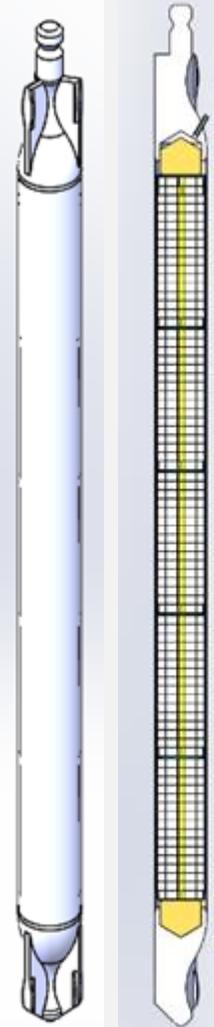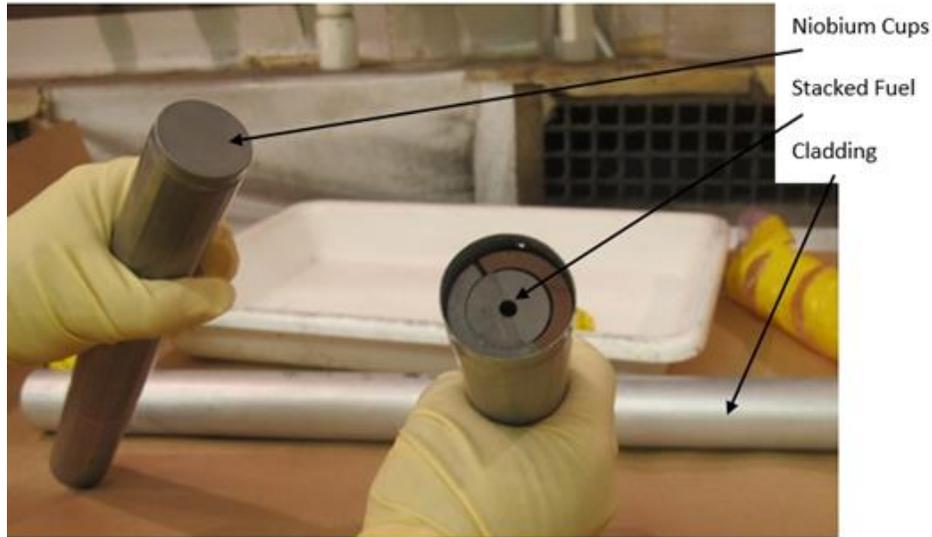
ACRR fuel element

- Stainless-steel cladding
  - OD~3.75 cm
  - L~54.5 cm
- Trifluted end fittings
- 5 niobium insulation cups
- 4 fuel pellet pieces formed into a disk and stacked in niobium cups

UO$_2$-BeO fuel pellets

6.35 THICK
22 OD
4.83 ID
22.35 ID
33.68 OD
Dimensions in mm

Background

Sandia Critical Experiments (SCX)

- 7uPCX

- Enrichment: 6.9 wt%

- 2175 fuel rods
  - OD ~0.6 cm
  - Fueled length ~48.8 cm

- Approach-to-critical experiments
  - Number of fuel rods and water height
  - Six critical benchmark evaluations (ICSBEP)

- Flexibility in design
  - Authorization Basis allows modifications to accommodate designs outside the current limits
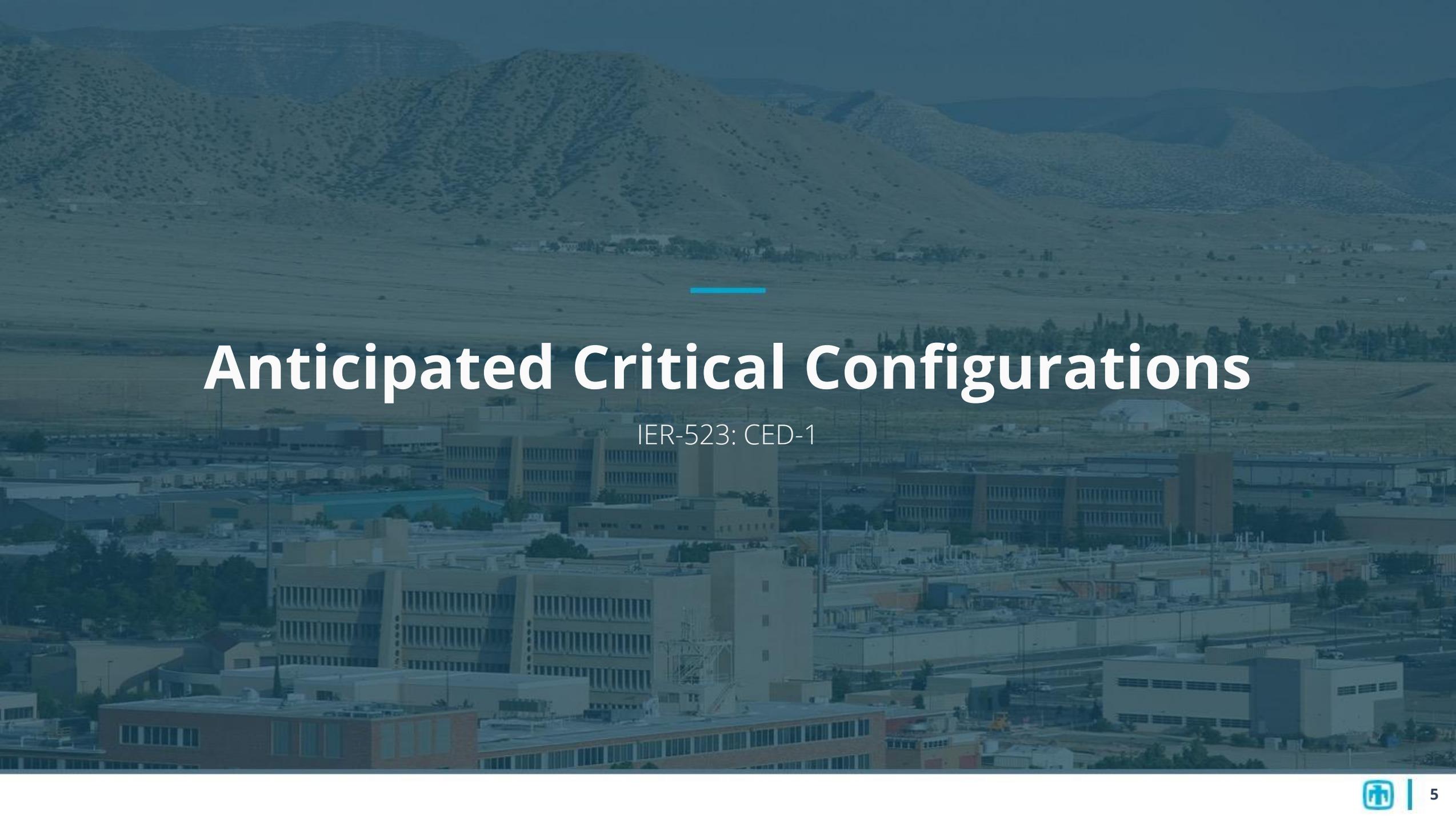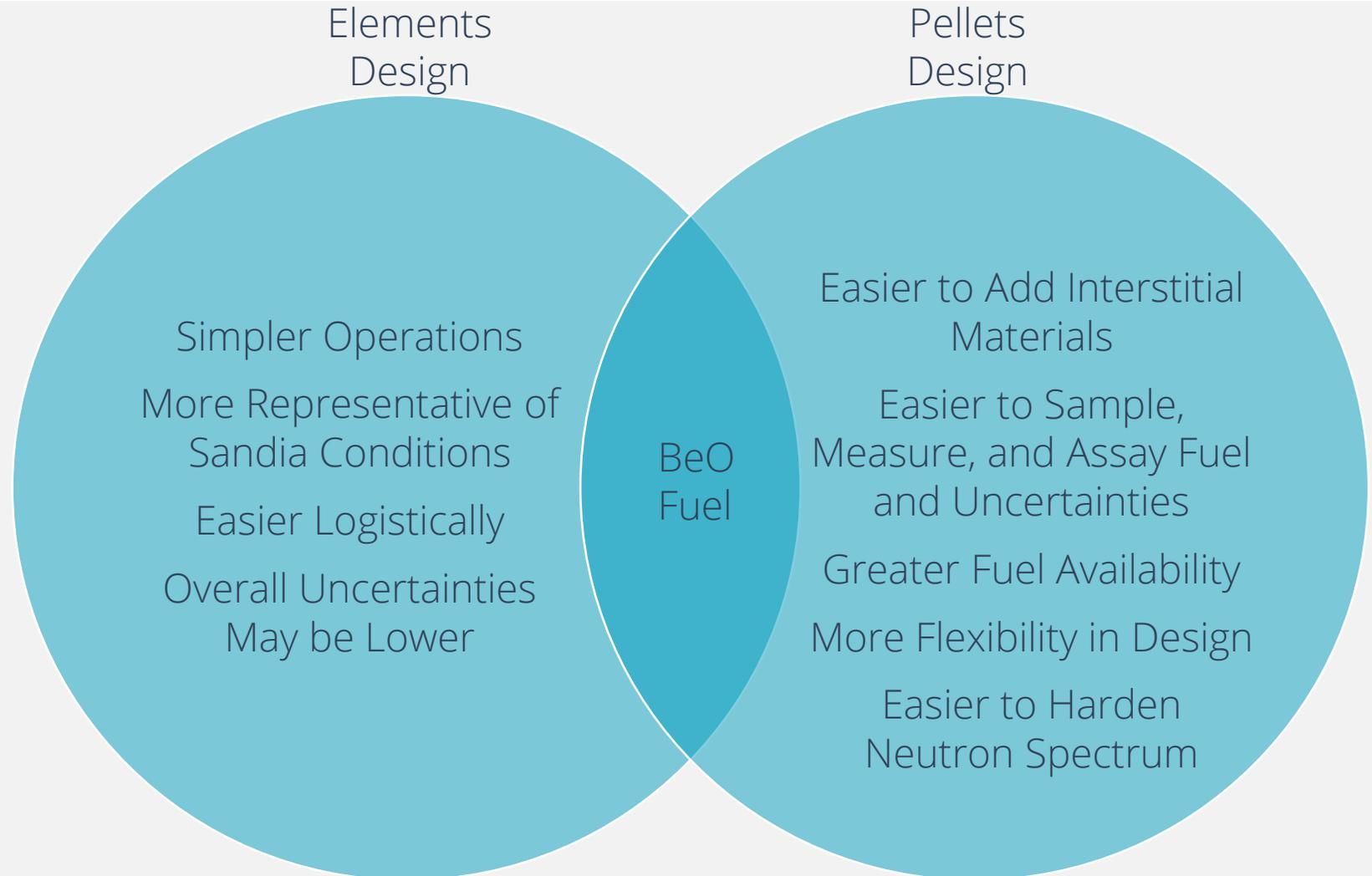
Anticipated Critical Configurations

IER-523: CED-1

Experiment Designs

- Both the loose BeO fuel pellets and the spare ACRR fuel elements were considered in CED-0

- In CED-1 phase, designs focused primarily on fuel element concepts
  - Pellet models (evolved from CED-0) are still presented and analyzed in CED-1 as prospective alternatives

Elements Design

Pellets Design

Simpler Operations

More Representative of Sandia Conditions

Easier Logistically

Overall Uncertainties May be Lower

BeO Fuel

Easier to Add Interstitial Materials

Easier to Sample, Measure, and Assay Fuel and Uncertainties

Greater Fuel Availability

More Flexibility in Design

Easier to Harden Neutron Spectrum

Experiment Design – Element Models

Element Models

- Central test region containing 7 or 19 BeO fuel elements

- Driver region = 7uPCX fuel rods
  - Tight-packed (hex pitch = 0.86 cm)
  - Loose-packed (hex pitch = 1.72 cm)

- Fully reflected and water moderated

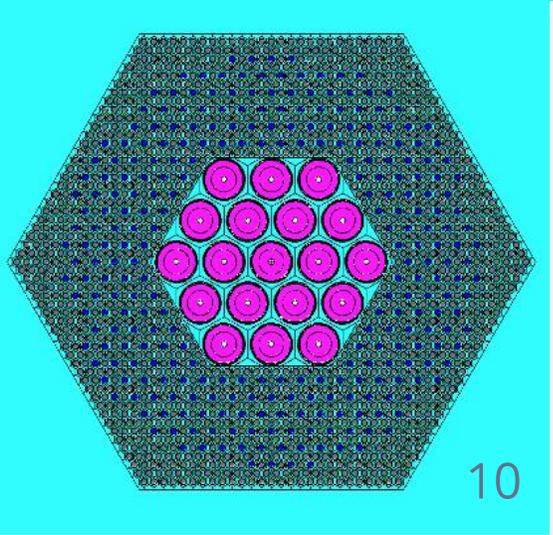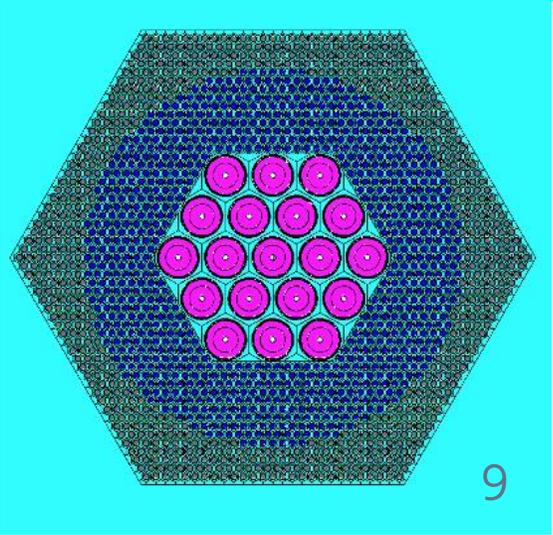- Additional moderator/reflector configurations
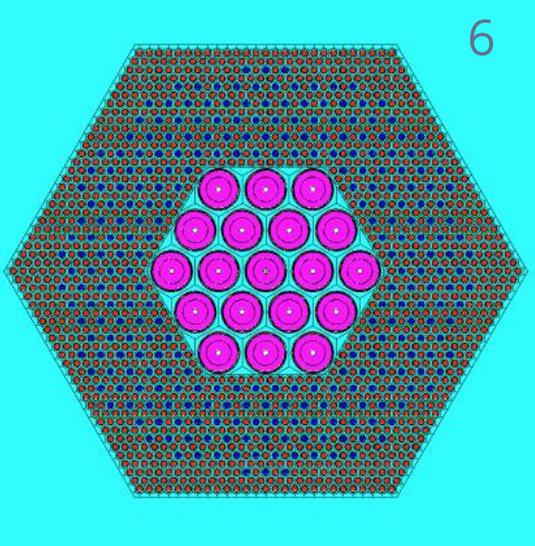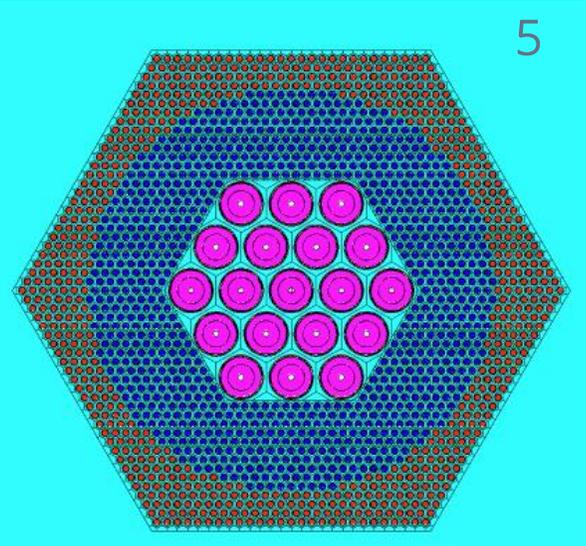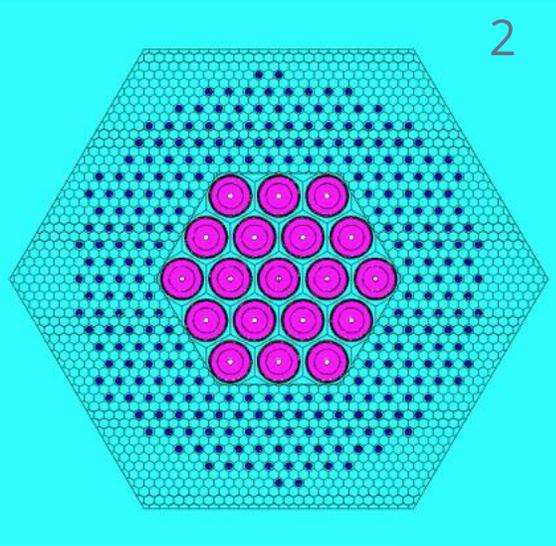 - Be metal rods
  - BeO rods

7uPCX

1

BeO Fuel Element
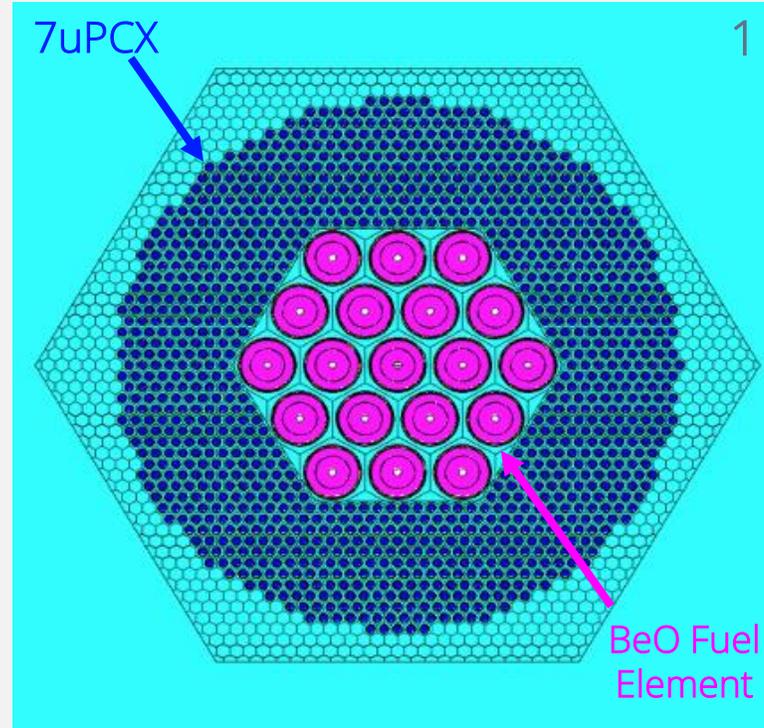
Top Cross Section View
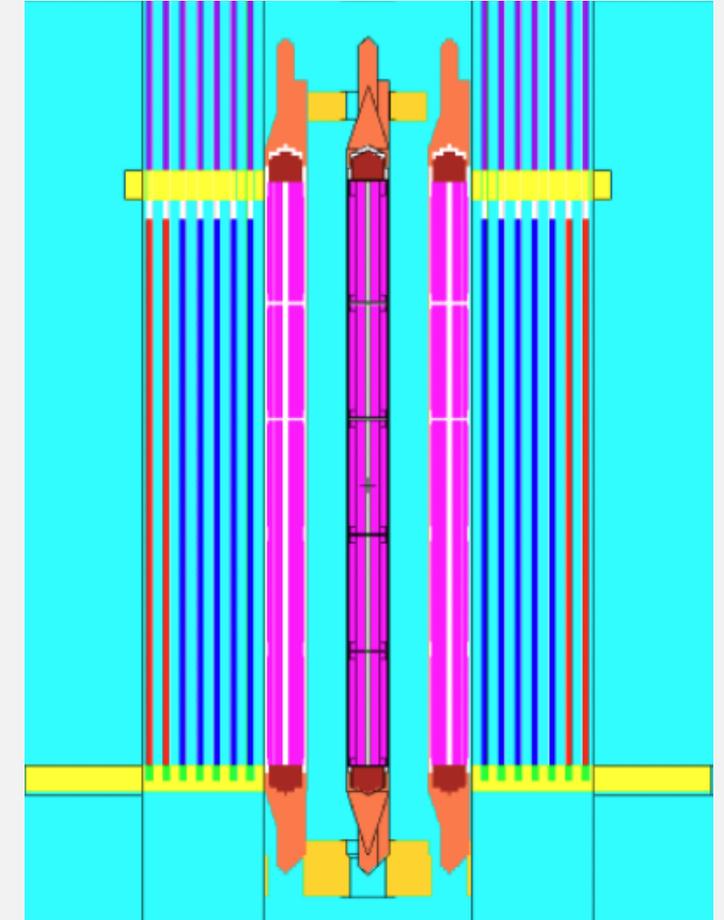
Side Cross Section View

Experiment Design – 19 BeO Element Configurations

Be Metal Rod

BeO Rod

Radial Cross Section View

Experiment Design – 7 BeO Element Configurations
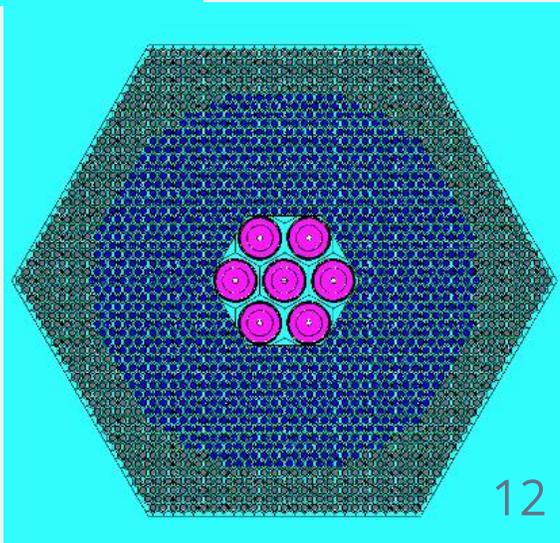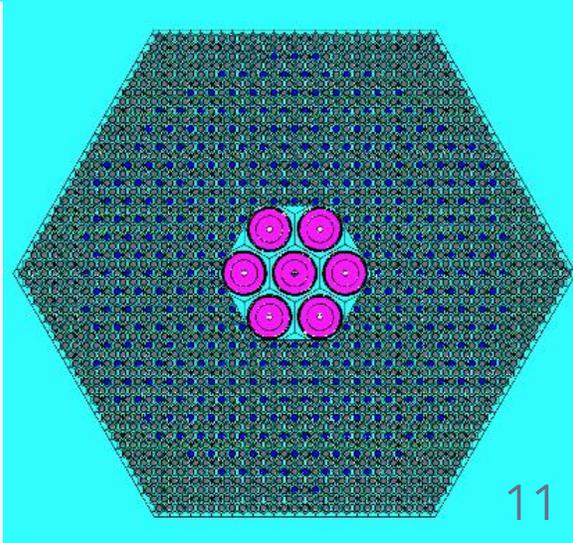
- ● Be Metal Rod
- ● BeO Rod

Radial Cross Section View

Experiment Design – Element Models Summary

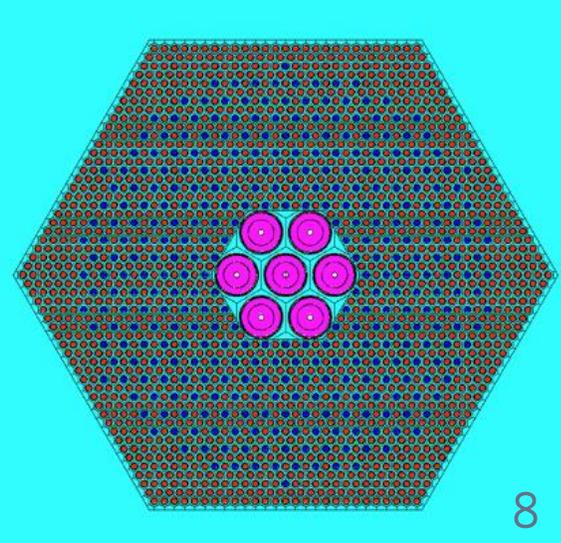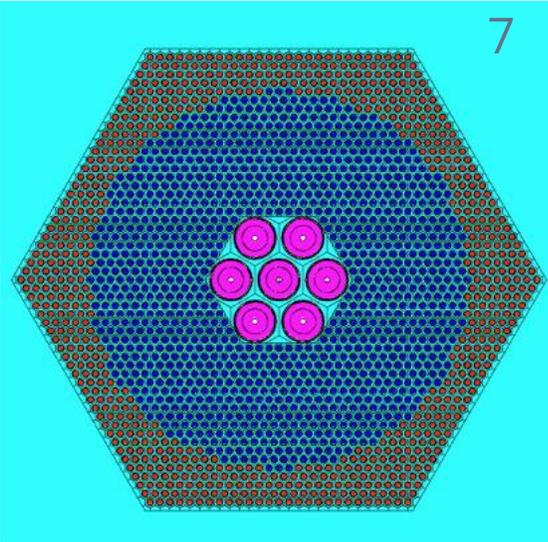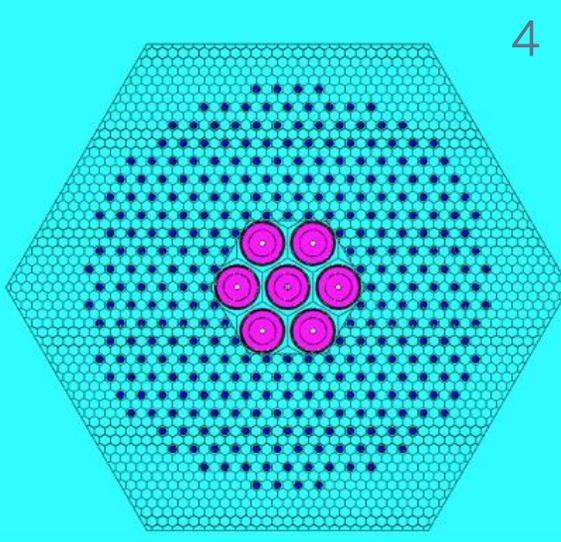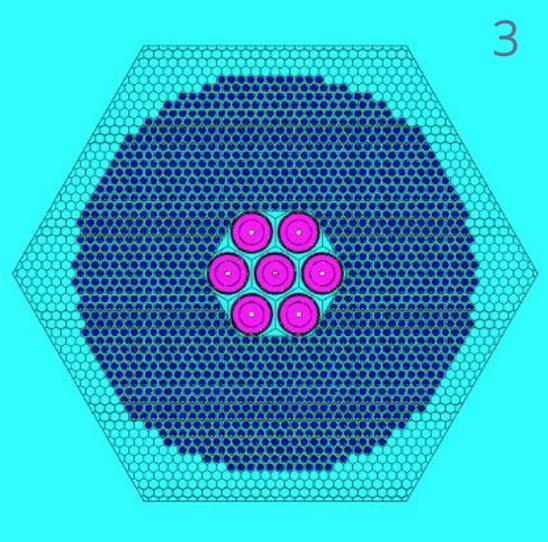| Config. #	# of 7uPCX	7uPCX Pitch (cm)	# of BeO Fuel	Ref. Rods	Mod. Rods	k-eff	Std. Dev.	EANLF (MeV)	3-Group Fission Fractions		
									<0.625 eV	0.625 eV - 100 keV	>100 keV
1	1129	0.86	19	None	None	1.0004	0.0007	3.64E-07	78%	17%	5%
2	264	1.72	19	None	None	0.9994	0.0006	9.03E-08	91%	8%	2%
3	1368	0.86	7	None	None	0.9992	0.0007	4.37E-07	77%	17%	6%
4	313	1.72	7	None	None	0.9996	0.0006	7.48E-08	93%	6%	2%
5	925	0.86	19	Be	None	1.0001	0.0007	3.52E-07	79%	17%	5%
6	284	1.72	19	Be	Be	1.0002	0.0007	1.13E-07	88%	10%	2%
7	1154	0.86	7	Be	None	0.9992	0.0007	4.31E-07	77%	17%	6%
8	347	1.72	7	Be	Be	0.9999	0.0006	9.46E-08	90%	8%	2%
9	900	0.86	19	BeO	None	0.9993	0.0007	3.51E-07	79%	17%	5%
10	288	1.72	19	BeO	BeO	0.9986	0.0007	1.14E-07	88%	10%	2%
11	1134	0.86	7	BeO	None	0.9998	0.0007	4.33E-07	77%	17%	6%
12	357	1.72	7	BeO	BeO	0.9993	0.0007	9.58E-08	90%	8%	2%

Alternative Design – Loose Pellet Models

- Central test region containing pellets in stacked cassettes
  - Each cassette is 5x5 array of cells
  - Cells are filled by sets of pellet pieces
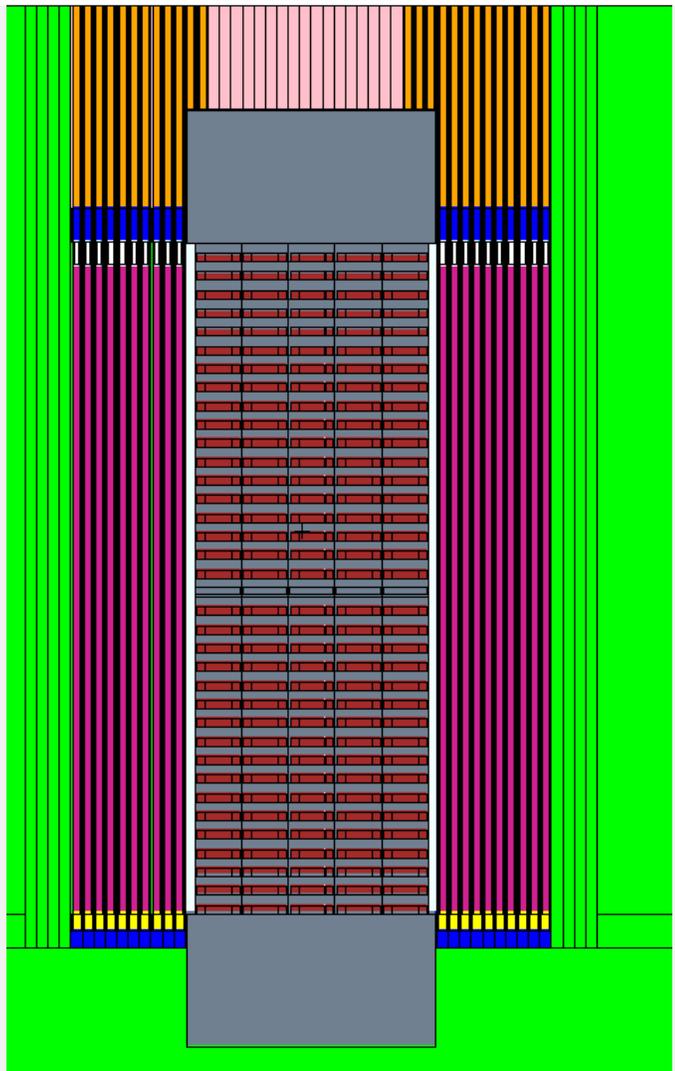- Many designs considered
  - Four presented in following slides

≥ 1289 available

≥ 3795 available

Experiment Design – UO₂BeO Pellet Variations

Legend:
- BeO Fuel (UO2-BeO)
- 7uP Fuel (UO2)
- Water
- Polyethylene (CH2)
- 6061 Aluminum
- 3003 Aluminum
- Air
- Void
- Beryllium Oxide
- AlBeMet

Baseline Pellet Model – Most Similar to CED-0

AlBeMet Tray Model

Experiment Design – UO$_2$BeO Pellet Variations
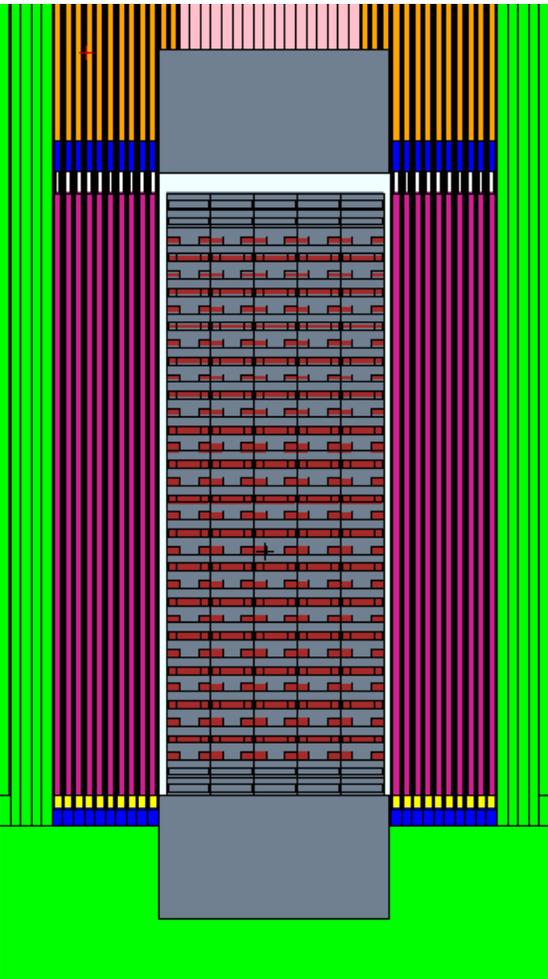
Offset Model
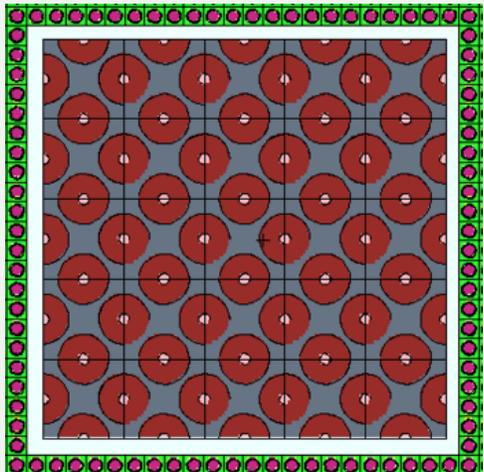
Legend:
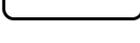
- BeO Fuel (UO2-BeO)
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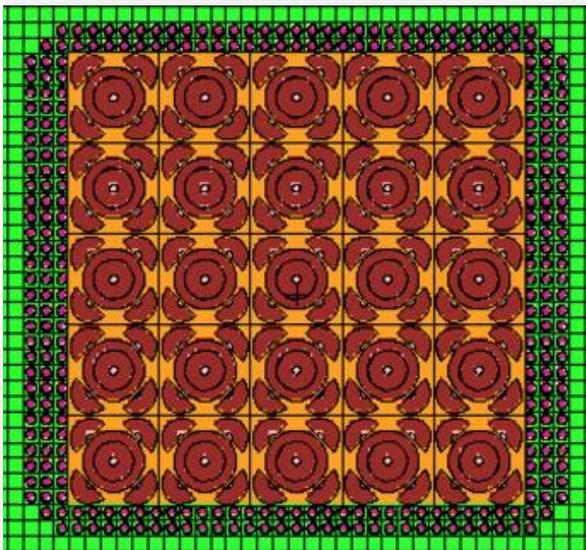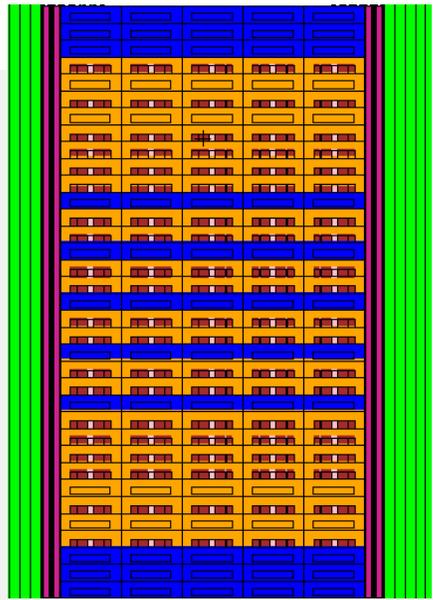
Poly-Al-X Model

Experiment Design – Element Models Summary

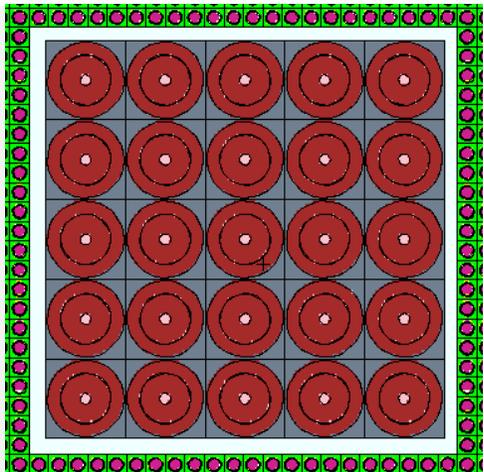| Config.	# of 7uPCX	# of Half Disk	# of Crescent Moon	Averaged Enrichment	k-eff	EANLF (MeV)	3-Group Fission Fractions		
#							<0.625 eV	0.625 eV - 100 keV	>100 keV
BaselineP	1280	1750	1750	7.60%	1.002	3.02E-07	80%	15%	5%
AlBeMet	1280	1750	1750	7.60%	0.998	3.01E-07	80%	15%	5%
Offset	1280	2350	750	7.47%	1.001	2.97E-07	80%	15%	5%
Poly-Al-X	298	3000	1000	9.80%	1.006	7.49E-08	93%	6%	2%
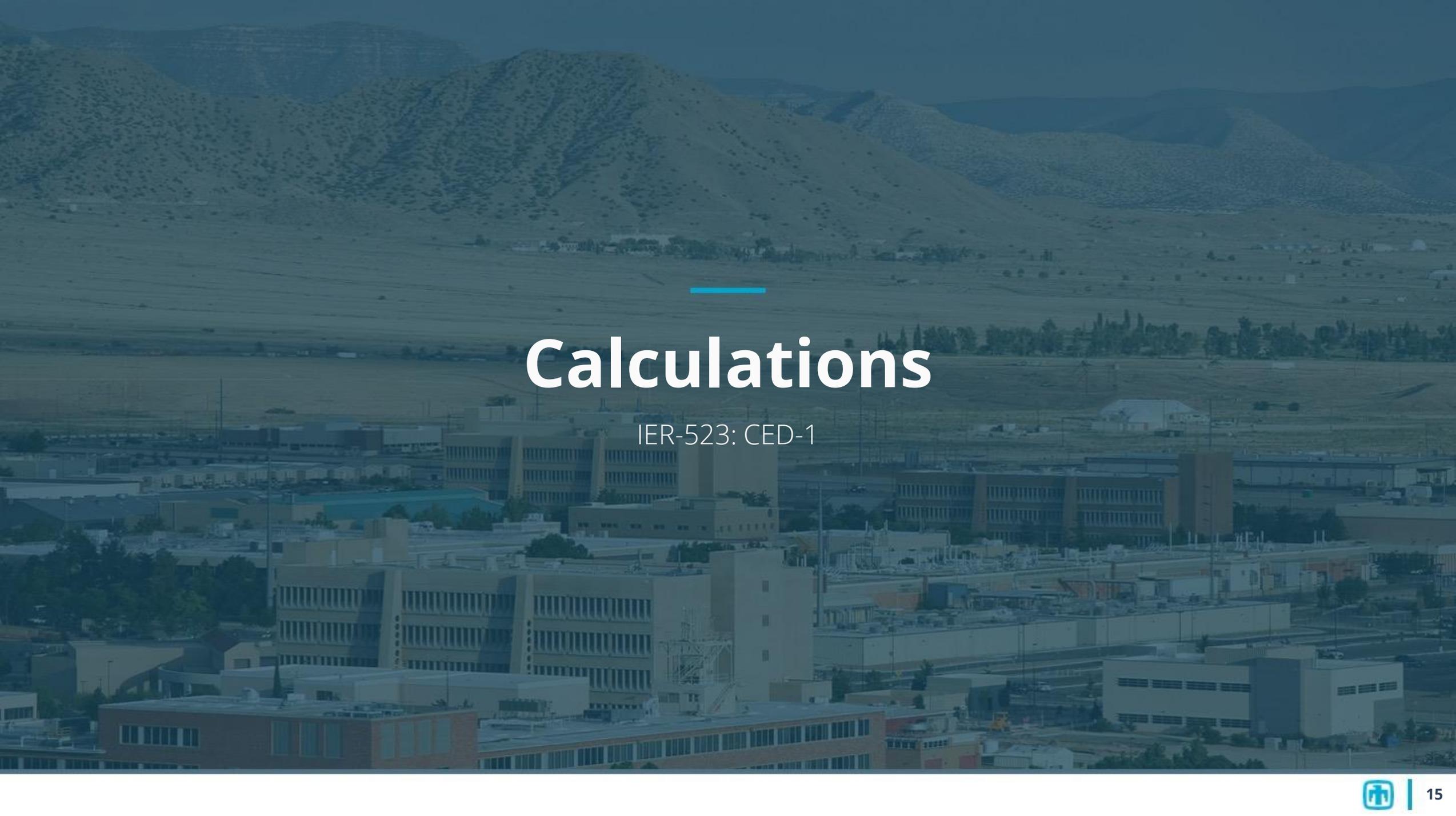
Calculations

IER-523: CED-1

Sensitivity Analysis

- Sensitivities $[(\Delta k/k)/(\Delta\sigma/\sigma)]$ computed for:
  - Various reactions
    - "Total Beryllium" Reaction is sum of ^{9}Be elastic, inelastic, (n,2n), (n,γ), & (n,α); be-o elastic, be-o inelastic, o-be elastic, and o-be inelastic; and be elastic and inelastic, as applicable
  - In energy 44-groups
  - For 12 Element Configurations,
  - 4 Pellet Configurations,
  - And selected existing Be benchmark models available at Sandia
    - HEU-COMP-INTER-003: UH$_3$ powder reflected with beryllium
   - HEU-MET-INTER-009 and HEU-MET-THERM-027: BeO Bricks with HEU foils ("Spade" Experiments)

| Configuration Identifier	3-Group Be Reaction Sensitivity		
	<0.625 eV	0.625 eV - 100 keV	>100 keV
EC (Element Conf.) 1	8.15E-03	1.81E-02	1.05E-01
EC 2	-2.19E-03	2.28E-03	9.43E-02
EC 3	9.81E-03	7.59E-03	3.25E-02
EC 4	3.51E-03	3.98E-03	4.53E-02
EC 5	-2.28E-02	2.66E-02	1.70E-01
EC 6	2.13E-02	4.46E-02	3.07E-01
EC 7	-1.66E-02	2.44E-02	1.35E-01
EC 8	-1.25E-02	4.57E-02	2.81E-01
EC 9	-6.79E-03	1.61E-02	1.54E-01
EC 10	-3.91E-03	4.17E-02	2.14E-01
EC 11	8.72E-04	1.32E-02	9.35E-02
EC 12	1.28E-02	3.04E-02	1.97E-01
BaselineP	-2.02E-02	3.95E-02	8.39E-02
AlBeMet	1.43E-02	2.40E-02	6.92E-02
Offset	2.06E-02	3.89E-02	7.30E-02
Poly-Al-X	1.02E-02	5.11E-03	7.36E-02
HCI-003-002	-1.89E-03	3.02E-02	2.29E-01
HCI-003-005	6.60E-04	3.30E-02	2.38E-01
HMI-009-001	1.74E-02	3.38E-01	6.21E-01
HMT-027-001	1.35E-01	5.96E-01	6.56E-01
HMT-027-005	3.26E-01	6.68E-01	6.19E-01

Sensitivity Analysis – Beryllium Reactions
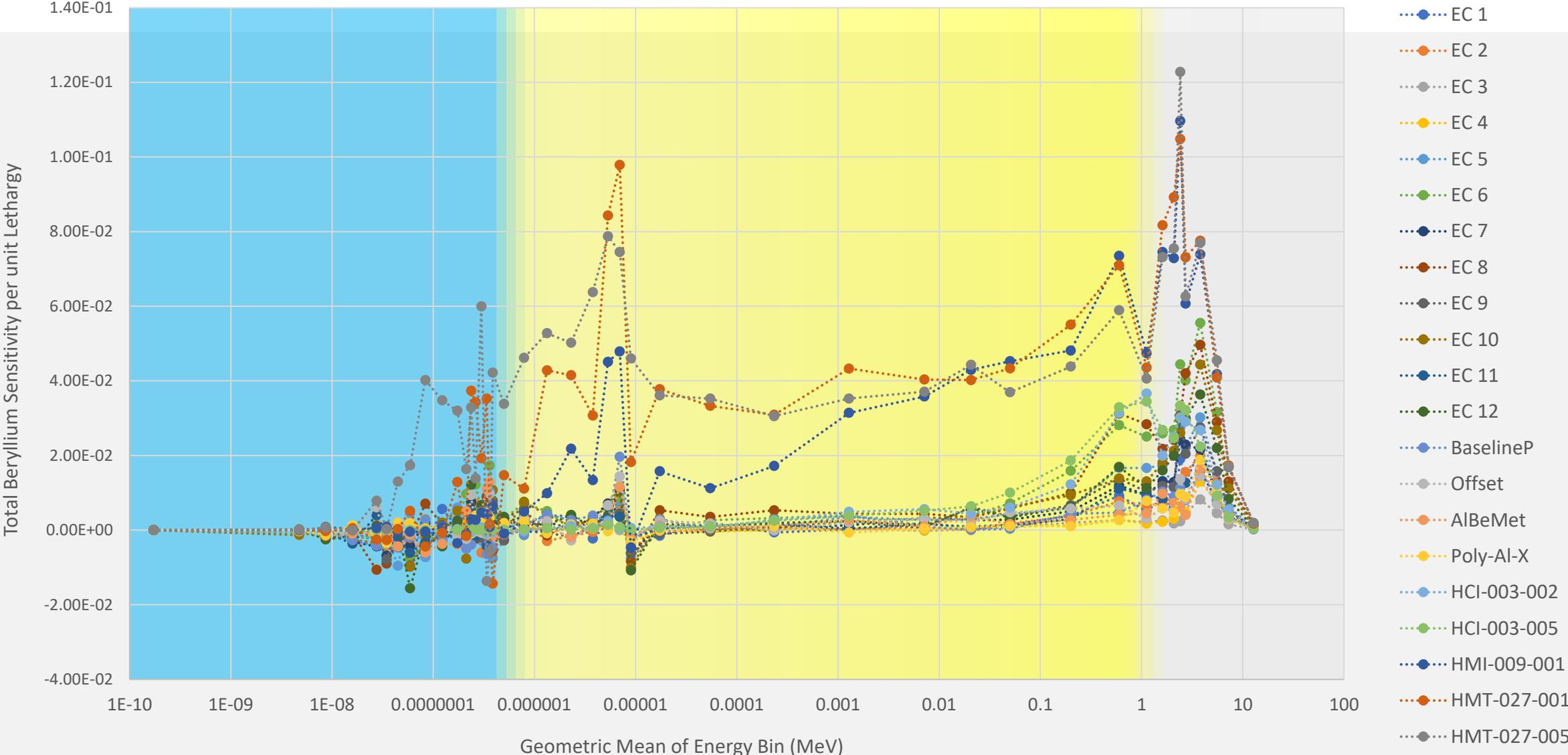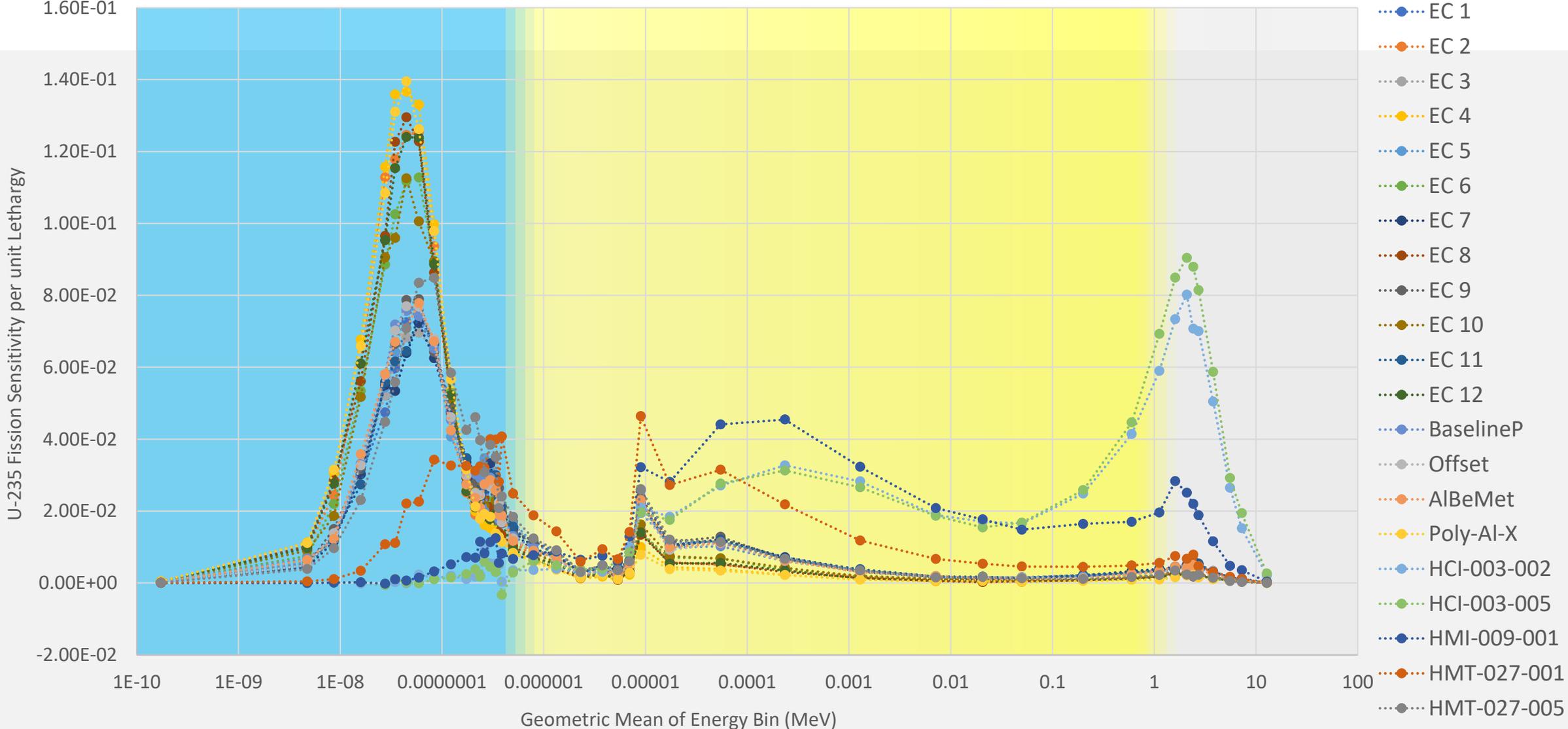
Sensitivity Analysis – Beryllium Reactions
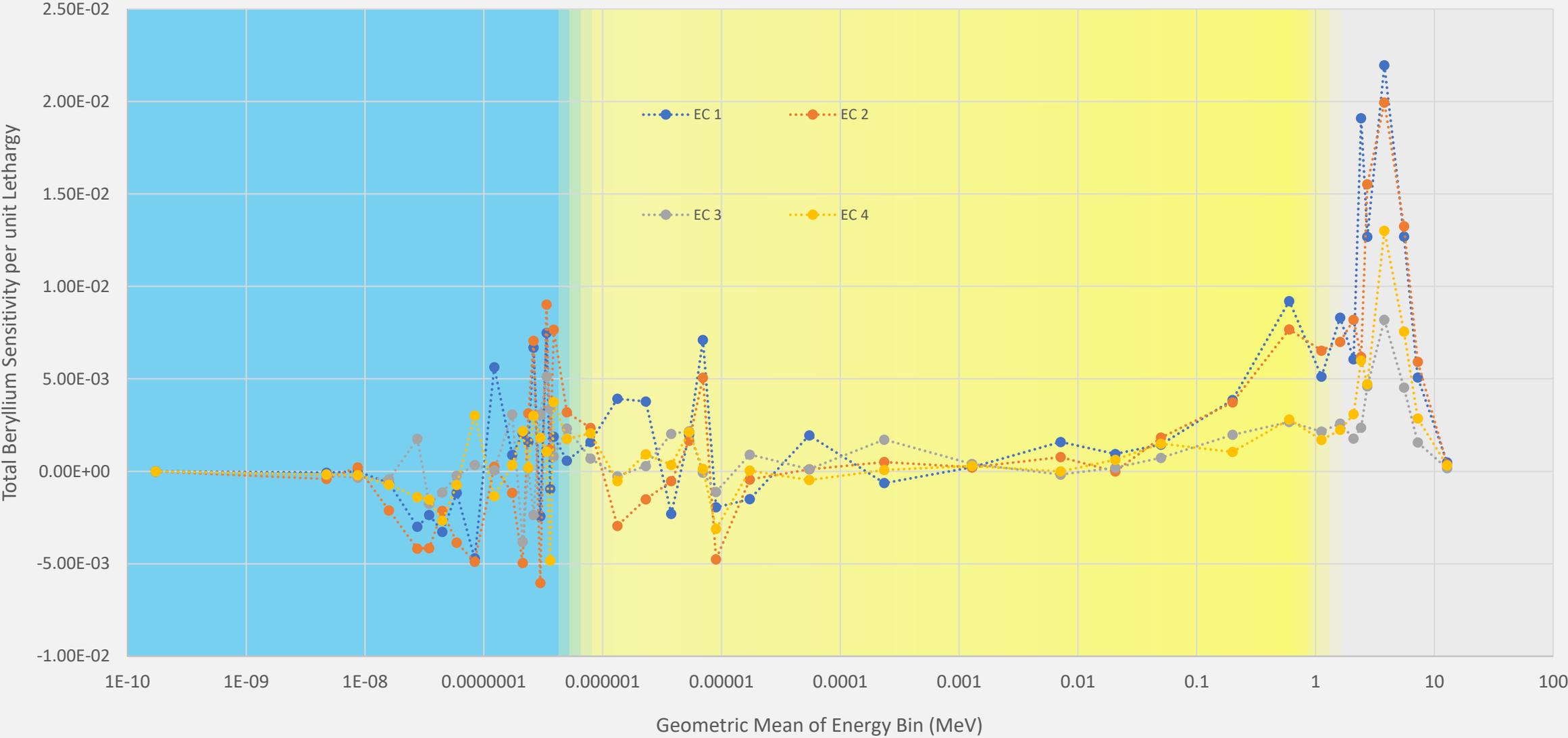
Sensitivity Analysis – Beryllium Reactions
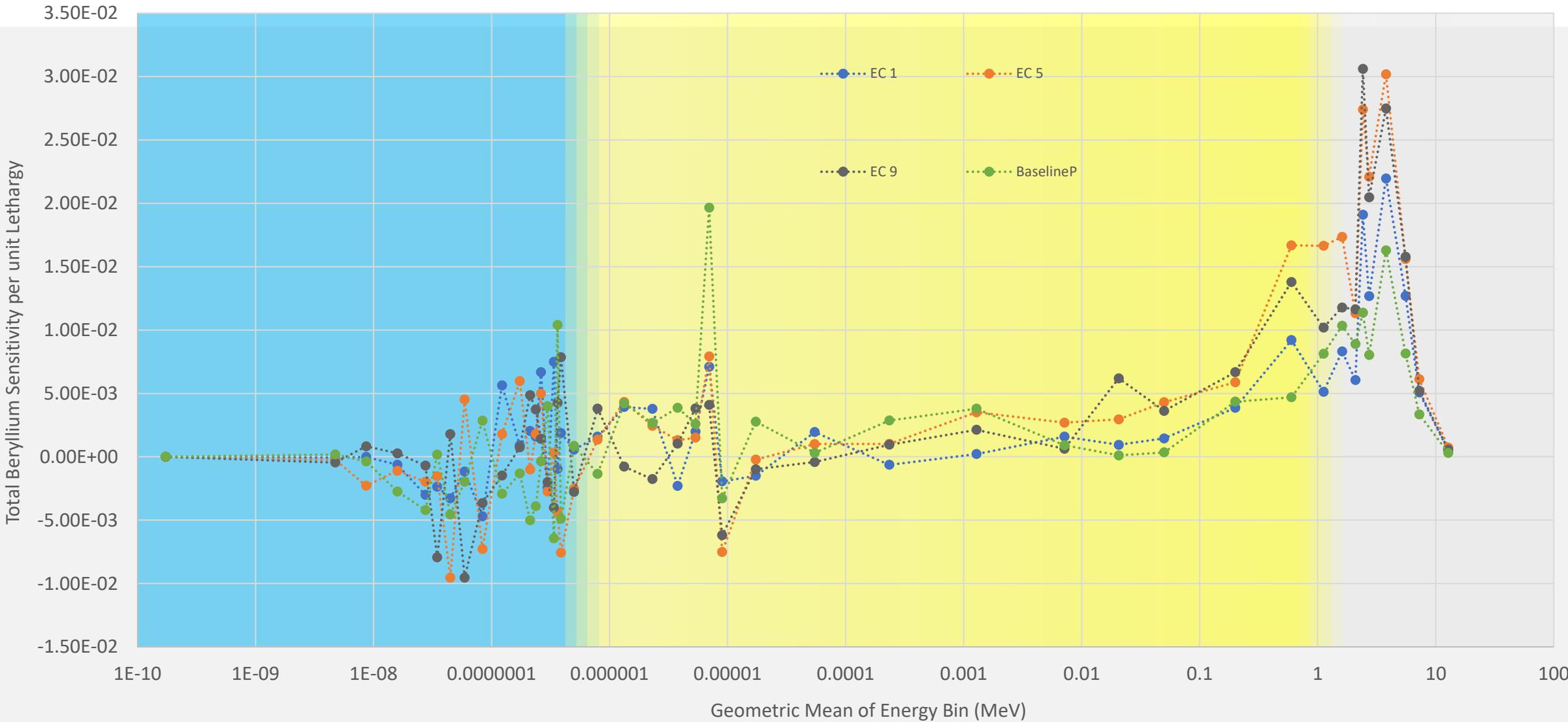
Sensitivity Analysis – BeO Thermal Scattering (be/o + o/be)
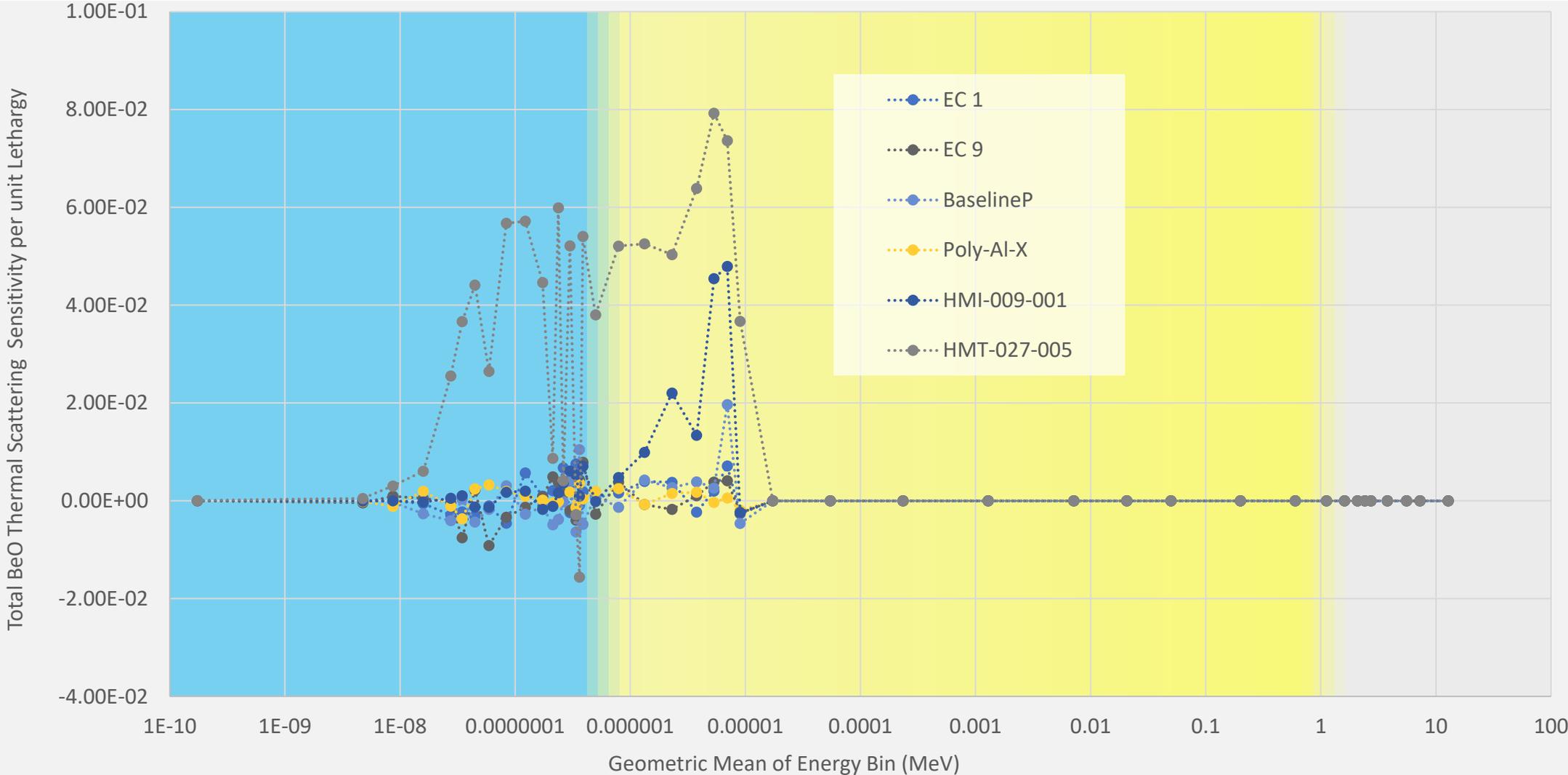
Sensitivity Analysis – ^{235}U Fission

Ability/Benefits to Perform work

- Engage New Management for Support
  - BeO material is available
  - Operations staff knowledgeable/available
  - Ongoing fuel health campaign
- Unique fuel offers NCS useful data
  - Beryllium
  - Beryllium-oxide
  - ^{235}U enrichment in 7%-35% range
- Supports Nuclear Deterrence (ND) mission
- Documented Safety Analysis (DSA) Update is Straightforward
  - 7uPCX is driver fuel in designs and UO_2-BeO is considered experimental material
  - DSA enrichment limit is based on a UO_2 fuel limit that is not challenged by UO_2-BeO fuel

Conclusions

- ACRR fuel element experimental design for continued work
  - 7 ACRR elements
  - 7uPCX driver rods
- Beneficial data for
  - NCS community
  - ND community
- Support to perform work
  - Management
  - Operations
- Potential for multiple experiments
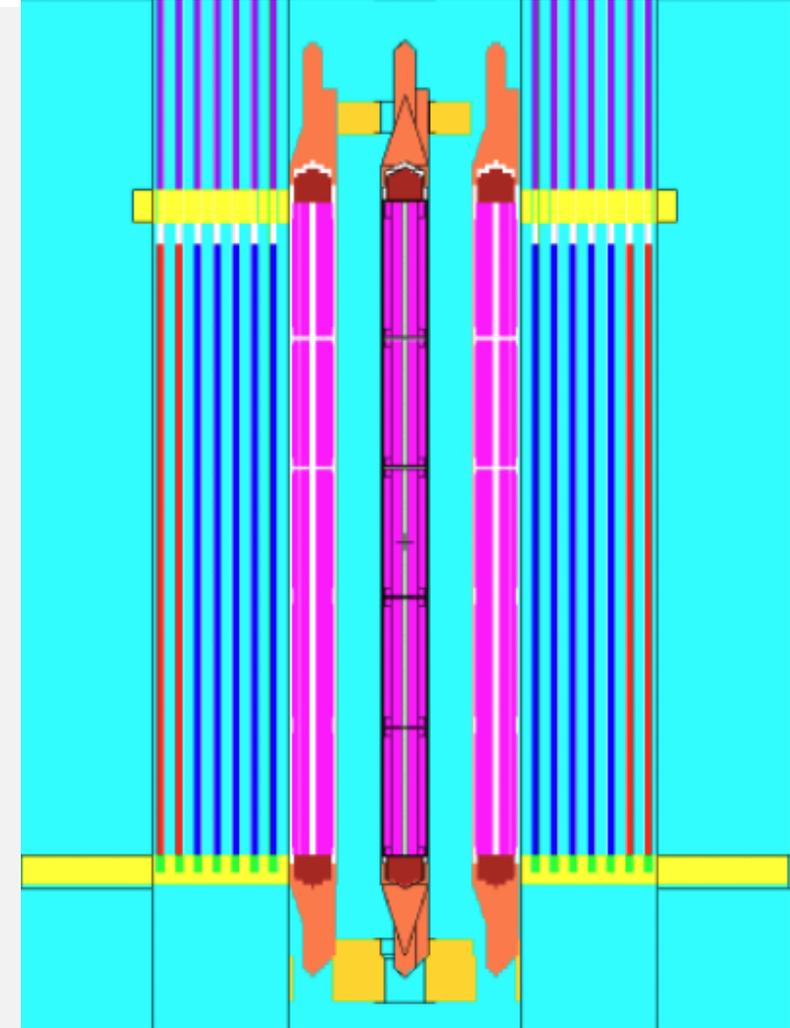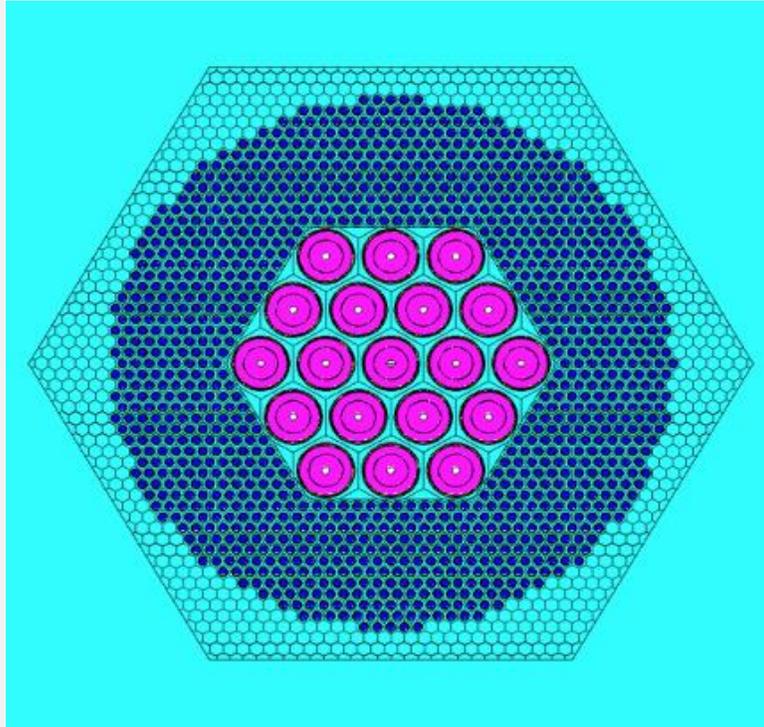
Acknowledgements

This work was supported/funded through the DOE-NCSP and NNSA

Thanks to the many contributors of this study

Thank you.

Questions?

Elements Models -Critical Configuration Analysis

Changes to Critical Configuration	Replace BeO fueled region with void	Replace BeO fuel elements with void	Replace BeO fuel elements with aluminum	Replace BeO fuel elements with water	Replace BeO fuel elements with 7uPCX rods
Configuration 1 Reactivity Worth	-13.5181 ± -0.0948	-10.3075 ± -0.0979	-16.1149 ± -0.1017	-16.2319 ± -0.0977	1.2834 ± 0.1011
Configuration 2 Reactivity Worth	-24.2625 ± -0.0824	-20.7613 ± -0.0839	-26.561 ± -0.0900	-26.542 ± -0.0852	2.9149 ± 0.0871
Configuration 3 Reactivity Worth	-4.3836 ± -0.0945	-3.2337 ± -0.0985	-4.0093 ± -0.1027	-4.1024 ± -0.0992	0.7736 ± 0.0971
Configuration 4 Reactivity Worth	-8.8515 ± -0.0823	-6.9437 ± -0.0864	-9.7038 ± -0.0844	-9.6097 ± -0.0858	0.7643 ± 0.0849
Configuration 5 Reactivity Worth	-14.7035 ± -0.0964	-10.9869 ± -0.1001	-17.1763 ± -0.0972	-3.0607 ± -0.0984	1.5738 ± 0.0977
Configuration 6 Reactivity Worth	-25.0205 ± -0.0994	-20.6085 ± -0.0963	-27.411 ± -0.0941	1.0378 ± 0.0977	1.6266 ± 0.1054
Configuration 7 Reactivity Worth	-4.6148 ± -0.0893	-3.4198 ± -0.0892	-4.0263 ± -0.0935	-2.9815 ± -0.0956	0.8637 ± 0.0941
Configuration 8 Reactivity Worth	-8.7745 ± -0.0922	-6.7124 ± -0.0885	-9.4516 ± -0.0865	2.0391 ± 0.0870	0.4550 ± 0.0891
Configuration 9 Reactivity Worth	-14.7300 ± -0.0891	-11.1604 ± -0.0902	-13.0278 ± -0.0910	-3.3745 ± -0.0941	1.7113 ± 0.0978
Configuration 10 Reactivity Worth	-25.0673 ± -0.0991	-20.7851 ± -0.0992	-23.6253 ± -0.0952	1.5523 ± 0.0980	1.2238 ± 0.1000
Configuration 11 Reactivity Worth	-4.6198 ± -0.0984	-3.4316 ± -0.0928	-3.6237 ± -0.0915	-3.4636 ± -0.1005	0.7931 ± 0.0948
Configuration 12 Reactivity Worth	-8.7429 ± -0.0950	-6.7585 ± -0.0907	-7.8443 ± -0.0921	2.5517 ± 0.0899	0.1861 ± 0.0948