LLNL-PRES-748248

IER-329 CED-1: Preliminary Design for TEX with U-233 ZPPR Plates and High-Density Polyethylene

TEX-23

W. Zywiec, J. Norris, C. Percher, A. Nelson, S. Coleman, D. Heinrichs

Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory, P.O. Box 808, L-198, Livermore, CA 94551-0808

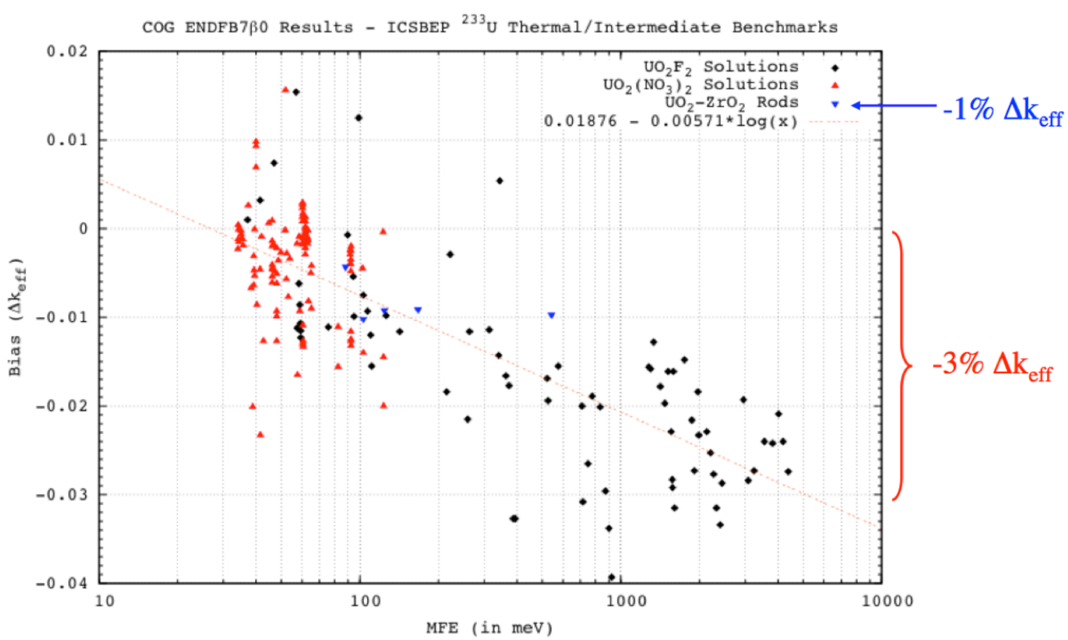
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

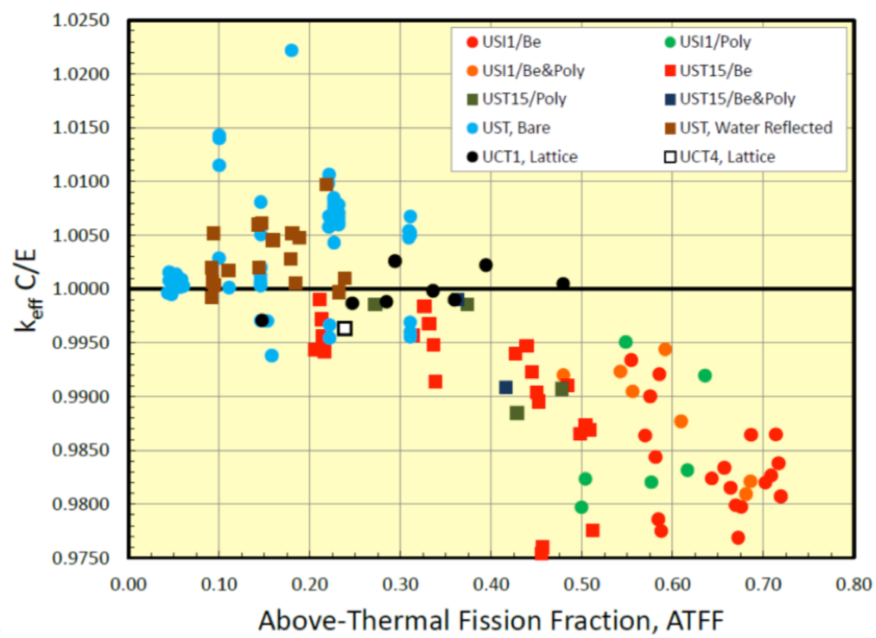
Thermal/Epithermal eXperiments (TEX) Overview

- **TEX Goals**
  - New critical experiments to address high priority nuclear data needs
  - Special emphasis on intermediate energy range
- **TEX Preliminary Design** (Sep 2012) IER-184 CED-1
  - Showed feasibility for three different fissile systems to create intermediate energy critical assemblies with various diluent materials
- **Addendum to CED-1** (Dec 2015) IER-297 CED-1
  - Determined optimal thickness of hafnium diluent for TEX-Hf using HEU Jemima plates moderated by polyethylene
- **TEX-Hf** (Jan 2018) IER-297 CED-2
  - 16 critical assemblies for benchmarking hafnium and U-235
- **TEX-23** (In Review) IER-329 CED-1
  - 13 critical assemblies for benchmarking U-233

TEX-23 Justification

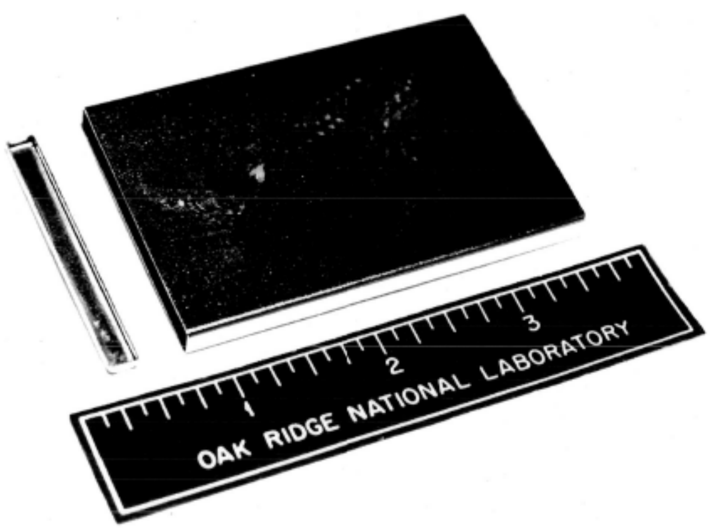
- COG and MCNP calculated results show a current downward trend in bias for existing U-233 benchmarks.
  - For thermal systems, k_{eff} values are **over-predicted** by **2%**.
  - Intermediate systems are **under-predicted** by up to **4%**.
  - Bad nuclear data, bad critical experiments, or both?

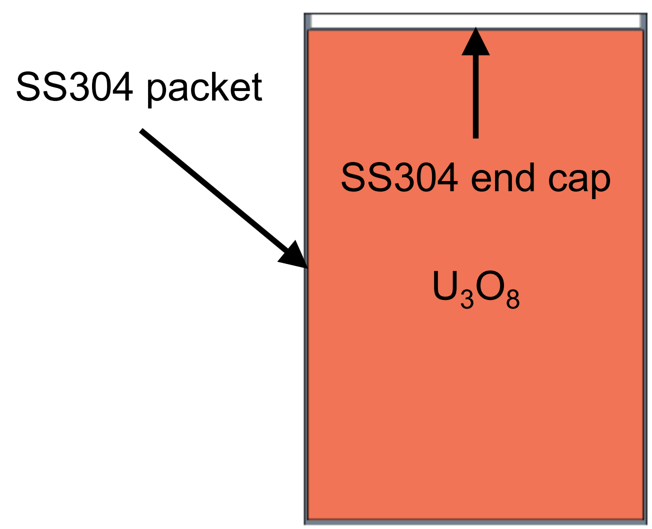




TEX-23 Models

- **U-233 ZPPR Plates**
  - Stainless steel (SS304) packets
  - Uranium oxide (U_3O_8 powder) fill
    - Density ~1.62 g/cm^3
    - 33 grams ± 2% (~28 grams U-233)
    - Impurities are quantified





TEX-23 Design using Optimus

Optimus

A general-purpose optimization software package that uses machine learning to design critical assemblies.

- Developed by the Nuclear Criticality Safety Division at Lawrence Livermore National Laboratory
- Simple to use for designing TEX and other critical/subcritical experiment designs
- Efficiently finds optimal critical assembly designs
- Acts as a code wrapper for COG and MCNP
- Written in Python
- Also currently being used to perform scoping calculations in support of criticality safety analysis

Art credit: Livio Ramondelli

TEX-23 Design using Optimus

- Generate U-233 ZPPR plate model
- Specify **degrees of freedom**:

  $\mathbf{P_x}$ = number of U-233 ZPPR plates along the x-axis

  $\mathbf{P_y}$ = number of U-233 ZPPR plates along the y-axis

  $\mathbf{L_z}$ = number of U-233 ZPPR plate layers (z-axis)

- Define **objective function**:

  $\mathbf{k_{eff}}$ = 0.99 to 1.025

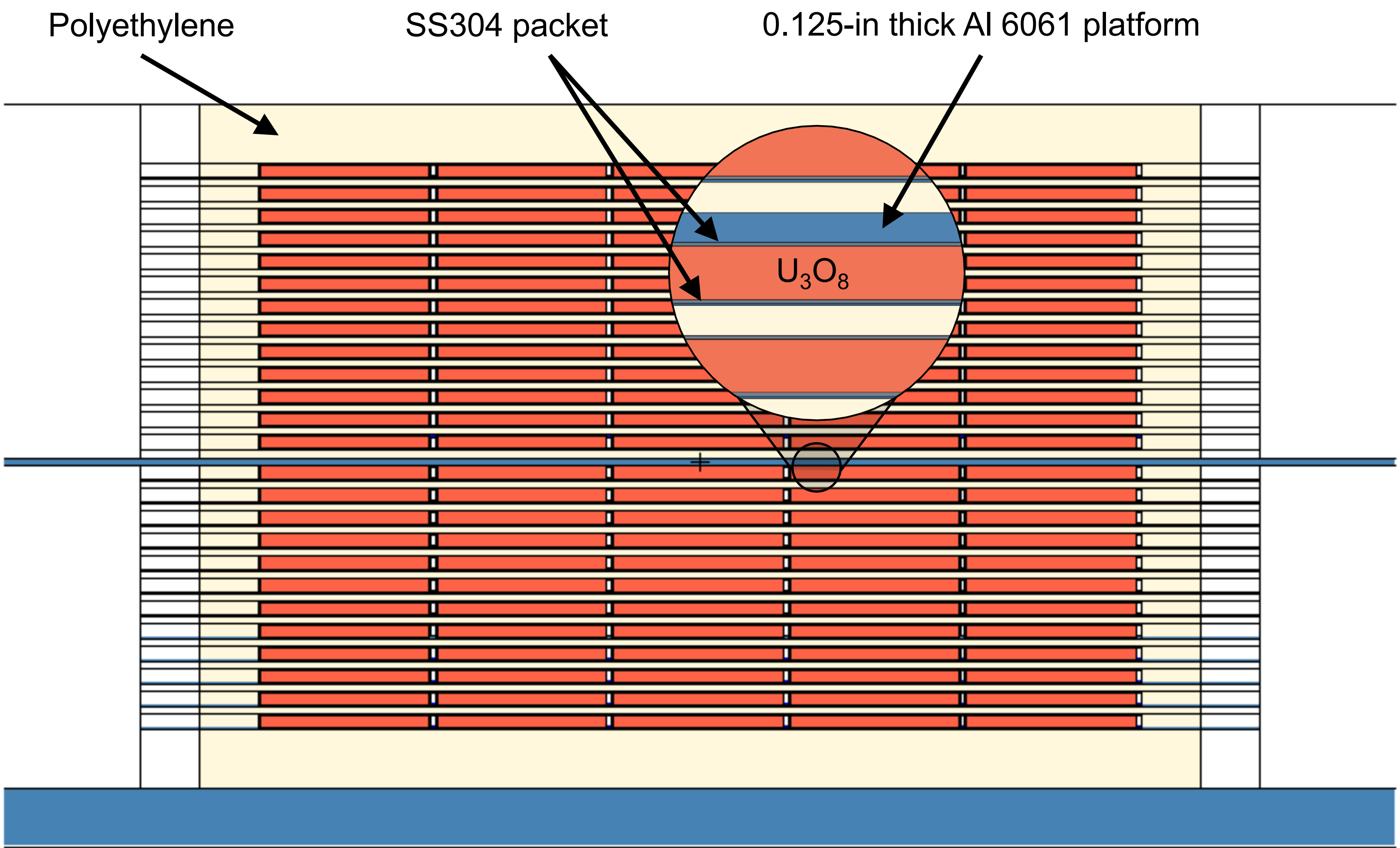
  Maximize **thermal energy** or **intermediate energy** fission fraction

- Other rules:

  $\mathbf{P_x \times P_y \times P_z} \leq 1{,}743$ (maximum number of U-233 ZPPR plates)

  $\mathbf{t_{reflector}}$ = 1 or 1.5 inches

TEX-23 Design using Optimus



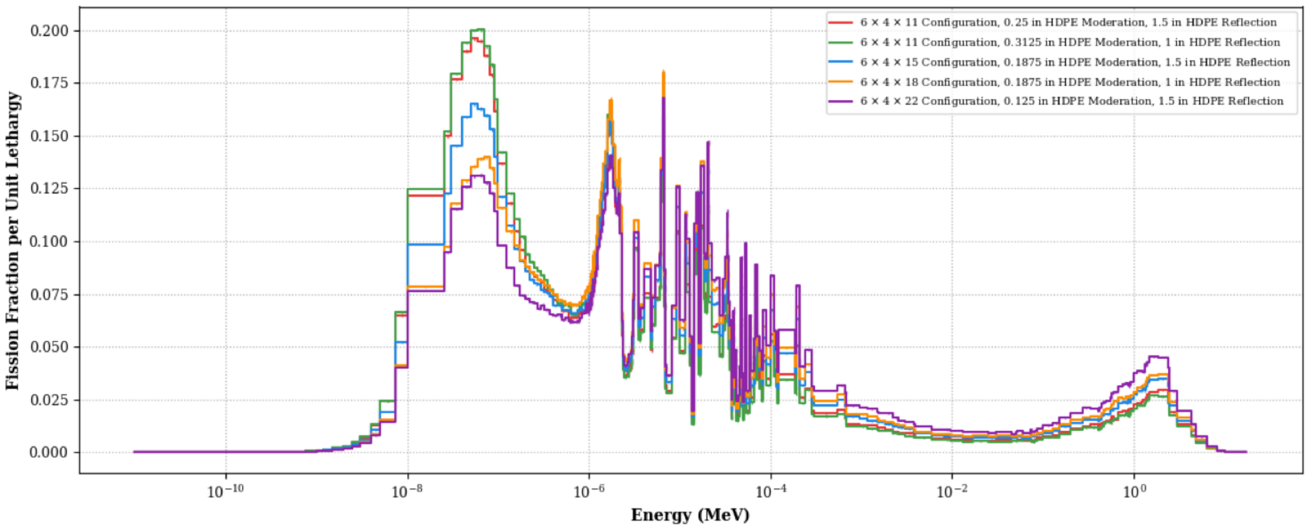
TEX-23 Results

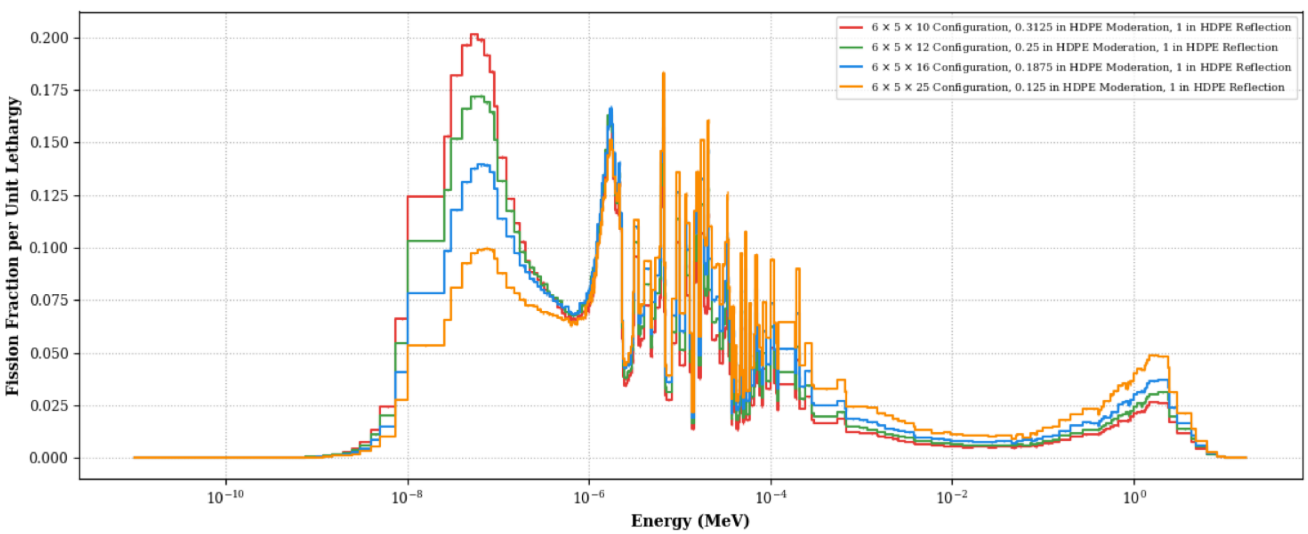
- **No fast** (unmoderated) critical assemblies were found.
  - Uranium oxide powder has a relatively low density.
  - This was an expected result.
  - Highest **fast** fission fraction: ~0.16
- More than **4,916** configurations were modeled and analyzed using Optimus.
- **14** critical assembly configurations were selected for further study in CED-2.
  - Five 6×4, two 6×5, three 7×4, one 7×5, two 8×6, and two 9×6 configurations were selected.
  - Highest **thermal** fission fraction: ~0.81
  - Highest **intermediate** fission fraction: ~0.57

TEX-23 Results

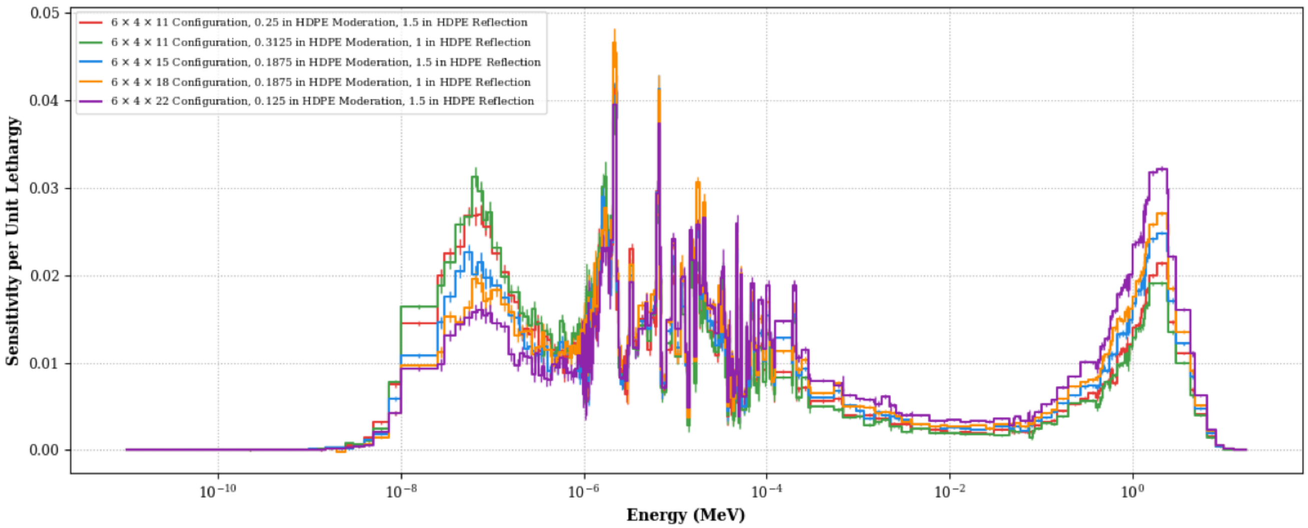
P_x	P_y	L_z	$t_{moderator}$ (in)	$t_{reflector}$ (in)	k_{eff}	Fission Fraction Integral		
						Thermal	Intermediate	Fast
6	4	11	0.3125	1	1.0062	0.53	0.41	0.06
6	4	11	0.25	1.5	0.9971	0.52	0.42	0.06
6	4	15	0.1875	1.5	1.0076	0.46	0.47	0.08
6	4	18	0.1875	1	0.9972	0.41	0.51	0.08
6	4	22	0.125	1.5	0.9911	0.38	0.52	0.10
6	5	16	0.1875	1	1.0012	0.41	0.51	0.08
6	5	25	0.125	1	1.0012	0.32	**0.57**	0.11
7	4	17	0.1875	1	1.0107	0.41	0.51	0.08
7	4	26	0.125	1	0.9983	0.32	**0.57**	0.11
7	5	6	1.875	1	1.0339	**0.81**	0.16	0.03
8	6	13	0.1875	1	1.0043	0.41	0.51	0.08
8	6	19	0.125	1	1.0035	0.32	**0.57**	0.11
9	6	13	0.1875	1	1.0229	0.41	0.51	0.08
9	6	18	0.125	1	1.0031	0.32	**0.57**	0.11

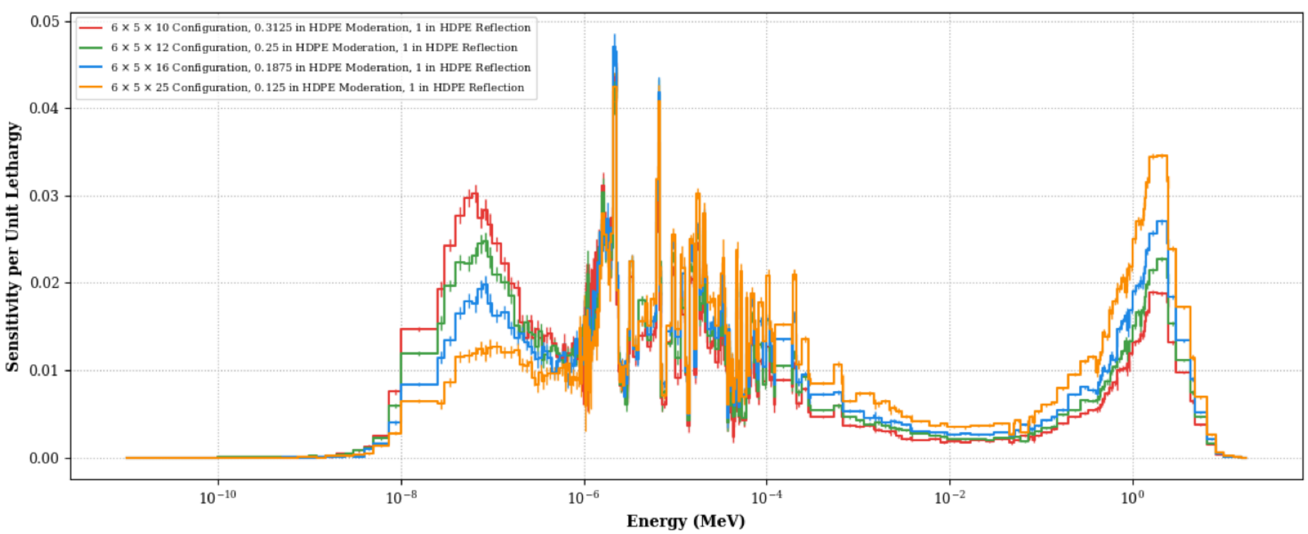
TEX-23 Results: U-233 Fission Spectra





TEX-23 Results: U-233 Fission Sensitivity





TEX-23 Recap and Plans for CED-2

- **No fast** (unmoderated) critical assemblies were found.
  - Uranium oxide powder has a relatively low density.
  - This was an expected result.
  - Highest **fast** fission fraction: ~0.16
- **14** critical assembly configurations were selected for further study in CED-2.
  - Highest **thermal** fission fraction: ~0.81
  - Highest **intermediate** fission fraction: ~0.57
- CED-2 will include more detailed analysis of U-233 ZPPR plate dimensional tolerances, component spacing, and uranium oxide powder composition.
- The input decks are pre-built and ready for Optimus to continue running more detailed calculations.