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

TEX-23

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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, $k_{\text{eff}}$ 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 (U₃O₈ powder) fill
    - Density ~1.62 g/cm³
    - 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:
  \[ P_x = \text{number of U-233 ZPPR plates along the x-axis} \]
  \[ P_y = \text{number of U-233 ZPPR plates along the y-axis} \]
  \[ L_z = \text{number of U-233 ZPPR plate layers (z-axis)} \]

- Define objective function:
  \[ k_{\text{eff}} = 0.99 \text{ to } 1.025 \]
  Maximize thermal energy or intermediate energy fission fraction

- Other rules:
  \[ P_x \times P_y \times P_z \leq 1,743 \text{ (maximum number of U-233 ZPPR plates)} \]
  \[ t_{\text{reflector}} = 1 \text{ or } 1.5 \text{ inches} \]
TEX-23 Design using Optimus

Polyethylene
SS304 packet
0.125-in thick Al 6061 platform

U₃O₈
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

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<th>P_x</th>
<th>P_y</th>
<th>L_z</th>
<th>t_{moderator} (in)</th>
<th>t_{reflector} (in)</th>
<th>k_{eff}</th>
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TEX-23 Results: U-233 Fission Spectra
TEX-23 Results: U-233 Fission Sensitivity

Graph showing the sensitivity per unit lethargy as a function of energy (MeV) for different configurations and moderation types.
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.