NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

LLNL-PRES-738222

Thermal/Epithermal eXperiments with Hafnium (TEX-Hf)

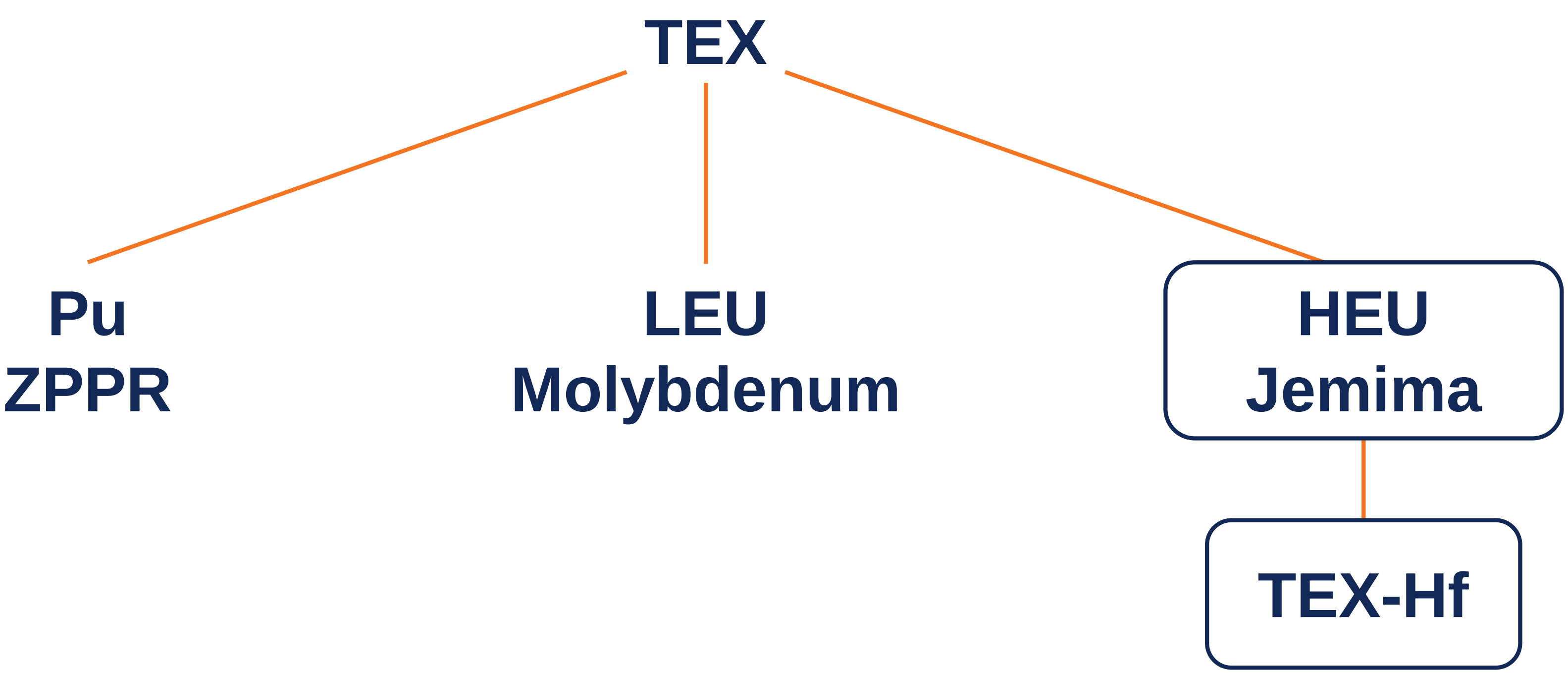
Presented at the ANS NCSD Topical Meeting
September 10-15, Carlsbad, NM

Tony Nelson, Catherine Percher, Will Zywiec, Dave Heinrichs
Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory, P.O. Box 808, L-384, 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

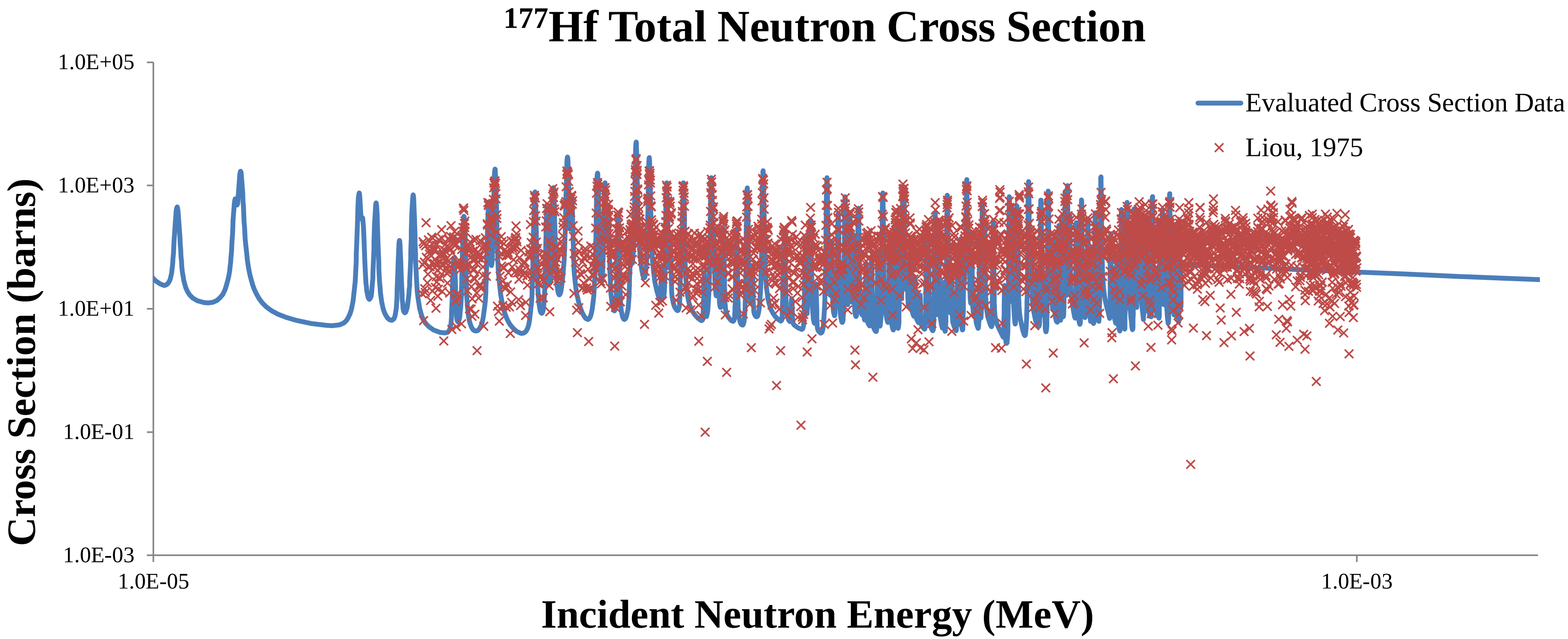
Thermal/Epithermal eXperiments (TEX) Overview

- **TEX Goals**
  - New critical benchmark experiments
  - Emphasis on intermediate energy range
  - Create test bed: can be easily modified for different diluents



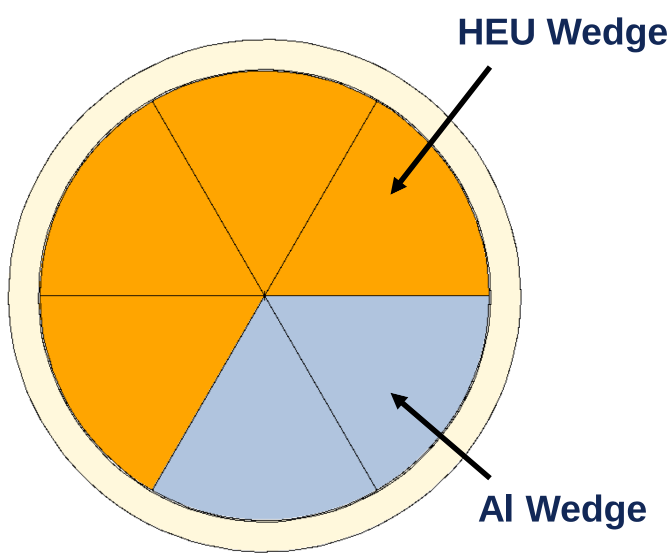
TEX-Hf Overview

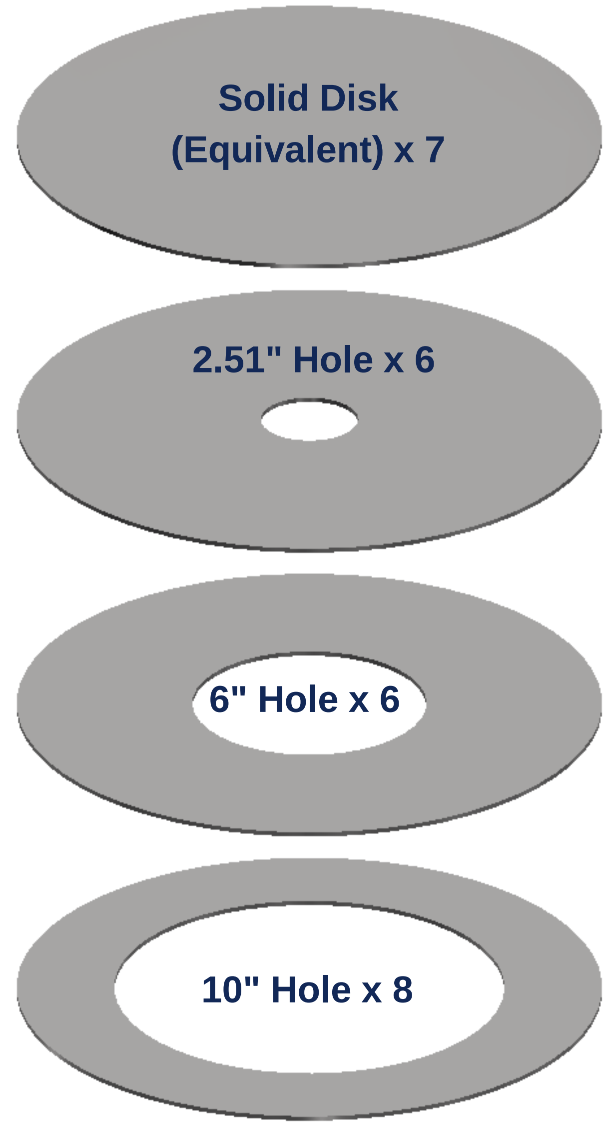
- **TEX-Hf Final Design** (in review) *IER-297 CED-2*
  - Hf is a strong neutron absorber
  - Used in naval propulsion reactors
  - No benchmarks sensitive to intermediate Hf cross sections



Jemima Plates

- Existing US asset at NCERC
- 93.13 - 93.5 wt% ^{235}U enrichment
- 3 mm thickness
- 15 inch outer diameter with central holes of various sizes
- 27 disks used in TEX-Hf
- Wedge plates used to adjust reactivity

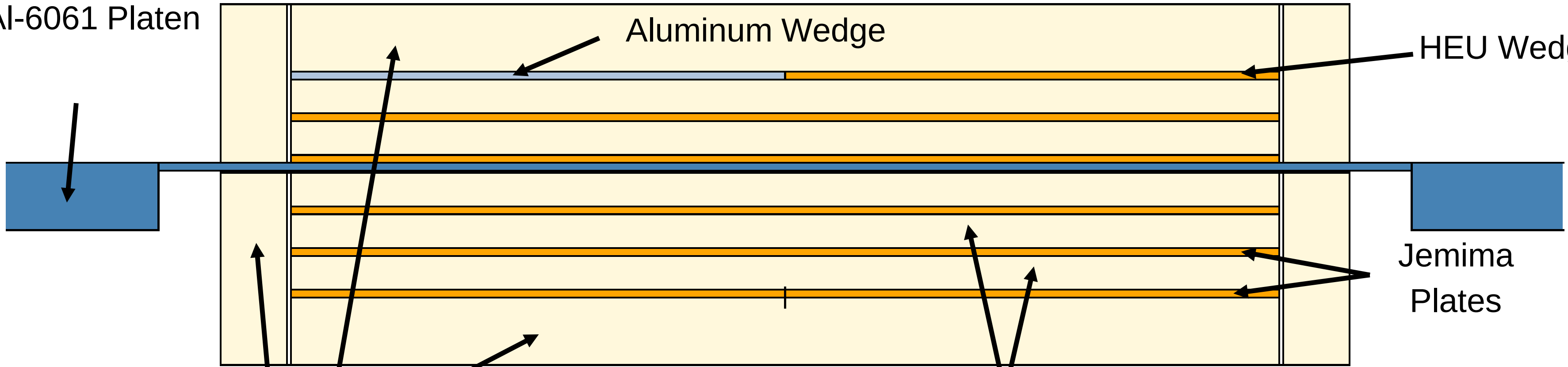




TEX-Hf Final Experiment Design

- Planet vertical lift machine
- 21 Critical Configurations
- 4 stacking methods
  - Baseline
  - Standard
  - Sandwich
  - Bunched HF

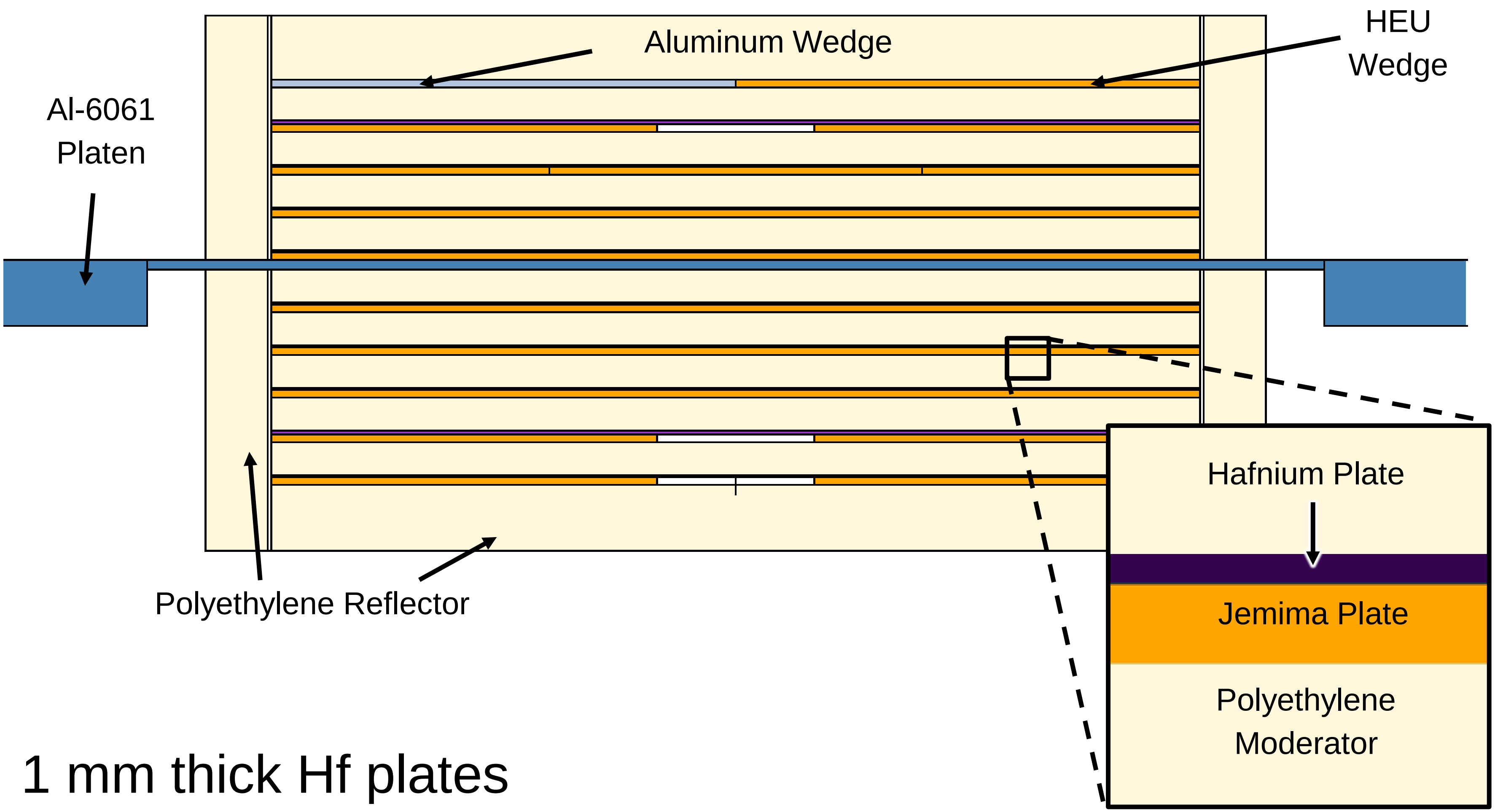
Baseline Configuration- No Hafnium



- Polyethylene reflector: 1”
- Jemima plates: 3 mm
- Polyethylene moderator plates: 0”-1.5”

↑PE Thickness = ↓Neutron Energy

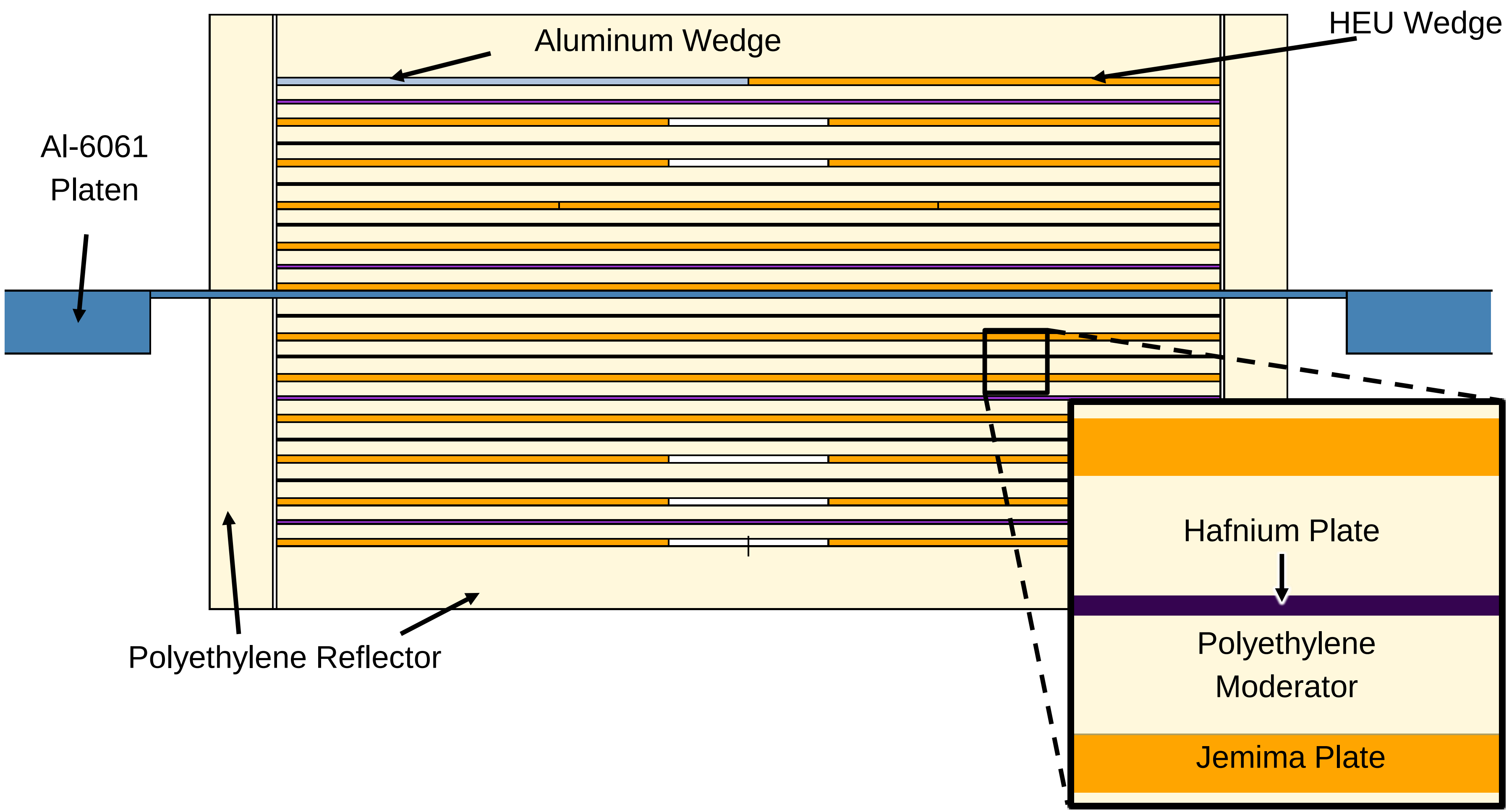
Standard Stacking Configuration



- 1 mm thick Hf plates

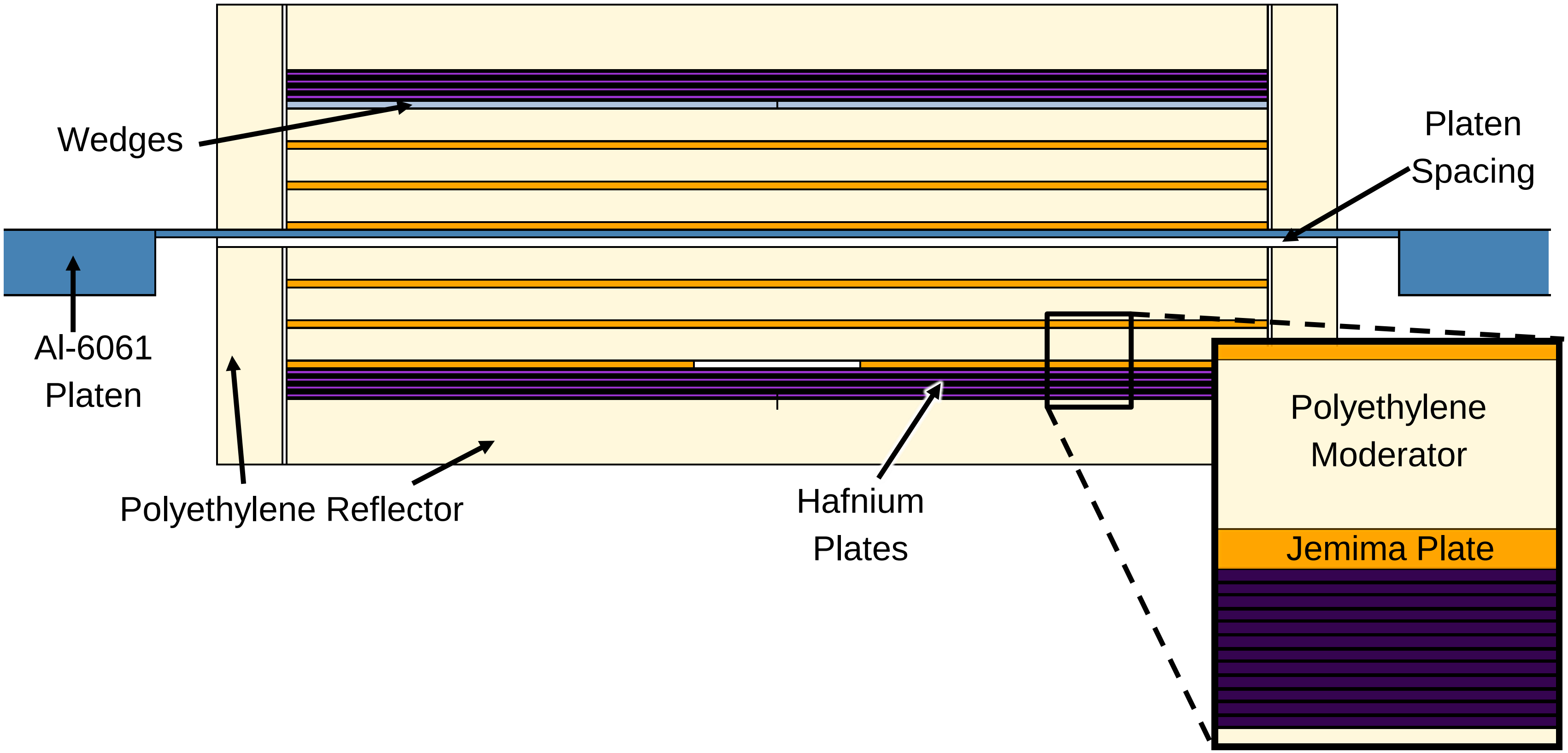
Sandwich Stacking Configuration

- Maximizes sensitivity in intermediate energy range

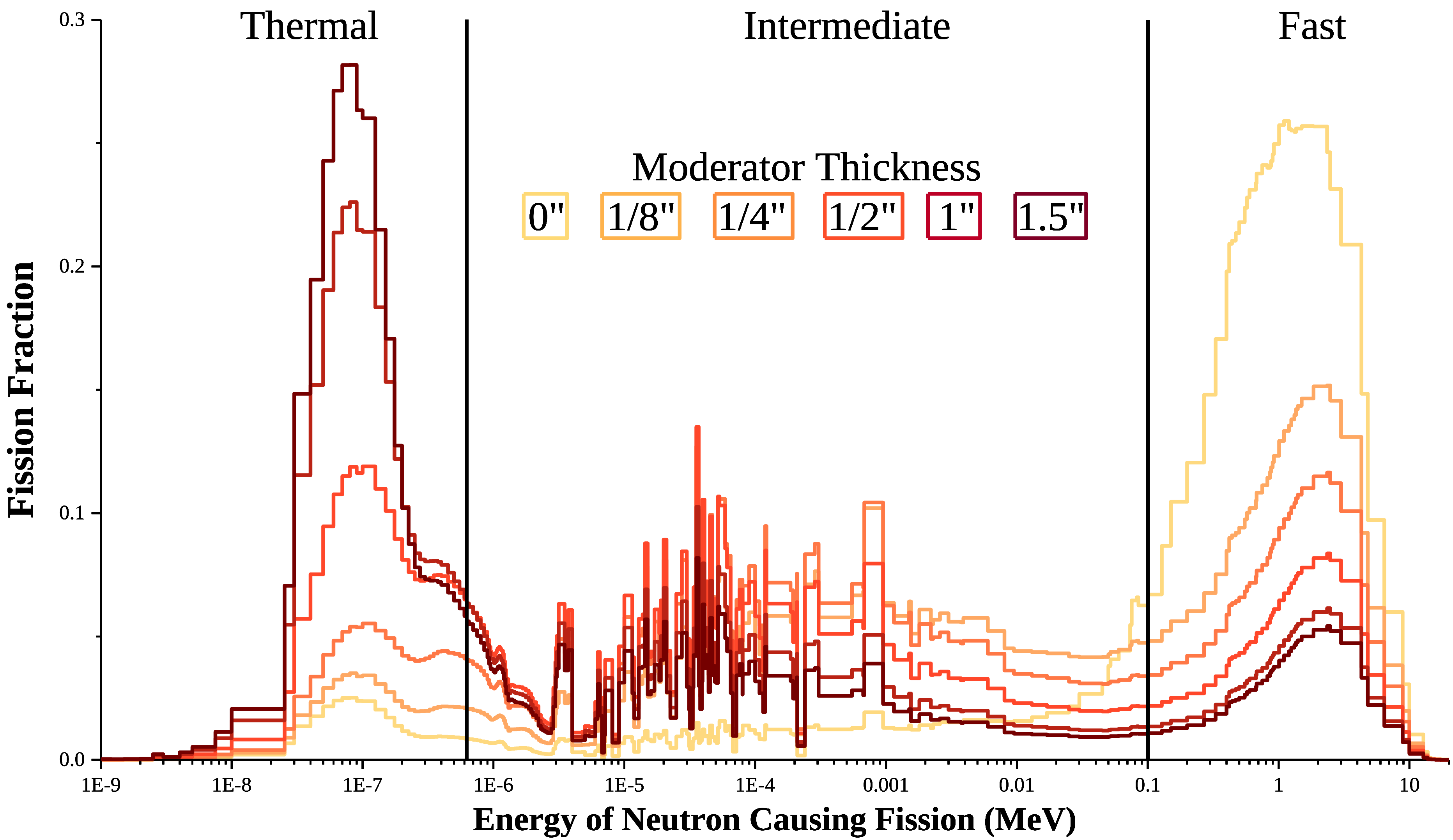


Bunched Hafnium Configuration

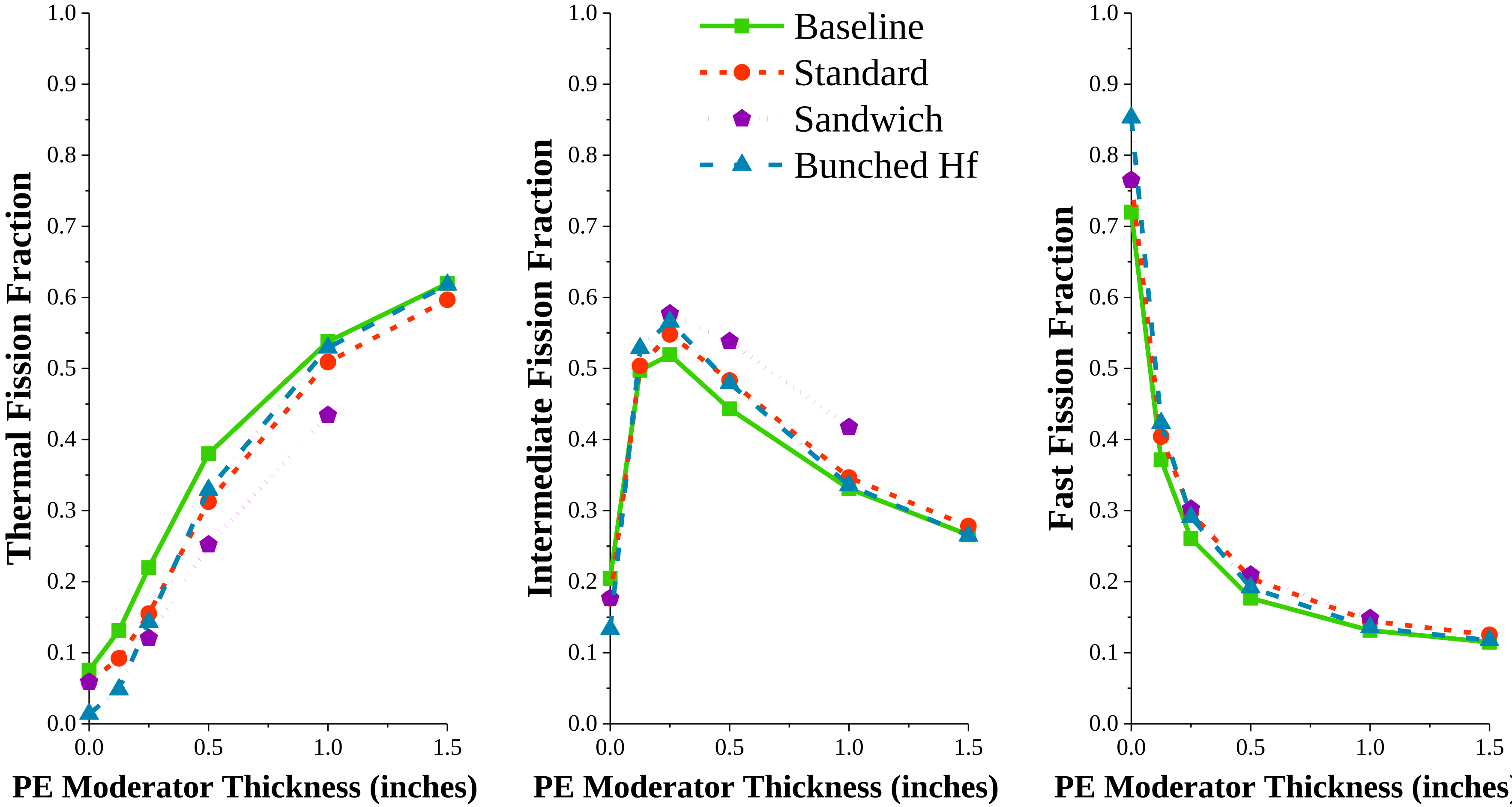
- Maximizes sensitivity to Hf scattering cross sections
- 12 Hf plates on top and bottom



Energy Spectrum



Energy Spectrum



Sensitivity

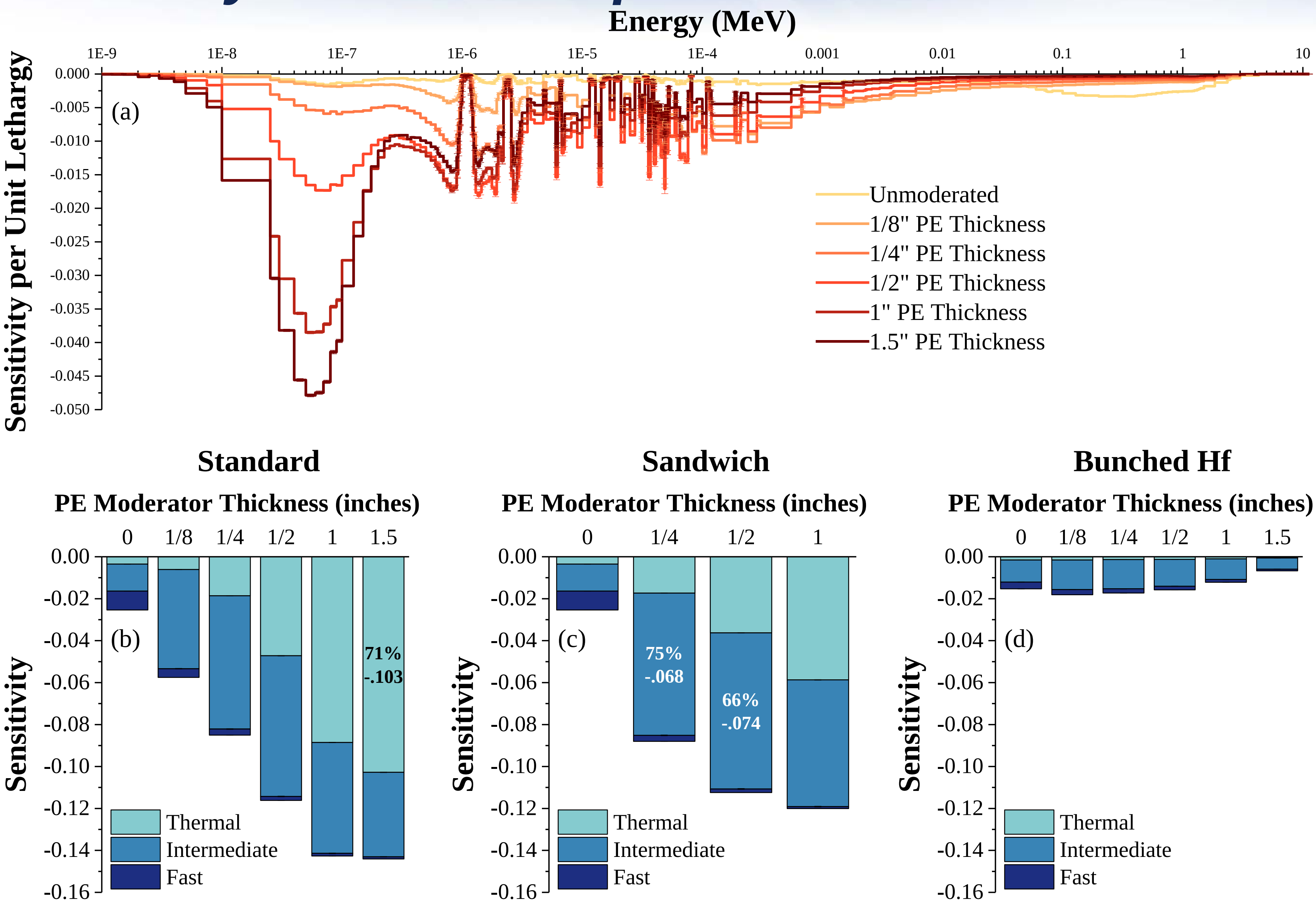
- Sensitivity of k_{eff} to changes in cross section:

$$S_{k_{eff},\sigma} = \frac{\Delta k_{eff}/k_{eff}}{\Delta\sigma/\sigma}$$

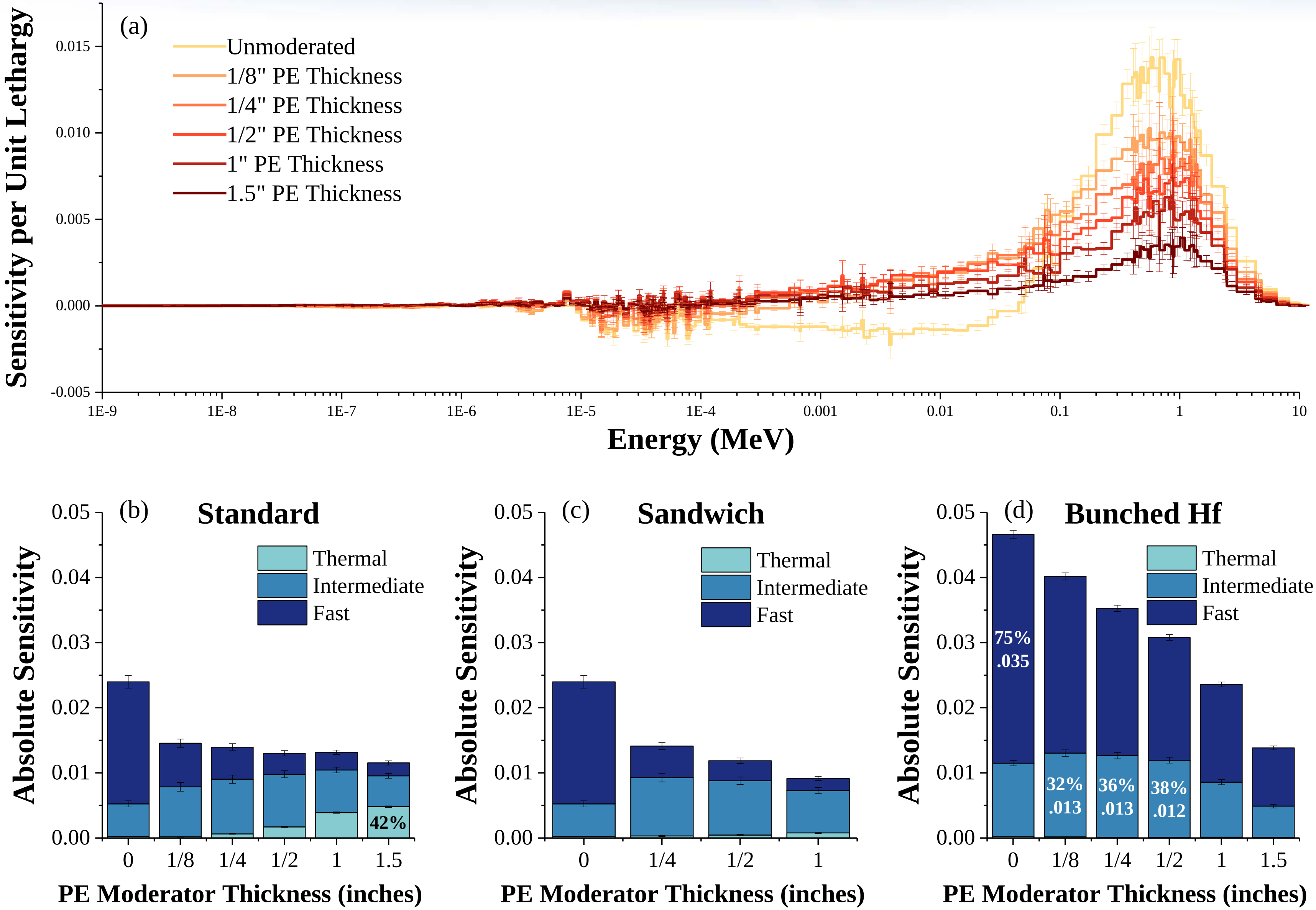
- So a sensitivity of 0.1 would mean that increasing σ by X% would increase k_{eff} by 0.1*X%

- All simulations run with MCNP6 using ENDF/B-VII.1
- Sensitivity calculated using KSEN card
- For Hf, isotope sensitivities summed

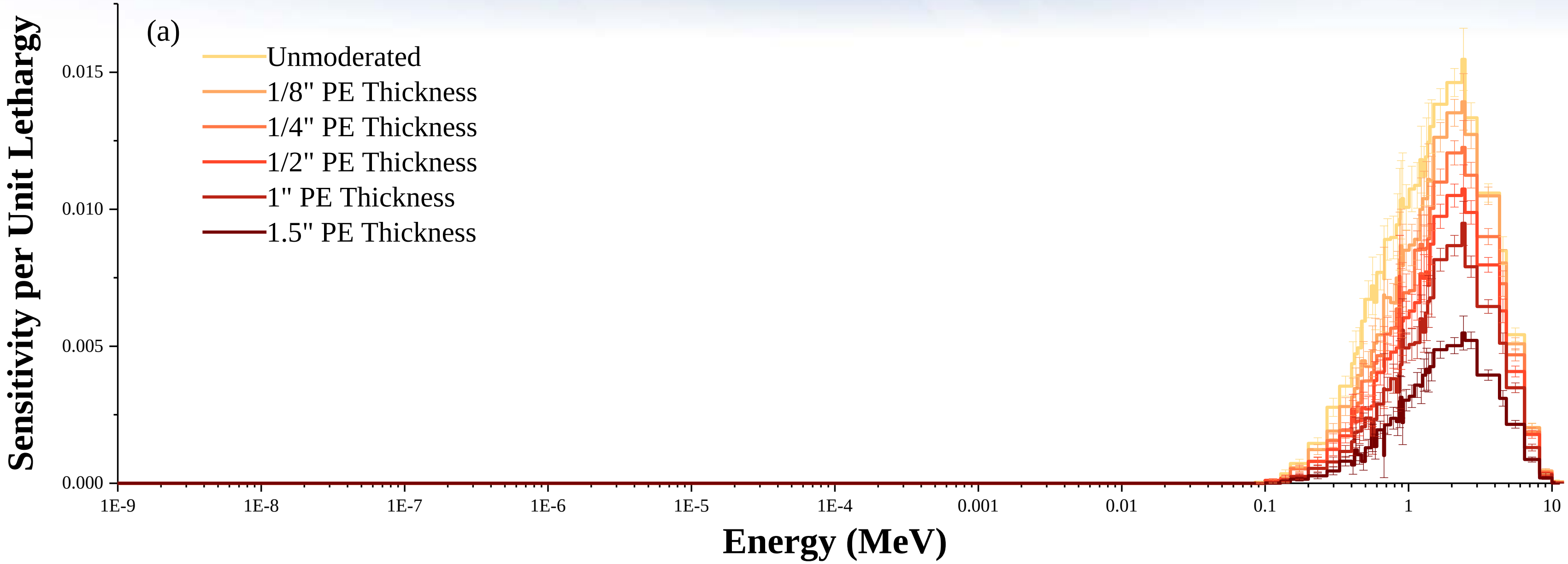
Sensitivity- Hafnium Capture

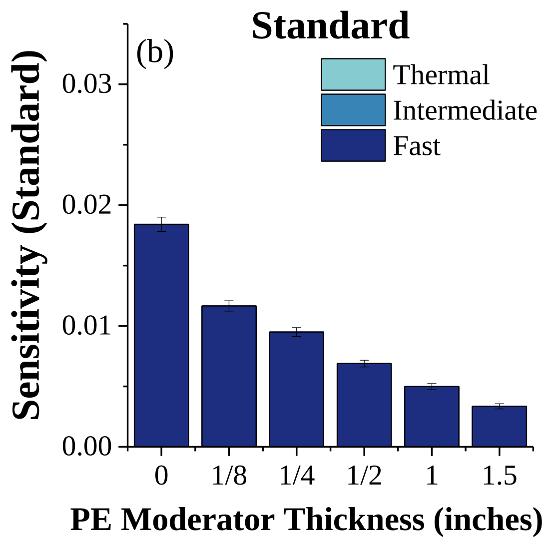


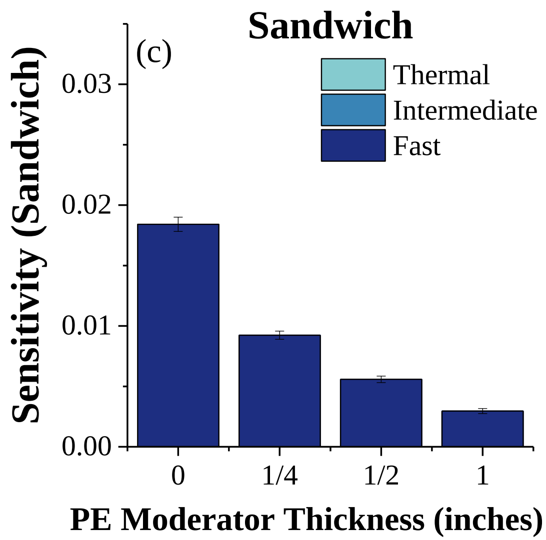
Sensitivity- Hafnium Elastic Scatter

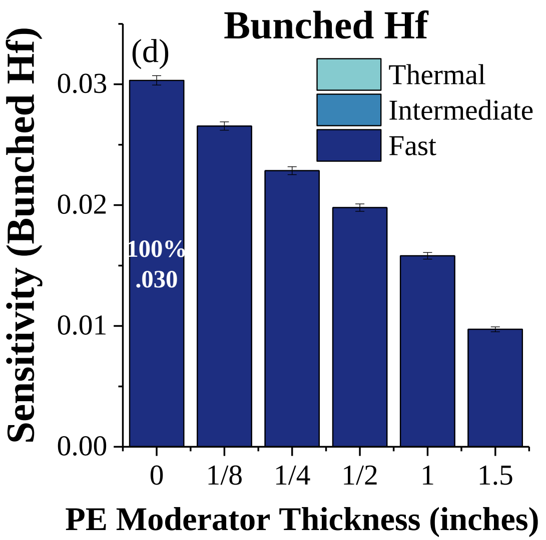


Sensitivity- Hafnium Inelastic Scatter

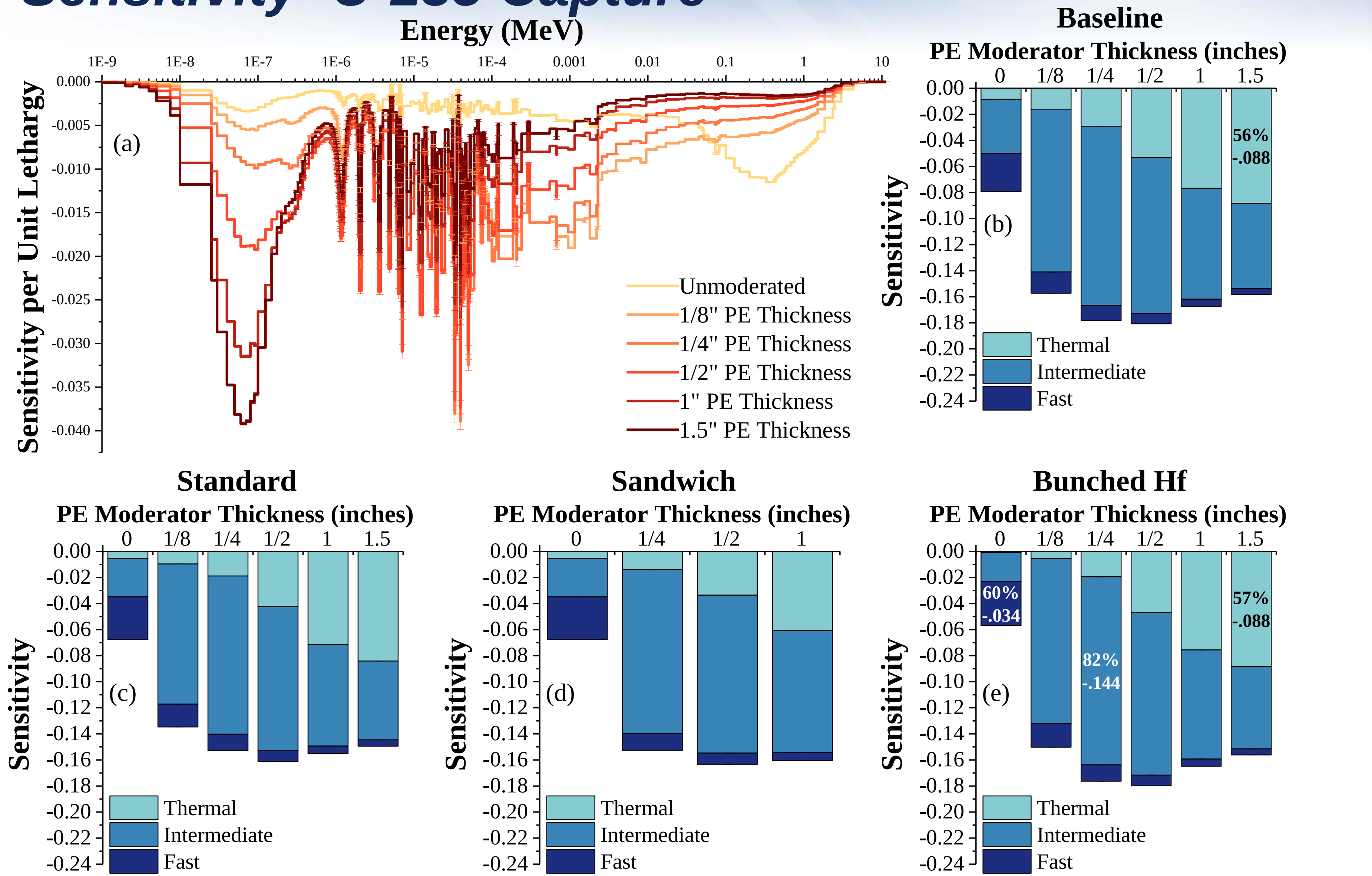




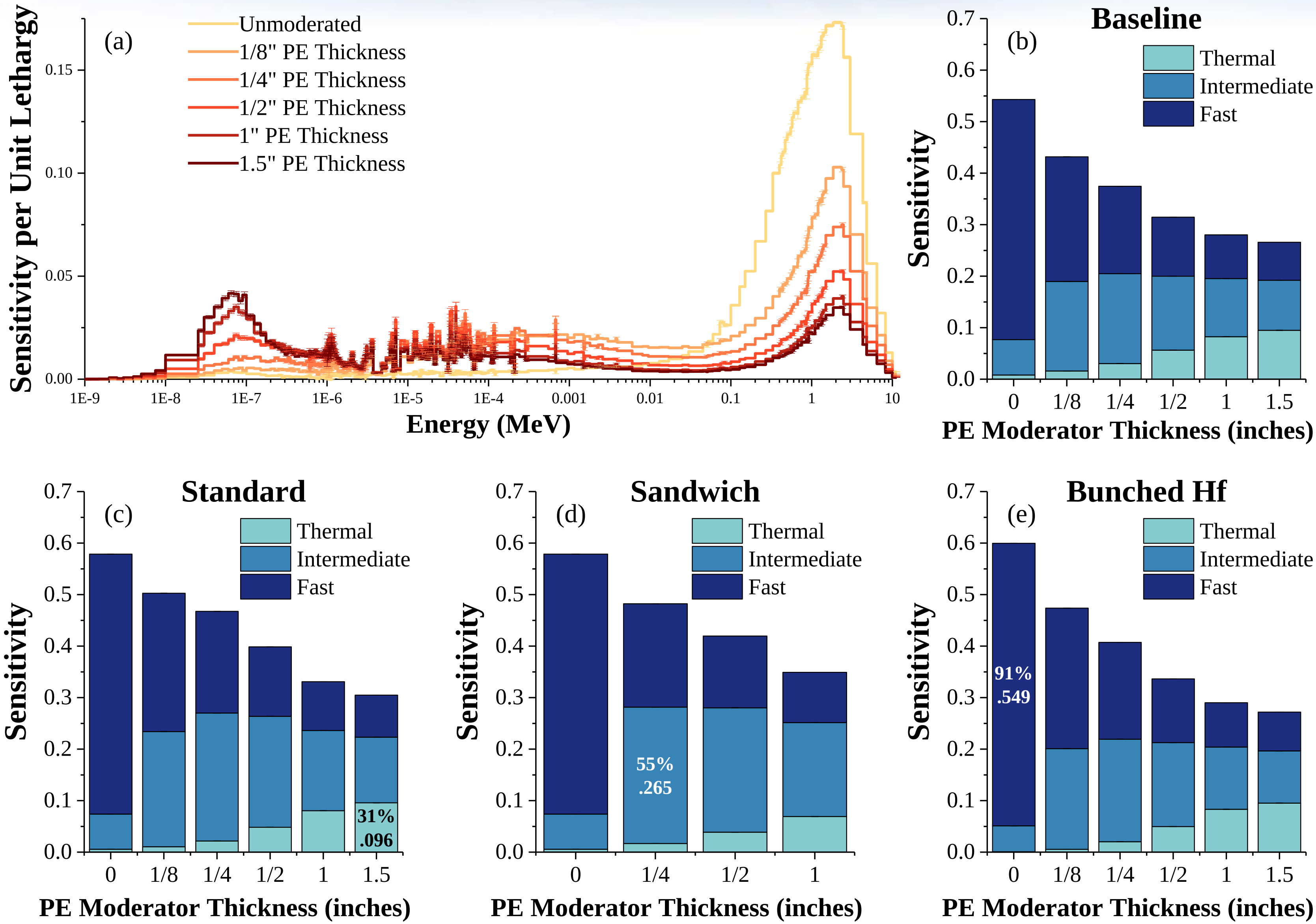




Sensitivity- U-235 Capture



Sensitivity- U-235 Fission



Future Work

Experiment execution planned for 2018

First:

- **Purchase Hf plates**
- **Fabricate PE parts**
- **Characterize all parts**

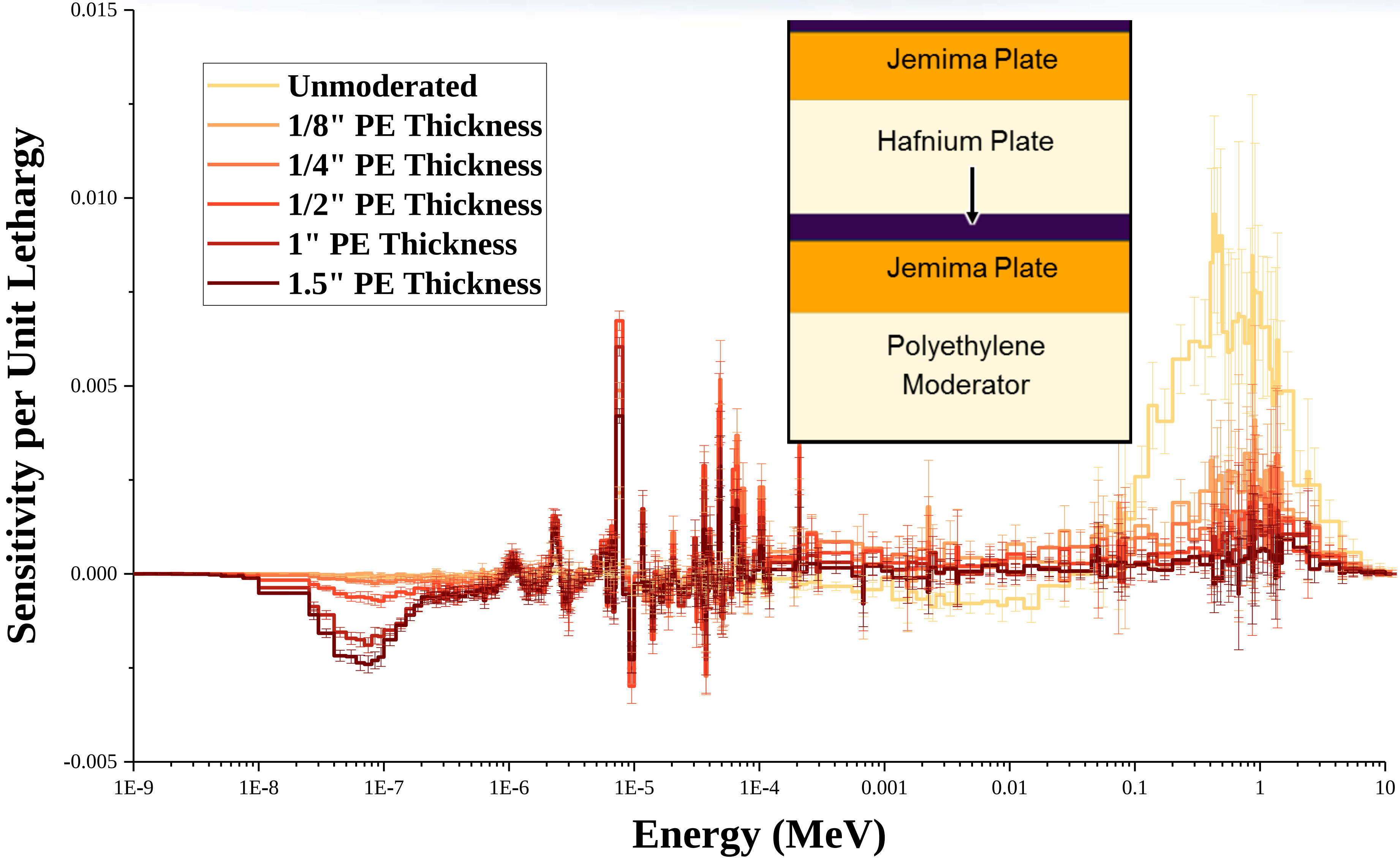
Then:

- **Submission to ICSBEP**

Acknowledgements

- Isabelle Duhamel and Mariya Brovchenko of the Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
- Dr. Michael Zerkle of Naval Nuclear Laboratory (NNL)
- This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA273444 and was funded by the U.S. Department of Energy Nuclear Criticality Safety Program.

Bonus- Hf Elastic Scattering



Uncertainty and Bias

Uncertainty

- Jemima plate mass
  - Uncertainty from previous ICSBEP benchmarks
- PE mass
  - Mass will be precisely measured after fabrication, reducing uncertainty
- Plate gaps
  - Height of stack will be measured before experiment to precisely determine gaps between plates
- U-235 enrichment
  - U-235 enrichment uncertainty based on standard deviation of measurements

Source of Uncertainty	Parameter Variation	Calculated Effect, Δk_{eff}
HEU Plate Mass	+0.03%	0.00016
HEU Plate Mass	-0.03%	-0.00006
PE Moderator Mass	+0.005 g/cm	0.00086
PE Reflector Mass	+0.005 g/cm	0.00040
HEU Plate Gaps	0.00127 cm	-0.00044
U-235 Enrichment	+0.11%	0.00042
Total Uncertainty	**0.00114**	

Bias

- Room return
  - Simulations excluding room return were found to underestimate k_{eff} by 0.00161
- Plate impurities
  - Jemima: measured impurities included but they could be omitted with increase in k_{eff} of 0.00019
  - Hafnium: omitting impurities would decrease k_{eff} by 0.00090
- Hafnium isotopic composition
  - Increasing Hf-177 content by 10% reduces k_{eff} by 0.00346
  - Will precisely measure this value before experiment

Conclusions

- **Thermal, intermediate, and fast critical configurations were designed using available Jemima plate inventory.**
- **Hafnium capture**
  - Standard stacking maximizes thermal sensitivity.
  - Sandwich stacking maximizes intermediate sensitivity.
  - No configuration was predominately sensitive to fast energy range.
- **Hafnium scatter**
  - Bunched hafnium configuration maximizes sensitivity to elastic and inelastic scattering at high energy.
- **U-235 fission**
  - Sensitivity in the intermediate and fast energy regime was verified.
  - No configuration was predominately sensitive to thermal energy range.
- **U-235 capture**
  - Baseline configuration maximized thermal sensitivity.
  - Bunched Hf configurations maximized intermediate and fast sensitivity.