NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

LLNL-PRES-726477

CED-2 for Thermal/Epithermal Experiments (TEX) with Highly Enriched Uranium Jemima Plates with Polyethylene and Hafnium

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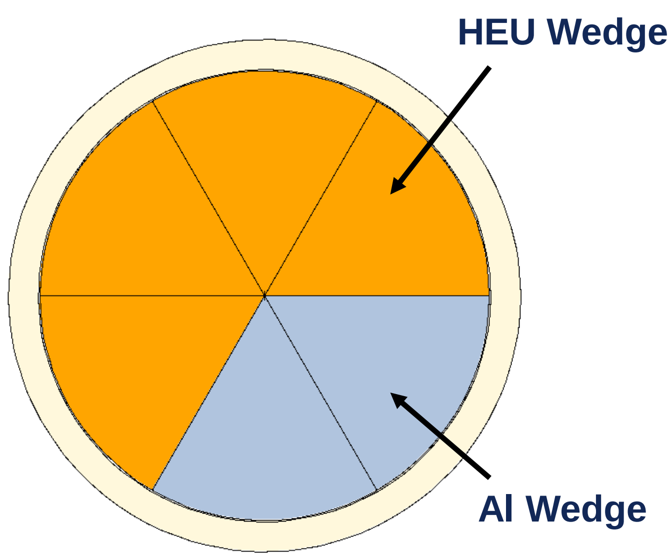
Thermal/Epithermal eXperiments (TEX) Overview

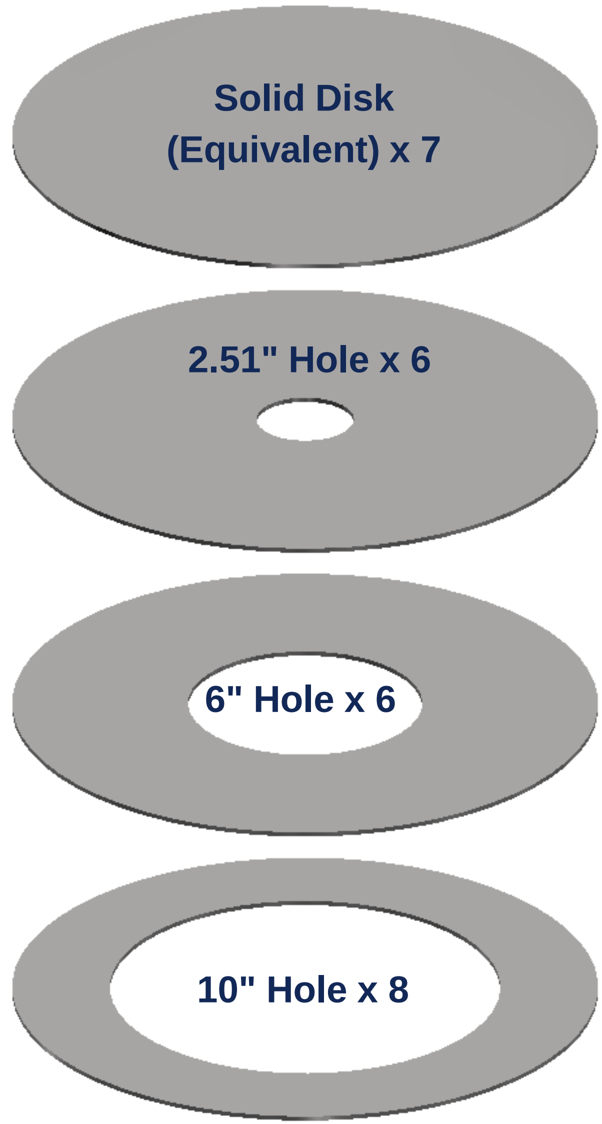
- **TEX Goals**
  - New critical experiments to address high priority nuclear data needs
  - Special emphasis on intermediate energy range
  - Create uranium test bed that can be easily modified for various diluents
- **TEX Preliminary Design** (Sep 2012) *IER-184 CED-1*
  - Showed feasibility for three different fissile systems to create intermediate energy 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 Final Design** (in review) *IER-297 CED-2*
  - Describes 21 critical experiments for benchmarking hafnium and uranium across entire energy range

TEX Feasibility Meeting
July, 2011
Nuclear Data Needs
Plutonium-239
Plutonium-240
Uranium-238
Uranium-235
Temperature Variation
Water Density Variation
Steel
Lead (reflection)
Hafnium
Tantalum
Tungsten
Nickel
Molybdenum
Chromium
Manganese
Copper
Vanadium
Titanium
Concrete

Jemima Plates

- 93.13 - 93.5 wt% ^{235}U enrichment
- Existing US asset at NCERC
- 3 mm thickness
- 15 inch outer diameter with central holes of various sizes
- 27 disks used in TEX-Hf
- 1 solid disk equivalent made from filling a 6” hole plate with a 6” OD plate
- 1 solid disk equivalent made from 6 wedges
- Wedge plates used to adjust reactivity

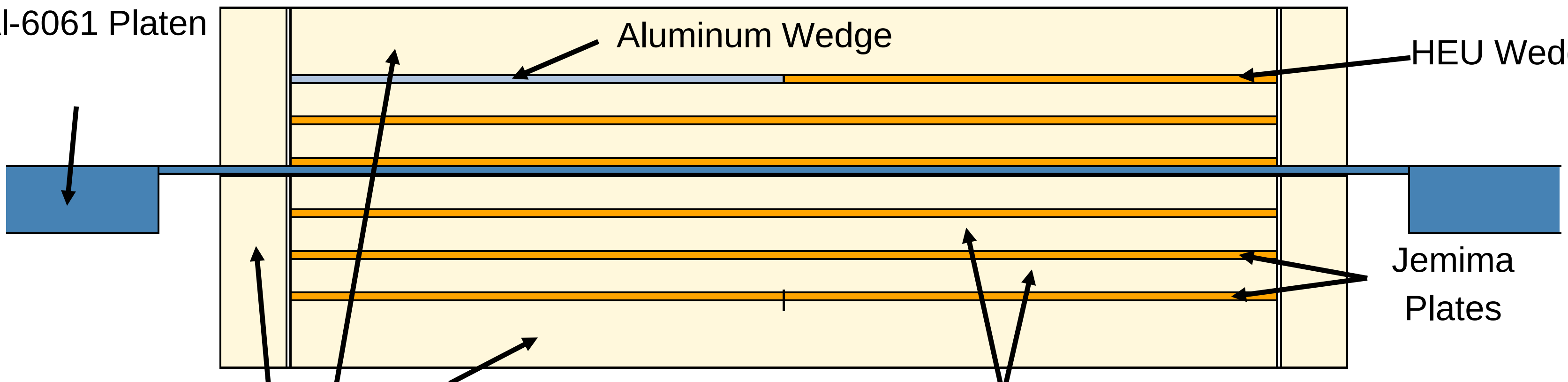




TEX-Hf Final Experiment Design

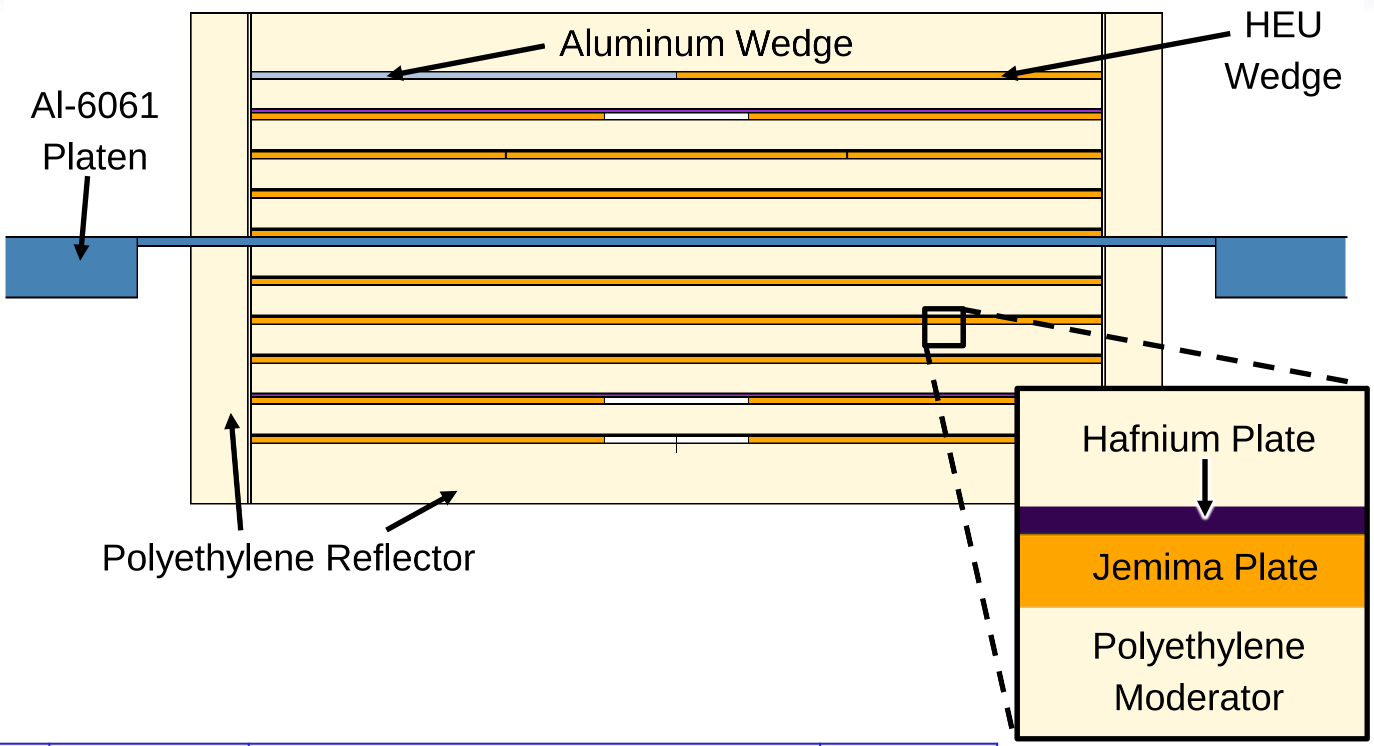
- 21 Critical Configurations
- Materials
  - 0.1 cm thick hafnium diluents
  - Varied polyethylene moderator thickness 0-1.5” to adjust energy spectrum
  - 1 inch polyethylene reflector around entire assembly
- Solid Jemima plates centrally located to maximize reactivity
- Calculational Model
  - Simulations run using MCNP6 with ENDF/B-VII.1 cross sections
  - Sensitivity calculated using KSEN card in MCNP6
- 4 stacking methods
  - Baseline
  - Standard
  - Sandwich
  - Bunched HF

Baseline Configuration- No Hafnium



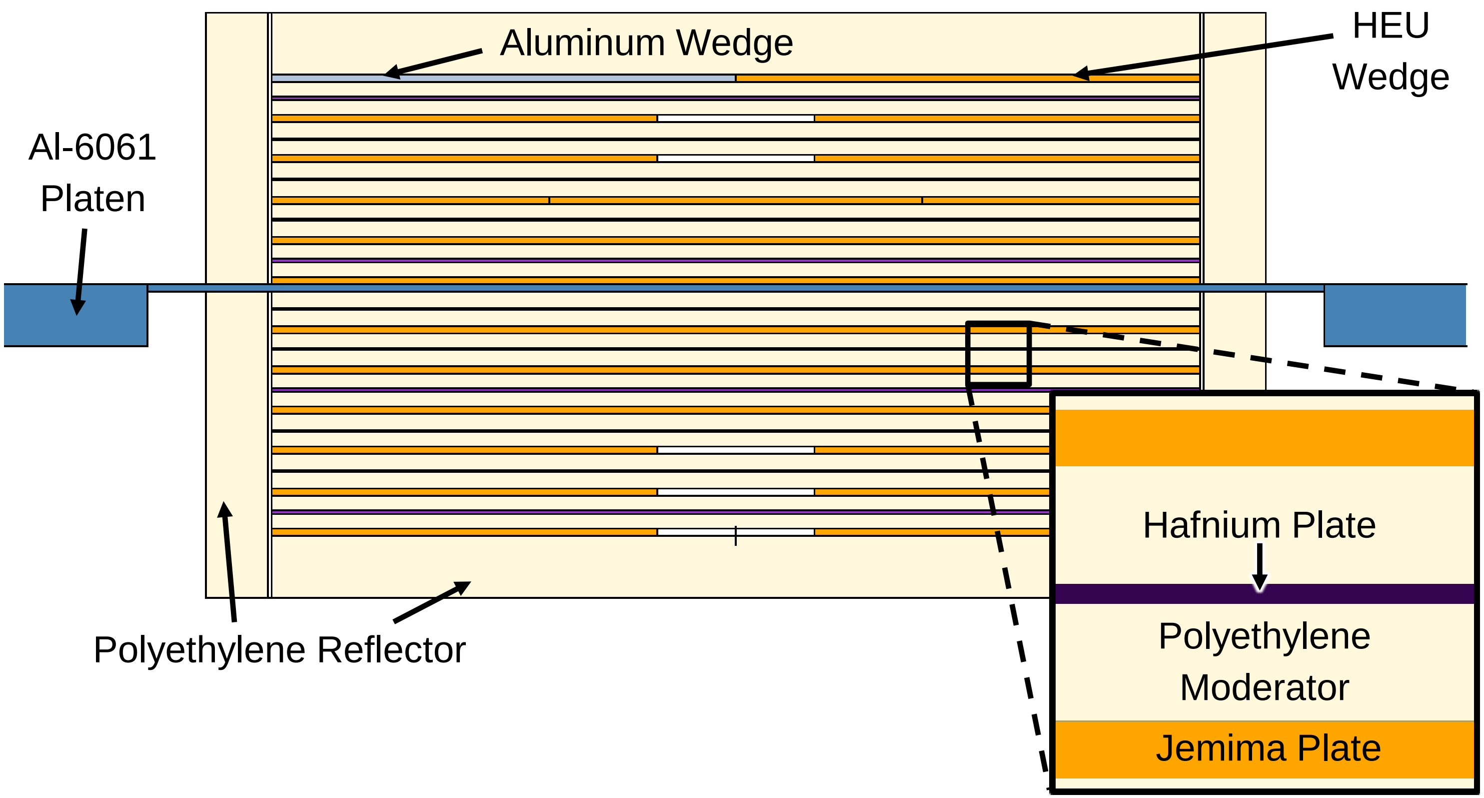
Polyethylene Thickness, inches	Number of HEU Plates	Number of Wedges in Top Plate	Gap Below Aluminum Platen, cm	Fission Fraction, %			k_{eff}
				Thermal (<0.625eV)	Intermediate (0.625eV-100keV)	Fast (>100keV)	
0	18	5	0	7.54%	20.46%	**72.00%**	1.00193
1/8	12	1	0.2	13.12%	49.74%	37.14%	1.00066
1/4	9	1	0.2	21.98%	**51.93%**	26.09%	1.00339
1/2	6	2	0.1	38.01%	44.31%	17.68%	1.00274
1	4	6	0.3	53.78%	33.08%	13.14%	1.00147
1.5	4	3	0	**61.95%**	26.58%	11.47%	1.00394

Standard Stacking Configuration



Polyethylene Thickness, inches	Number of HEU Plates	Number of Wedges in Top Plate	Gap Below Aluminum Platen, cm	Fission Fraction, %			k_{eff}
				Thermal (<0.625eV)	Intermediate (0.625eV-100keV)	Fast (>100keV)	
0	26	6	0.1	5.87%	17.65%	**76.48%**	1.00097
1/8	15	6	0	9.21%	50.37%	40.42%	1.00172
1/4	13	4	0	15.51%	**54.79%**	29.70%	1.00069
1/2	10	4	0	31.24%	48.31%	20.45%	1.0044
1	8	1	0	50.90%	34.65%	14.45%	1.00333
1.5	9	6	0	**59.66%**	27.83%	12.51%	1.00424

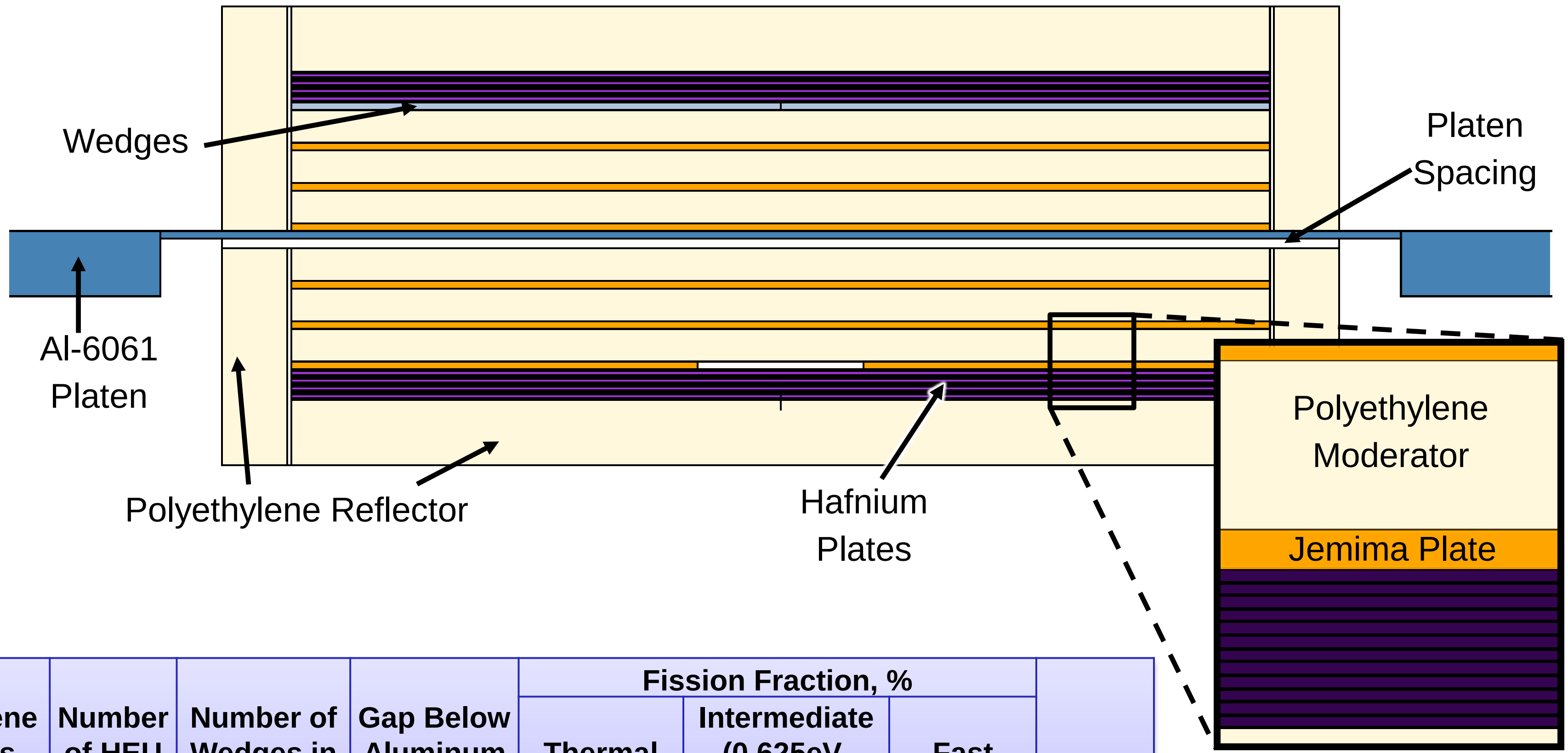
Sandwich Stacking Configuration



Polyethylene Thickness, inches	Number of HEU Plates	Number of Wedges in Top Plate	Gap Below Aluminum Platen, cm	Fission Fraction, %			k_{eff}
				Thermal (<0.625eV)	Intermediate (0.625eV-100keV)	Fast (>100keV)	
0	26	6	0.1	5.87%	17.65%	**76.48%**	1.00097
1/4	15	1	0.1	12.06%	***57.71%***	30.23%	1.00325
1/2	12	4	0	25.22%	53.81%	20.96%	1.00359
1	12	1	0	**43.42%**	41.73%	14.85%	1.00384

Unmoderated case identical to standard stacking

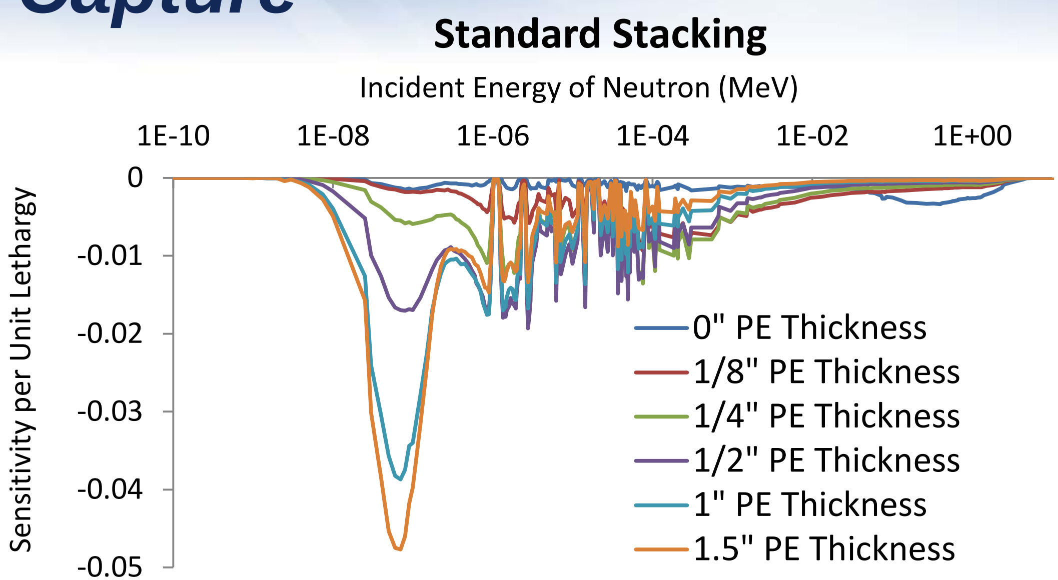
Bunched Hafnium Configuration

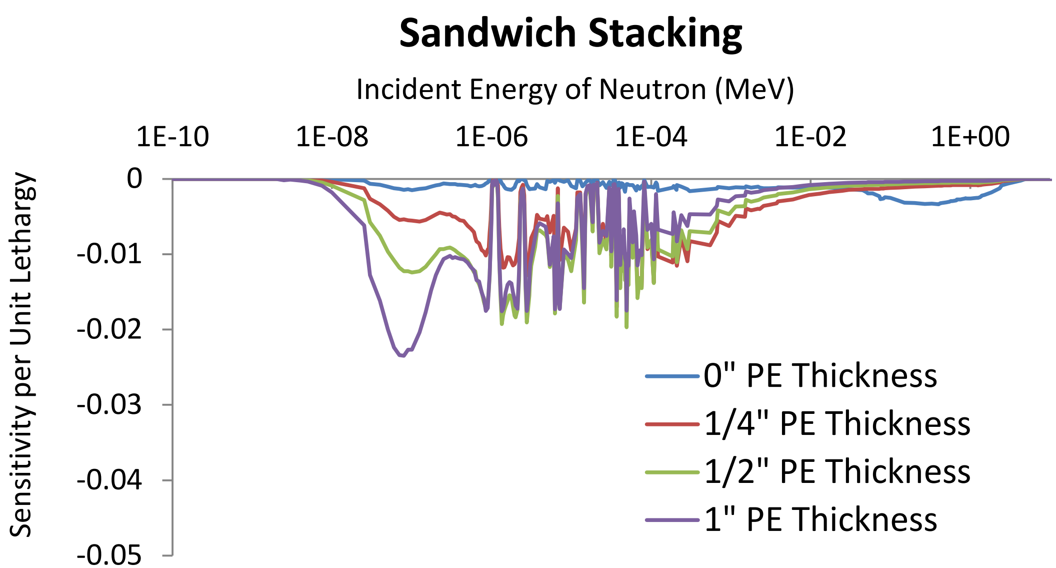


Polyethylene Thickness, inches	Number of HEU Plates	Number of Wedges in Top Plate	Gap Below Aluminum Platen, cm	Fission Fraction, %			k_{eff}
				Thermal (<0.625eV)	Intermediate (0.625eV-100keV)	Fast (>100keV)	
0	23	5	0	1.39%	13.32%	<u>**85.29%**</u>	1.00440
1/8	13	5	0	4.83%	52.86%	42.31%	1.00424
1/4	10	2	0.1	14.33%	**56.58%**	29.09%	1.00282
1/2	7	1	0.4	32.90%	47.93%	19.17%	1.00268
1	5	1	0.6	52.91%	33.54%	13.55%	1.00183
1.5	5	1	1.6	**61.79%**	26.47%	11.74%	1.00307

Sensitivity- Hafnium Capture

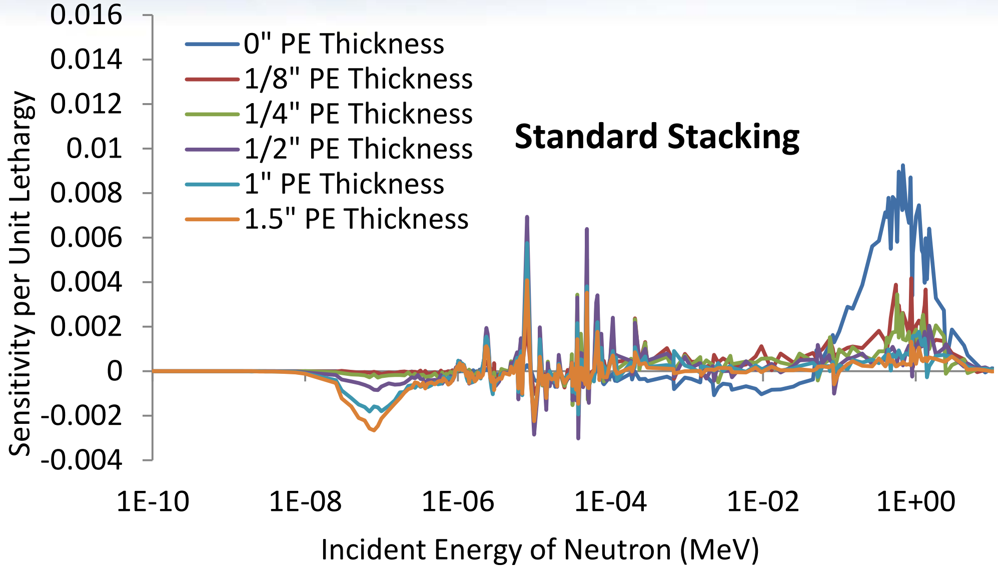
- Thermal Regime:
  - Standard 1.5” PE
    - Total sensitivity = -0.144
    - 71.3% thermal
- Intermediate Regime:
  - Sandwich 1/2” PE
    - Total sensitivity = -0.112
    - 66.3% intermediate
  - Sandwich 1/4” PE
    - Total sensitivity = -0.088
    - 77% intermediate
- Fast Regime:
  - Unmoderated Standard/Sandwich
    - Total sensitivity = -0.025
    - 35.6% fast
    - Still a predominantly (50.8%) intermediate system

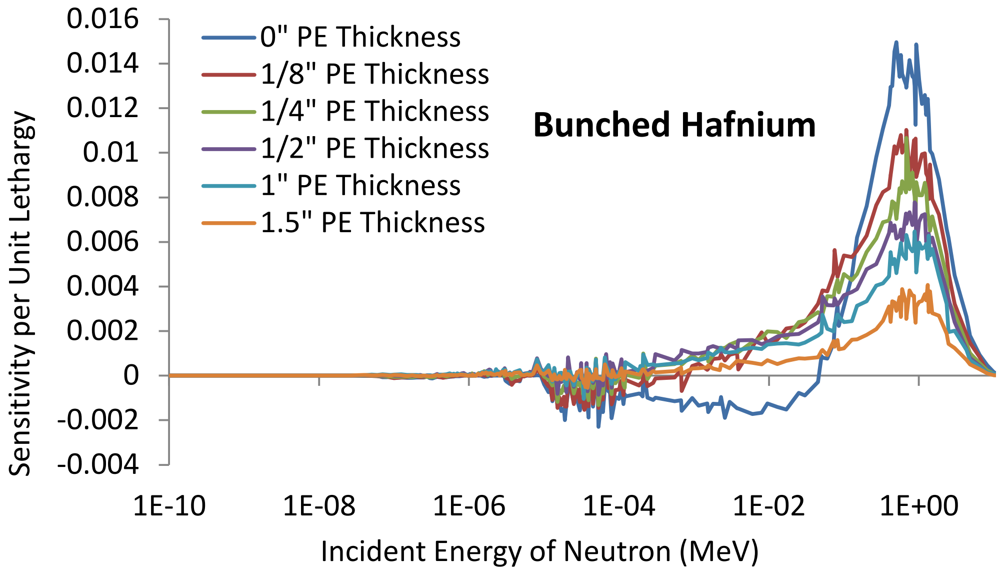




Sensitivity- Hafnium Elastic Scatter

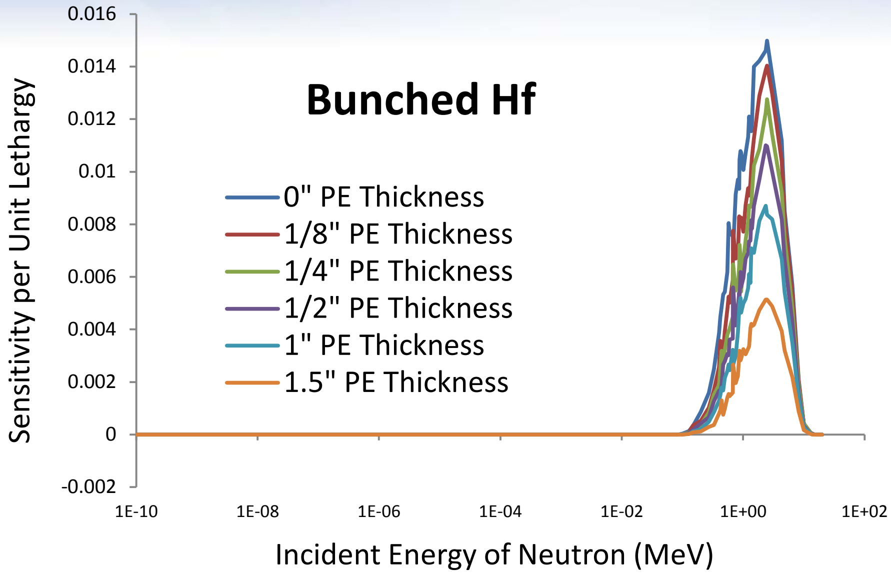
- Sensitivity *Magnitude*
  - Absolute value of sensitivity
- Thermal Regime:
  - Standard 1.5” PE
    - Total sensitivity = 0.005
    - 42.4% thermal
- Intermediate Regime:
  - Bunched Hf 1/8” PE
    - Total sensitivity = 0.0130
    - 32.1% intermediate
  - Sandwich 1” PE
    - Total sensitivity = 0.0065
    - 72.3% intermediate
- Fast Regime:
  - Unmoderated Bunched Hf
    - Total sensitivity = 0.0352
    - 75.6% fast

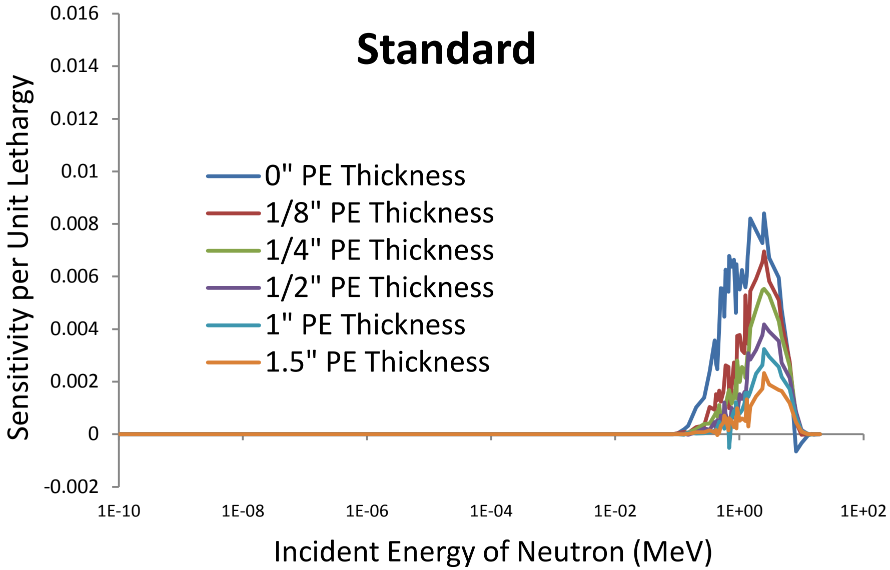


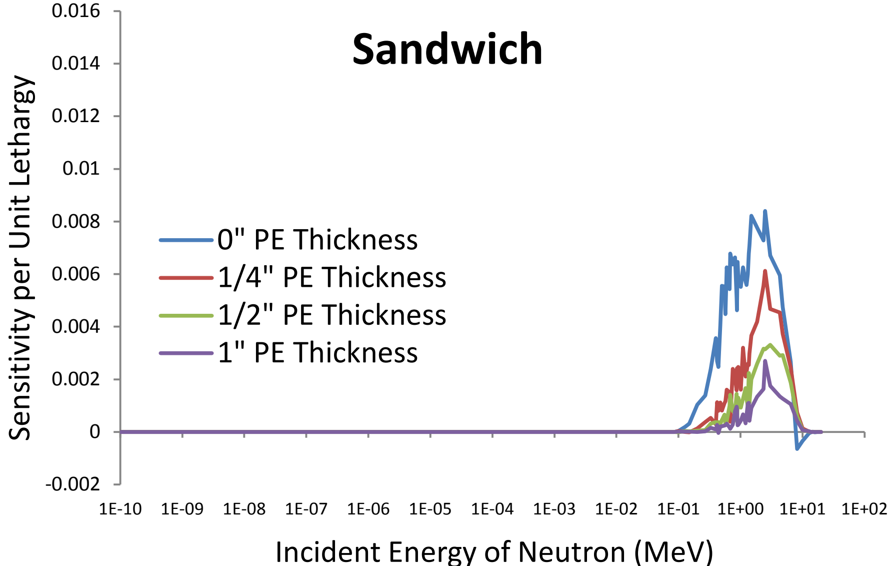


Sensitivity- Hafnium Inelastic Scatter

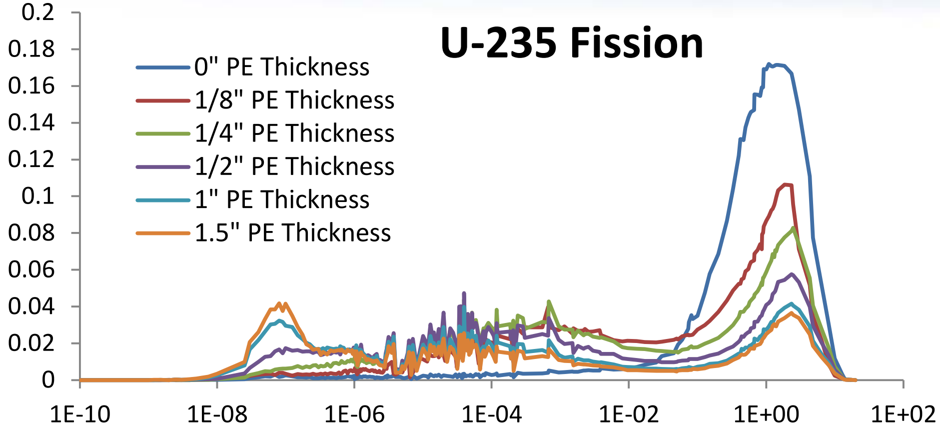
- Inelastic scattering only occurs at high energy
- Bunched hafnium is almost twice as sensitive
  - Unmoderated configuration
  - Sensitivity = 0.031
  - ~100% fast

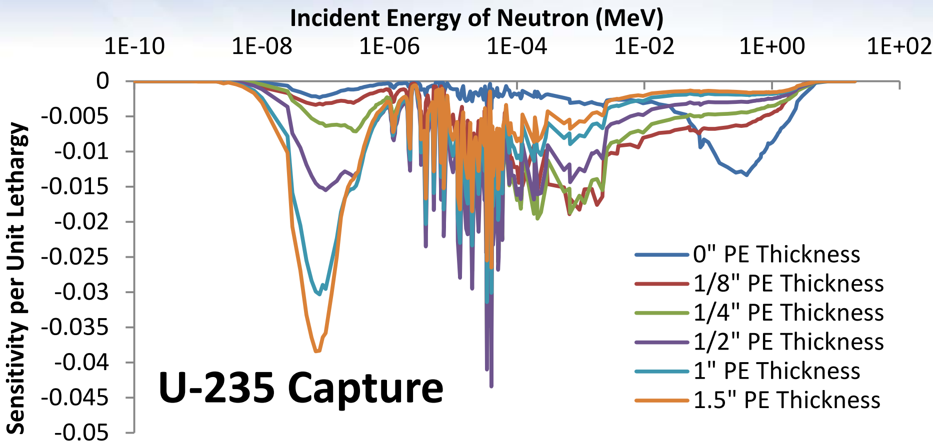






Sensitivity- U-235





- Thermal Regime:
  - Standard 1.5” PE
  - Total sensitivity = 0.305
  - 31.2% thermal
- Intermediate Regime:
  - Sandwich 1/4” PE
  - Total sensitivity = 0.481
  - 54.7% intermediate
- Fast Regime:
  - Unmoderated bunched
  - Total sensitivity = 0.600
  - 91.4% fast

- Thermal Regime:
  - Baseline 1.5” PE
  - Total sensitivity = -0.158
  - 55.8% thermal
- Intermediate Regime:
  - Bunched 1/8” PE
  - Total sensitivity = -0.150
  - 84.3% intermediate
- Fast Regime:
  - Unmoderated bunched
  - Total sensitivity = -0.057
  - 58.9% fast

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.
- **Uncertainty**
  - Total predicted uncertainty for the experiments was 0.00114 Δk_{eff}, which can be further reduced with measurement of PE parts.

Schedule

CED-3 Schedule

- **FY 2017- Quarter 3 and Quarter 4**
  - **Project Introduction:** prepare facility documentation and reactor safety and experimental plans.
  - **Procurements and Fabrication:** polyethylene, aluminum, and hafnium parts.
    - Hafnium plates provided by external sponsor
    - Cost to NCSP for other parts estimated to be around $10,000
- **FY 2018- Quarter 1, 2, & 3**
  - **Experiment Execution:** LLNL will work with NCERC personnel to schedule and conduct the 21 experiments for TEX-Hf.

CED-4 Schedule

- **Laboratory Reports:** A laboratory report summarizing each critical configuration will be completed one month after the completion of each experiment. These laboratory reports will record the experimental details needed for the ICSBEP benchmark.
- **ICSBEP Evaluations:** ICSBEP evaluations for all experiments will be completed in FY2018 Q4 and FY2019 Q1-2 for review by the ICSBEP review group in May of 2019.

Acknowledgements

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