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IER 203 CED-2: Final Design for New Critical Experiment Design to Investigate Composite Reflection Effect

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Catherine Percher, Soon Kim, Dave Heinrichs
Lawrence Livermore National Laboratory

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

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What is Composite Reflection?

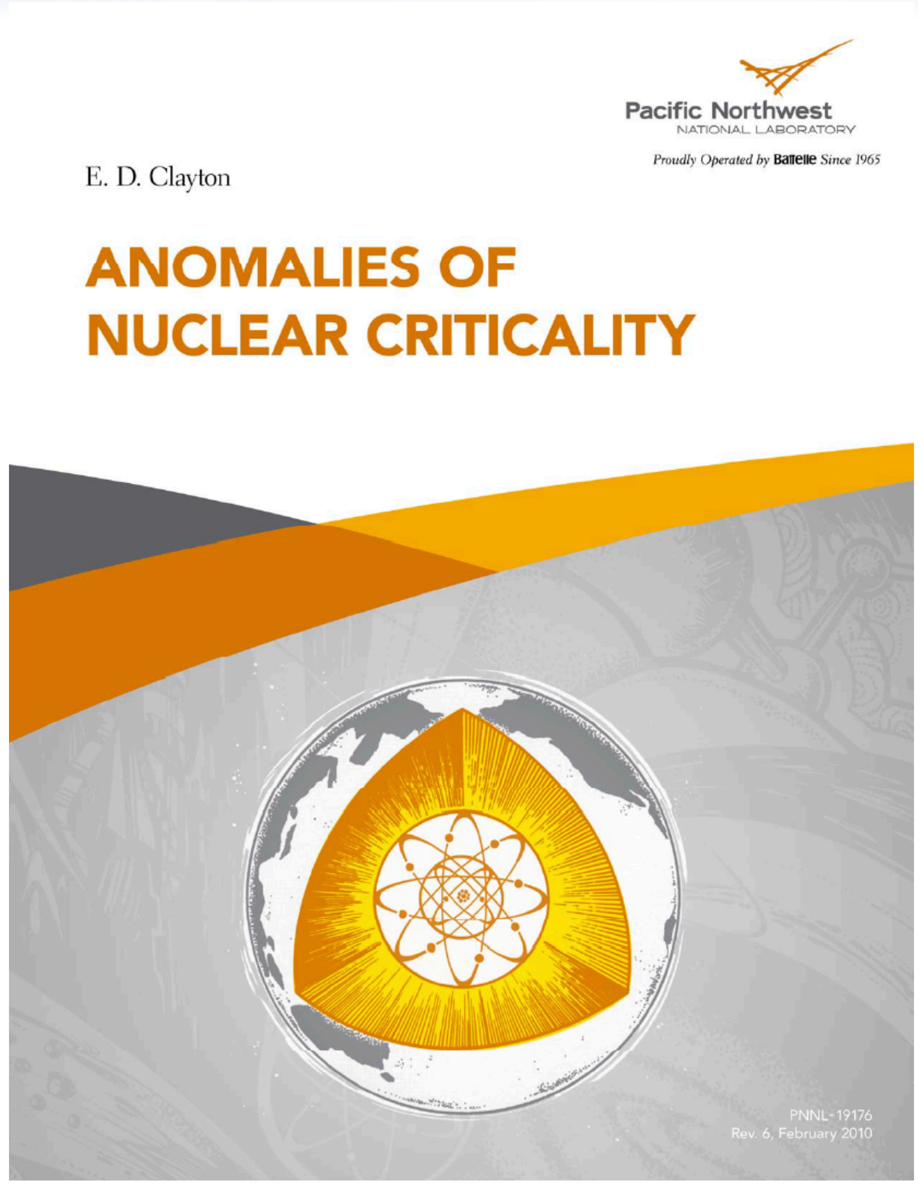
- A combination of two reflectors that acts in concert to produce more reactive nuclear systems than either single reflector separately
- LLNL's Nuclear Criticality Safety Division calculated surprisingly reactive configurations when a thin, moderating reflector was backed by a thick metal reflector
  - More reactive than either single reflector materials separately
  - Resulted in a stricter-than- anticipated criticality control set, impacting programmatic work

Previous Work

- *Anomalies of Nuclear Criticality*, Section K, “Complex Reflectors”
  - Brief Description of two cases of composite reflectors
    - **Paxton experiment:**

      1.27 cm Ni backed by 20 cm of depleted U (DU) yielded a smaller critical mass than either infinite reflector separately
    - **PNNL Experiment:**

      Arrays of low-enriched UO_2 rods with 2 cm of water reflection backed by 7.6 cm of DU, more effective than either thick water or DU



Previous Work

- RFNC-VNIITF Paper from ICNC 1995
  - Calculations and experimental investigations of combinations of Be and Polyethylene (PE) reflectors
  - Combinations of PE and Be reflectors were found to be more effective than either material as a single reflector of the same thickness
    - PE layer as an inner reflector had an optimal thickness of 1-1.5 cm, resulting in Δk/k ≈ 0.7%
    - Be-PE assemblies with total reflector thicknesses between 8 and 20 cm also showed effect, max Δk/k ≈ 1.5%

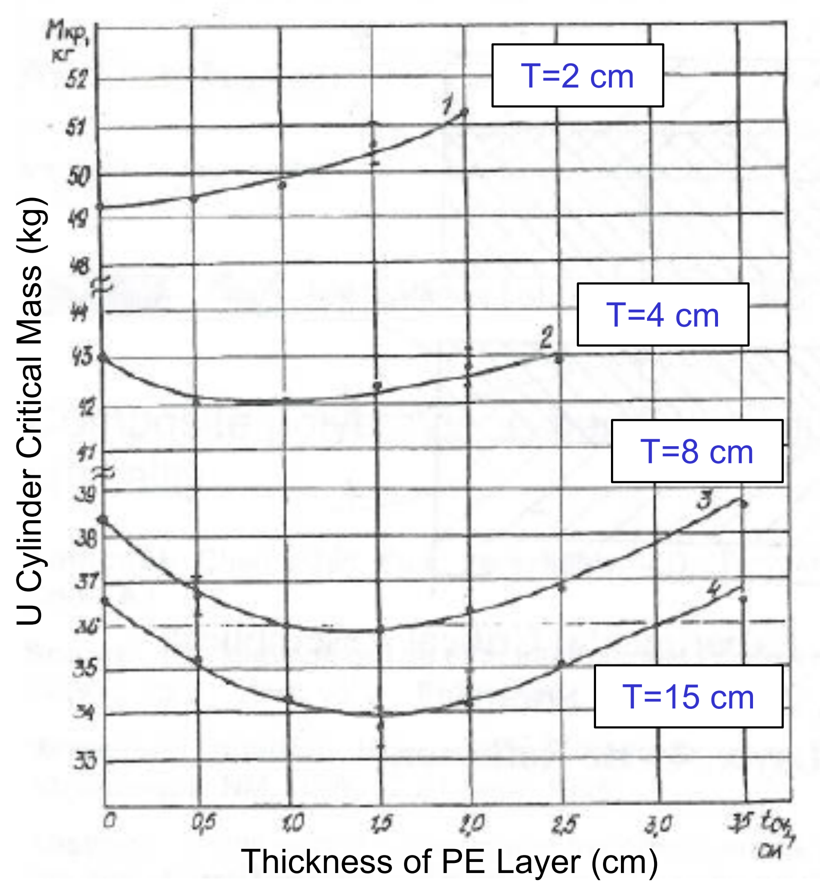


Figure: Experimental Results of Critical Masses of Solid ^{235}U Cylinders (20-cm diameter) as a function of PE Layer Thickness for Different Total Reflector Thicknesses (T)

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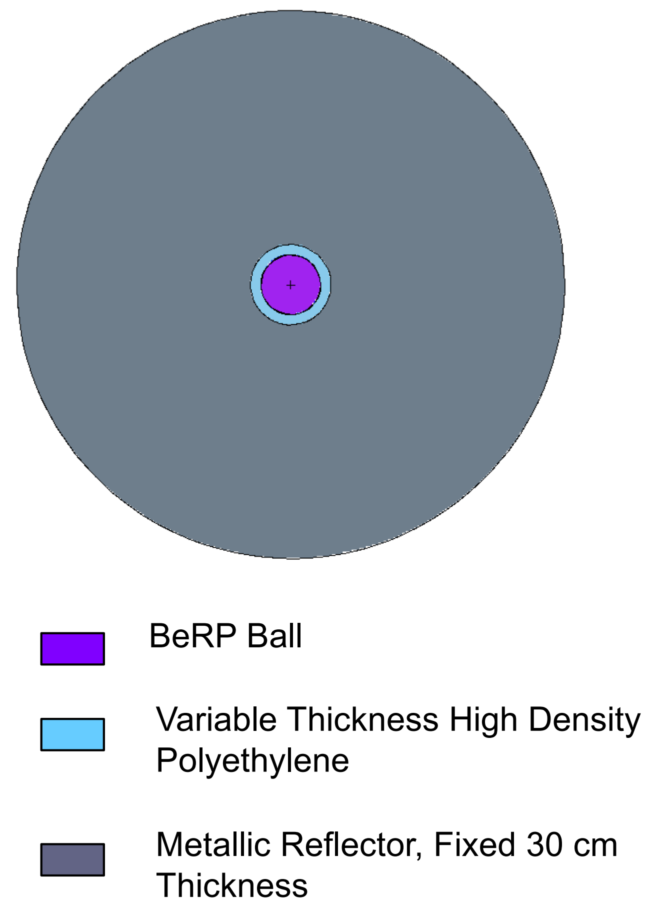
Current Work

- Based on prior experimental evidence, the composite reflector effect is believed to be real and experimentally viable
- CED-1 completed in FY14
  - BERP Ball with various combinations of polyethylene and other reflectors in spherical geometry
  - Showed feasibility BERP Ball critical with polyethylene backed by nickel reflectors
- CED-2 (Final Design) completed in FY16, focusing on:
  - Reasonable cost for nickel reflector fabrication
  - Realistic understanding of experimental uncertainties to ensure criticality is acheivable

Feasibility Studies (CED-1) Completed in FY14

- MCNP5 calculations with ENDF/B-VII.1 cross sections
- **Be**ryllium **R**eflected **P**lutonium (BeRP) Ball
  - 4.484 kg Pu (~6% ^{240}Pu)
- Composite Reflectors with Polyethylene
  - Varying thicknesses of PE in direct contact with the BeRP Ball
  - Additional fixed 30 cm of 12 different reflector materials outside the PE layer
    - Ni, Fe, Cr, Ti, Mn, Zr, W, Al, Pb, Co, Cu, U (depleted)



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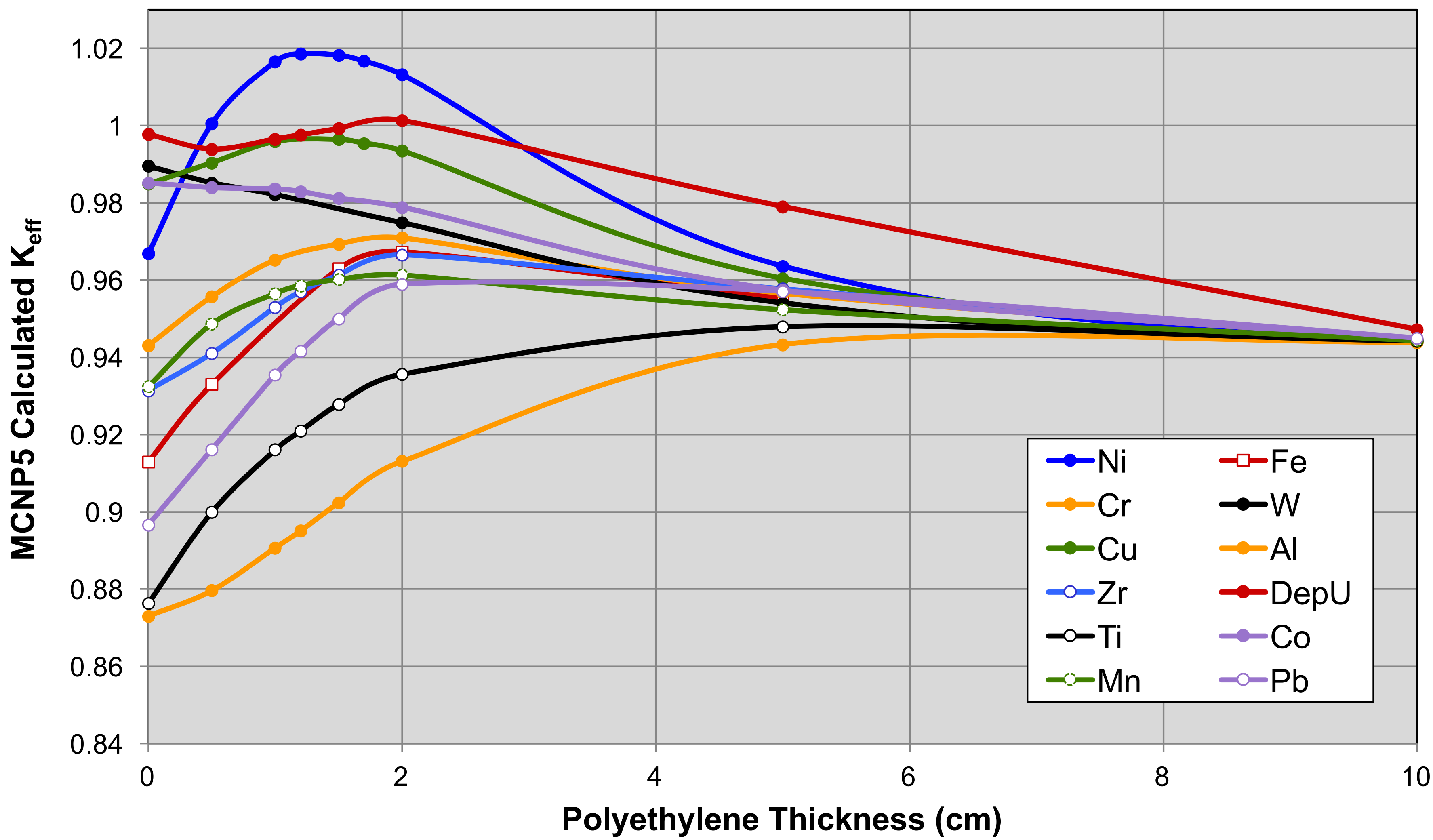
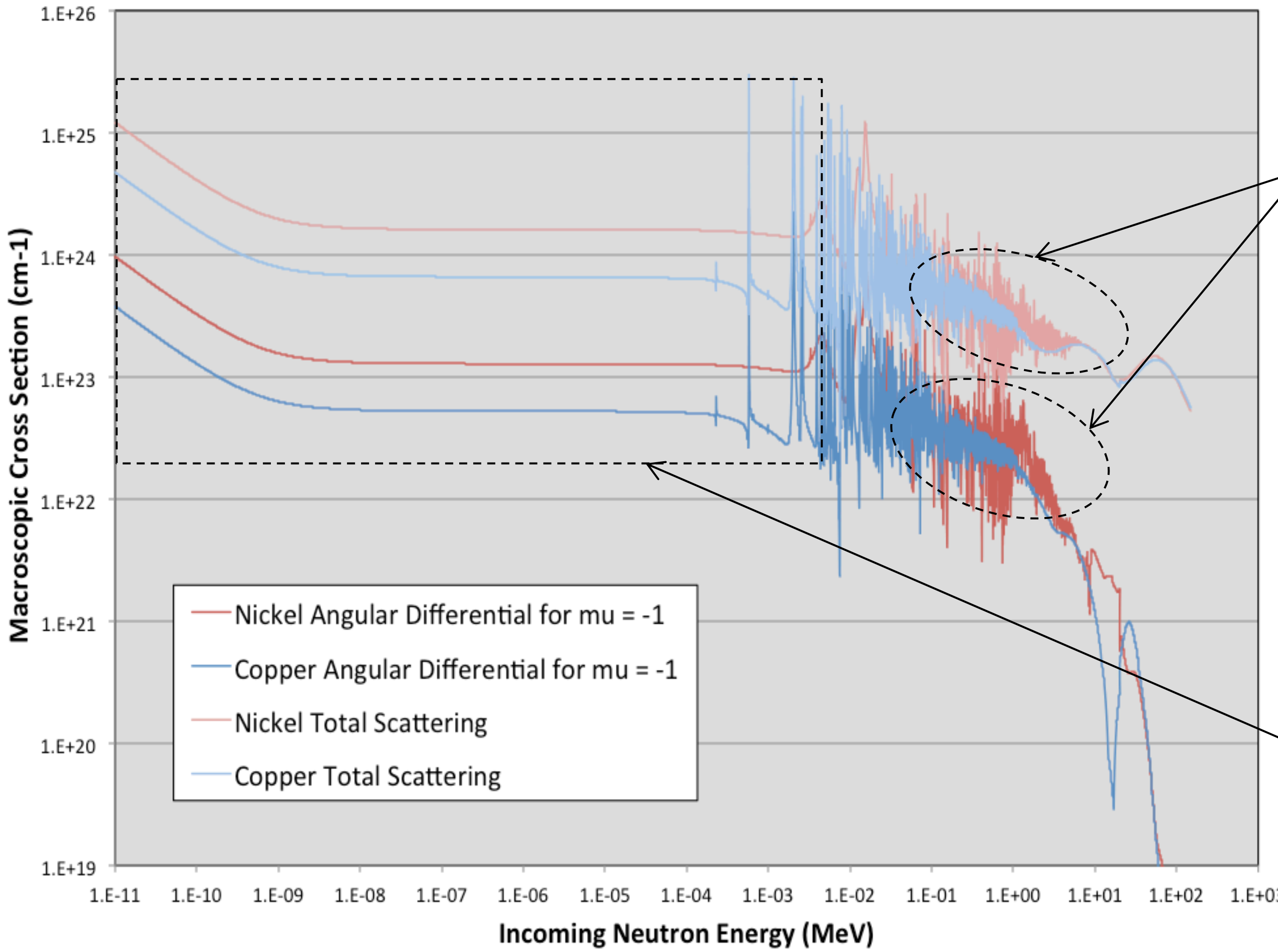
Results for Composite Reflection Calculations



Initial Results Overview

- Tungsten and Cobalt did not show a composite reflection effect with PE- higher k_{eff} with no PE
- All other studied reflectors showed some degree of composite reflection effect with PE
- DU and 2 cm PE predicted to be a just critical configuration
- Nickel and PE were shown to have the largest effect, peaking at 1.2 cm PE (k_{eff} = 1.0186(2))
  - Increase of 3.5% over purely Ni-reflected case and 9.3% over purely CH_2-reflected case

Why is Nickel so effective ?



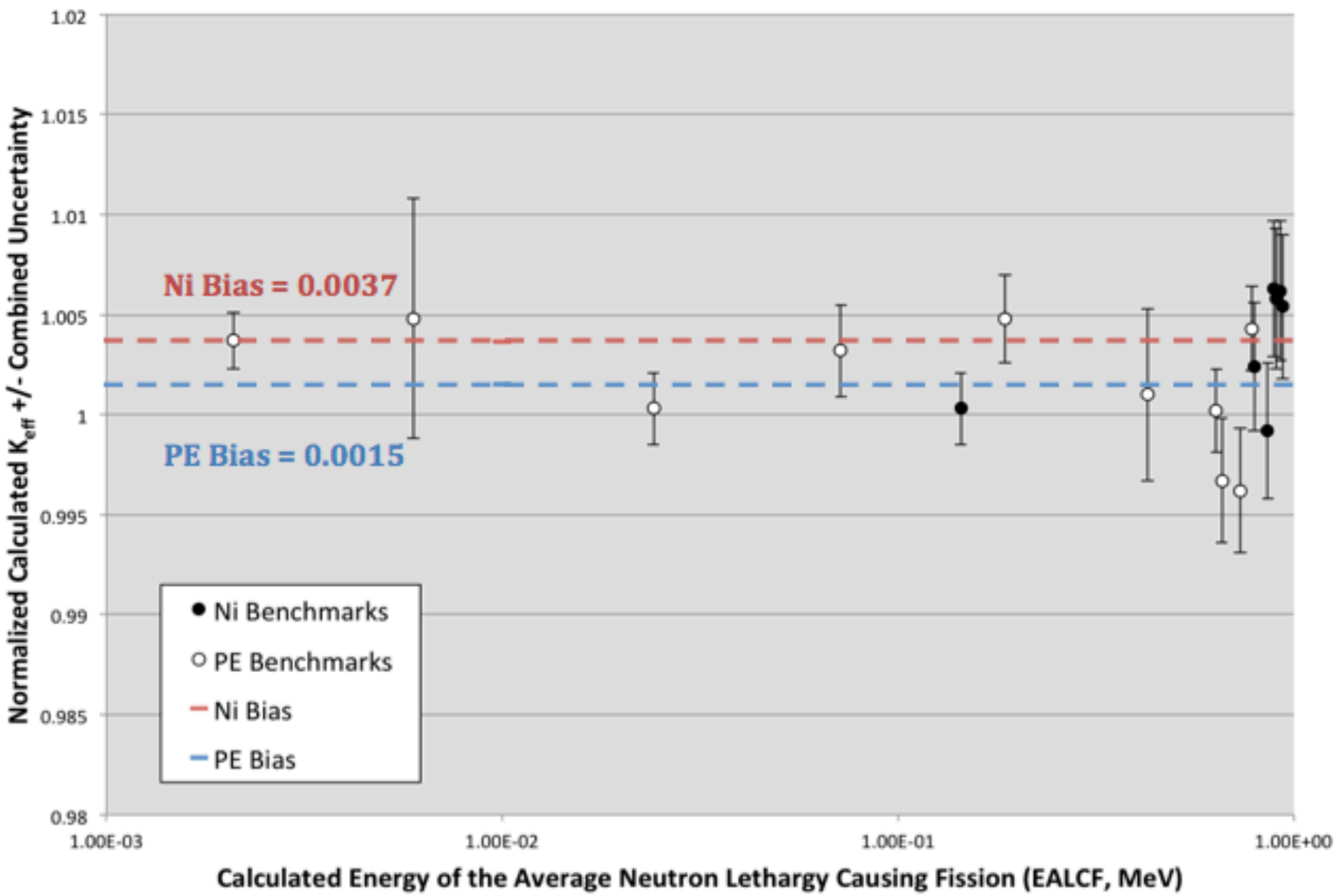
Higher cross section and resonance behavior in Ni for fast neutrons compared with Cu

Cross sections at lower energies are considerably higher (4-5 times more likely for neutrons to be scattered in Ni than Cu)

Estimation of Calculational Bias

- Calculational bias was investigated to determine if the MCNP5 calculations were believable
- The International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook was consulted for fast benchmark experiments with nickel or polyethylene reflection
  - Seven Ni-reflected experiments
  - 11 CH2-reflected experiments
- These 18 cases were run in MCNP5 using ENDF/B-VII.1 data libraries

Bias Calculation Results

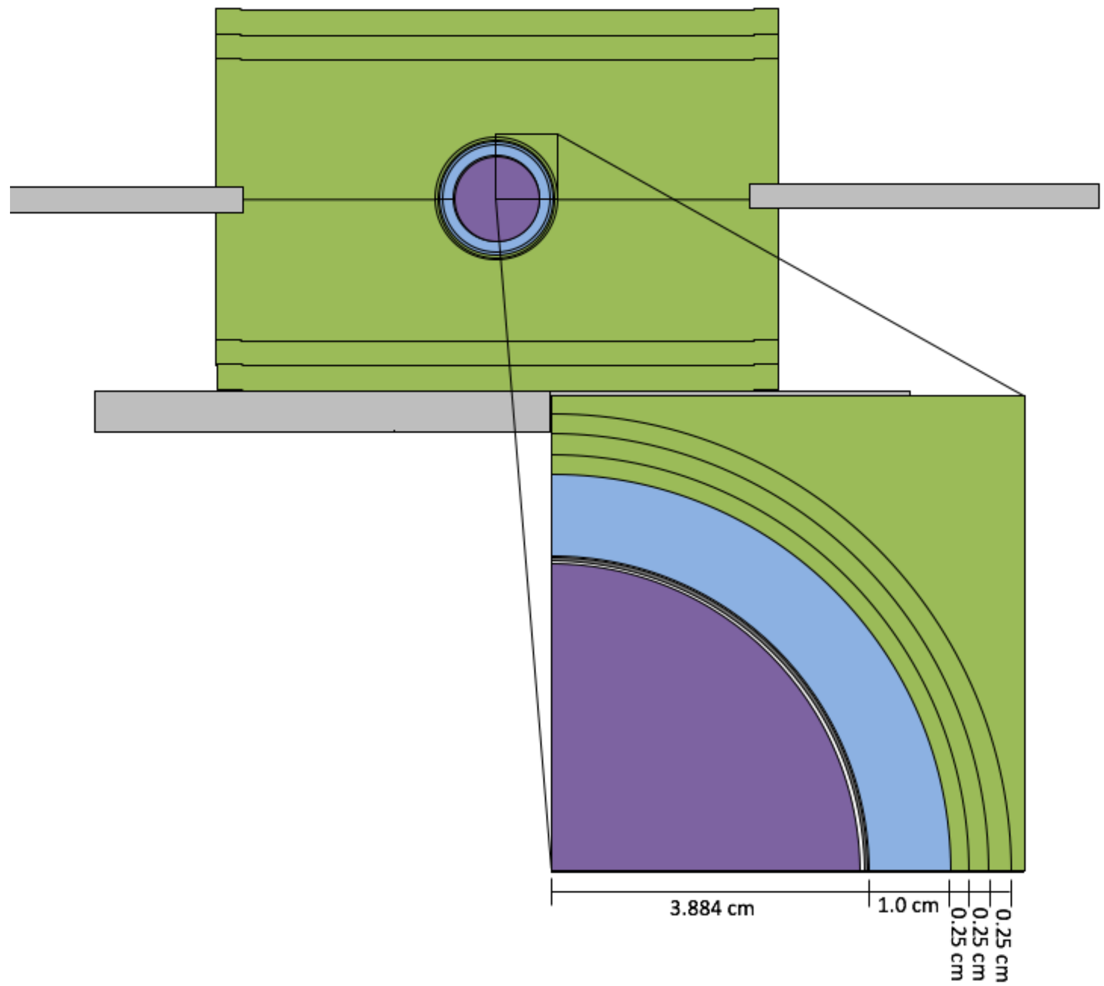


Conclusions from CED-1

- Polyethylene backed by nickel around the BeRP Ball was found to be the most reactive of all composite reflectors studied
- The optimal polyethylene thickness was found to be 1.2 cm and the corresponding critical nickel thickness is 12 cm. With 20 cm of Ni reflector, keff was calculated to be 1.0128
- Available ICSBEP evaluations point to a small positive bias for both Ni and PE when used as a reflector (0.0052 combined)
- Even taking this bias into account, it is appears that a critical system can be designed using the BeRP ball with a composite CH_2-Ni reflector

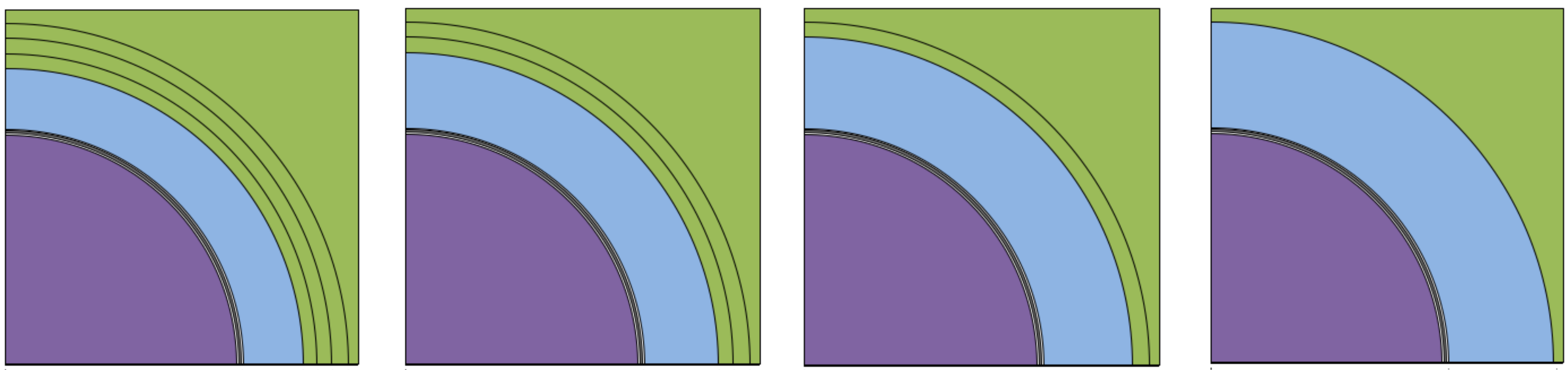
Final Design

- Cost of nesting Nickel Shells was prohibitively expensive (~$500K)
- A cylindrical Ni reflector was designed and analyzed
  - Two 5" thick, 20" diameter Ni monoliths, with internal spherical cavity
  - ½" and 1" thick Ni plates for reactivity shims
  - Thin (0.25 cm) Ni shells for adjustment of PE thickness



Four Critical Configurations with Varying PE

- PE shells designed to close-fit around the BERP ball
  - Four shells at different thicknesses- 1”, 1.25”, 1.5” and 1.75”
  - Will be combined with thin Ni shells to entirely fill Ni reflector cavity
- Allow for four different critical configurations and to hone in on optimal PE thickness



1 cm
PE Reflection

1.25 cm
PE Reflection

1.5 cm
PE Reflection

1.75 cm
PE Reflection

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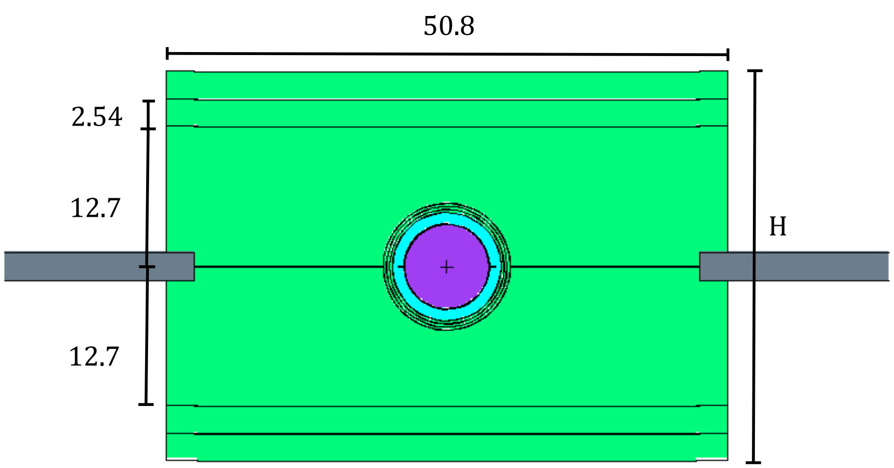
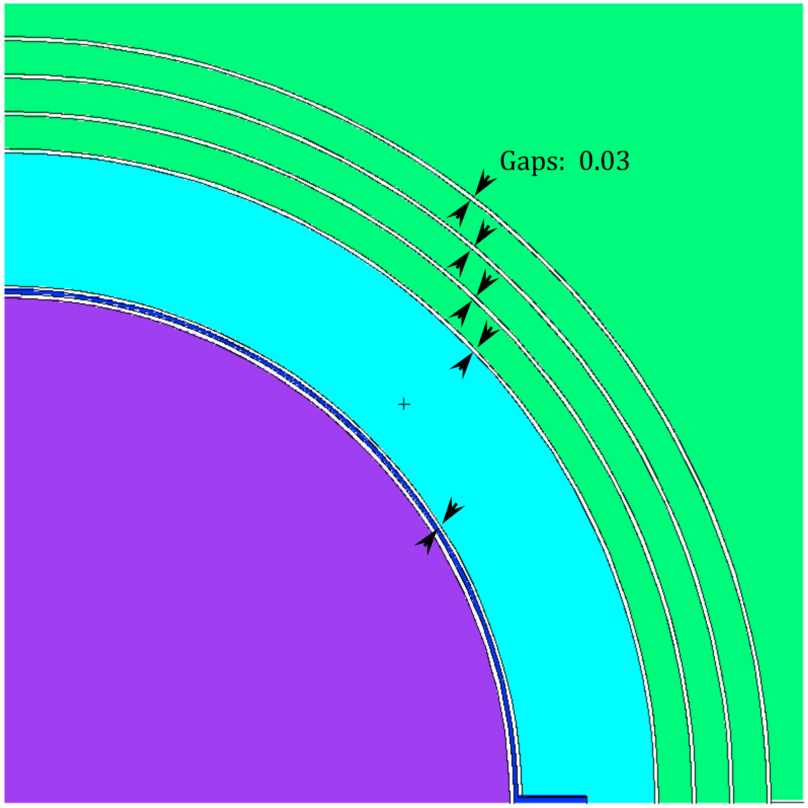
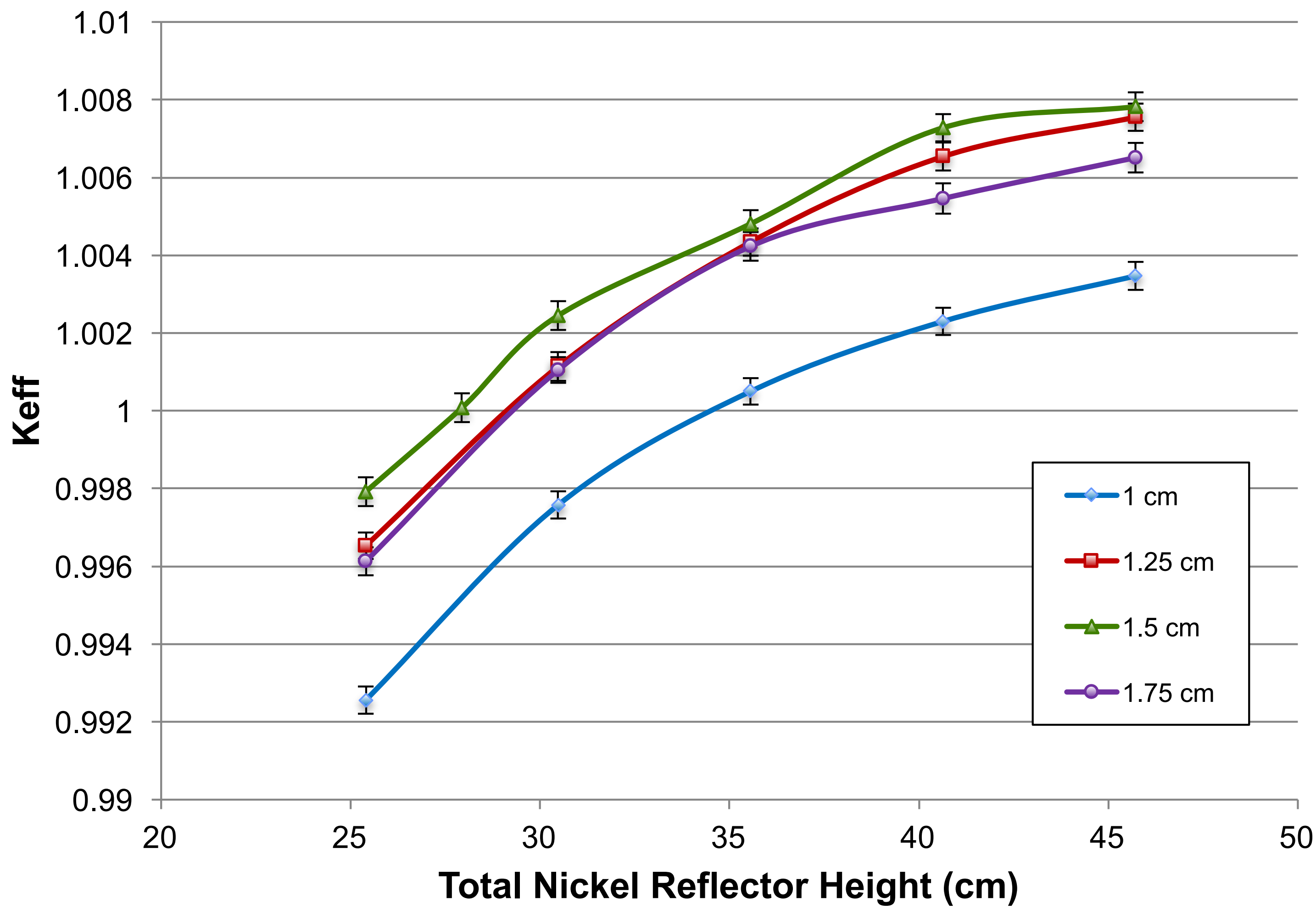
MCNP5 Modeling

- Detailed model of BERP ball based on 2014 LANL ICSBEP evaluation for FUND-NCERC-PU-HE3-MULT-001 (*Nickel-Reflected Plutonium-Metal-Sphere Subcritical Measurements*, B. Richard and J. Hutchinson)





MCNP Results for Calculations



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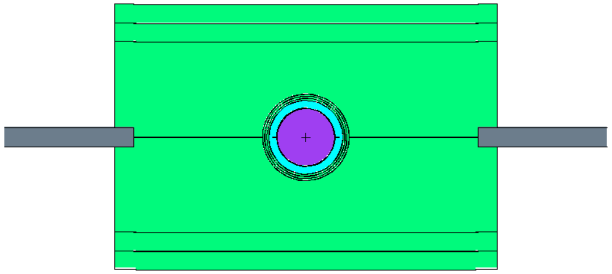
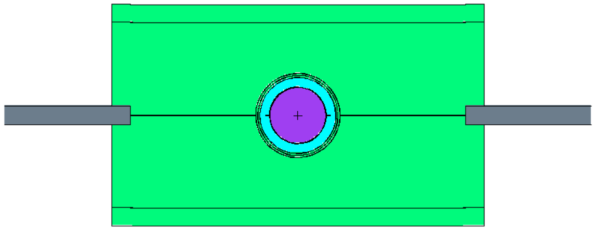
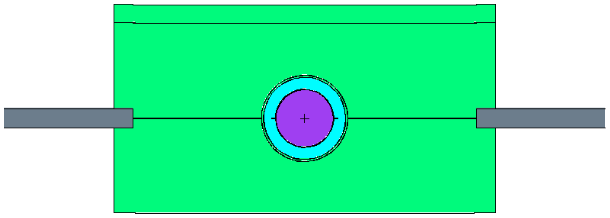
Predicted Critical Configurations

Experiment Number	Thickness of PE Shell (cm)	Critical Ni Reflector Height, H (cm)	Number of 1" Ni Plates	Approximate Total Ni Weight (kg)	$k_{eff} \pm \sigma$
1	1	35.56	4	636.73	1.00050 ± 0.00034
2	1.25	30.48	2	544.39	1.00114 ± 0.00037
3	1.5	27.94	1	497.78	1.00008 ± 0.00037
4	1.75	30.48	2	542.72	1.00105 ± 0.00033


H = 35.56 cm (14")


H = 30.48 cm (12")


H = 27.94 cm (11")

Analysis of Uncertainties and Model Bias

- Uncertainties for BERP Ball mirrored FUND-NCERC-PU-HE3-MULT-001- Fissile mass and radius, stainless steel mass and radius
- Density variations and machine tolerances for PE and Ni reflectors

Estimate of total uncertainties in k_{eff}: 0.00226

- Largely due to estimated uncertainties in PE and Ni reflector masses and dimensions
- Can be mitigated by characterization measurements

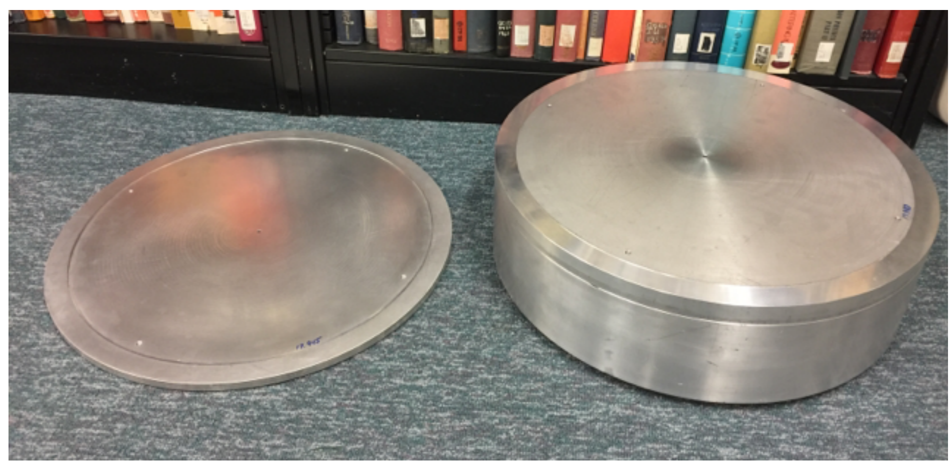
- Main sources of bias were BERP Ball vertical positioning, fissile and reflector impurities, temperature (up to 60 C), and room return

Estimate of total bias in k_{eff}: 0.00081

Costs and Schedule

- Fissile Material is existing
- Estimation for fabrication of all reflector parts: $100K
- Estimate for fabrication of Aluminum Platen: $5K

- Due to the cost of the Ni reflectors, LLNL is holding off on fabrication until the LANL Critical Experiment Safety Committee approves the IER-203 Experiment Plan, which is currently being drafted.
- Execution of the experiments is tentatively scheduled for early FY18.



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