NCSP
NUCLEAR CRITICALITY SAFETY PROGRAM

Lawrence Livermore National Laboratory

New Critical Experiment Design to Investigate Composite Reflection Effect

Catherine Percher, Soon Kim, David Heinrichs

2014 ANS Winter Meeting, Anaheim, CA

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

What is Composite Reflection?

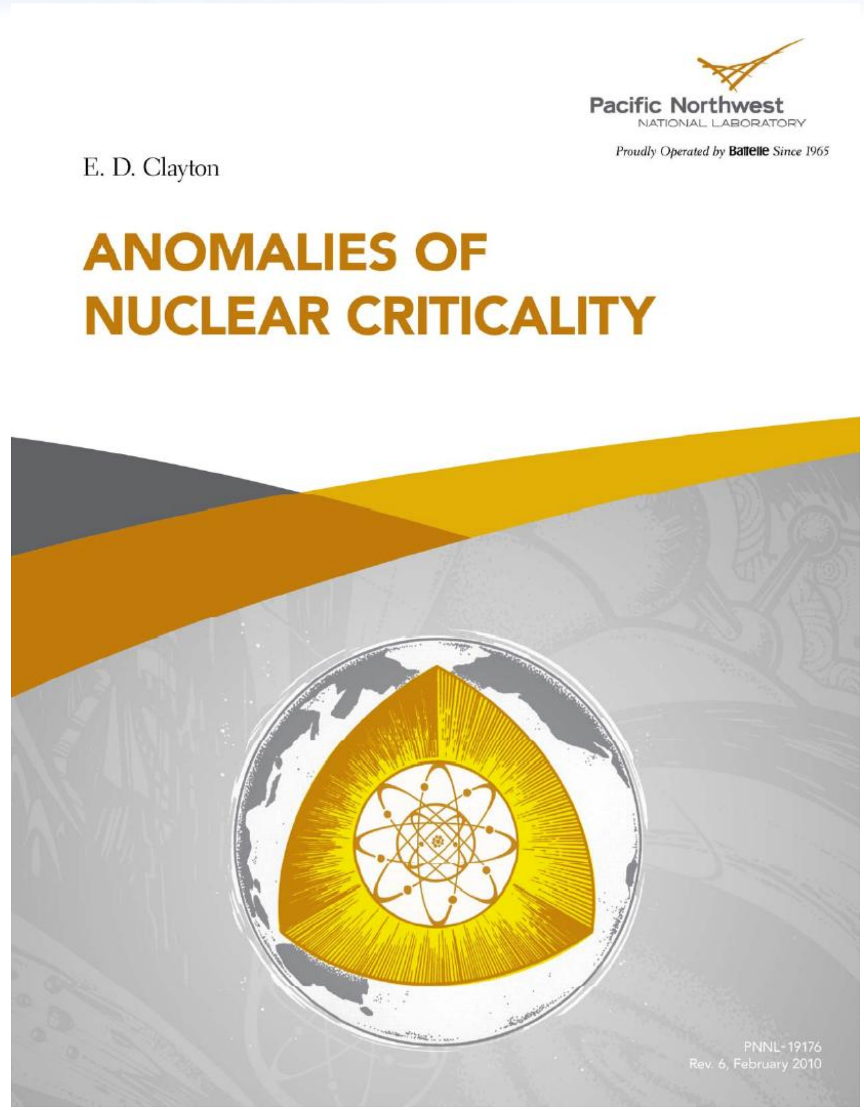
- A combination of two reflectors that acts in concert to produce more reactive nuclear systems than either single reflector separately
- LLNL's Nuclear Criticality Safety Division calculated surprisingly reactive configurations when a thin, moderating reflector was backed by a thick metal reflector
  - 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 CH_2 reflectors
  - Combinations of CH_2 and Be reflectors were found to be more effective than either material as a single reflector of the same thickness
    - CH_2 layer as an inner reflector had an optimal thickness of 1-1.5 cm, resulting in $\Delta k/k \approx 0.7\%$
    - Be-CH_2 assemblies with total reflector thicknesses between 8 and 20 cm also showed effect, max $\Delta k/k \approx 1.5\%$

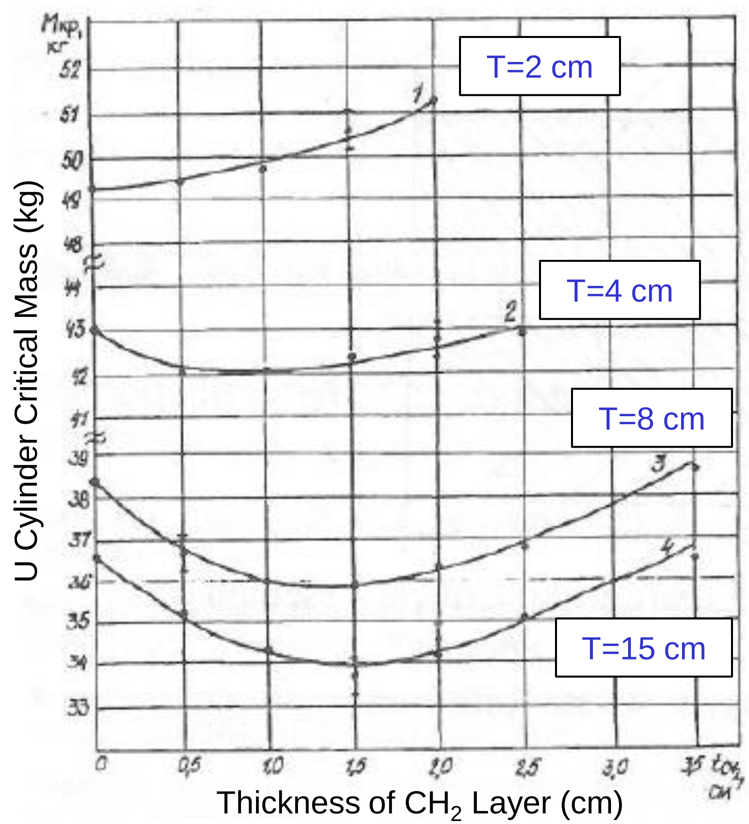


Figure: Experimental Results of Critical Masses of Solid ^{235}U Cylinders (20-cm diameter) as a function of CH_2 Layer Thickness for Different Total Reflector Thicknesses (T)

Lawrence Livermore National Laboratory

Current Work

- Based on prior experimental evidence, the composite reflector effect is believed to be real and experimentally viable

- Aim of current study to design an experiment using an existing plutonium sphere and common reflector materials in combination that will drive it critical

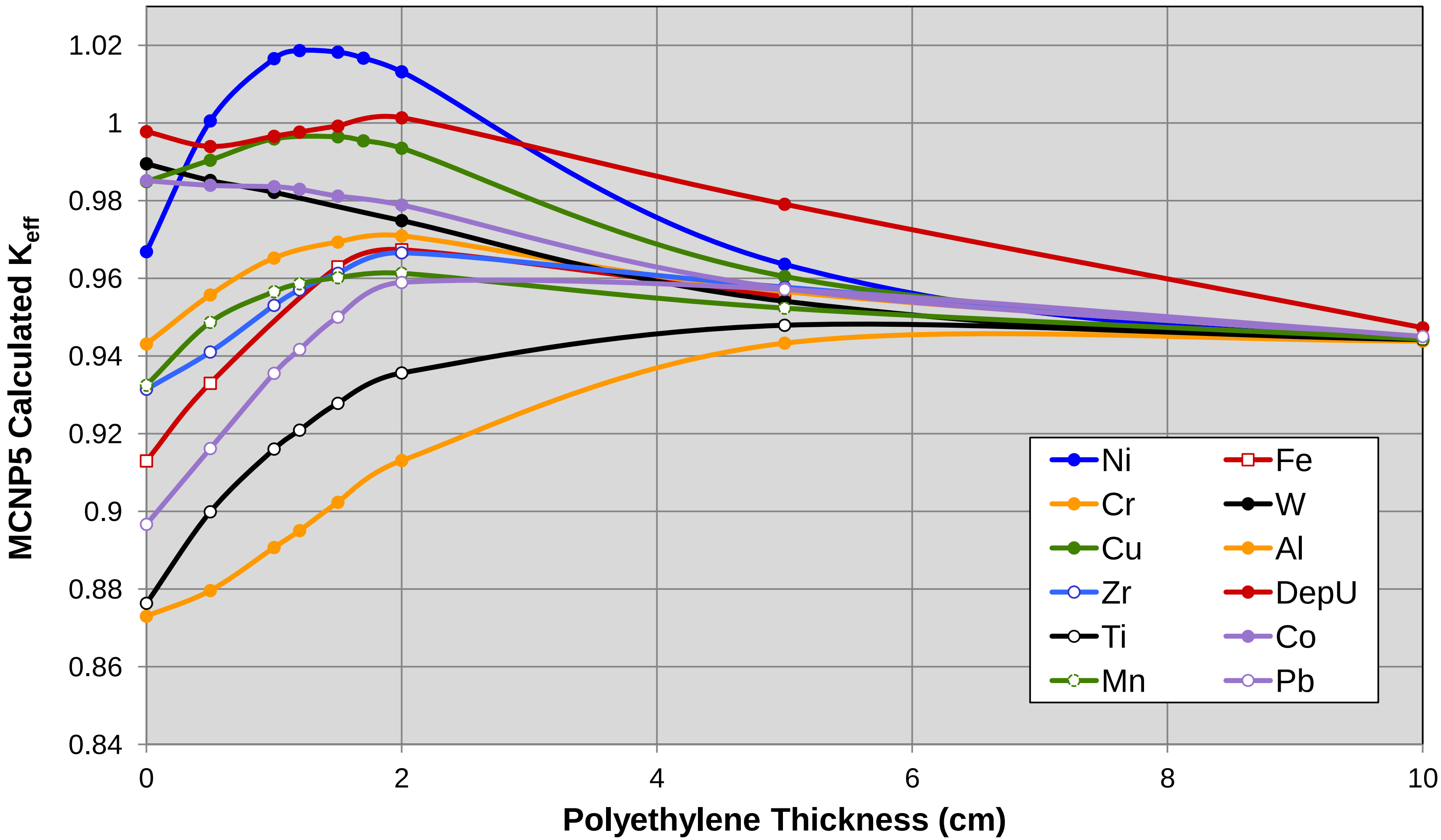
- Study could alert criticality practitioners to the potential hazard of composite reflection with common reflector materials

Feasibility Studies with the Pu BeRP Ball

- 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 CH_2 in direct contact with the BeRP Ball
  - Additional fixed 30 cm of 12 different reflector materials outside the CH2 layer
    - Ni, Fe, Cr, Ti, Mn, Zr, W, Al, Pb, Co, Cu, U (depleted)

Lawrence Livermore National Laboratory

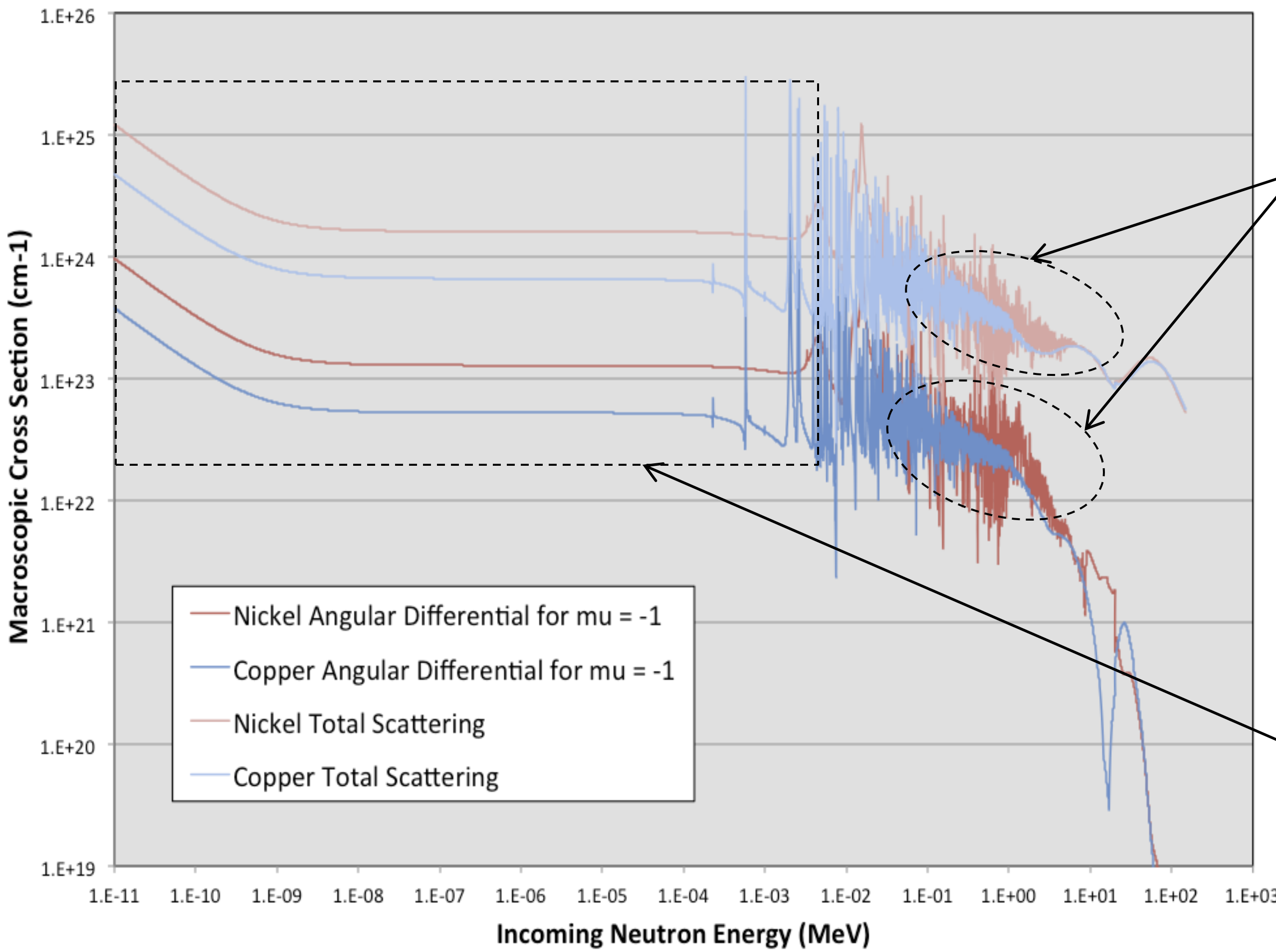
Results for Composite Reflection Calculations



Initial Results Overview

- Tungsten and Cobalt did not show a composite reflection effect with CH_2- higher k_{eff} with no CH_2
- All other studied reflectors showed some degree of composite reflection effect with CH_2
- DU and 2 cm CH2 predicted to be a just critical configuration
- Nickel and CH_2 were shown to have the largest effect, peaking at 1.2 cm CH_2 (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)

Reducing Ni Reflector Thickness

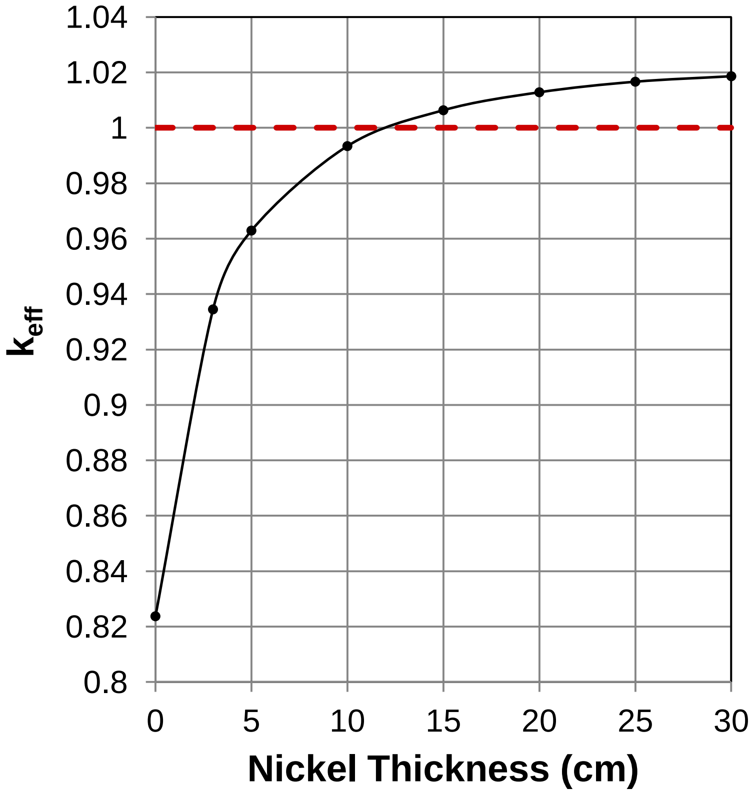


Figure: K_{eff} of the BeRP Ball as a Function of Varying Thicknesses of Nickel Outer Reflection with a Fixed 1.2 cm Inner Polyethylene Reflector

- Previous calculations used a fixed 30 cm Ni reflector
- Ni reflector thickness was varied to see the expected critical configuration
- 1.2 cm of CH2 backed by 12 cm of Ni is the predicted critical configuration
- 20 cm Ni reflector gives excess reactivity greater than 1% (keff = 1.0128(2))

Estimation of Calculational Bias

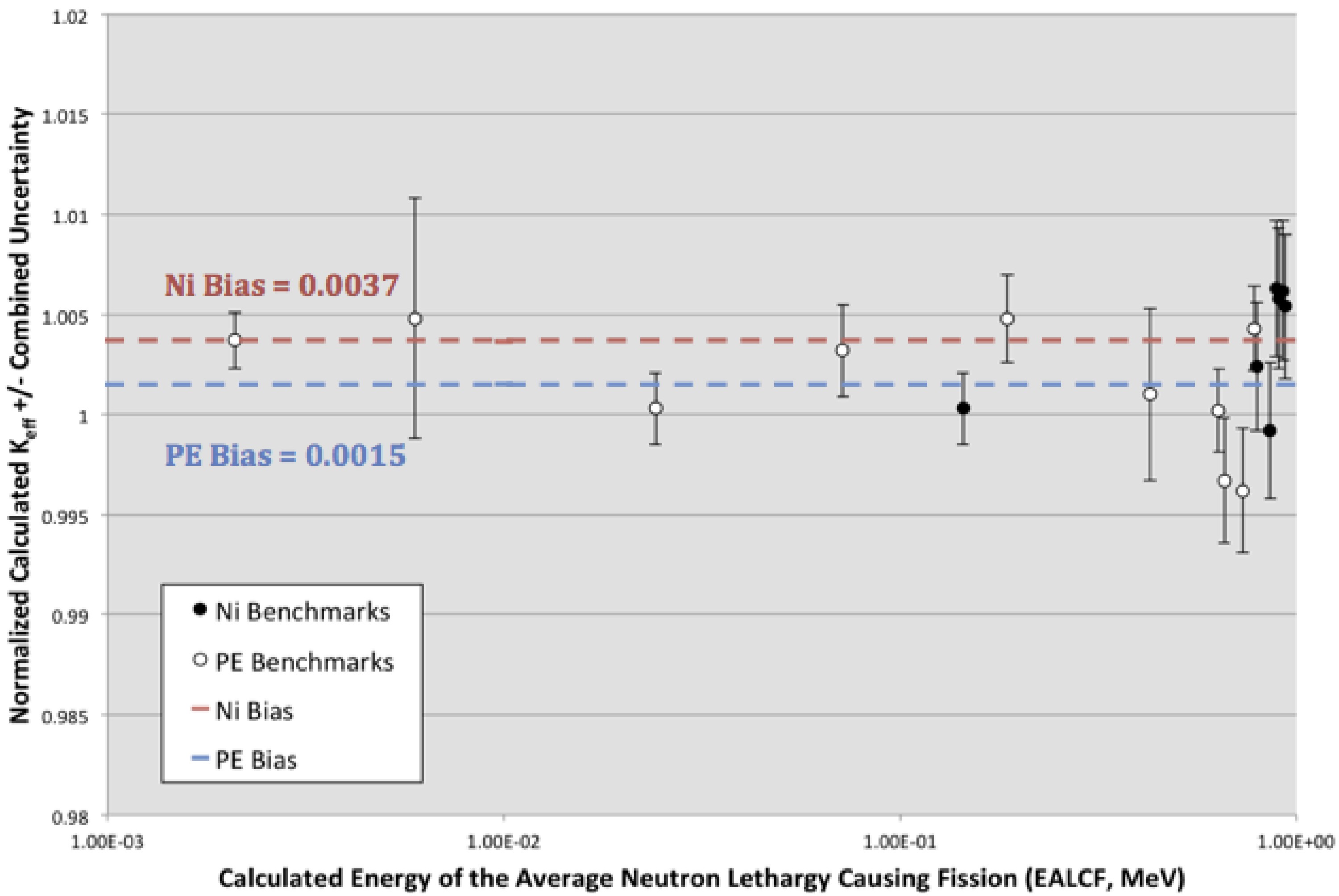
- Calculational bias was investigated to determine if the MCNP5 calculations were believable

- 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

Lawrence Livermore National Laboratory

Bias Calculation Results



Conclusions

- 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 CH2 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 of a critical experiment is currently underway as a joint LLNL/LANL project