SAND2009-2352C

# Benchmark Critical Experiments Containing Rhodium

## Advances in Nuclear Fuel Management IV

**Hilton Head Island, SC**

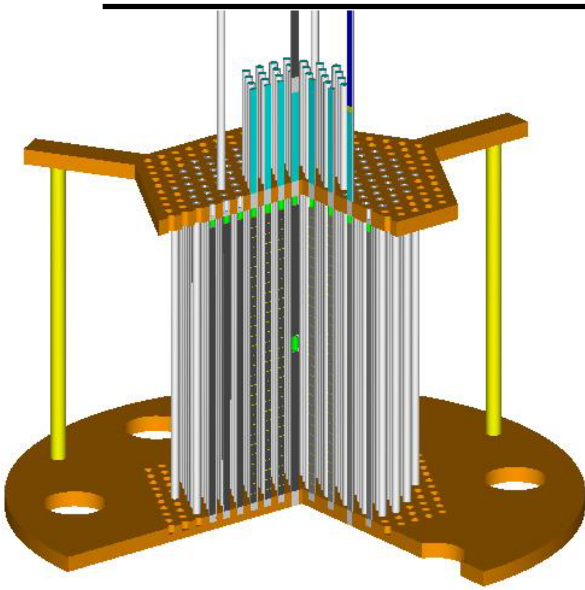
**April 12-15, 2009**

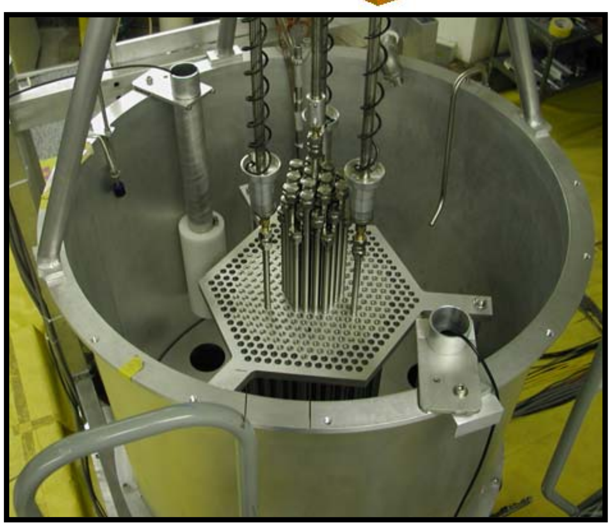
**Gary A. Harms**

**Sandia National Laboratories**
**Albuquerque, NM**

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

# We have built a new critical experiment capability that can be used to address burnup credit issues





- The Burnup Credit Critical Experiment (BUCCX) was funded by the Nuclear Energy Research Initiative (NERI)
- We built a critical assembly in which we could insert fission product simulants to measure reactivity effects
- The NERI funding was used to bring the experiment capability up and perform the first set of experiments
- We have completed a set of experiments with rhodium
- The experiment is documented as LEU-COMP-THERM-079 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments



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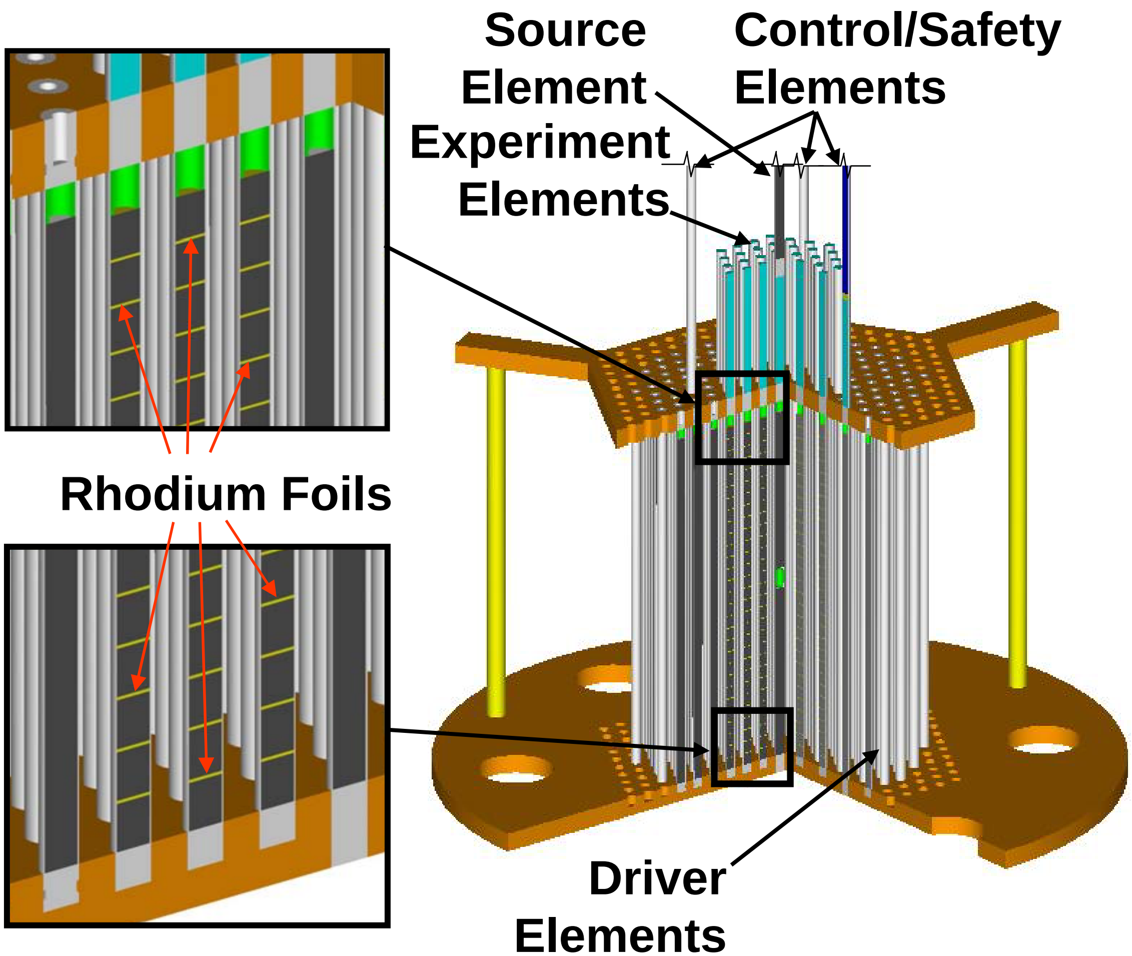
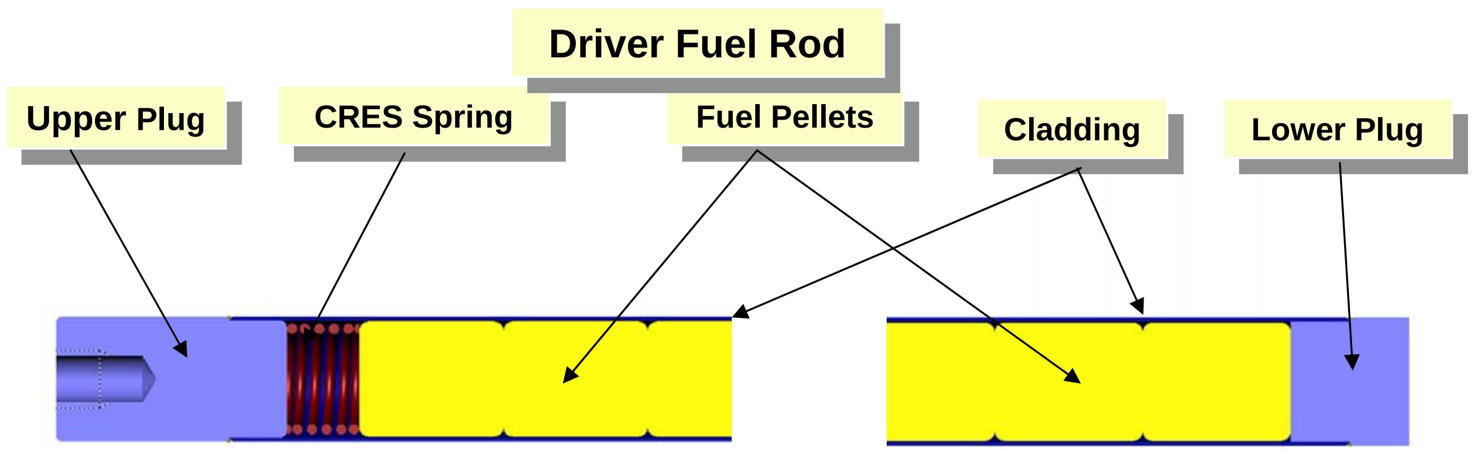
# The BUCCX core was designed to be easy to model




- The assembly is a triangular-pitched array of Zircaloy-4 clad $U(4.31\%)O_2$ fuel (driver) elements
- The assembly has 3 control/safety elements
  - the $B_4C$ absorber is decoupled from the assembly by a polyethylene spacer
  - the absorber is followed by a fuel rod
- Test materials are placed between the fuel pellets in "experiment elements"
- The source is in the central fuel element
- The grid plates are aluminum
  - the grid plates "line up" with the plugs at the top and bottom of the fuel rods
- The pitch of the array is modified by replacing the grid plates

# We used driver fuel rods that were fabricated for an earlier critical experiment

**The fuel was built for an earlier critical experiment. The $UO_2$ pellets come from fuel that was used in experiments at the Critical Mass Laboratory at Pacific Northwest Laboratories (now PNNL) documented in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC/95 (experiment LEU-COMP-THERM-002 and others). The uranium is 4.31% enriched and was well characterized at PNNL. Originally in aluminum tubes, the pellets were rebuilt into Zircaloy-4 tubes.**



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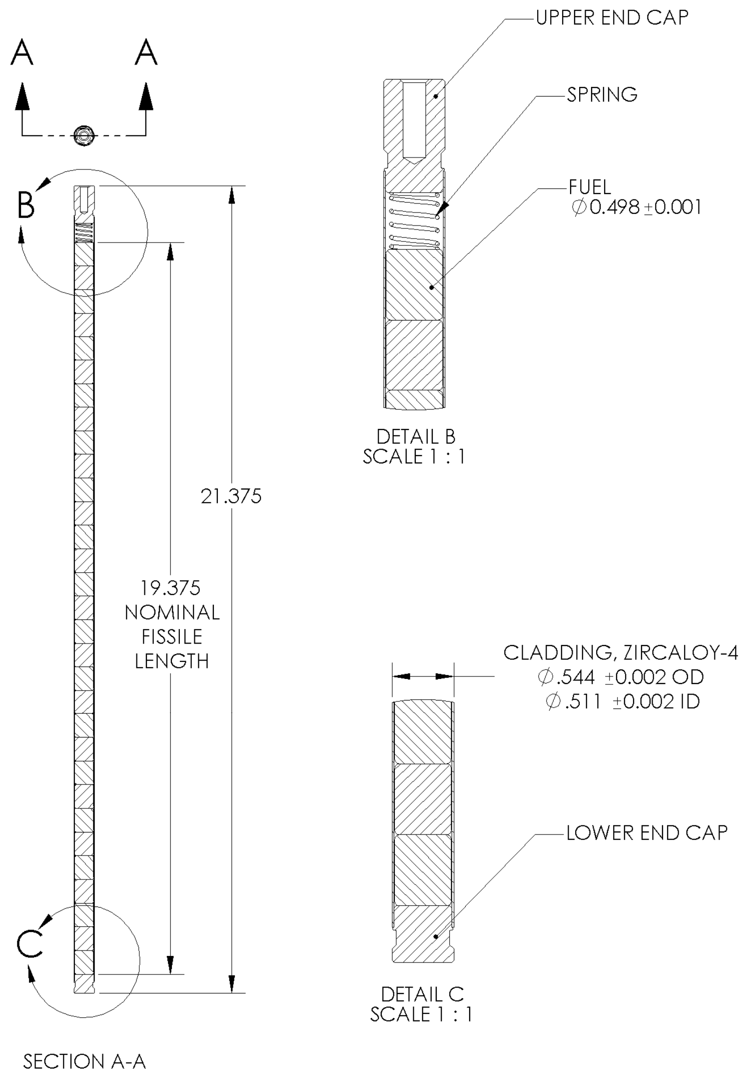
# We used driver fuel rods that were fabricated for an earlier critical experiment

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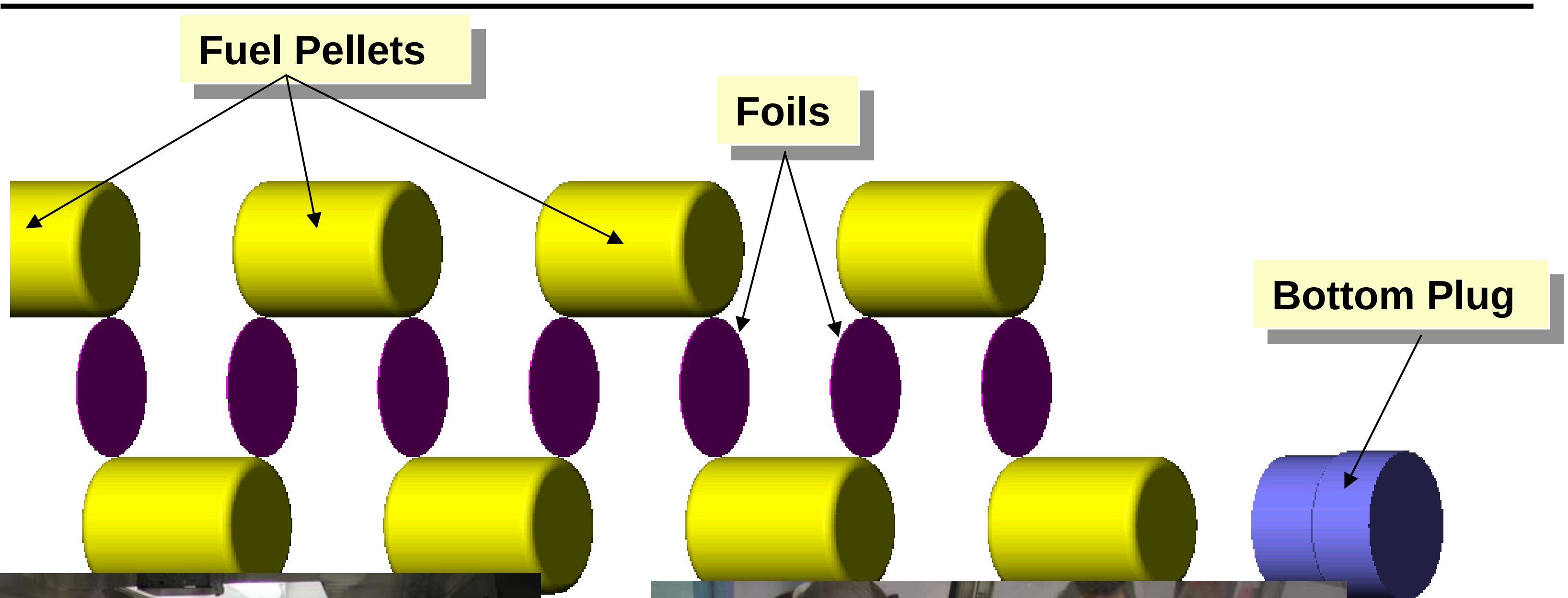
# We built special experiment fuel rods that give us access to the fuel pellets

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# The BUCCX assembly operated in the reactor room of the SPR Facility

# The BUCCX core shown at the end of an approach-to-critical experiment



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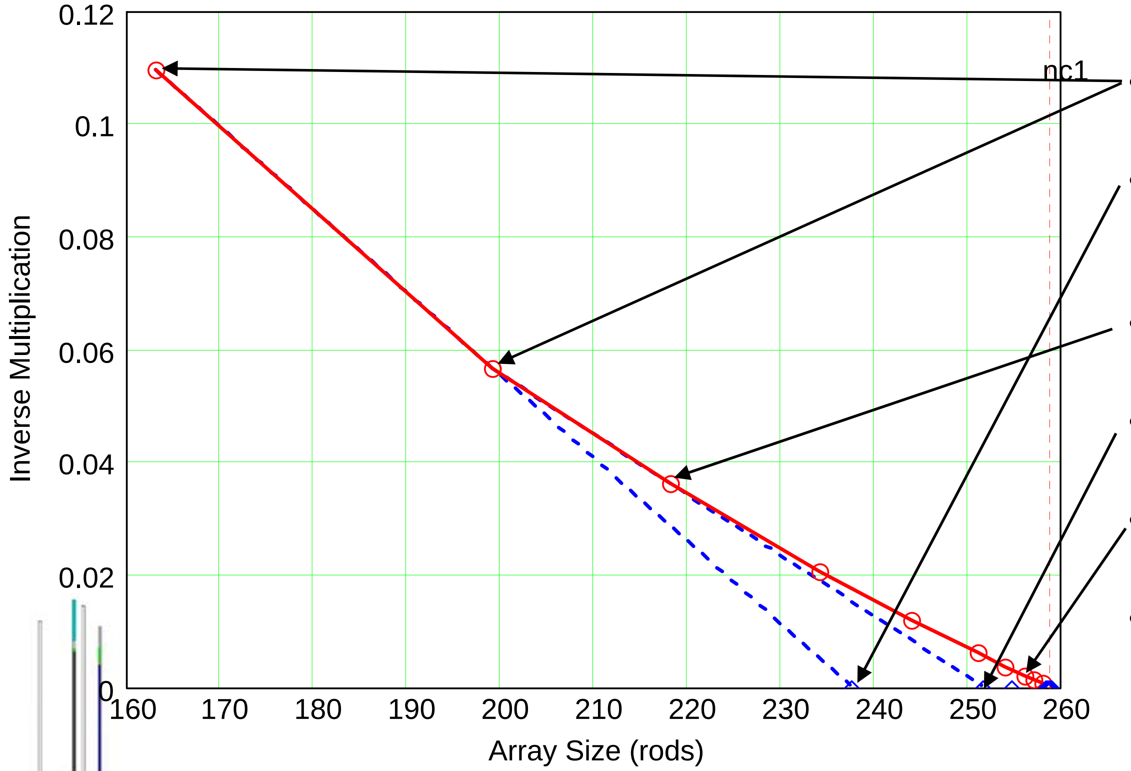
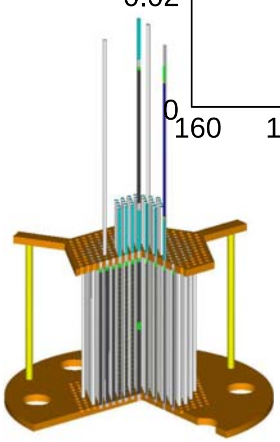
# We did 1/M approaches to critical to get the benchmark data




- **Pick two points each with calculated $k_{eff}$ less than 0.95**
- **Plot inverse multiplication and project to the axis for an estimate of the critical array size**
- **Add half the fuel difference between the estimate and the last array size**
- **Replot inverse multiplication and get a new estimate**
- **Repeat the fuel additions until the fuel increments get down to 1 rod**
- **Walk up the curve in 1 rod increments until a period is measured**



# We completed ten critical experiments

- **We used two grid plate sets**
  - **2.0 cm pitch – gives fuel-to-water ratio about the same as a PWR fuel element**
  - **2.8 cm pitch – gives a softer spectrum**
- **We did five experiments at each pitch**
  - **Driver fuel only**
  - **36 experiment elements with no foils**
  - **36 experiment elements each with 31 Rh foils (25 micron) between the 32 fuel pellets (1116 foils total)**
  - **36 experiment elements each with 31 Rh foils (50 micron)**
  - **36 experiment elements each with 31 Rh foils (100 micron)**



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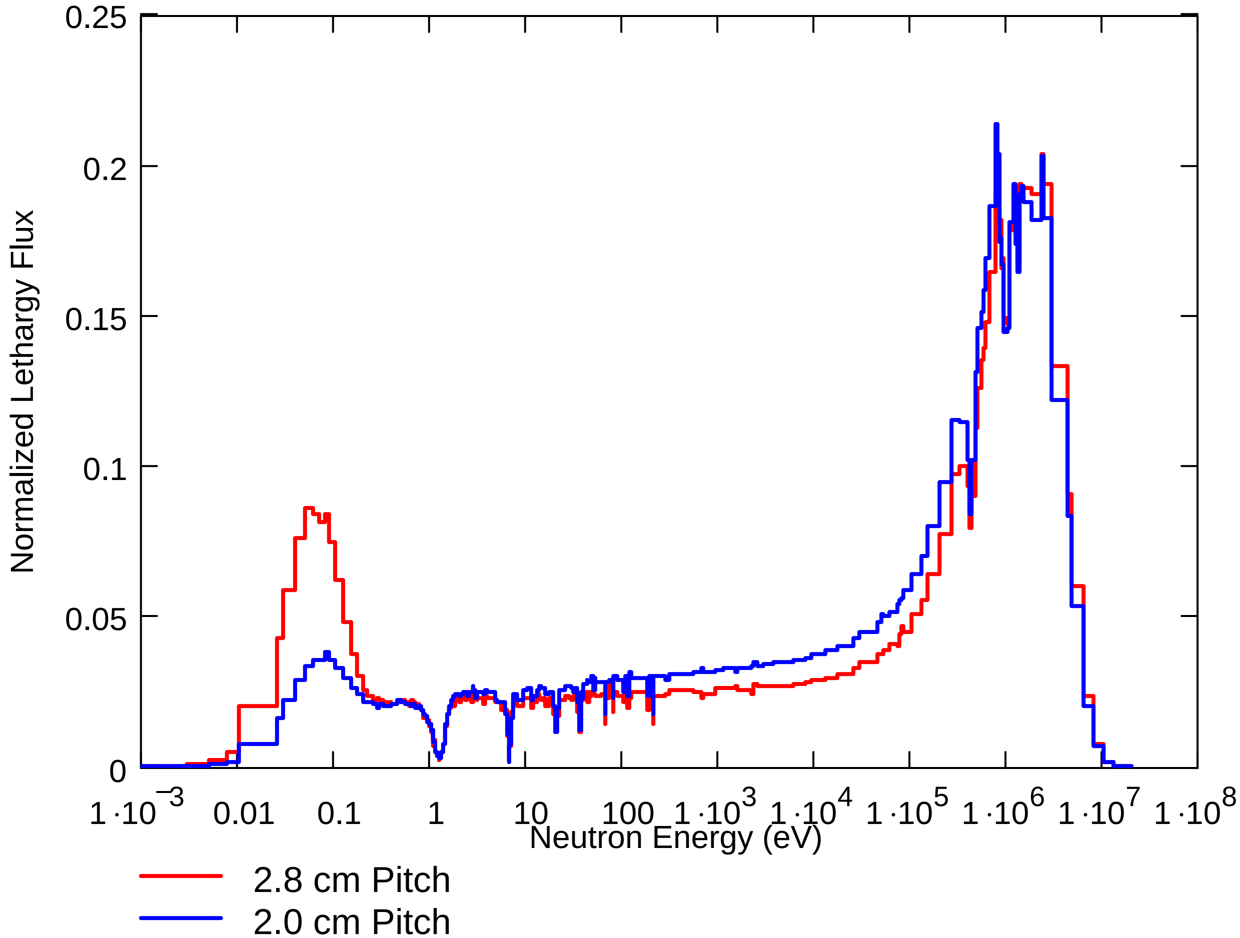
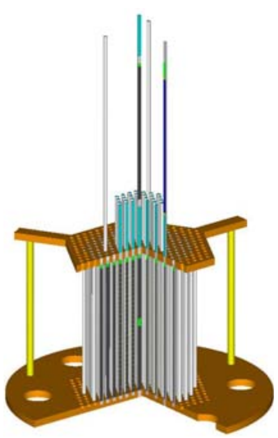
# The relative contributions from different parts of the spectrum change with fuel rod pitch




**The neutron spectra at 2.0 and 2.8 cm pitch in 0.1 mm rhodium foils**





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# The experimental uncertainties are relatively small

| Uncertainty | 2.0 cm Pitch | 2.8 cm Pitch |
|---|---|---|
| Pitch | 0.00074 | 0.00007 |
| Clad OD | 0.00123 | 0.00023 |
| Clad Thickness | 0.00032 | 0.00012 |
| Fuel OD | 0.00008 | 0.00005 |
| Upper Reflector Thickness | 0.00000 | 0.00000 |
| Rhodium Foil Diameter | 0.00007 | 0.00011 |
| Fuel Mass | 0.00003 | 0.00002 |
| Fuel Enrichment | 0.00045 | 0.00062 |
| Uranium Mass Fraction in Fuel | 0.00029 | 0.00017 |
| Zircaloy Clad Composition | 0.00029 | 0.00020 |
| Aluminum Grid Plate Composition | 0.00016 | 0.00011 |
| Source Capsule Composition | 0.00004 | 0.00000 |
| Rhodium Foil Composition | 0.00002 | 0.00004 |
| Water Moderator/Reflector Comp. | 0.00009 | 0.00015 |
| Assembly Temperature | 0.00008 | 0.00002 |
| **Sum in Quadrature** | **0.0016** | **0.0008** |

# The experimental uncertainties are relatively small

| Uncertainty | 2.0 cm Pitch | 2.8 cm Pitch |
|---|---|---|
| Assembly Dimensions | 0.00147 | 0.00029 |
| Fuel Effects | 0.00054 | 0.00064 |
| Composition Effects | 0.00034 | 0.00028 |
| Assembly Temperature | 0.00008 | 0.00002 |
| **Sum in Quadrature** | **0.0016** | **0.0008** |

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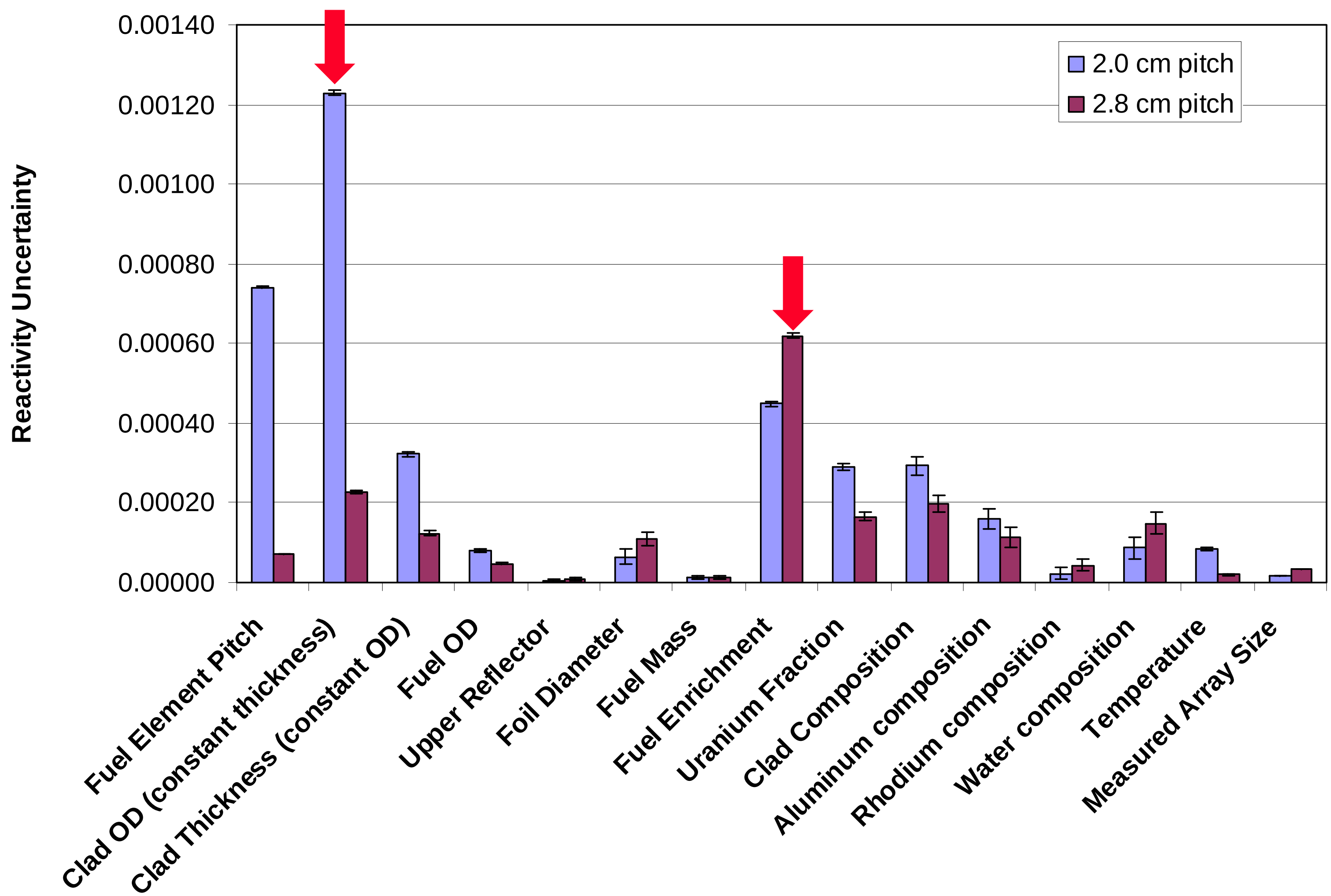
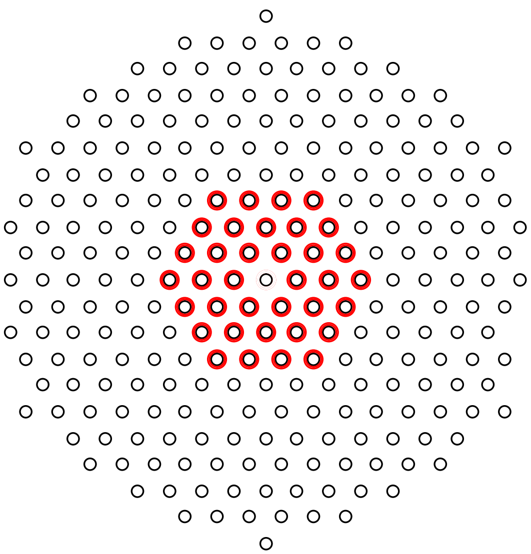
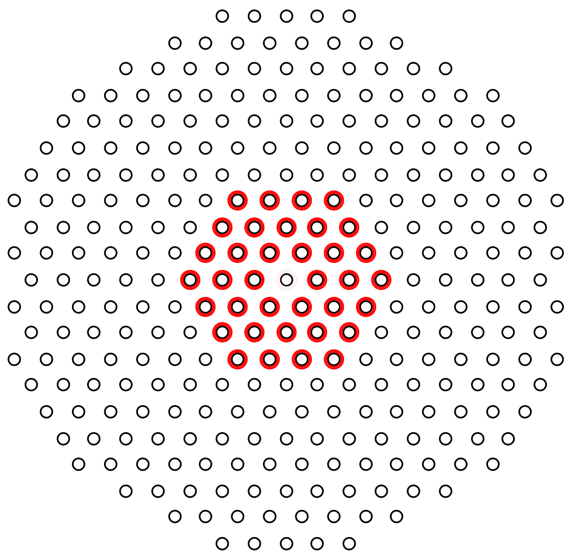
# The experimental uncertainties are relatively small



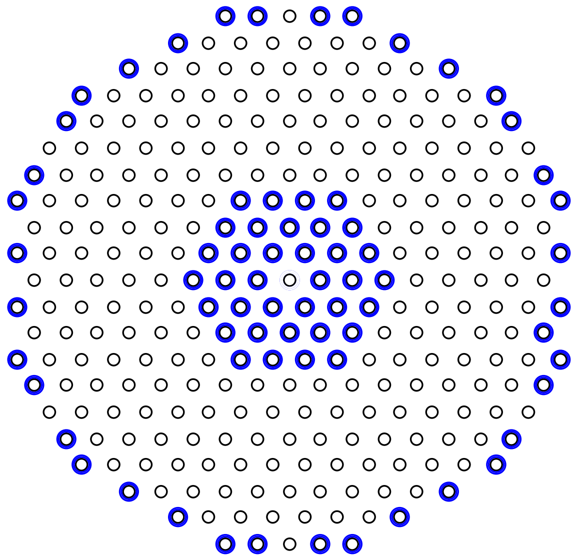
# Reduced uncertainties can be obtained for intercomparison of the experiment cores



Case 2



Case 5



Array Differences Highlighted

# The reduced uncertainties are smaller

| Uncertainty | 2.0 cm Pitch | 2.8 cm Pitch |
|---|---|---|
| Pitch | 0 | 0 |
| Clad OD | 0.00023 | 0.00006 |
| Clad Thickness | 0.00005 | 0.00002 |
| Fuel OD | 0.00005 | 0.00013 |
| Upper Reflector Thickness | 0.00000 | 0.00000 |
| Rhodium Foil Diameter | 0.00007 | 0.00011 |
| Fuel Mass | 0.00001 | 0.00001 |
| Fuel Enrichment | 0.00016 | 0.00033 |
| Uranium Mass Fraction in Fuel | 0.00003 | 0.00015 |
| Zircaloy Clad Composition | 0.00003 | 0.00007 |
| Aluminum Grid Plate Composition | 0 | 0 |
| Source Capsule Composition | 0 | 0 |
| Rhodium Foil Composition | 0.00000 | 0.00001 |
| Water Moderator/Reflector Comp. | 0 | 0 |
| Assembly Temperature | 0.00008 | 0.00002 |
| **Sum in Quadrature** | **0.0003** | **0.0004** |

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# The reduced uncertainties are smaller

| Uncertainty | 2.0 cm Pitch | 2.8 cm Pitch |
|---|---|---|
| Assembly Dimensions | 0.00024 ← | 0.00014 |
| Fuel Effects | 0.00016 | 0.00036 ← |
| Composition Effects | 0.00012 | 0.00017 |
| Assembly Temperature | 0.00008 | 0.00002 |
| **Sum in Quadrature** | **0.0003** | **0.0004** |



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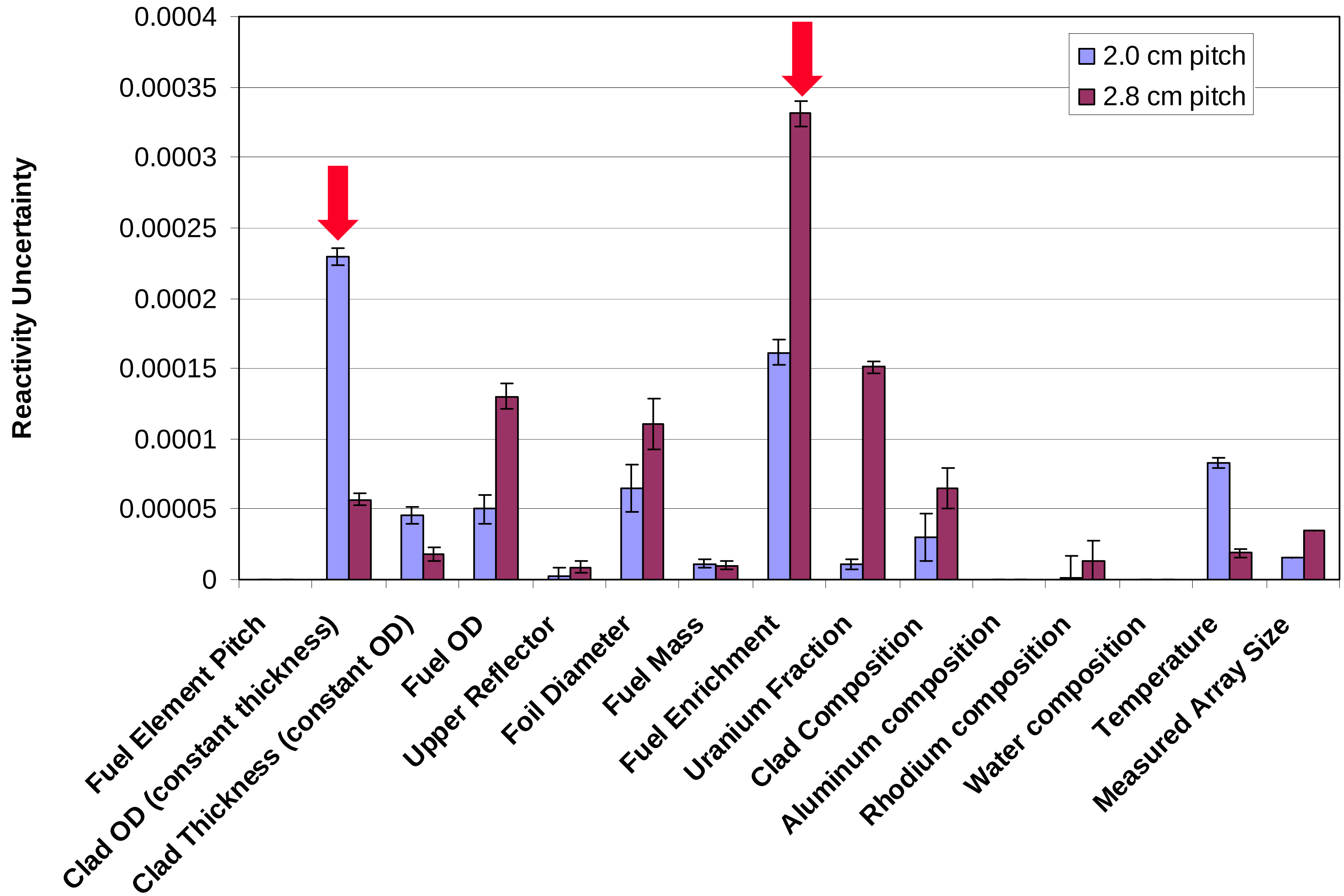
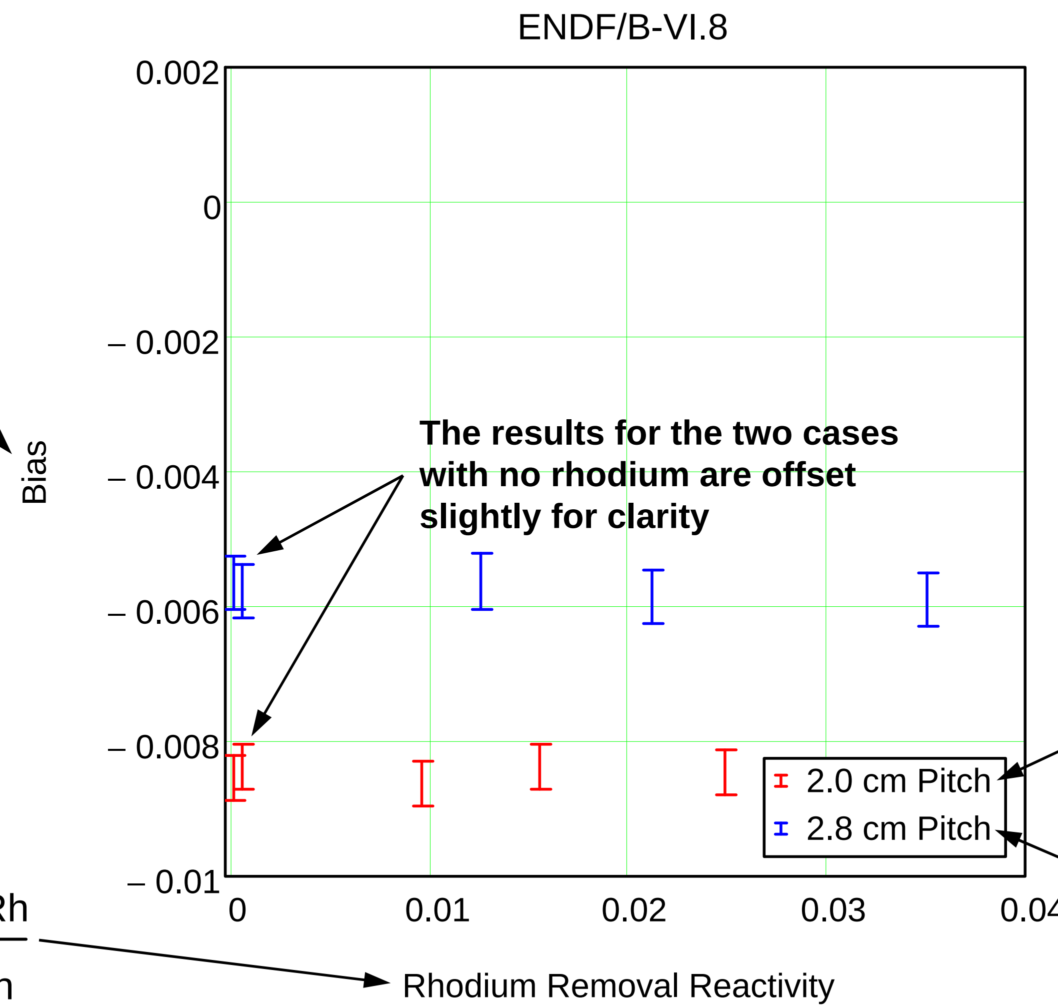
# The reduced uncertainties are smaller



# A brief explanation of the content on the next three slides

$k_{calc} - k_{expt}$




$$\frac{k_{no\_Rh} - k_{with\_Rh}}{k_{no\_Rh} \cdot k_{with\_Rh}}$$

**Approximate PWR Fuel to Water Ratio**

**Near Optimum Moderation**



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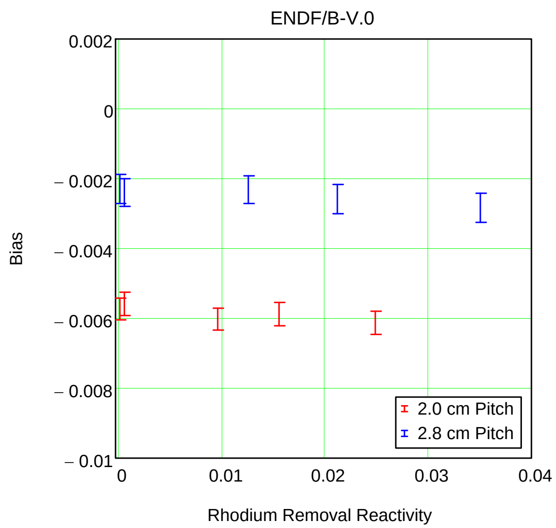
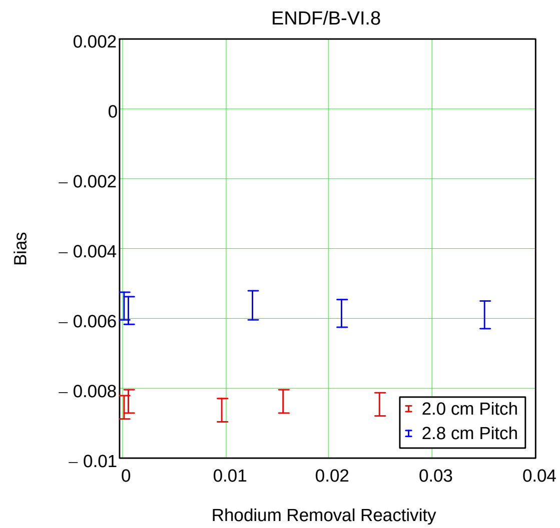
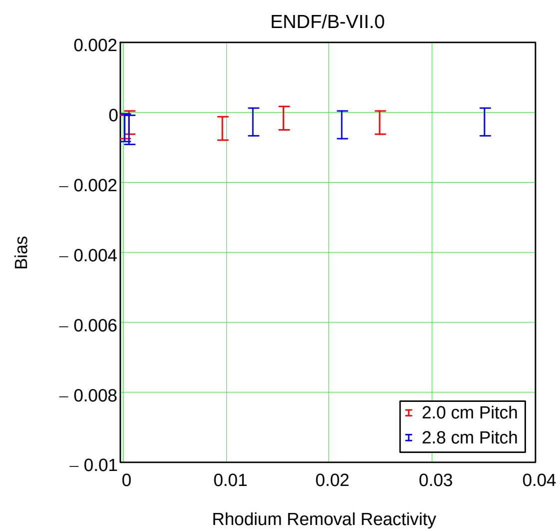
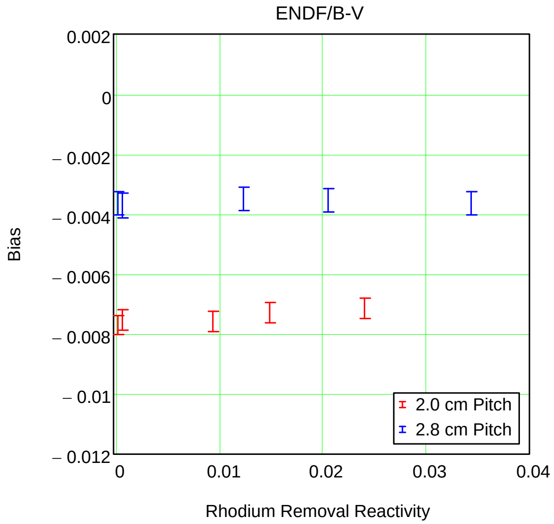
# Bias in MCNP5 and Its Continuous-Energy Cross Sections

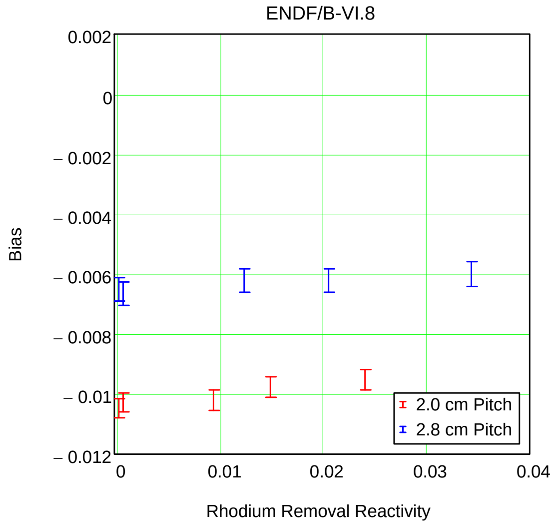


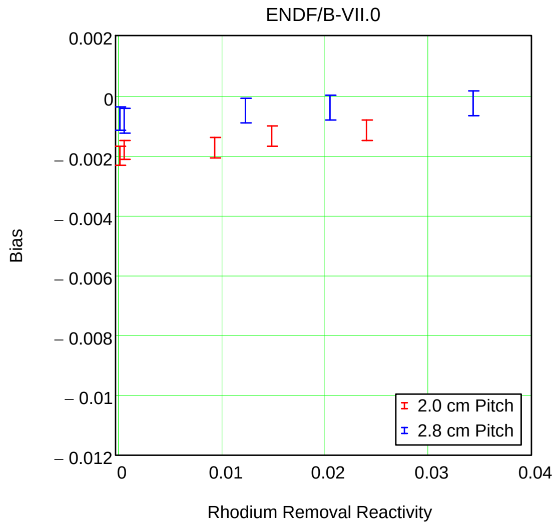



# Bias in SCALE6.0 and Its 238-group Cross Sections



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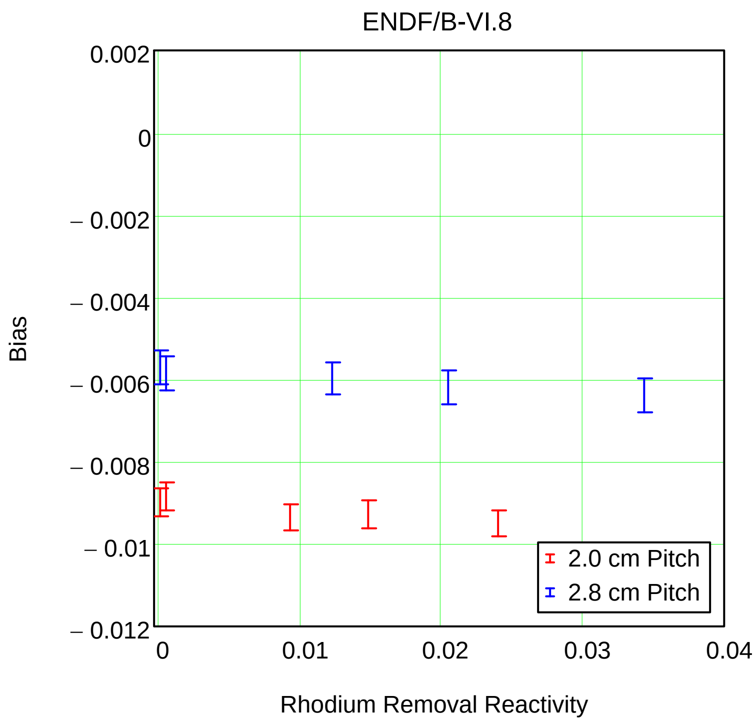
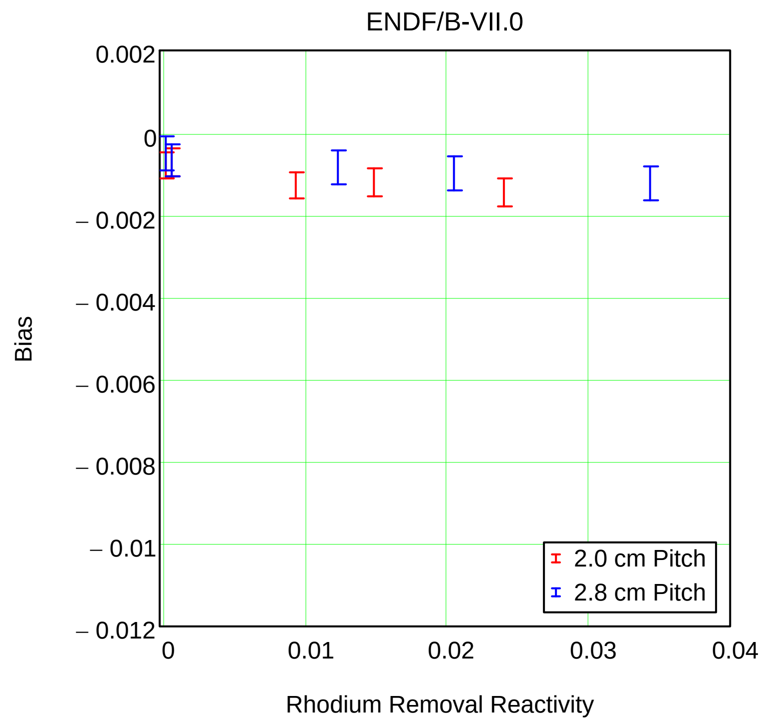
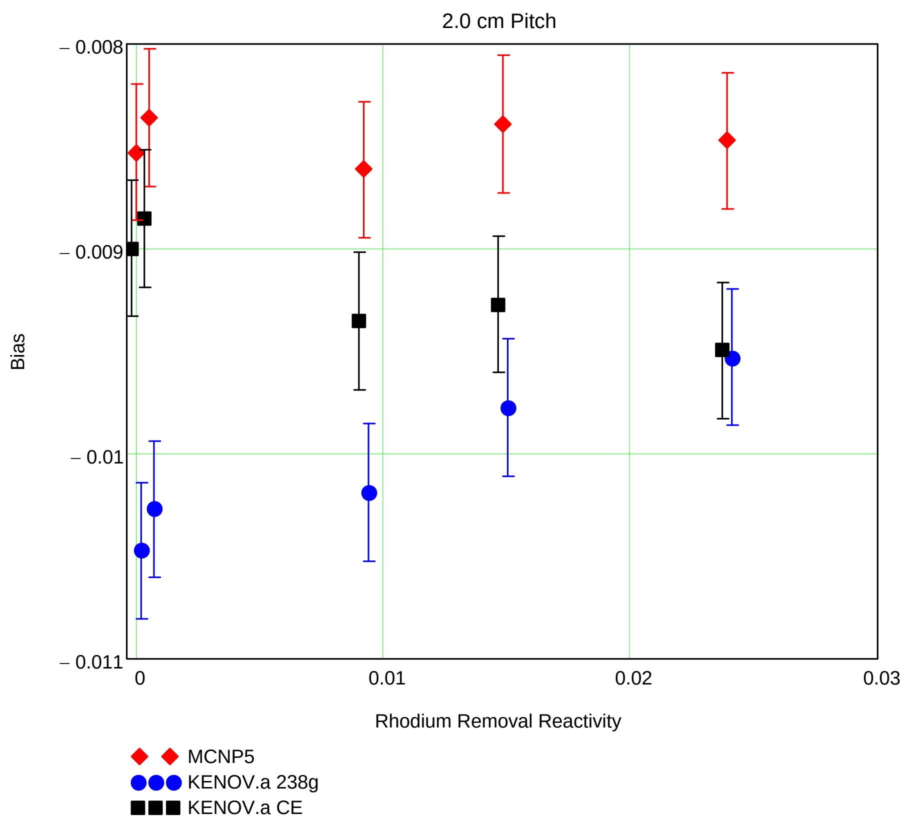
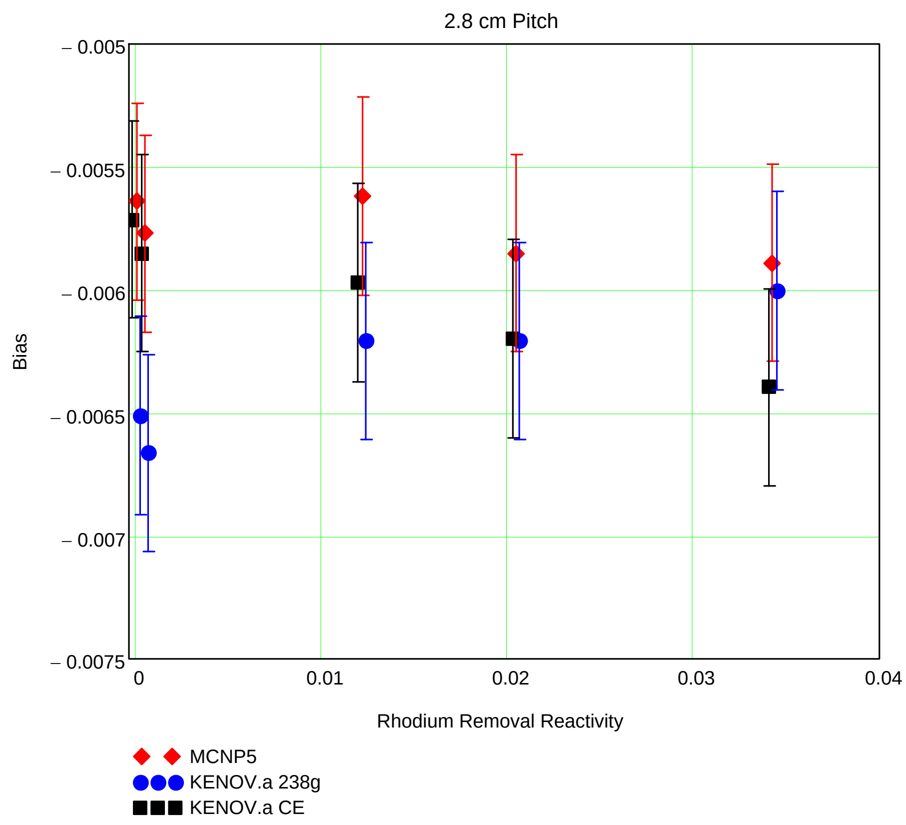


# Comparisons of MCNP5 and SCALE6.0 with ENDF/B-VI.8 Cross sections

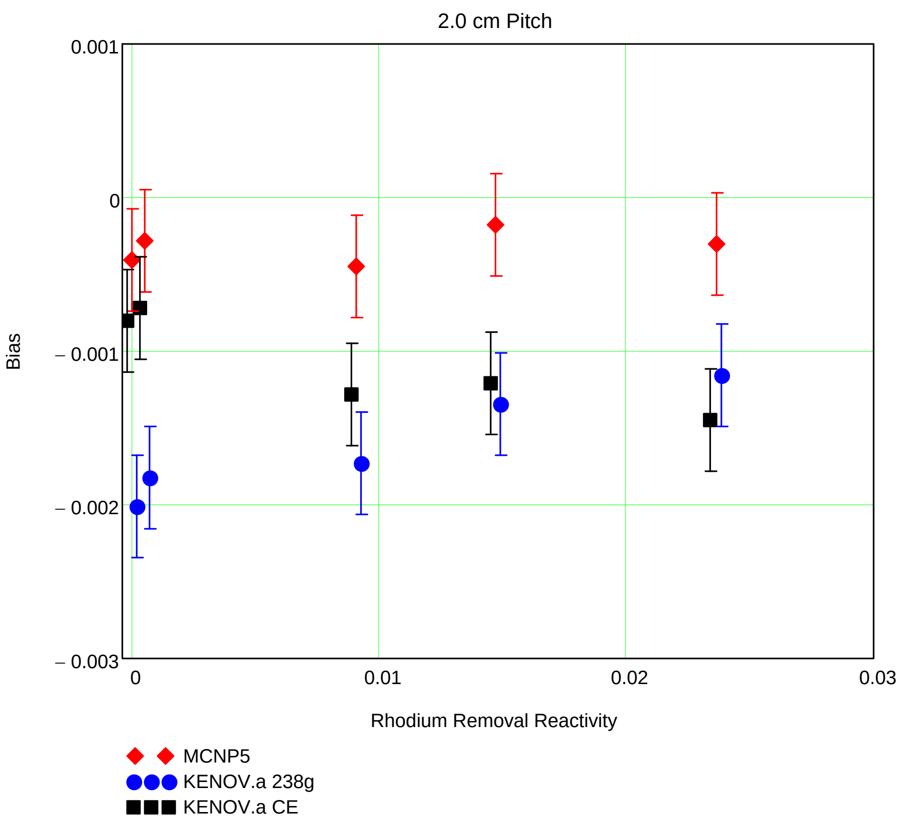



**Approximate PWR Fuel to Water Ratio**

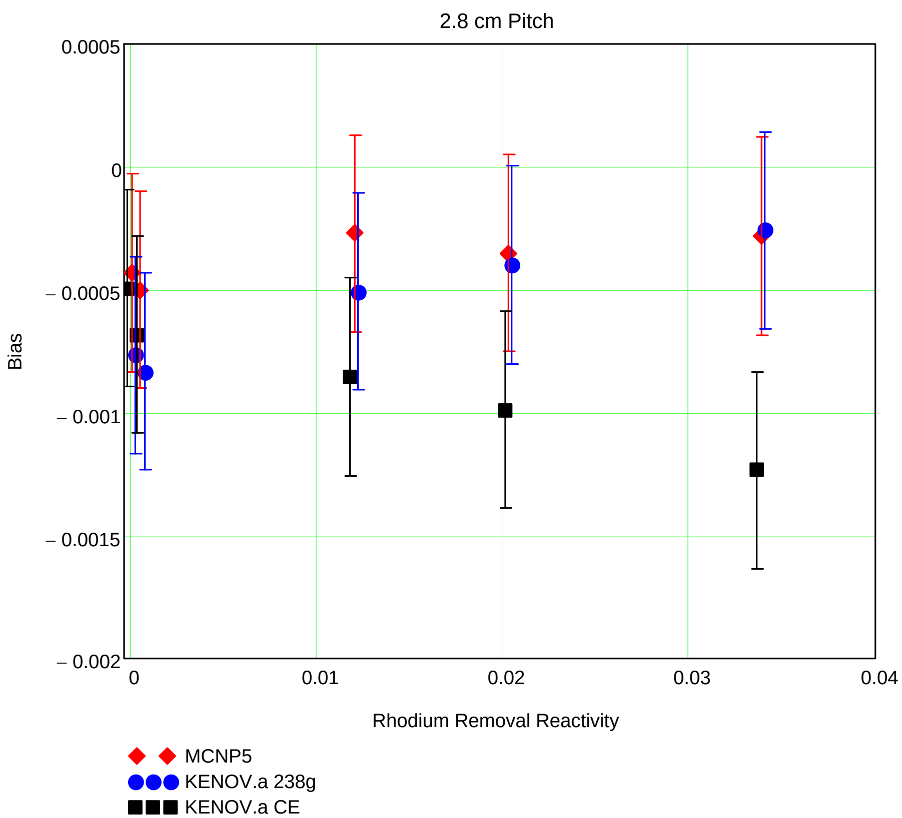



**Near Optimum Moderation**

# Comparisons of MCNP5 and SCALE6.0 with ENDF/B-VII.0 Cross sections




Approximate PWR Fuel to Water Ratio




Near Optimum Moderation



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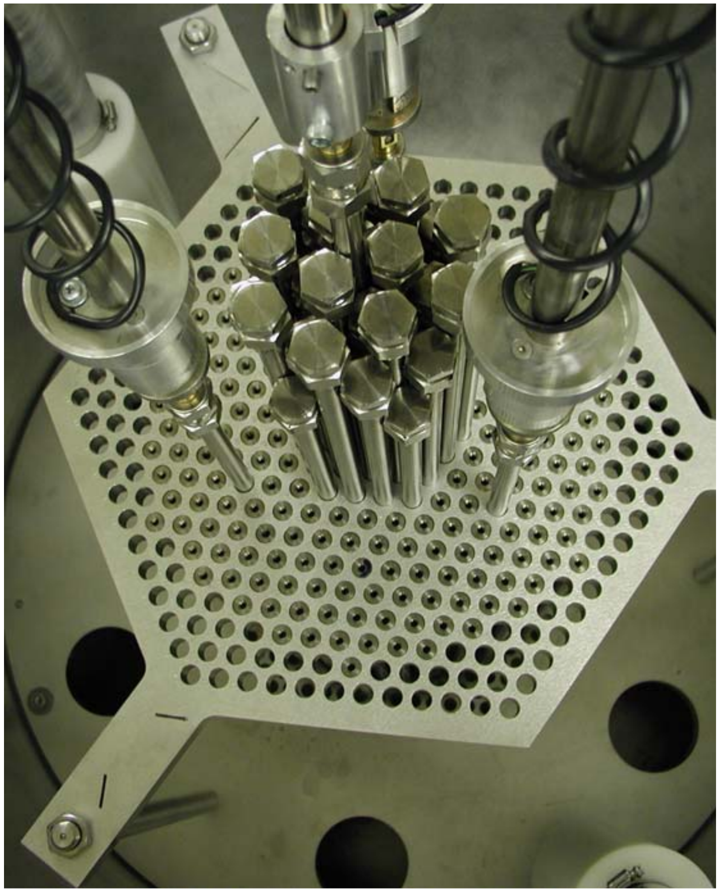
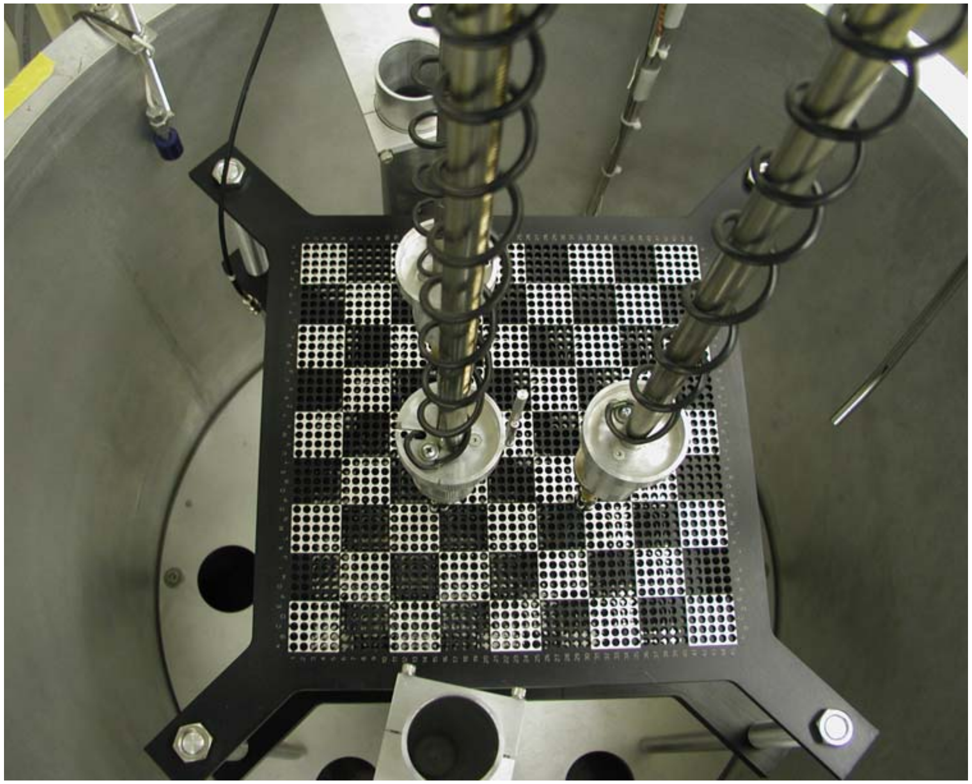
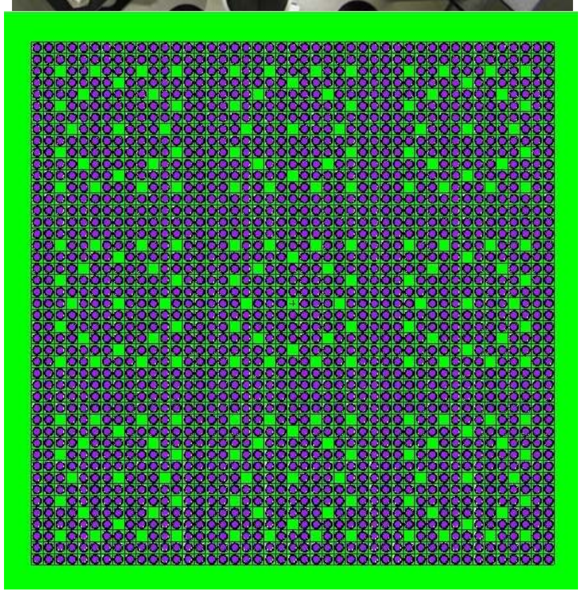
# We have changed the core in the critical assembly





**The cores are different.**
**The balance of the assembly hardware is the same**

# The 7uPCX core will simulate a 3x3 array of commercial fuel assemblies



**Project Objective:** ***Design, perform, and analyze critical benchmark experiments for validating reactor physics methods and models for fuel enrichments greater than 5-wt% $^{235}U$***

- **We have built new 7% enriched experiment fuel**
- **We have modified the existing critical assembly to accommodate the new core**
- **The core is a 45x45 array of rods to simulate 9 commercial fuel elements in a 3x3 array**
- **The experiment is a reactor physics experiment as well as a critical experiment**
- **Additional measurements will be made**
  - **Fission density profiles**
  - **Soluble poison worth**

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# Status of the Sandia critical experiments capability

- **Current status of the of the CX capability**
  - **Fuel and hardware are in hand**
  - **The Authorization Basis has been approved**
  - **The Operational Readiness Review was completed in November**
  - **Corrective actions were completed and transmitted to our regulator in March**
  - **When the corrective actions and the start-up plan are approved, we will begin the first critical**
  - **The first critical experiment should occur in late April or in May, 2009**



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