Reference (Axially Graded) Low Enriched Uranium Fuel Design for the HFIR

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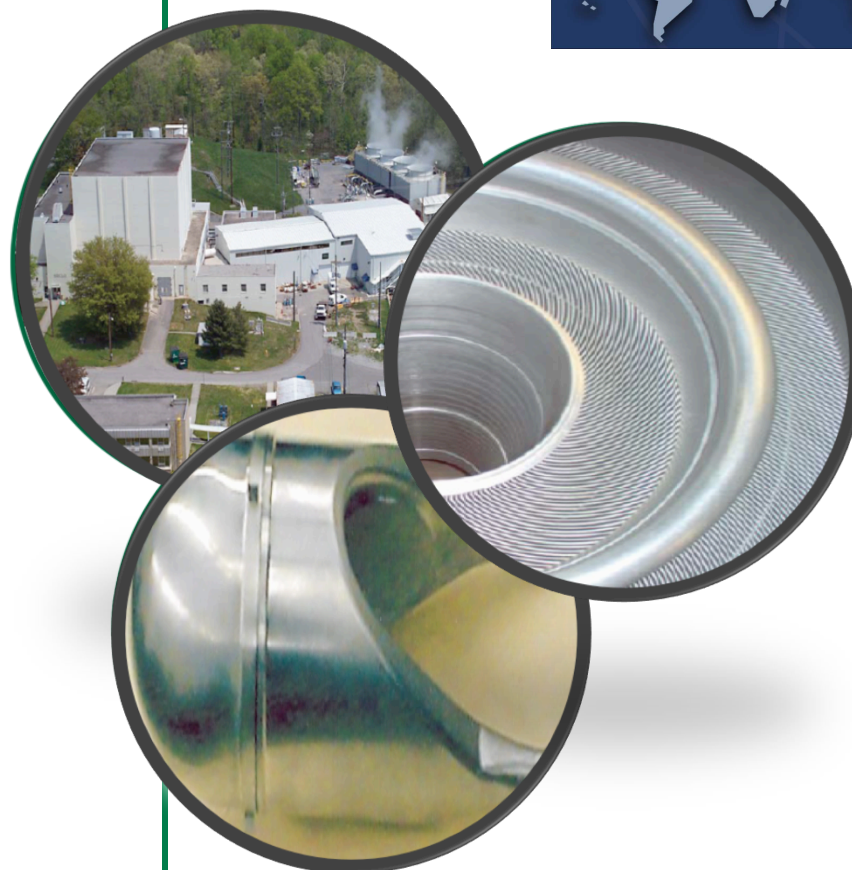
Presented at the TRTR 2010 Conference, Knoxville, TN
September 20, 2010



National Nuclear Security Administration
GTRI
U.S. DEPARTMENT OF ENERGY
HFIR
OAK RIDGE NATIONAL LABORATORY
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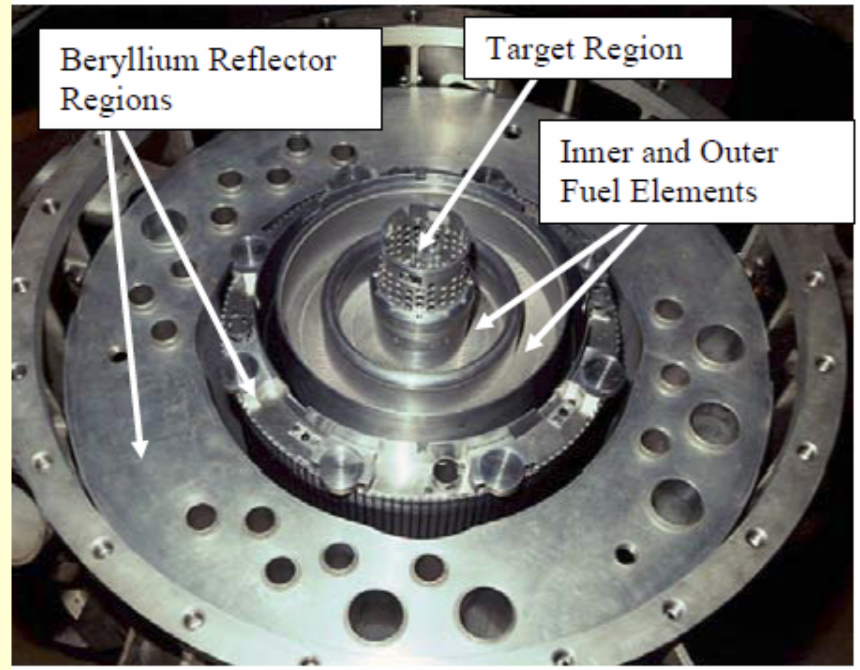
The goal of this presentation is to convince you that we're right

- Constraints that limited areas of study for HEU-to-LEU conversion
- The LEU fuel design
- Validity of physics studies
- Validity of thermal hydraulics studies
- Ability to fabricate LEU fuel

Full paper will be posted on IGORR site

Assumptions for HFIR LEU design studies were established and studies started in FY2006

- Build new reactor – out of scope ($)
- No changes to:
  - Physical dimensions - tight
  - Geometry – need Cf target
  - Al clad material or thickness - testing
  - Fuel filler material (Al) - testing
  - Fuel cycle length (~26 days) - users
  - Margin of safety in TSR bases – not less safe!
  - Coolant flow rate (no increase) – major infrastructure
  - Subcriticality of elements – handling, manufacture, transportation
  - Storage/handling methods – major infrastructure
- Elements must "look the same"



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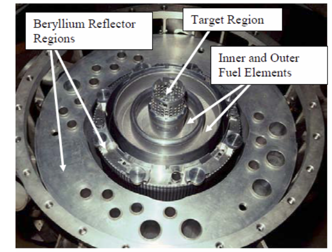
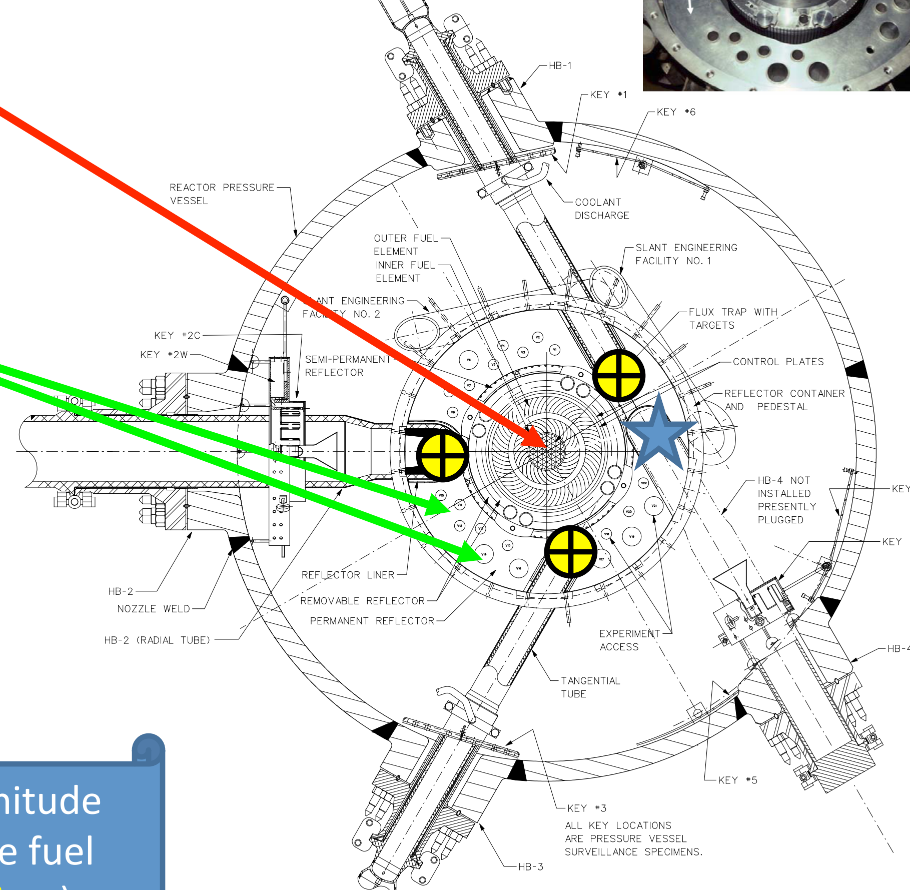
Flux performance goals are to retain the levels currently achieved at 85MW with HEU fuel after conversion

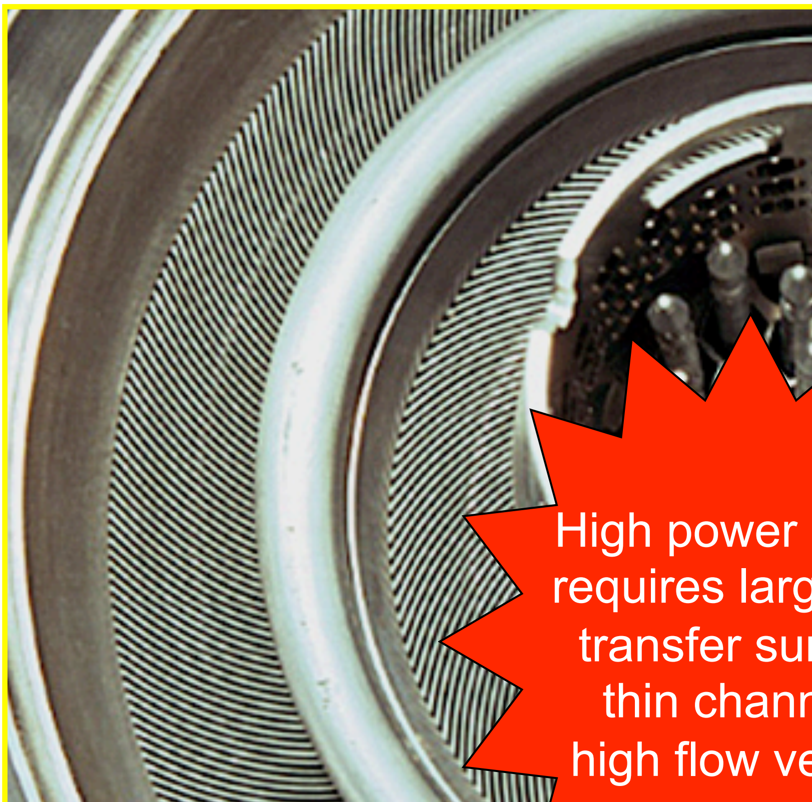


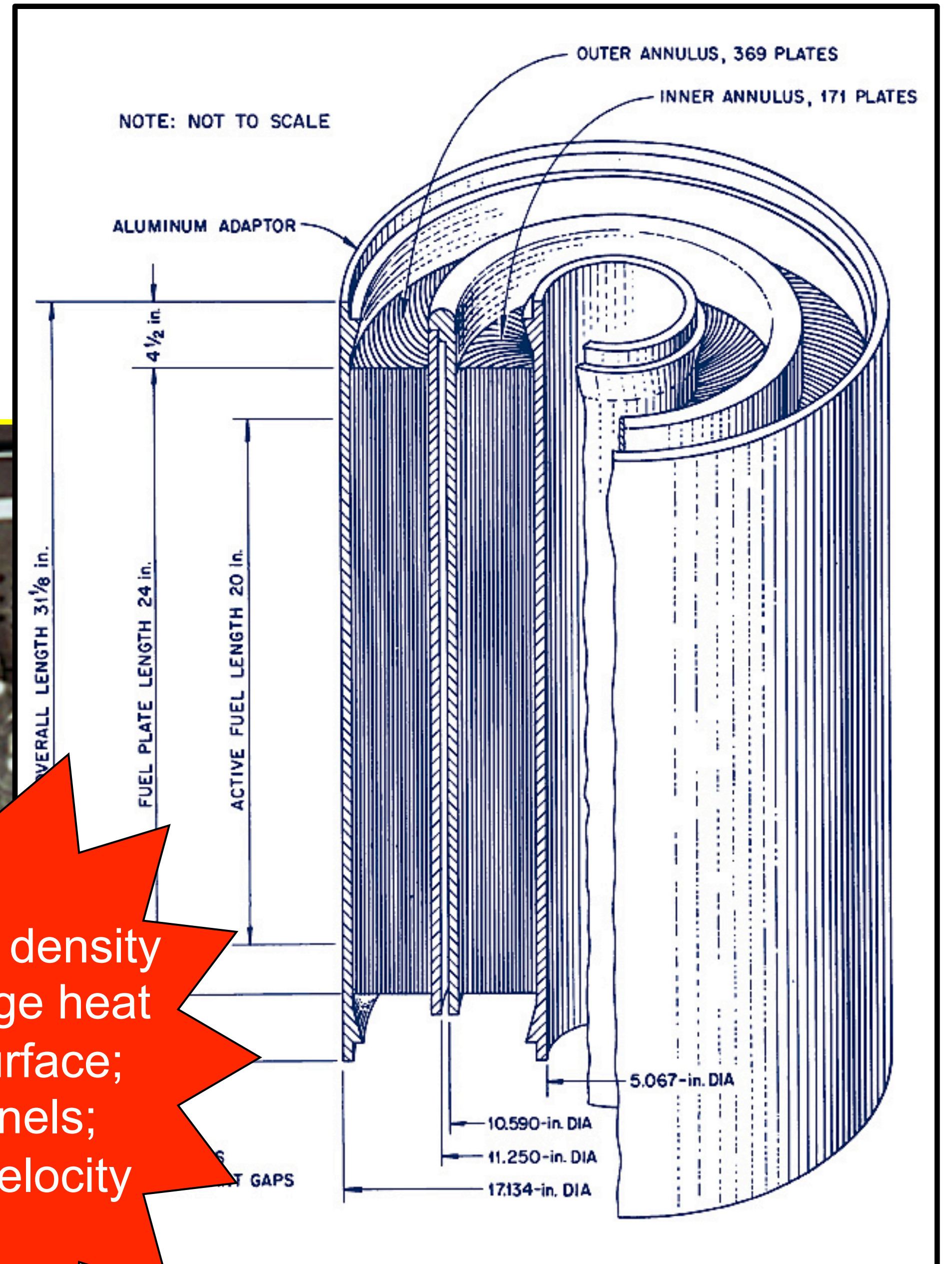
- Flux in central target region
- Flux at RB positions
- Flux at two neutron activation facilities
- Flux at cold source [HB-4] (heat load at cold source)
- Flux to HB-1, 2, and 3 beam tubes



Same neutron energy and magnitude at each point at each time in the fuel cycle (**neutron energy, space, time**)

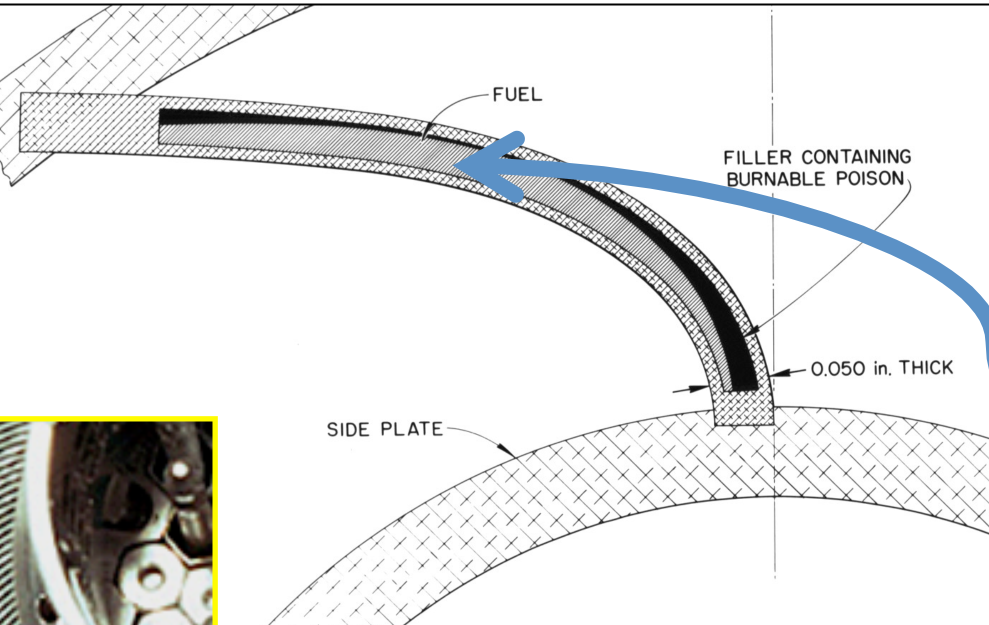
Even though limited to the fuel element, could plate thickness/coolant channel thickness change?





High power density requires large heat transfer surface; thin channels; high flow velocity

Only the interior of the fuel plates is changed – U_3O_8/Al to U-10Mo



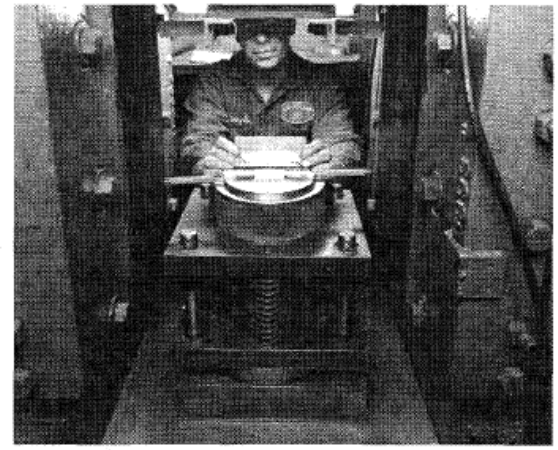
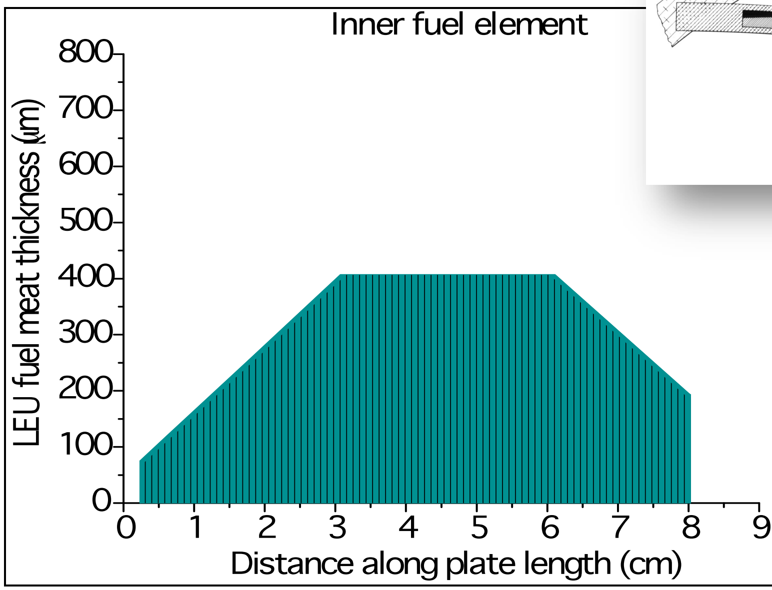


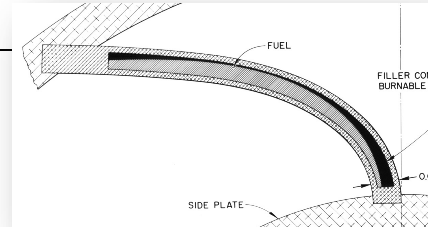
Fig. 15. Contouring the fuel section of the HFIR compact.

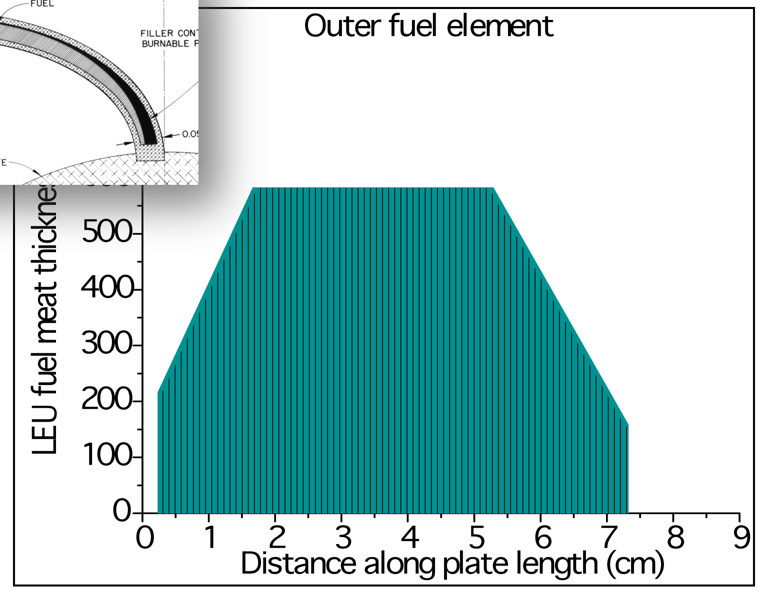
This "hand-formed" shape is unique to HFIR HEU fuel

- Monolithic graded LEU "foil" constraints
  - ~75 micron minimum thickness
  - ~750 micron maximum thickness

ORNL staff have performed the neutronics and thermal hydraulics studies to design an LEU fuel







Current HFIR loading – 10 kg HEU

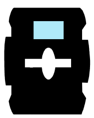
Future HFIR LEU fuel

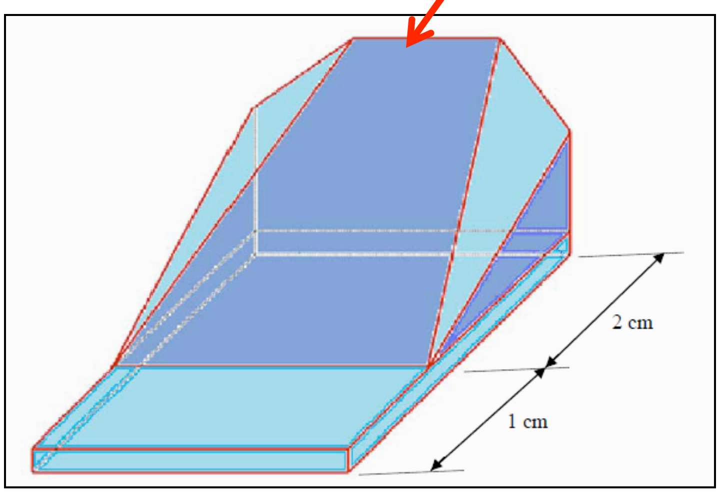
Uranium	Load (kg)
^{235}U	25.2
^{238}U	101.9
total	127.5

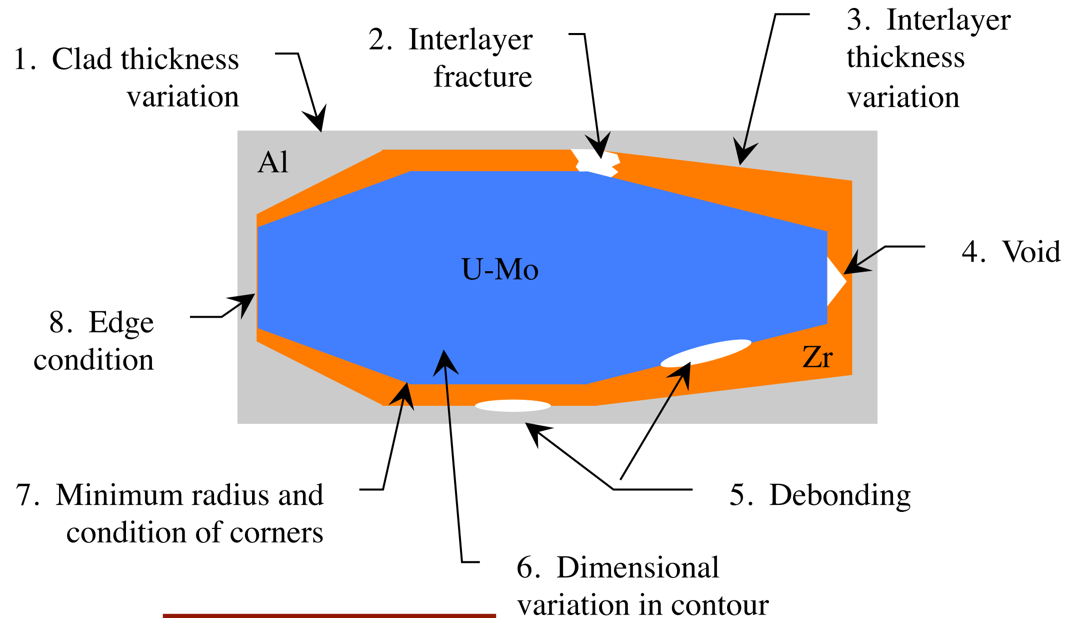
LEU fuel is much denser than HEU; LEU elements are 30% heavier.

One technology change required – radial profile PLUS axial tapering of U-10Mo foil (U/Mo razor edge)

Shapes of bottom edges of LEU plates



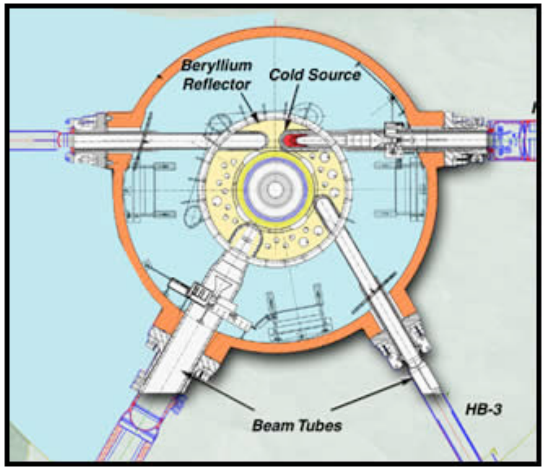




LEU in HFIR is theoretically possible but requires a reactor power increase to 100 MW

Showing parity to HEU performance requires examining several locations in the reactor; HEU at 85 MW, LEU at 100 MW

	Time	Fuel	Thermal flux (n/cm²s)	Epithermal flux (n/cm²s)	Fast flux (n/cm²s)
Central target	BOC	HEU	2.2×10^{15}	1.3×10^{15}	1.1×10^{15}
		LEU	2.3×10^{15}	1.3×10^{15}	1.1×10^{15}
	EOC	HEU	2.3×10^{15}	1.1×10^{15}	1.0×10^{15}
		LEU	2.5×10^{15}	1.2×10^{15}	1.0×10^{15}
Cold source edge	BOC	HEU	6.9×10^{14}	2.4×10^{14}	0.9×10^{14}
		LEU	8.3×10^{14}	2.9×10^{14}	1.0×10^{14}
	EOC	HEU	8.4×10^{14}	2.4×10^{14}	0.9×10^{14}
		LEU	8.5×10^{14}	2.8×10^{14}	1.0×10^{14}
Reflector r=27cm	BOC	HEU	6.0×10^{14}	6.5×10^{14}	4.1×10^{14}
		LEU	7.1×10^{14}	7.8×10^{14}	4.8×10^{14}
	EOC	HEU	8.1×10^{14}	6.6×10^{14}	4.0×10^{14}
		LEU	7.4×10^{14}	7.5×10^{14}	4.6×10^{14}



(neutron energy, space, time)

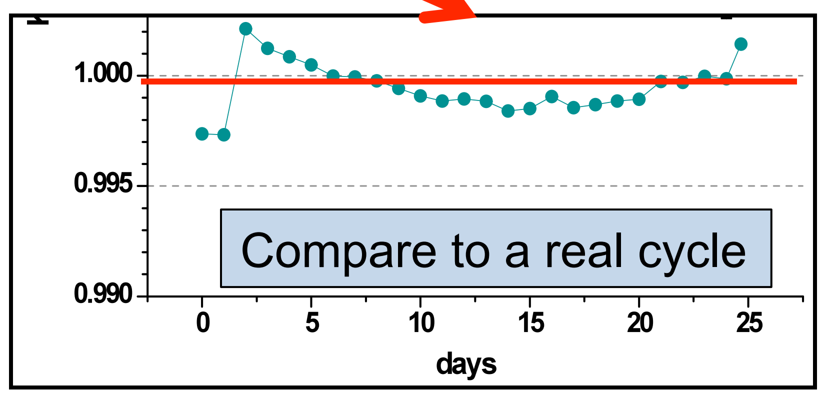
Estimated HFIR replacement cost is more than $1 billion.

How do you know you're right?

(neutron energy, space, time)

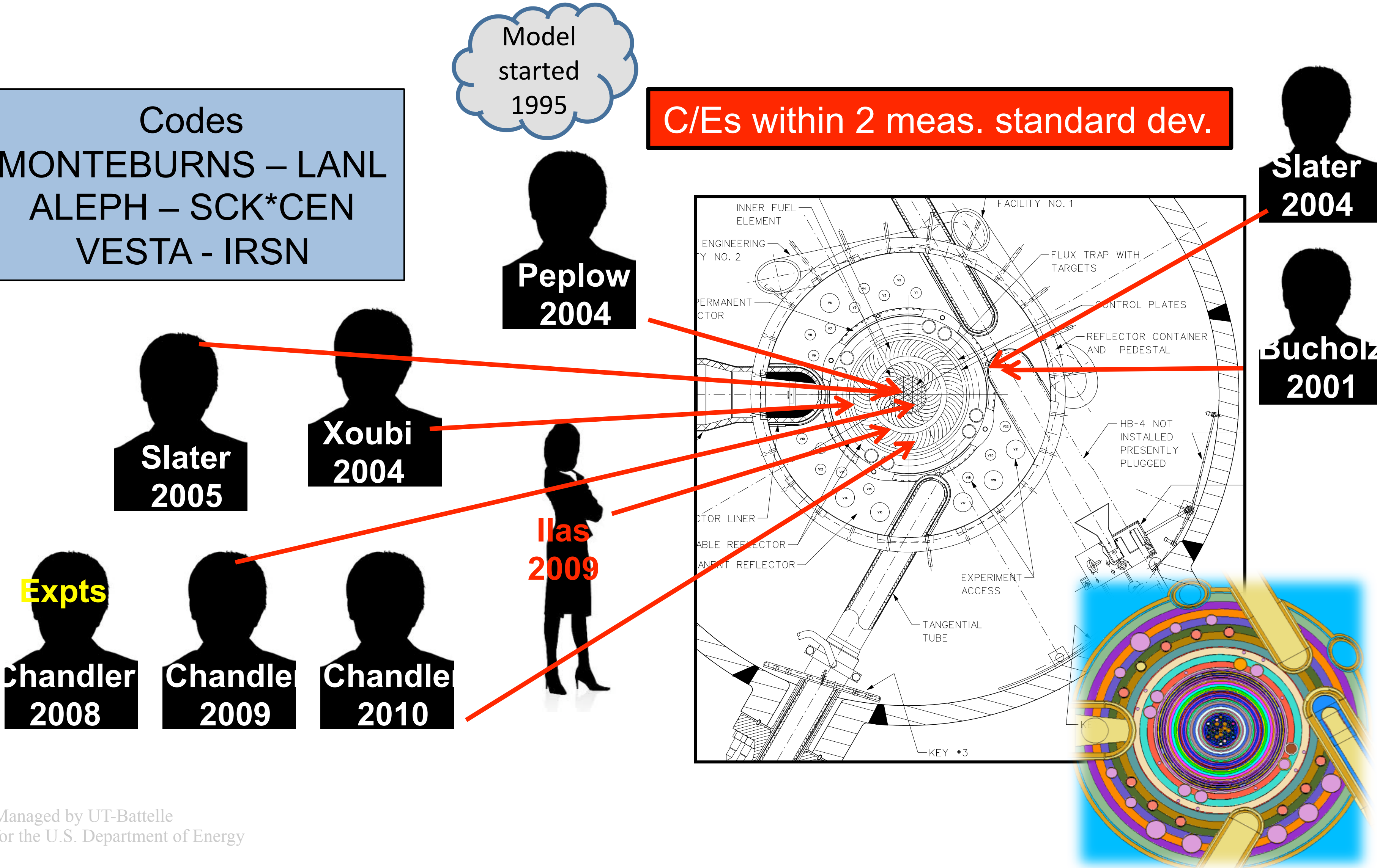
Continuous energy nuclear data
"everything ever measured is used"
Minimum "manipulation" of data

Reactor geometry doesn't change!
Model every part of the reactor.



Years of validation studies with Monte Carlo (MCNP code) and Monte Carlo/depletion (MCNP/ ORIGEN) were performed with HEU data

Codes
MONTEBURNS – LANL
ALEPH – SCK*CEN
VESTA - IRSN



So what could go wrong?

- Significant quantity of molybdenum in reactor – 12 kg *(more Mo in LEU-fuelled HFIR than HEU today)*
- Mo is a “mild” neutron absorber (10b to 100b)
- ^{238}U impacts – 100 kg versus 0.7 kg
- Fast fissions in ^{238}U; fission product distribution differences; plutonium production

There is a lot of operating experience with 20% enriched fuel but everything happens faster in HFIR

The thermal hydraulic analyses for LEU fuel are bounding not predictive

- **LEU design uses 45-year-old HFIR HEU custom-written computer program**
- **Written to justify safety of HEU fuel, not performance as reactor physics does**
- **Models single inner element plate and channel and single outer element plate and channel (OK)**

- **Only models the heat flux from the plate surface and the water in the channel; goal is compute thickness of narrow channel** (oxide growth, manufacturing tolerances, bowing, thermal deformation)

The code "does not care" what fuel is inside the plate

So what could go wrong?

- Analyses based on HEU tolerances/uncertainties in specifications/measurements; what will LEU be?
- Differences in radiation induced phenomena (swelling)
- Thermally-induced deflection differences
- Flow induced effects? Not likely. U/Mo plate more rigid
- HFIR pressure, coolant velocity, clad material don't change

Our posture: Fuel development and fabrication tasks know the goals they must meet

Each part of the U/Mo fuel fabrication process seems well-known

a) Health Physics Research Reactor fuelled with U-10Mo alloy

b) Contoured rolling of U/Mo foil

c) Placing "Razor" edge on bottom of U/Mo foil

d) Fabricate thin Zr foil for diffusion barrier

e) Borated Al for inner plate

f) Hot isostatic pressing of U/Mo, Zr, Al clad and borated Al if inner plate

g) Since U/Mo foil is contoured, top of pressed plate must be machined to be flat

So what could go wrong?

- Bonding; in the HIP process and subsequent forming to involute shapes
- Measurement techniques/uncertainties
- Robustness (variation) of fabrication process; repeatability
- Can the pieces be put together?
- Cost

Our posture: Fabrication knows the goals they must meet but feedback to design process is still possible

With methods reported here, additional analyses offer diminished returns unless new information made available

- Rather than analyses, need data, data, data
- ATR fuel development tests
- Fabrication process development tests
- Instrumentation
- One exception - better thermal hydraulics analyses (subject of later talk by Dr. Jim Freels)
- Communication with other reactors as they convert (HFIR last)

Convinced?

Questions/ comments welcome