Analysis of an LEU Fuel with Spatially-dependent Thickness in Two Dimensions

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Lyon, France
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UT-BATTELLE

HFIR

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

This fuel development study concerns the High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory, USA.

Will present:

- **History/purpose/scope of study**
- **Description of HFIR with comparison to High Flux Reactor (HFR), Petten, The Netherlands**
- **Limits of study**
- **Methods, models, and results**
- **Conclusions and future work**

The purpose of the study is to investigate the conversion of the HFIR from HEU to LEU

RERTR Implementation

Office of Global Threat Reduction

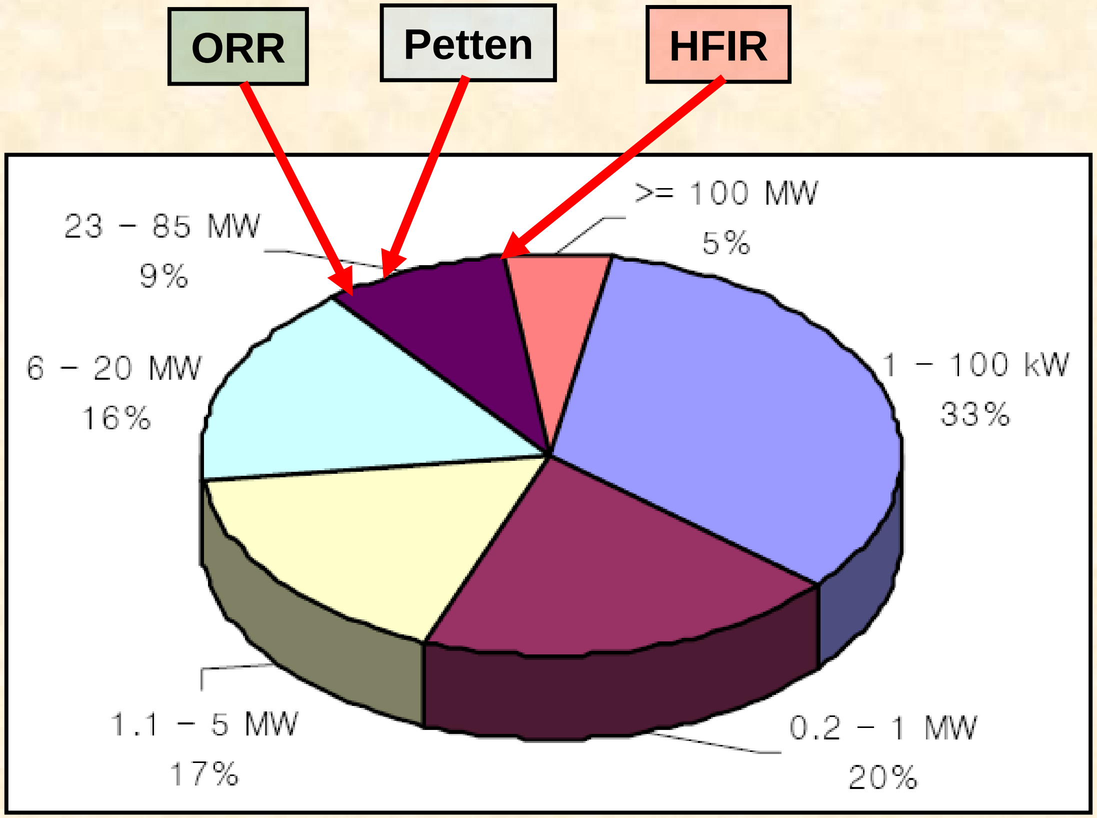
National Nuclear Security Administration
Defense Nuclear Nonproliferation

1) Ensure that the ability of the reactor to perform its scientific mission is not significantly diminished.
2) Work to ensure that an LEU fuel alternative is provided that maintains a similar service lifetime for the fuel assembly.
3) Ensure that conversion to a suitable LEU fuel can be achieved without requiring major changes in reactor structures or equipment.
4) Determine, to the extent possible, that the overall costs associated with conversion to LEU fuel does not increase the annual operating expenditure for the owner/operator.
5) Demonstrate that the conversion and subsequent operation can be accomplished safely and the LEU fuel meets safety requirements.

Started Fall 2005

The Petten (HFR) reactor recently converted from HEU to LEU

- **In preparing to study HFIR conversion, useful to study successful, similarly sized reactor**
- **Excellent presentation on Petten conversion provided at IGORR meeting, 2005 by P. M. Stoop**
- **Familiarity of RRFM with local reactor; easier to understand the HFIR challenge if compared to Petten**

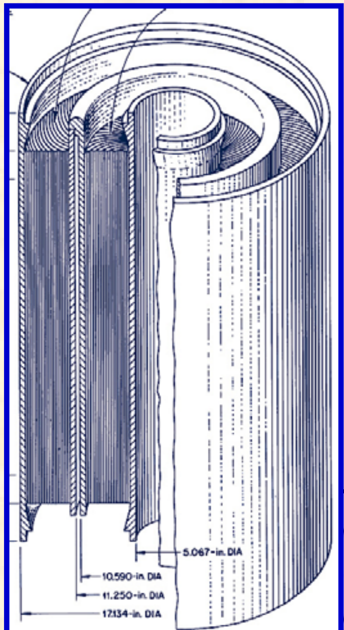


World distribution of research reactors; from B. J. Jun, HANARO, KAERI

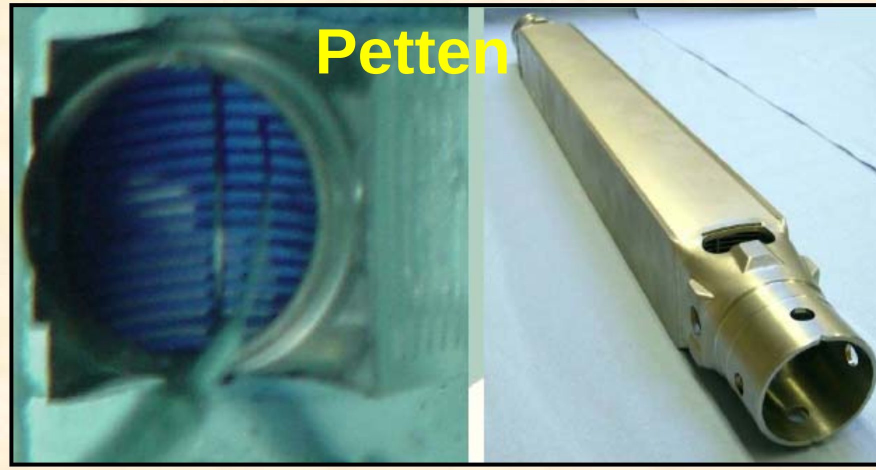
Some physical characteristics of the reactors are similar

HFIR (Oak Ridge)	HFR (Petten)
• Power level – 85 MW	45 MW
• Reflector – Be	Be
• Coolant – H_2O	H_2O
• Startup – 1965	1961
• Lifetime – 2035-2040	beyond 2015
• Cycle length – 26 days	28 days
• Plate-type, Al clad fuel	- same -
• Principal uses – radioisotopes; neutron source to beam tubes; materials irr.	- same -

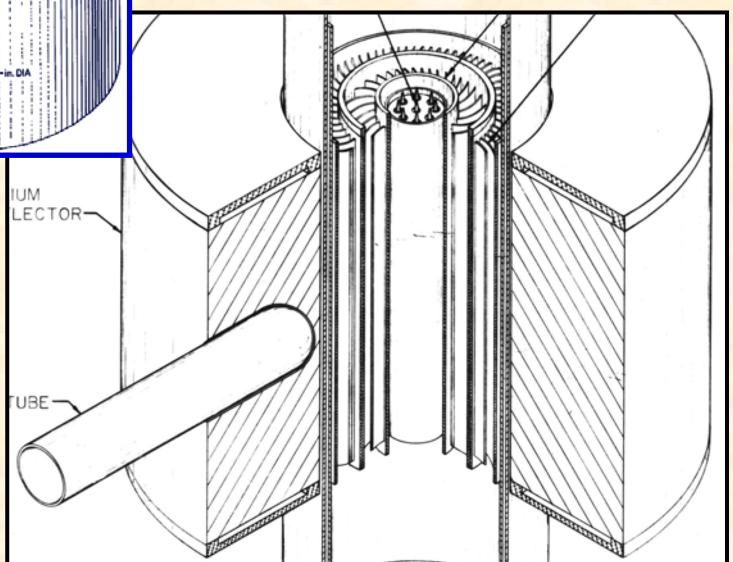
There are no “fuel shuffling” operations at HFIR

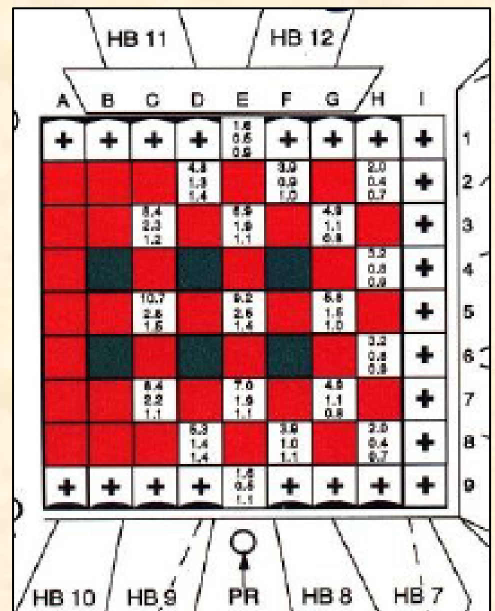


42 cm



HFIR



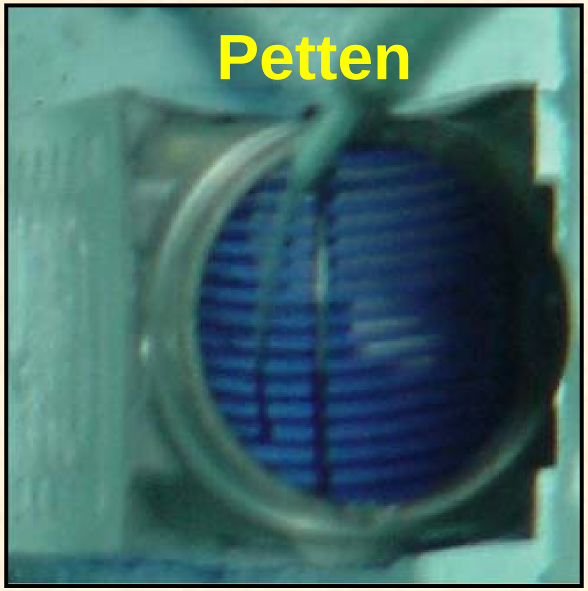


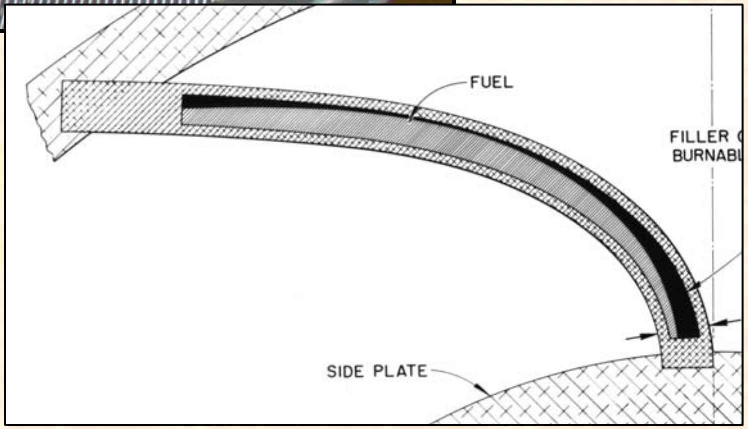
75 cm

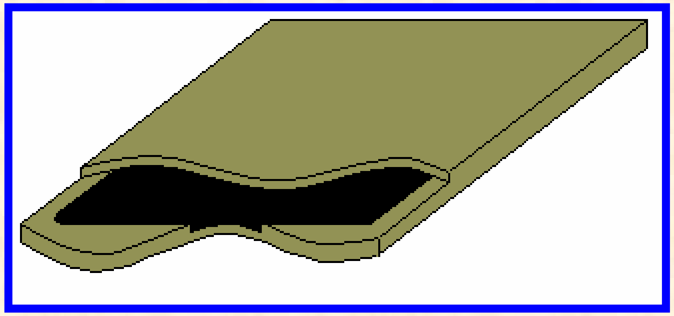
HFIR plates have a variable fuel thickness

Dimensions (mm)

HFIR		Petten
0.23-0.69	Fuel	0.51
0.76	Fuel+filler	-
0.25	Clad	0.38, 0.57
1.27	Total	1.27, 1.65
508	Fuel length	600

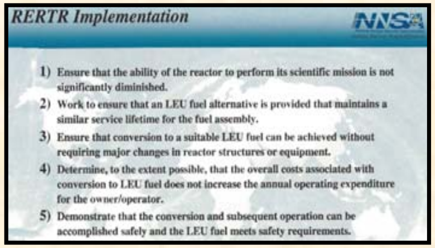






Studies considered design options for the “region between the clad” only (criterion 3 from RERTR program).

- **No changes to:**
  - **Physical dimensions**
  - **Geometry**
  - **Clad material or thickness**
  - **Fuel filler material (Al or Al-Si)**
  - **Fuel cycle length (~26 days)**
  - **Power level (85 MW); hence average heat flux**
  - **Margin of safety in TSR bases**
  - **Coolant flow rate**
  - **Subcriticality of elements**
  - **Storage/handling methods**
- **Elements must “look the same”**


RERTR Implementation

NNSA

1) Ensure that the ability of the reactor to perform its scientific mission is not significantly diminished.
2) Work to ensure that an LEU fuel alternative is provided that maintains a similar service lifetime for the fuel assembly.
3) Ensure that conversion to a suitable LEU fuel can be achieved without requiring major changes in reactor structures or equipment.
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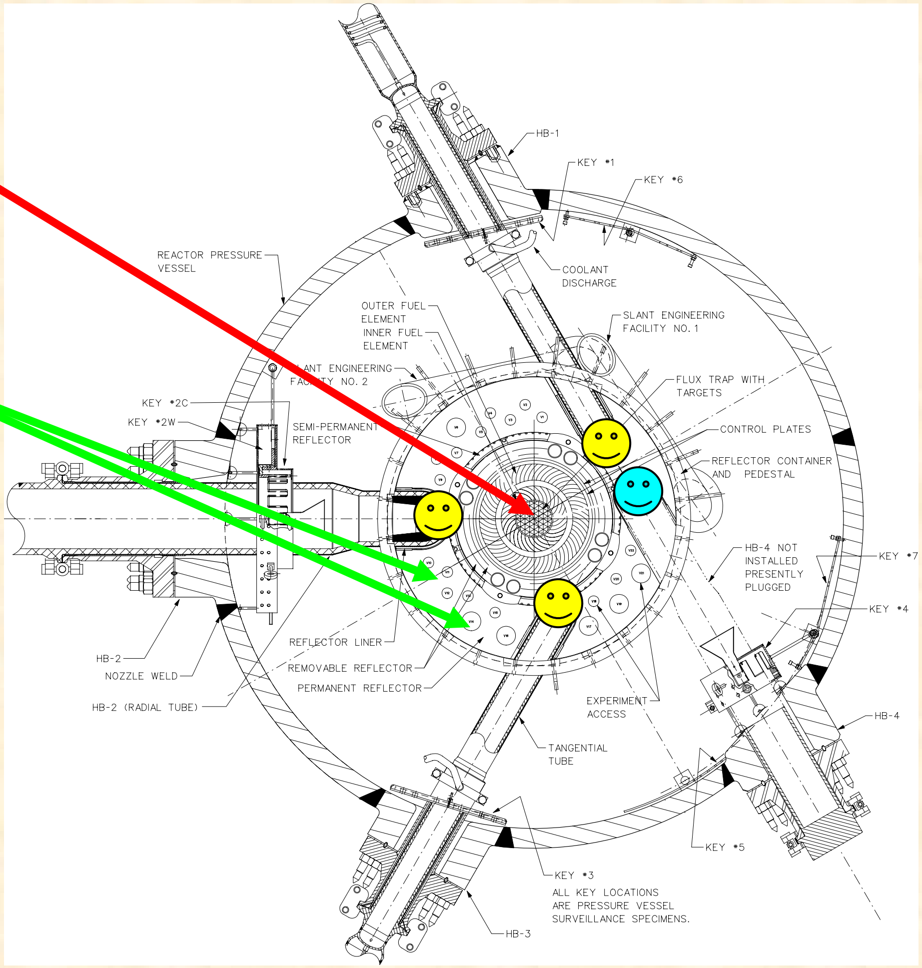
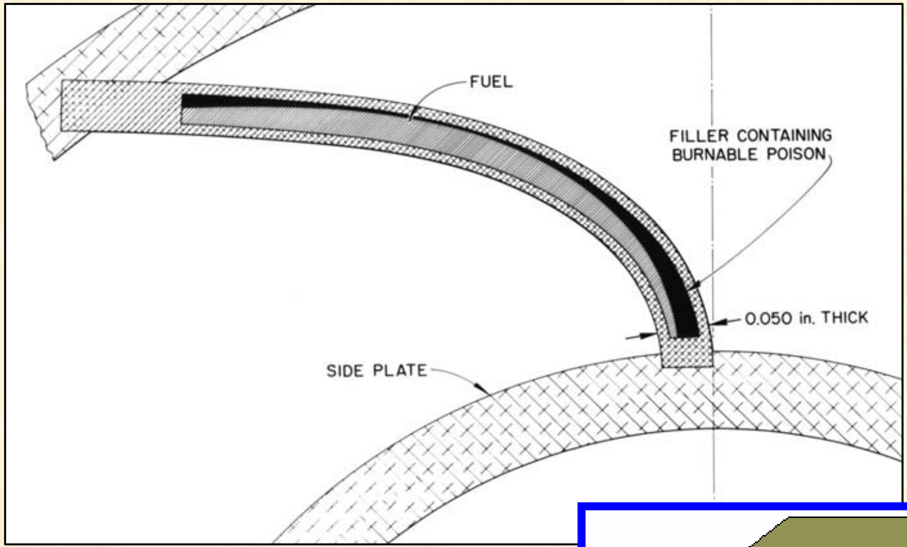
5) Demonstrate that the conversion and subsequent operation can be accomplished safely and the LEU fuel meets safety requirements.

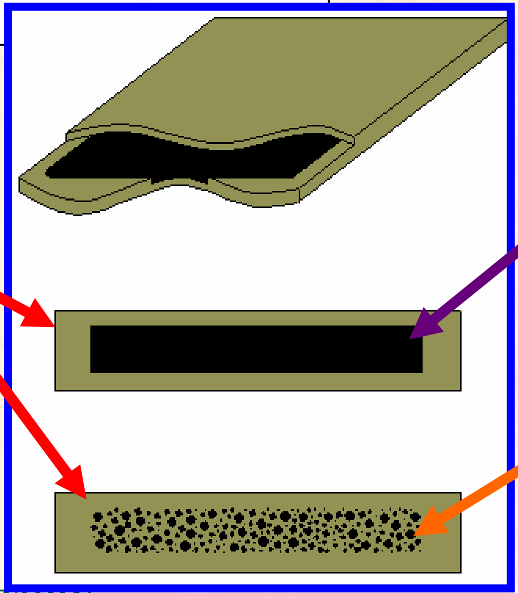
Performance goals to insure scientific mission maintained are to retain currently achieved thermal (<0.625 eV) flux values for:

- **Flux in central target region**
  (2.7×10^{15} n/cm^{2}s)
- **Flux at two neutron activation facilities**
  (0.12 and 0.04 * 10^{15} n/cm^{2}s)
- **Flux at cold source [HB-4]**
  (1.7×10^{15} n/cm^{2}s)
- **Flux to HB-1, 2, and 3 beam tubes**
  (1.4 to 1.7 * 10^{15} n/cm^{2}s)



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

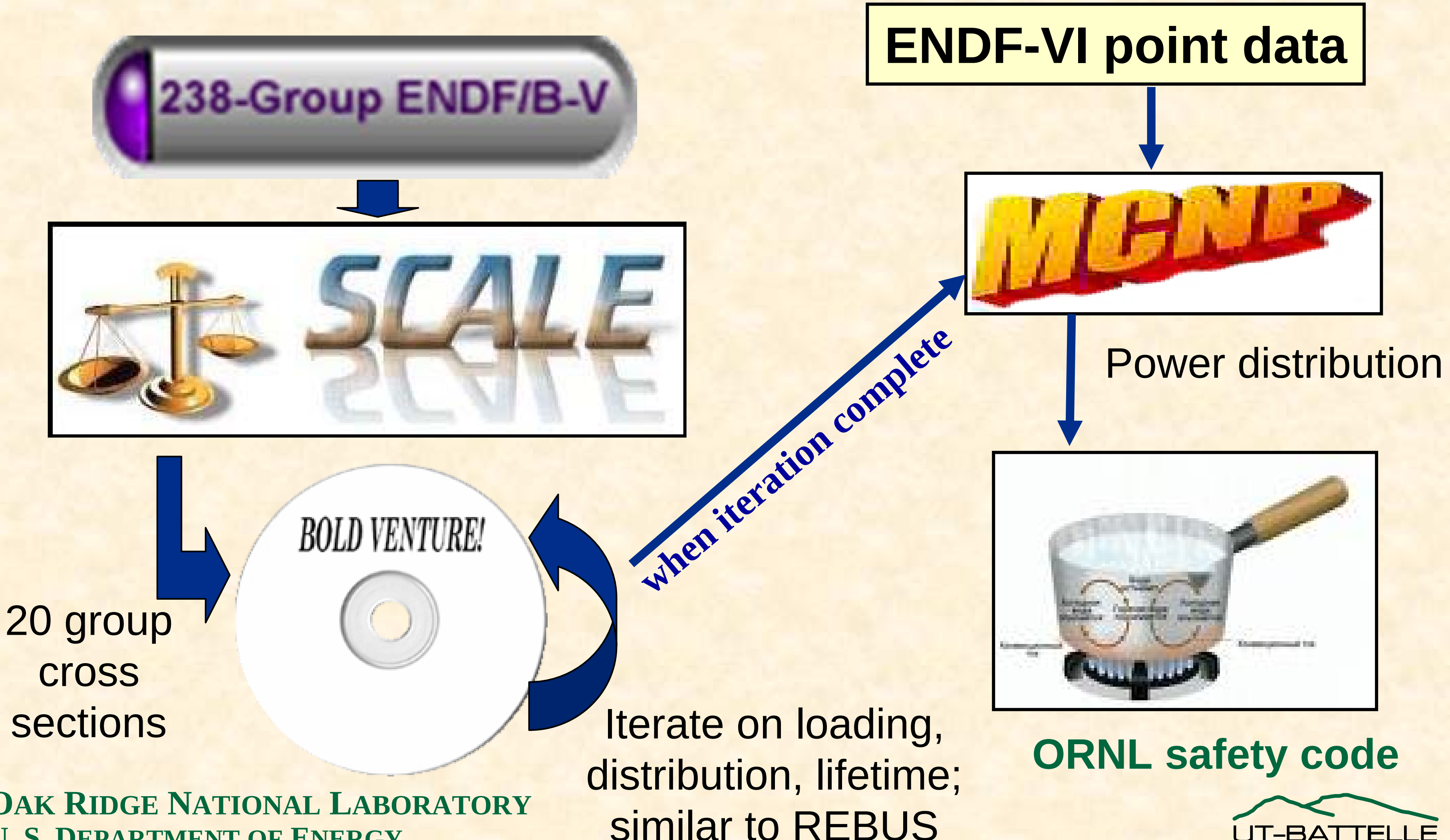




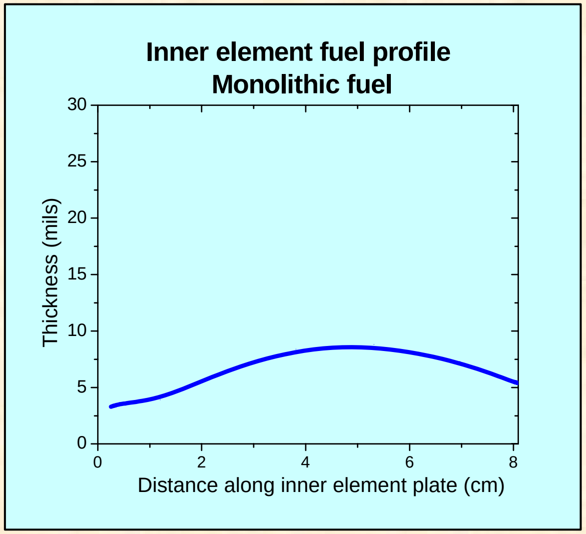
Grade this region keeping "meat + filler" thickness at current value

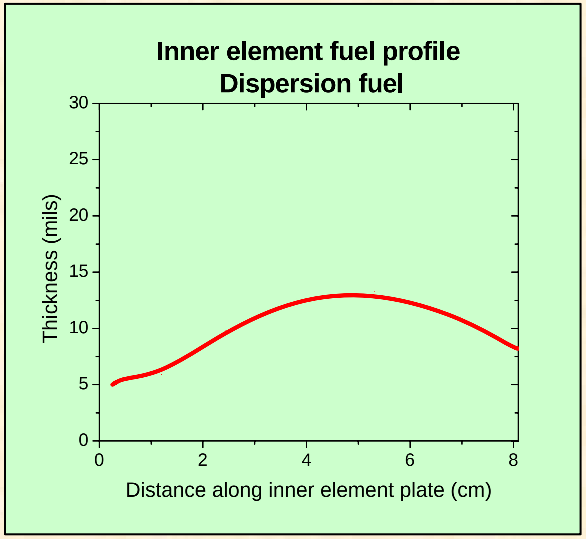
- **Petten uses LEU$_3$Si$_2$**
- **U_3Si_2 density too low for HFIR; shortens cycle length by ~50%**
- **First consider only radial grading as in the current HEU design**
- **Consider U-10Mo monolithic fuel; determine profile**
- **With profile, determine requirements for dispersion fuel based on U-10Mo**

Verified and validated methods and data used for support of current HFIR operations also used for LEU analyses



Fuel profiles were found that permitted HFIR operation with LEU at 85 MW

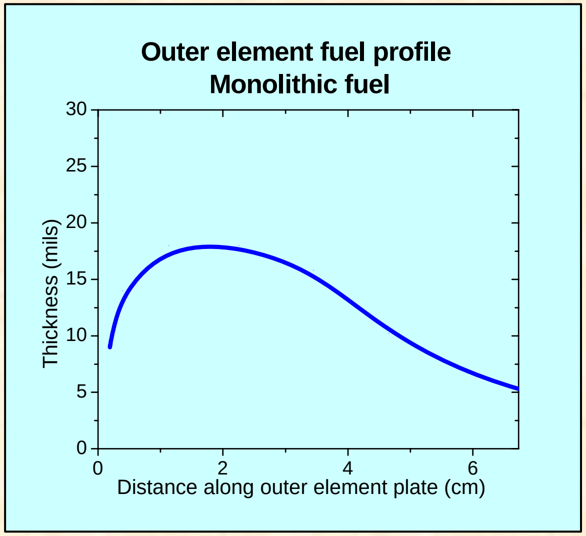


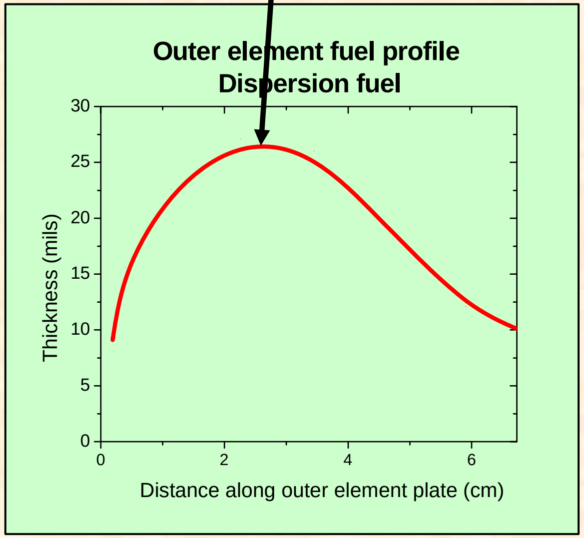


Just made it

Monolithic case

Dispersion case





The LEU dispersion case that satisfies criteria has a much higher fuel/Al ratio than current HEU

- **U-7wt%Mo Fuel** *(denser than U-10Mo)*
- **55 volume percent for U-Mo (45 volume percent for Al)** *[HFIR HEU fuel meat is about 13 volume percent U_3O_8 in Al]*
- **Uncoated U-7Mo particles** *(Stabilizing Si in Al matrix surrounding particles)*
- **Yields 8.7 gU/cm^3**

Denser fuel reduces flux to the reflector

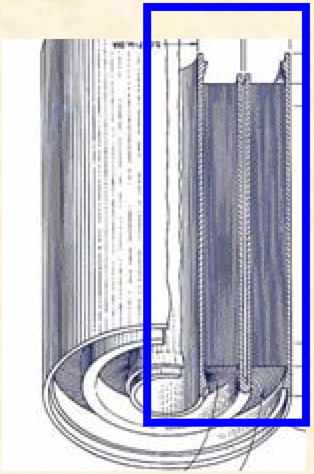
Peak Flux (n/cm^2s)	HEU (Current)	LEU (MonolithicU-10Mo)	LEU (High density dispersion, U-7Mo)
Be Reflector			
BOC	1.1×10^{15}	1.1×10^{15}	1.1×10^{15}
EOC	**1.7×10^{15}**	1.5×10^{15}	1.5×10^{15}
Central target			
BOC	2.6×10^{15}	2.5×10^{15}	2.6×10^{15}
EOC	2.7×10^{15}	2.5×10^{15}	2.5×10^{15}

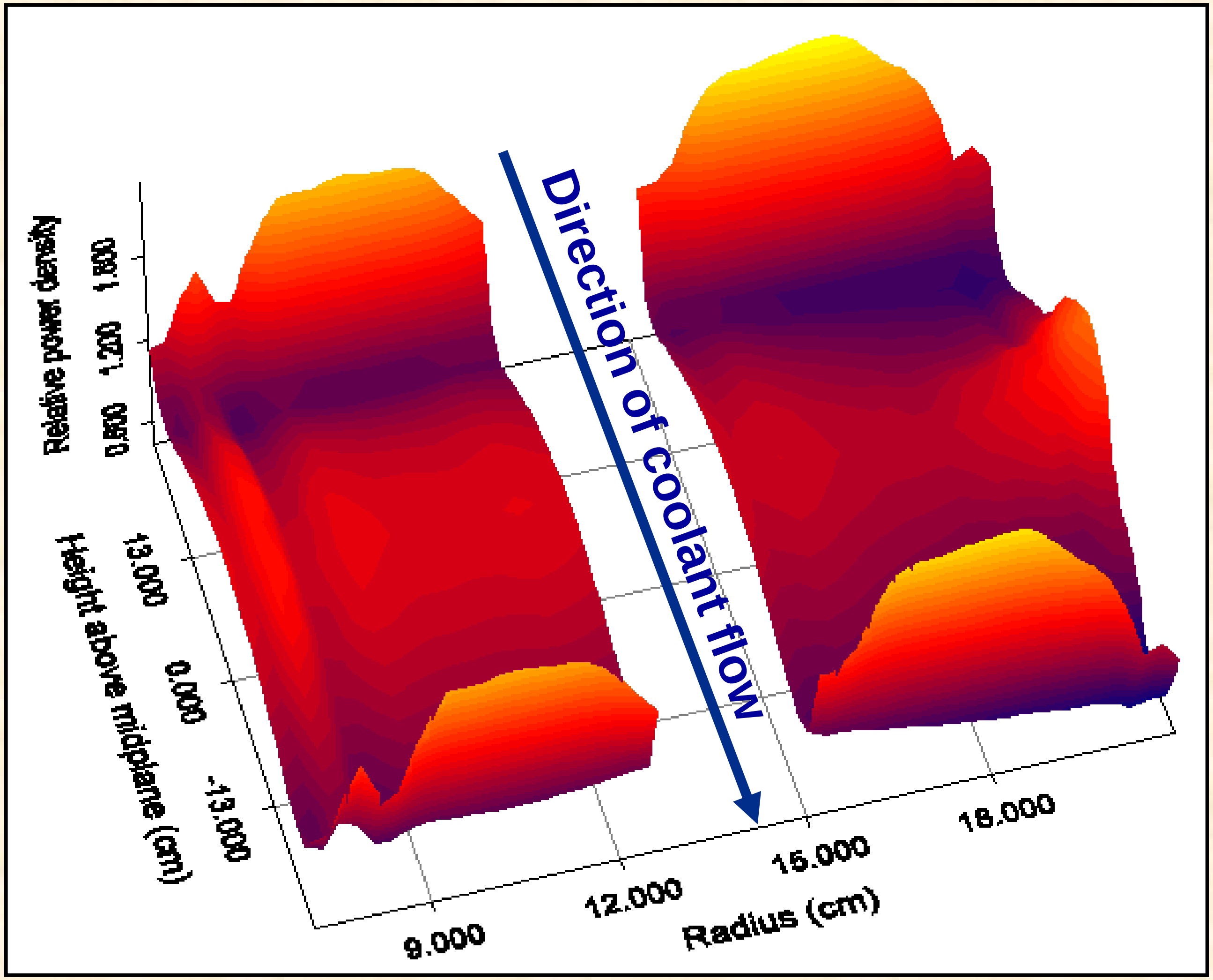
Maintaining flux level important to sponsor

Note: VENTURE results agreed excellently with MCNP results

Margin to incipient boiling is lowest at the bottom edge of the core

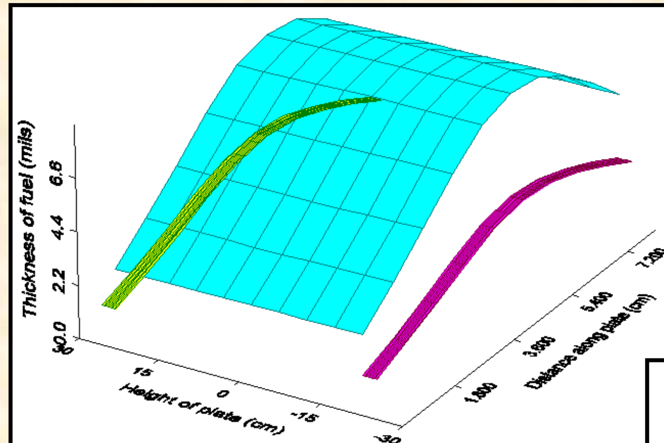
Graph shows relative power densities for this region



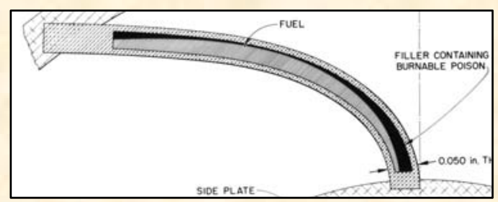


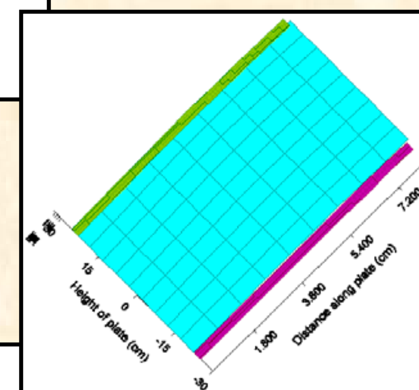
Removing ½ the fuel in the top and bottom inch (2.5 cm), both elements, allows operating power to increase to 100 MW

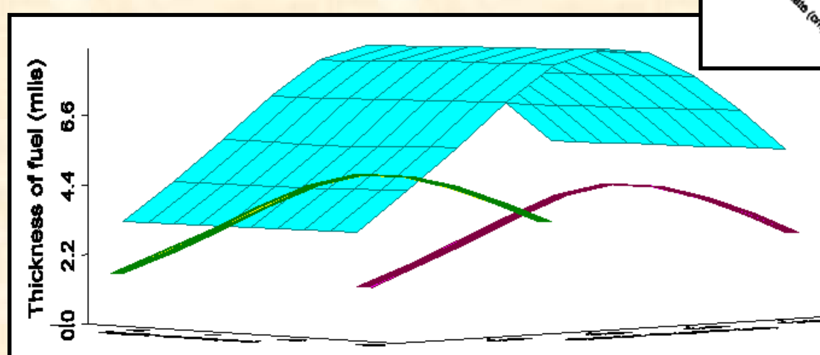
- **Flux performance restored to current level**
- **Constraining point in time may move from BOC to EOC (but slight difference)**
- **Optimal length yet to be found; optimal shape likely not step function; but fabricator may prefer 2 zones**



Views of 2D inner element plate profile



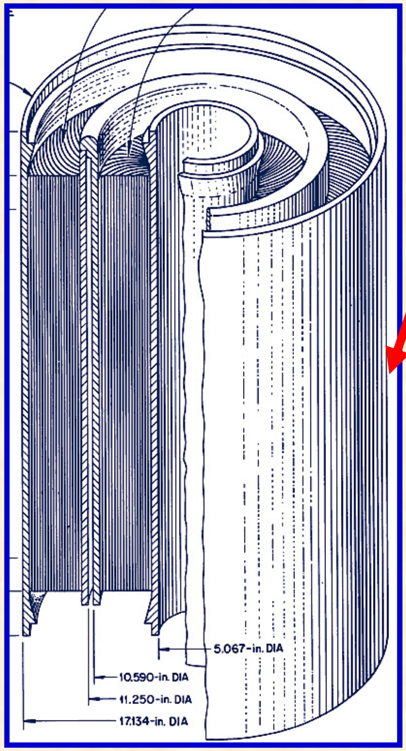




The maximum heat flux is at BOL and occurs at the outside edge of the outer element at axial midplane

- **Local-to-core-average power density is 1.51**
- **Predicted peak fuel zone temperature is 137°C**
- **Surface heat flux is 322 W/cm²**
- **Heat flux in RERTR-6 reported as 100-200 W/cm²**
- **Heat flux in RERTR-7 reported as expected to be >300 W/cm²**

Maximum local power density here



Performance parameters for LEU are less than for current HEU core at 85MW but would be restored at 100 MW

Location	LEU		% Difference [100*(LEU-HEU)/HEU]	
	BOL	EOL	BOL	EOL
HB2 beam tube	$9.625 \times 10^{+14}$	$1.267 \times 10^{+15}$	–3.85	–11.58
ISVXF-7 (activation)	$8.086 \times 10^{+13}$	$1.061 \times 10^{+14}$	–4.22	–10.84
EF3 (activation)	$3.192 \times 10^{+13}$	$4.100 \times 10^{+13}$	–4.97	–10.09

Presence of ^{238}U generally increases safety margins

Reactivity coefficient	LEU		HEU	
	BOL	EOL	BOL	EOL
Doppler (300K to 500K)	-2.42×10^{-5} %ΔK/K/C	-2.38×10^{-5} %ΔK/K/C	-2.41×10^{-6} %ΔK/K/C	-2.46×10^{-6} %ΔK/K/C
Void (10%)				
Outer element	–0.0793 %ΔK/K/%v	–0.0679 %ΔK/K/%v	–0.0765 %ΔK/K/%v	–0.0558 %ΔK/K/%v
Inner element	**–0.156** %ΔK/K/%v	–0.136 %ΔK/K/%v	–0.185 %ΔK/K/%v	–0.135 %ΔK/K/%v
Central target region	+0.0211 %ΔK/K/%v	+0.0266 %ΔK/K/%v	+0.0265 %ΔK/K/%v	+0.0317 %ΔK/K/%v

Post-shutdown cooling requirement increases for LEU but spent fuel storage cooling unaffected

Decay heat (watts)

Fuel/Source		Discharge	0.5 year	1 year	5 years	30 years
HEU	Actinide	$4.1 \times 10^{+3}$	3.9×10^{-1}	3.9×10^{-1}	3.8×10^{-1}	3.4×10^{-1}
	FP	$4.4 \times 10^{+6}$	$4.6 \times 10^{+3}$	$1.4 \times 10^{+3}$	$1.1 \times 10^{+2}$	$4.2 \times 10^{+1}$
	Total	$4.4 \times 10^{+6}$	$4.6 \times 10^{+3}$	$1.4 \times 10^{+3}$	$1.1 \times 10^{+2}$	$4.2 \times 10^{+1}$
LEU	Actinide	$7.9 \times 10^{+4}$	$1.2 \times 10^{+0}$	$1.2 \times 10^{+0}$	$1.2 \times 10^{+0}$	$1.3 \times 10^{+0}$
	FP	$5.0 \times 10^{+6}$	$4.6 \times 10^{+3}$	$1.4 \times 10^{+3}$	$1.1 \times 10^{+2}$	$4.1 \times 10^{+1}$
	Total	$5.1 \times 10^{+6}$	$4.6 \times 10^{+3}$	$1.4 \times 10^{+3}$	$1.1 \times 10^{+2}$	$4.3 \times 10^{+1}$

Denser LEU fuel reduces spent fuel dose rate; LEU increases Pu production

Dose rate

(30 years after discharge; rem/hr)

Source	LEU	HEU
Inner element	158	356
Outer element	243	596
HFIR core assembled	243	596

LEU – 306 g Pu/cycle; 3 kg per year
HEU – 18 g Pu/cycle; 0.2 kg per year

Alternative ideas – it is always easier if the other guy does the work

Analyst, “make 2D fuel”

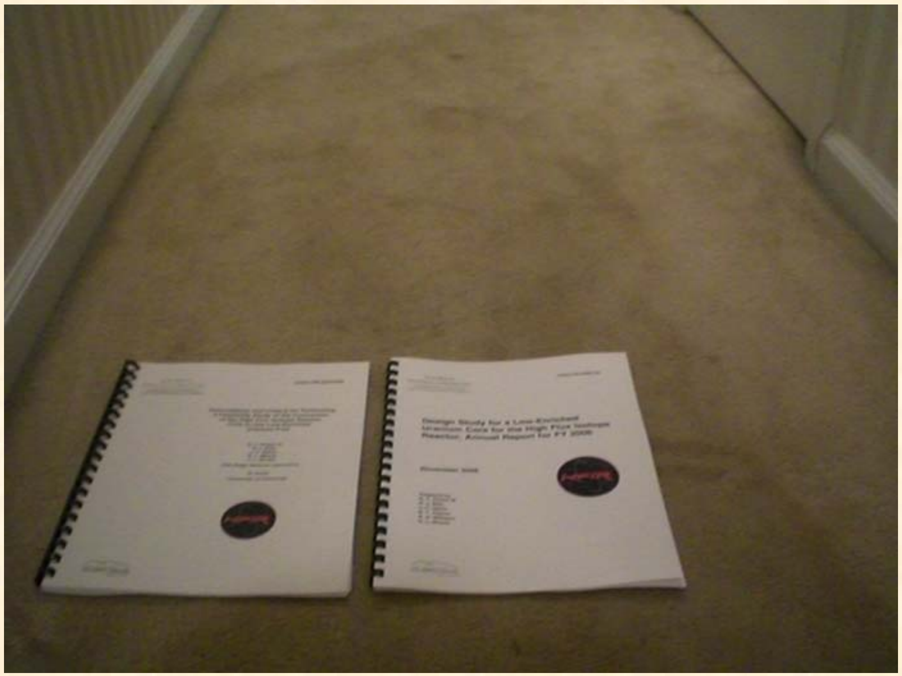
BWXT
BWX Technologies, Inc.

Put boron in endplate

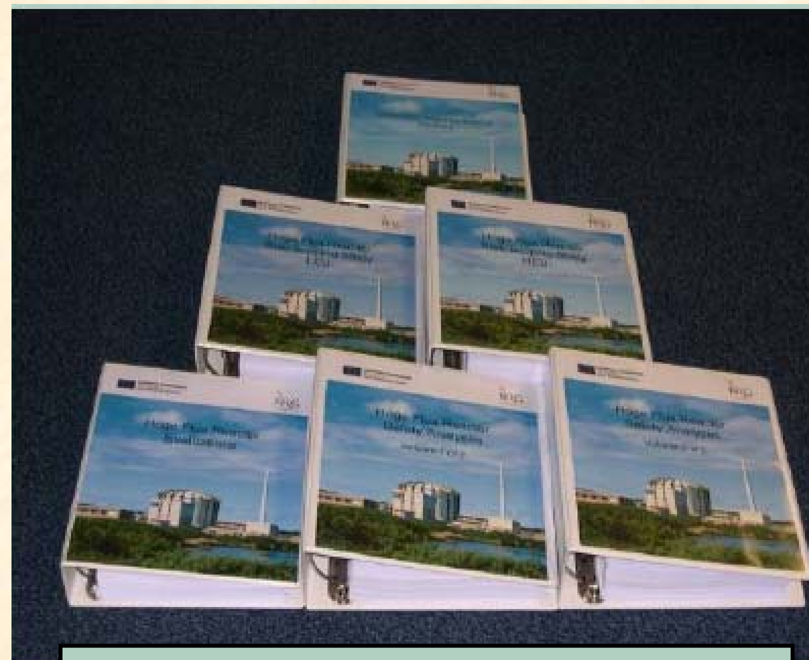
Make a better computer code

The cost and time for licensing and/or "permitting" documentation is under study

HFIR LEU documents



Petten LEU documents



- Licensing project started 01-01-2001
- License renewal request 23-12-2003
- Public hearing 15-03-2004
- Receipt of new license 23-02-2005

"The future's so bright, you've got to wear shades"