A Computational Model of the High Flux Isotope Reactor: Validation and Application to Low Enriched Uranium Fuels

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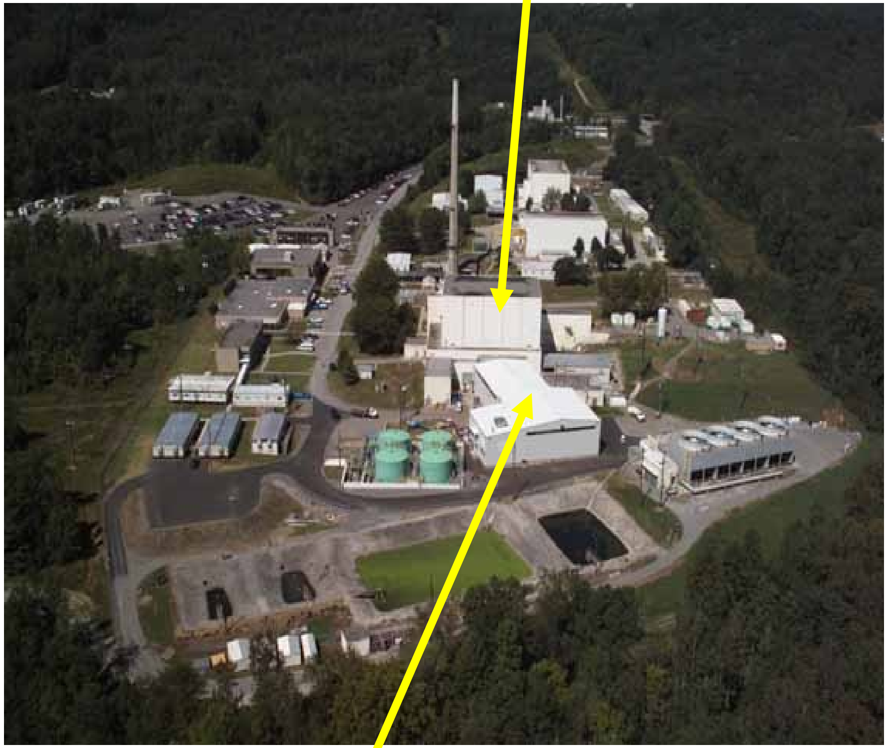
High Flux Isotope Reactor

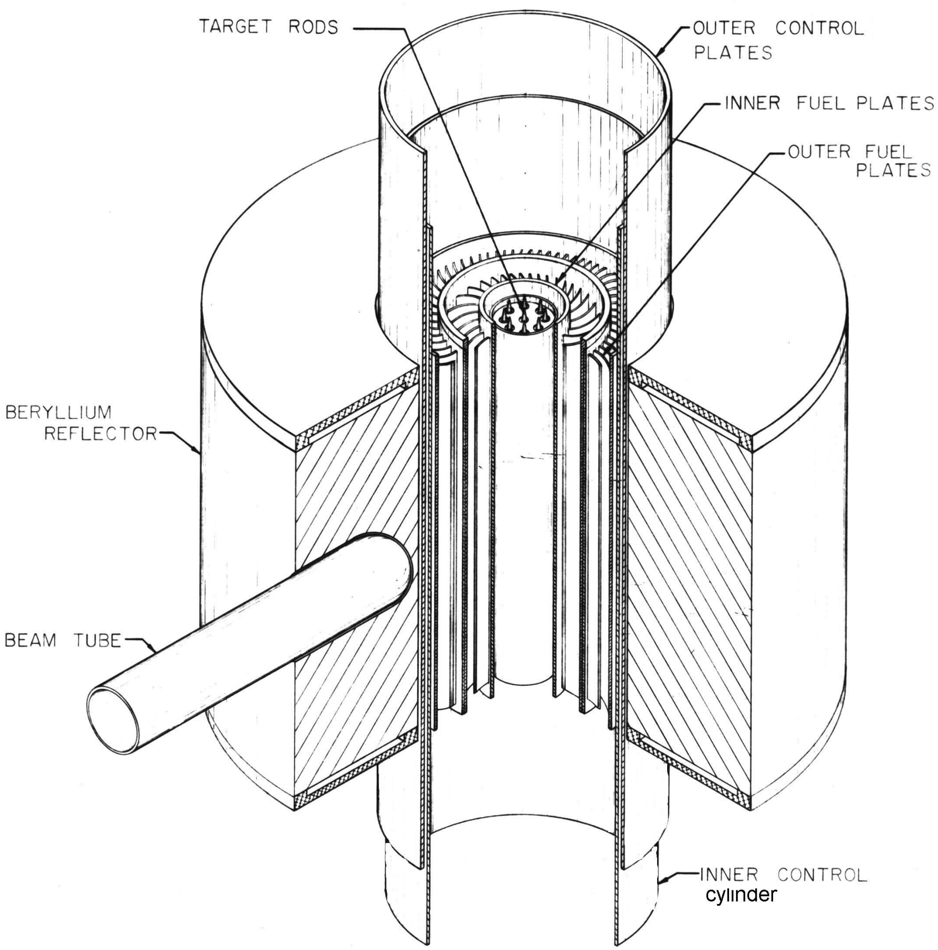
- 100-MW (currently operating at 85 MW)

- Highest thermal flux in world
- Pressurized LW cooled and moderated
- Beryllium reflected
- Fuel: Al clad U_3O_8 plates

  -9.4 Kg ^{235}U
- 24 days fuel cycle @85 MW

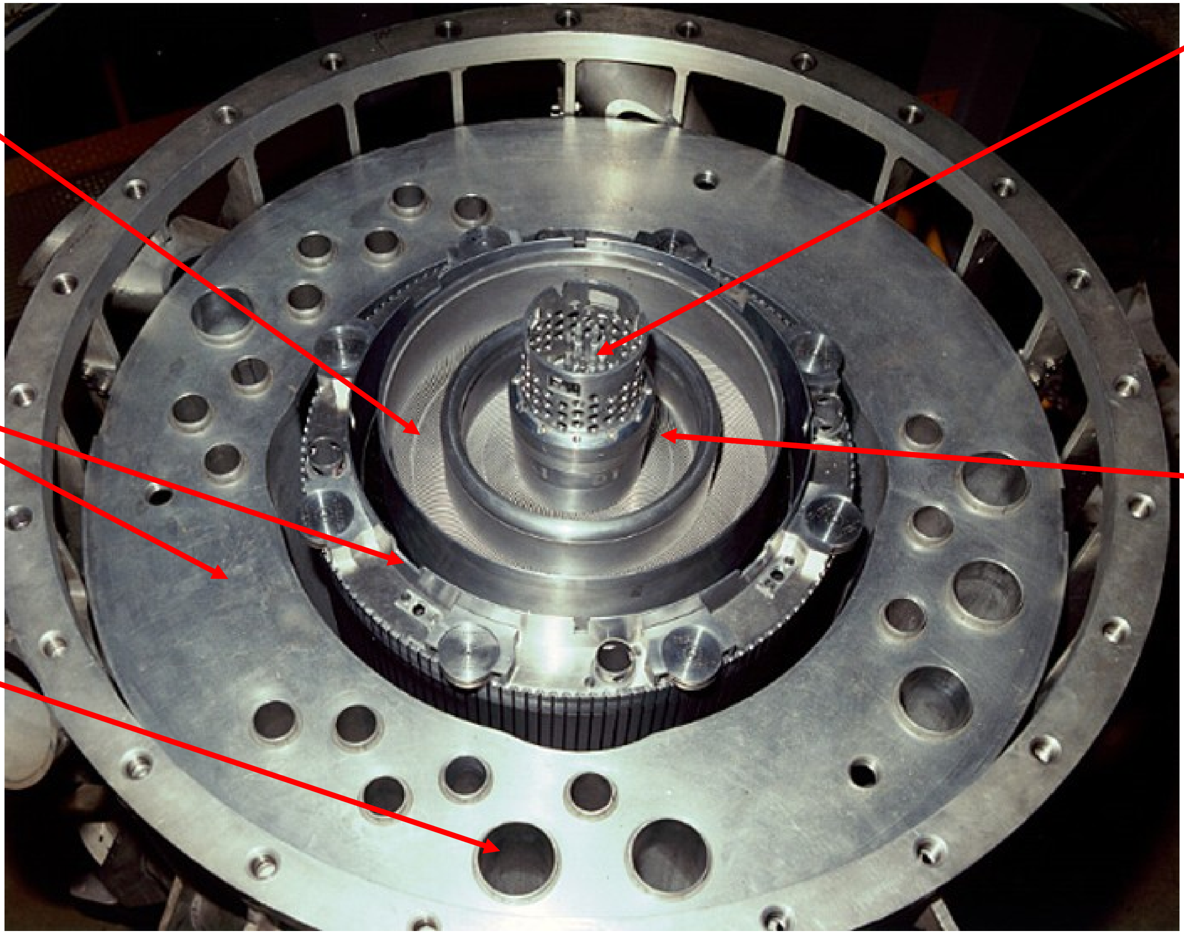


HFIR configuration is simple in concept – an interesting challenge to model

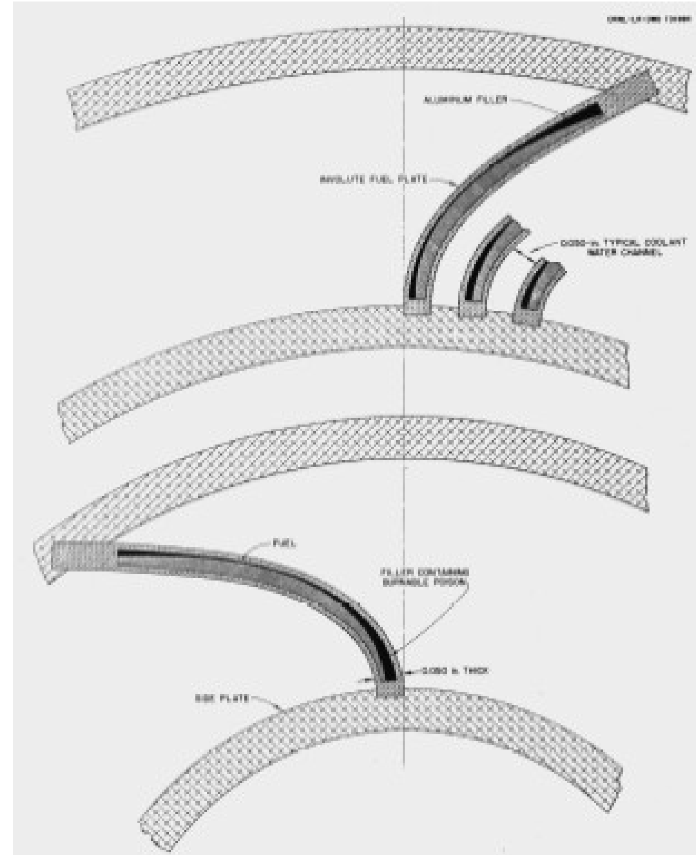


- Compact core— high-power density
- Flux-trap design
- Concentric cylinders
  - Target
  - Fuel
  - Control
  - Reflector

Top View of Reactor and Beryllium Reflector

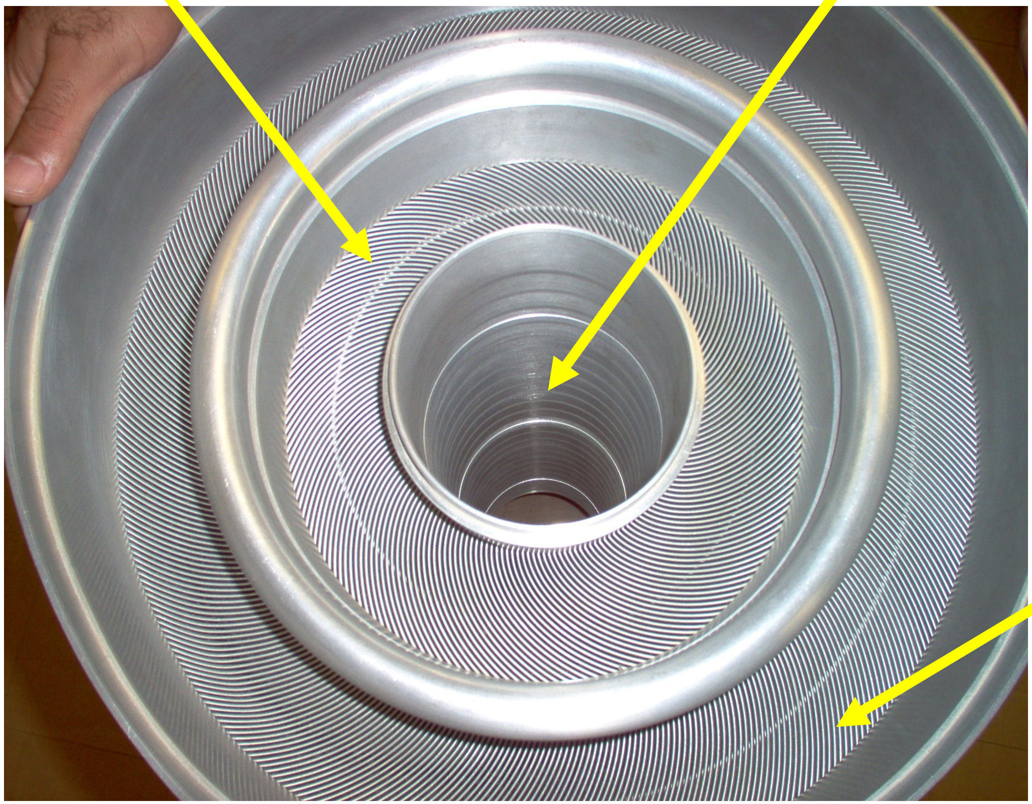


<u>Grading</u> – varying the relative thicknesses of the fuel and aluminum filler regions – <u>minimizes power peaking</u>.



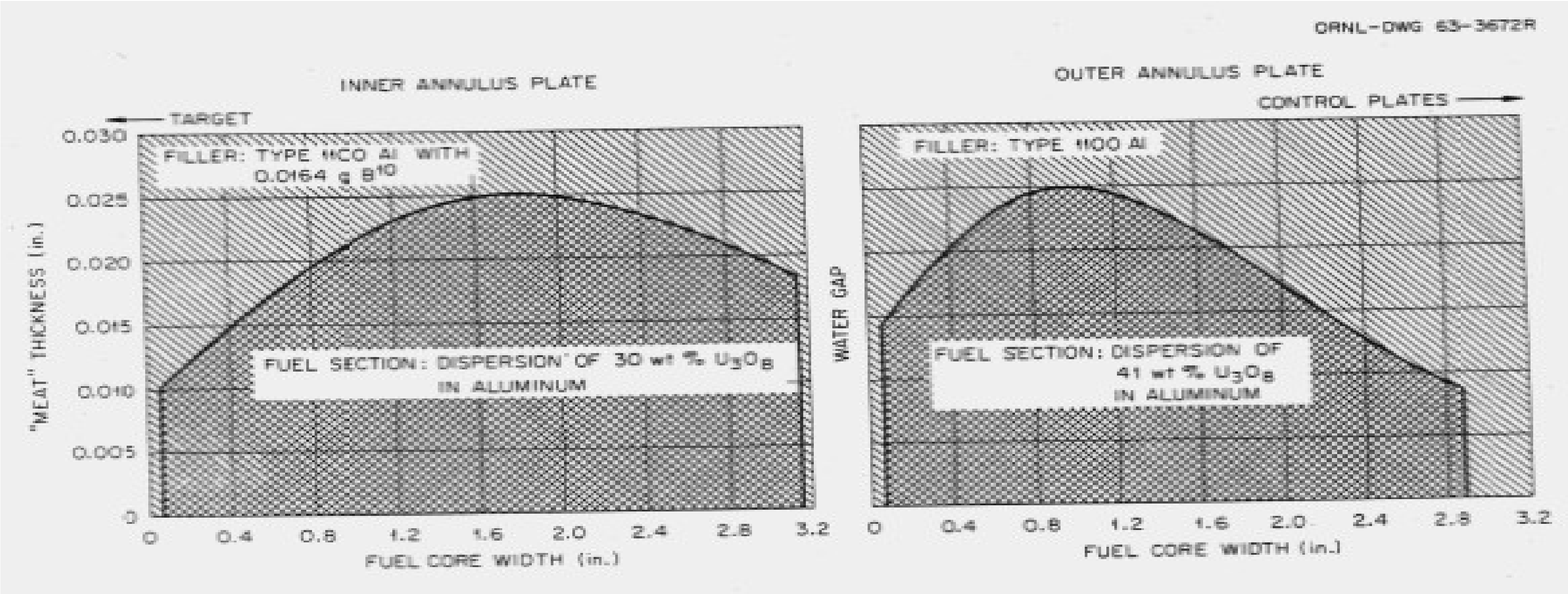
171 Fuel Plates

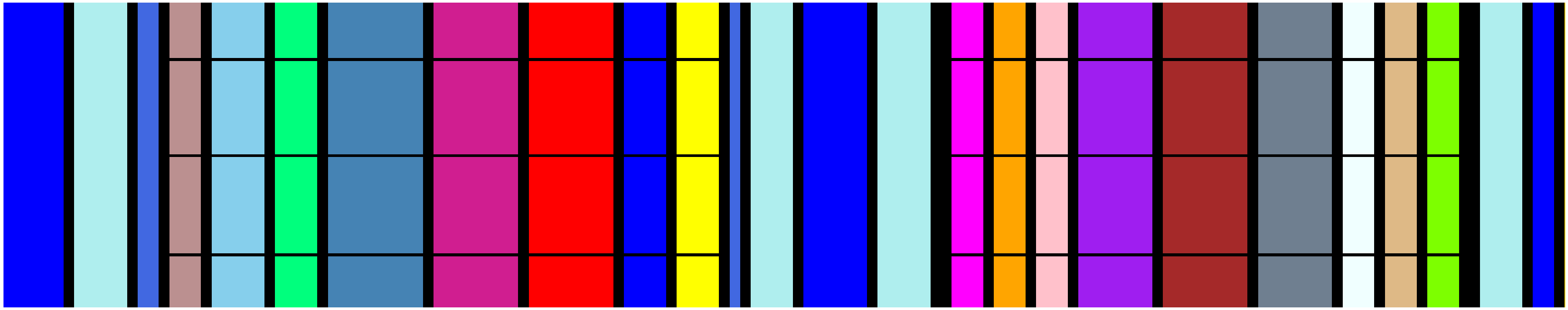
Flux Trap Region



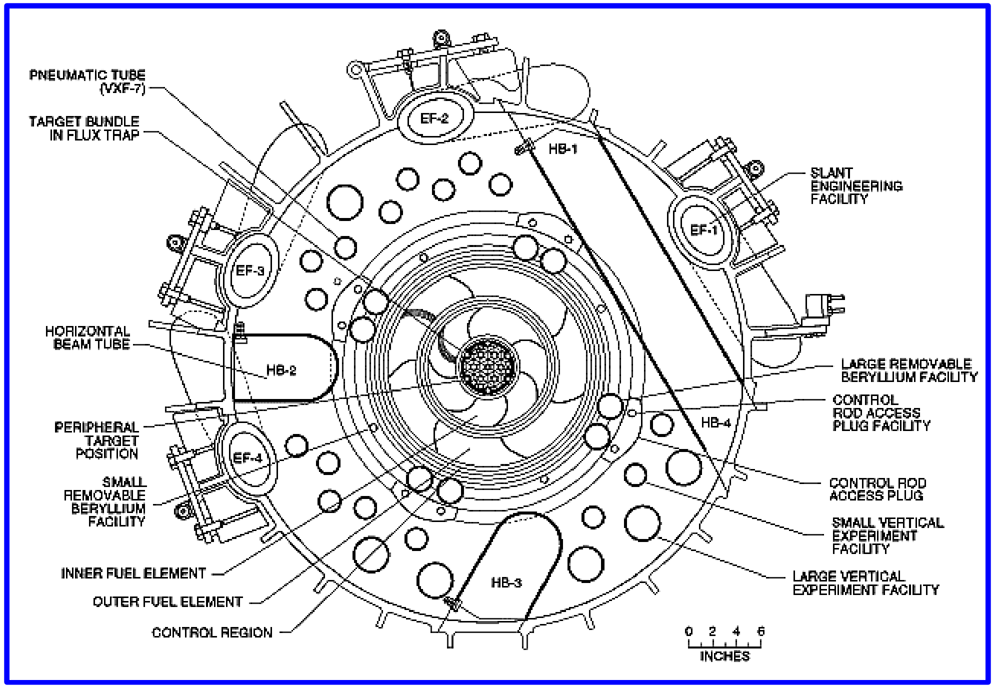
369 Fuel Plates

Fuel "meat" distributions



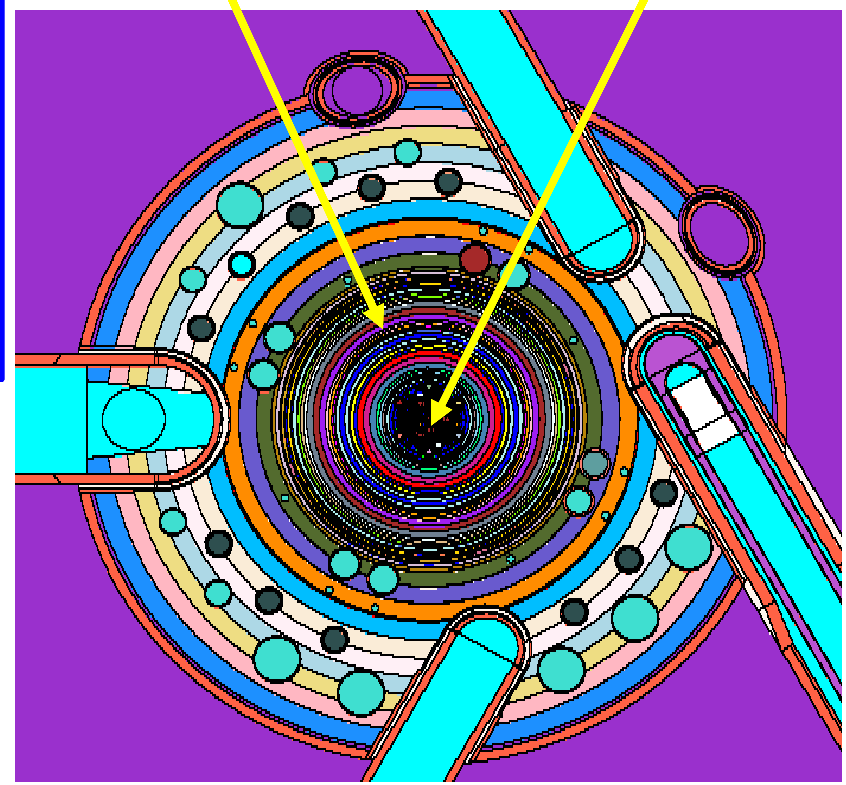


Existing model (Smith, Gehin originators) updated to April 2004 and documented.



Rings to simulate grading

Central target detail on following slides



From Modeling of the High Flux Isotope Reactor Cycle 400, ORNL/TM-2004/251, August 2005

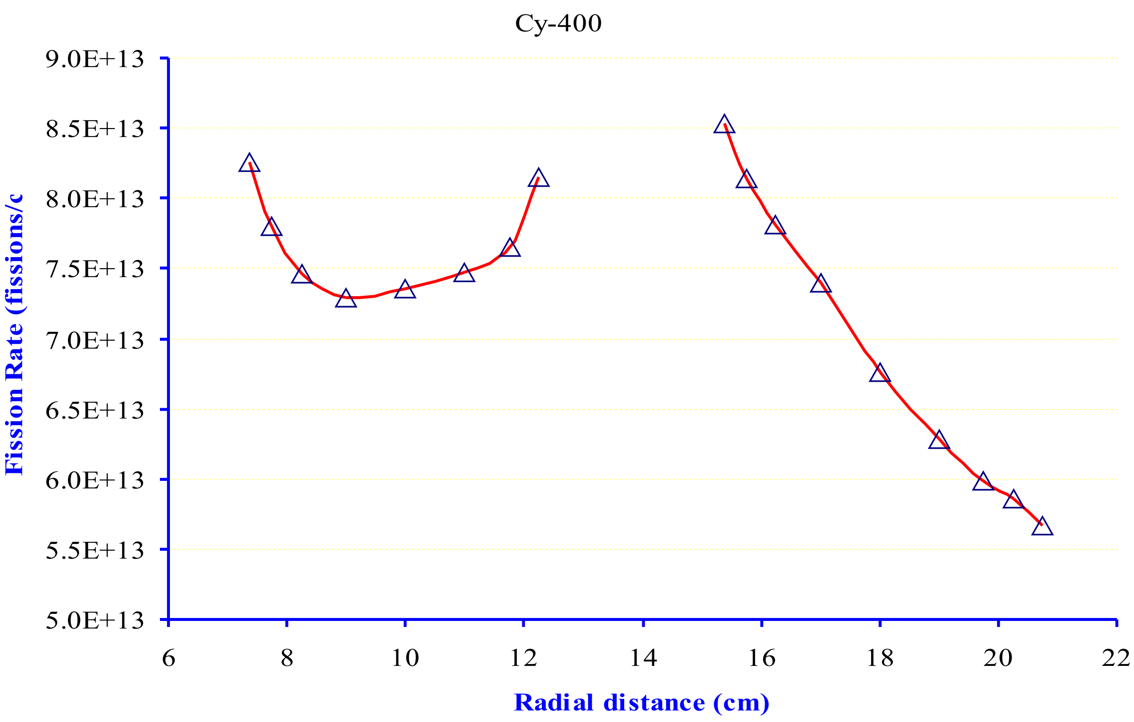
Contains description of MCNP model and comparison to engineering drawings.

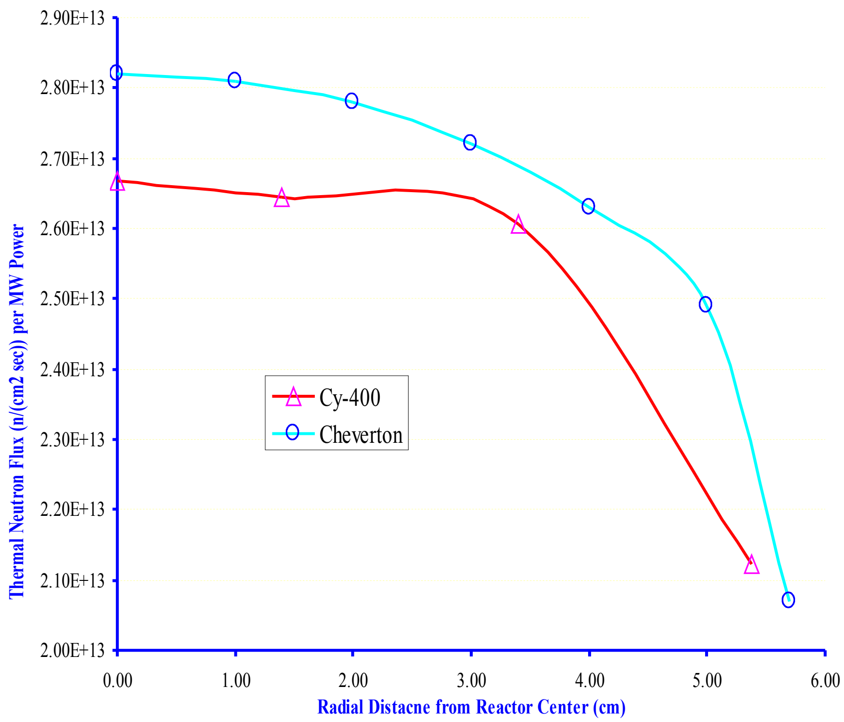
BENCHMARK RESULTS

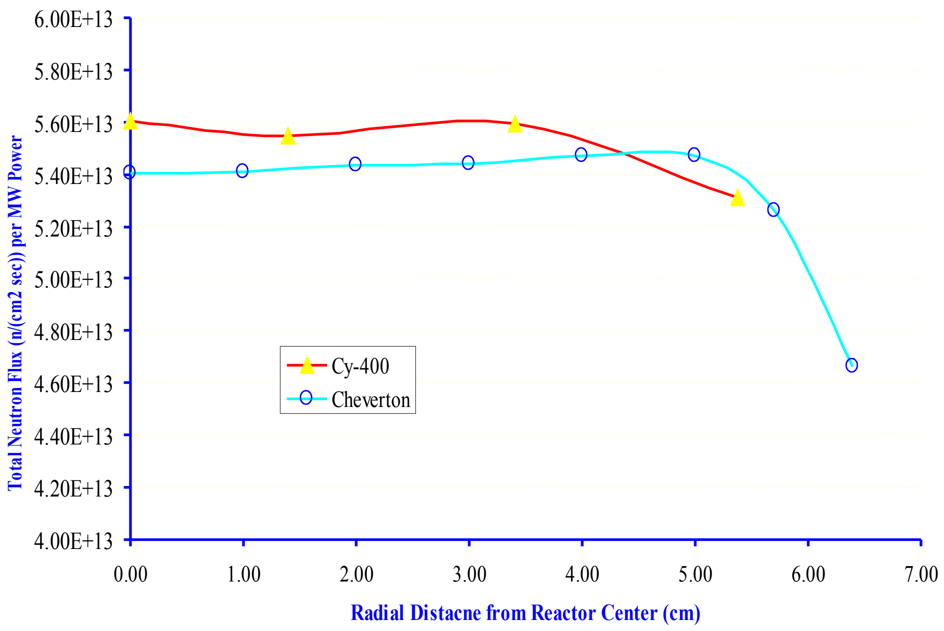
keff (combined collision/absorption/track-length)	1.00870 ± 0.00013
Number of neutrons produced per fission	2.439
Average neutron energy causing fission	0.023304 ev.
Fission neutrons produced per neutron absorbed (capture + fission) in cells w/ fission	1.7412

- Six critical experiments exist for HFIR, have been modeled with diffusion theory (VENTURE) by RTP.
- Future work will be to model with MCNP

REACTOR PARAMETERS CALCULATIONS







MCNP has existed for more than 25 years and you're just doing this now?!

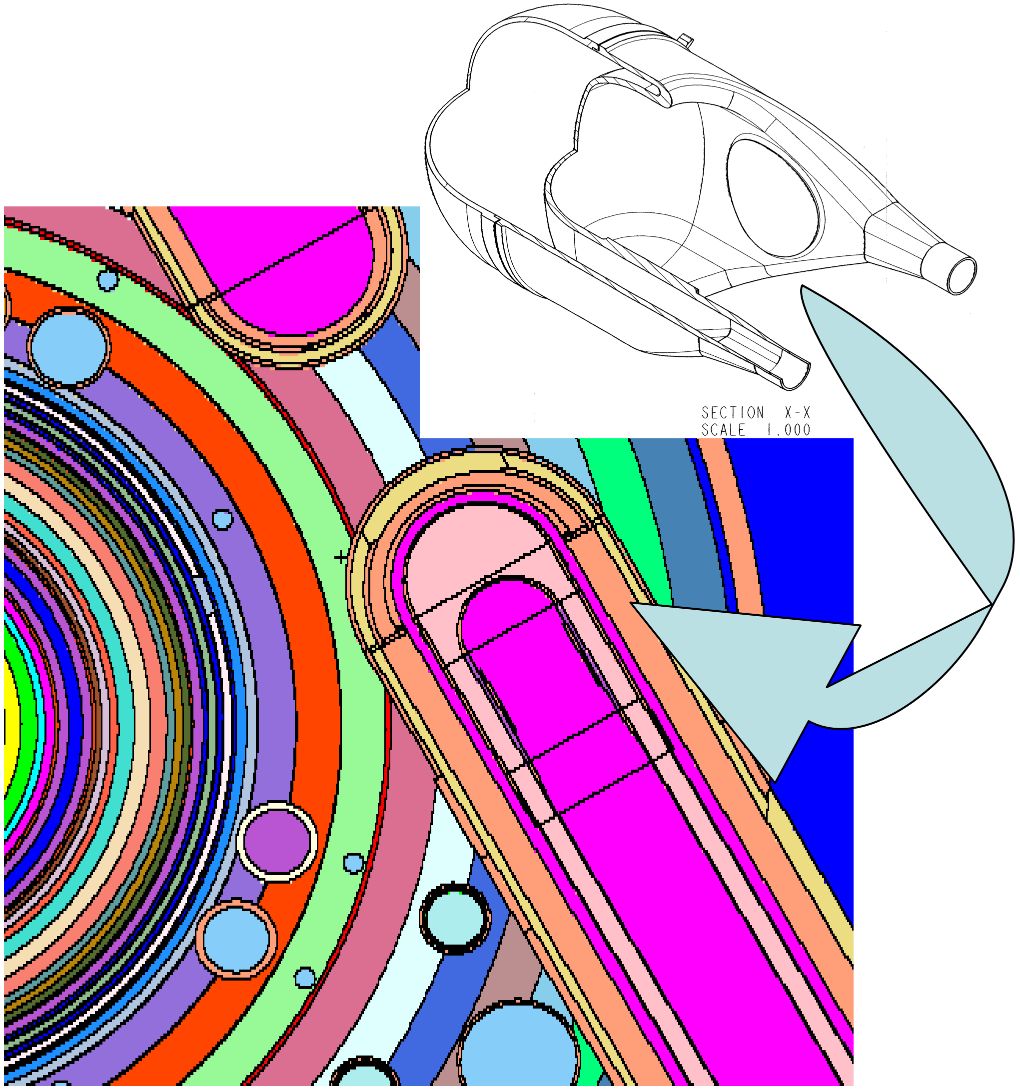
- "Licensing" meaning safety analyses, based on experiments conducted in early 60s.
- Generally, until recently, measurements bounded operating and some transient conditions
- Diffusion theory models existed since 1970s and were benchmarked; discrete ordinates models developed during 80's and 90's.
- MCNP models of HFIR have existed at ORNL for at least 10 years but were not documented or poorly documented; did not meet today's DOE requirements for software quality assurance

New projects spurred need for developing a model to current DOE software standards

- **Installation of cold source at ORNL**
- **Installation of two new hydraulic tubes in the central target region of the reactor**
- **Proposal for installation of “internal Be reflector” in target region of the reactor**
- **Consideration of longer cycle length achieved via increased ^{235}U loading (density) –** *to be discussed at Winter 2005 ANS meeting*
- **Request to establish LEU fuel development criteria**

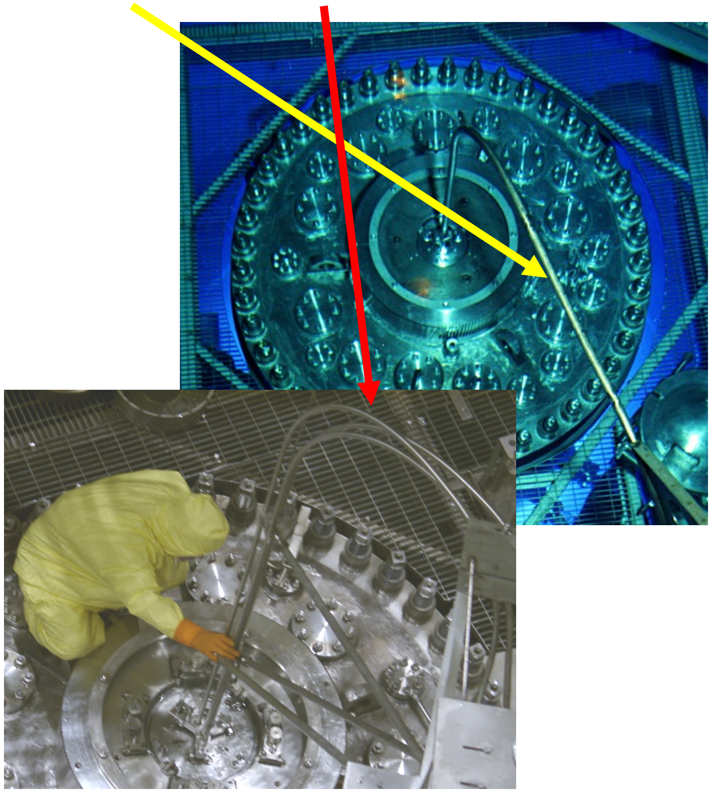
Application – prediction of heating rates in cold source moderator vessel

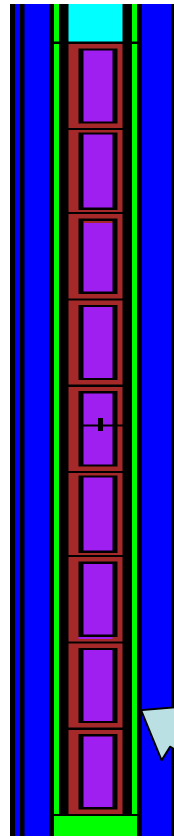
- Liquid hydrogen flows inside Al vessel with He coolant
- Al has heating from prompt fission gamma, delayed gamma, neutron absorption, activation product decay
- Total heating rates calculated by Slater verified earlier work by Bucholz, ORNL
- Hottest spot for nominal conditions at reactor power of 85 MW – 2.6 W/g



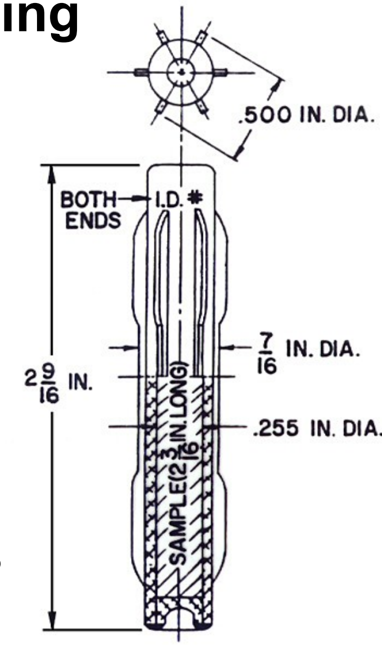
Application – irradiation experiment safety

Number of hydraulic tubes increased from one to three in June 2005.





- Tube allows access to the high flux region with the reactor operating
- Each tube can accommodate 9 targets
- MCNP model to be used for estimating target worth and heat rates

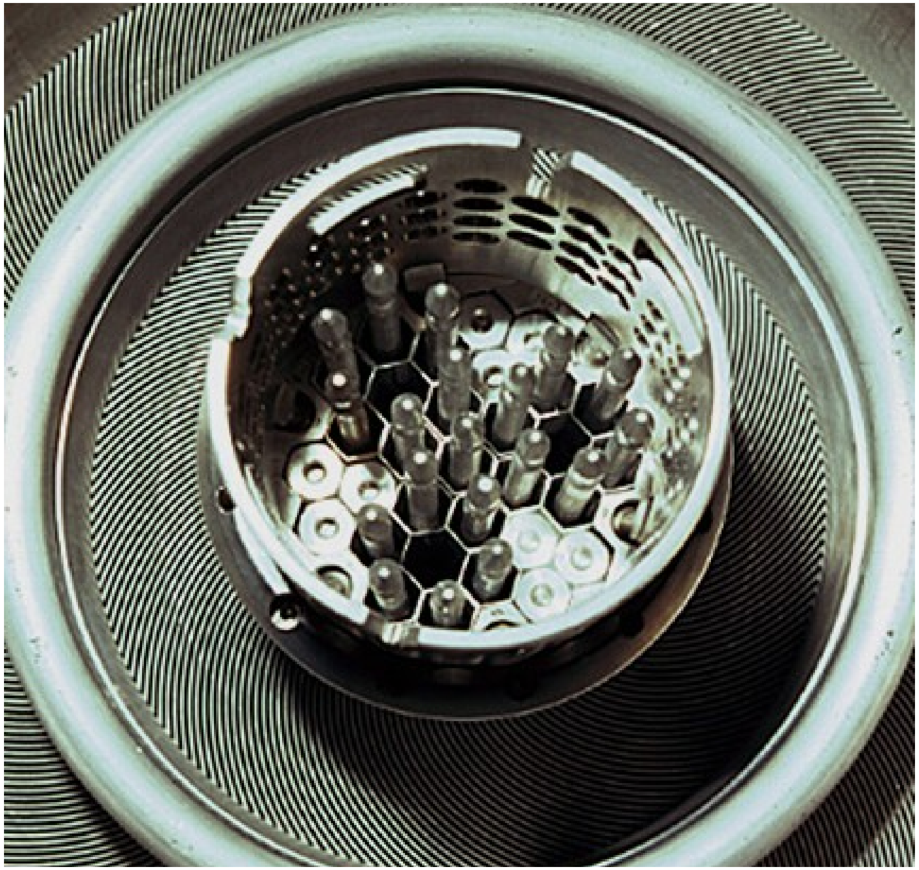


- Model validated with Cd rabbit measurements, C. O. Slater, ORNL/TM-2005/94 and activation wires, D. E. Peplow, ORNL/TM-2004/237

Measured worths varied from 1 to 50 cents. Calculations agreed with measurements to within one standard deviation (5 cents).

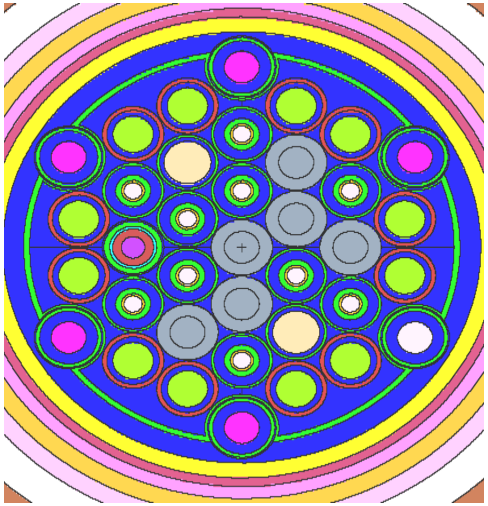
Application of Model
Study of internal Be reflector

- Improve neutron economy
- Investigate the use of beryllium rods in the target region to increase the reactivity of the HFIR
- Consequently increase the fuel cycle length
- Confirm that perturbation in power profile acceptable



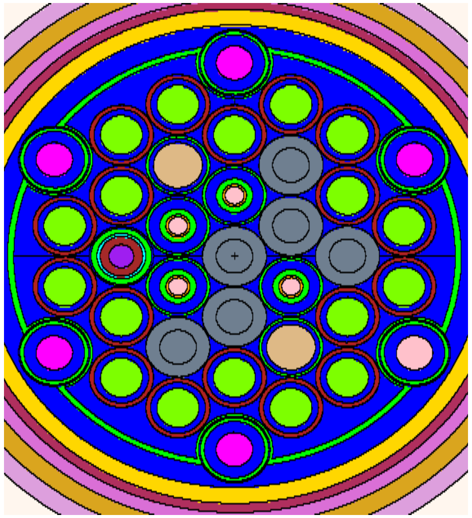
Target Basket in Fuel Element

Beryllium Loading Arrangements

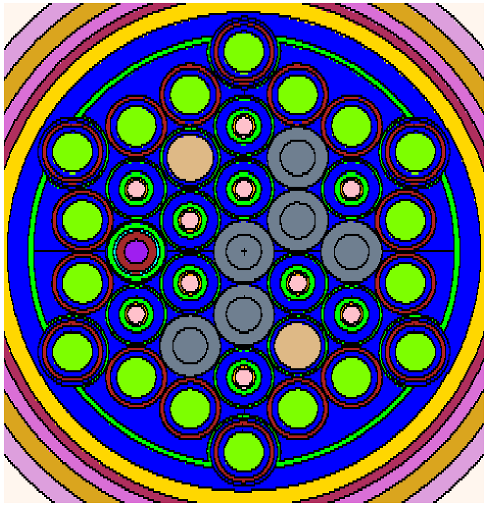


Case 1

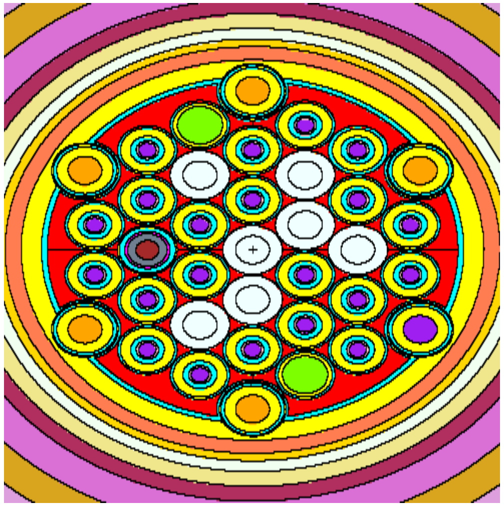
5 Cases Investigated



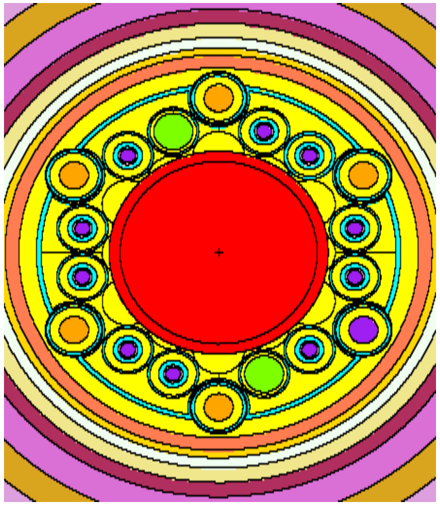
Case 2



Case 3



Case 4



Case 5

MCNP calculation results for Be reflector effect on BOC core reactivity

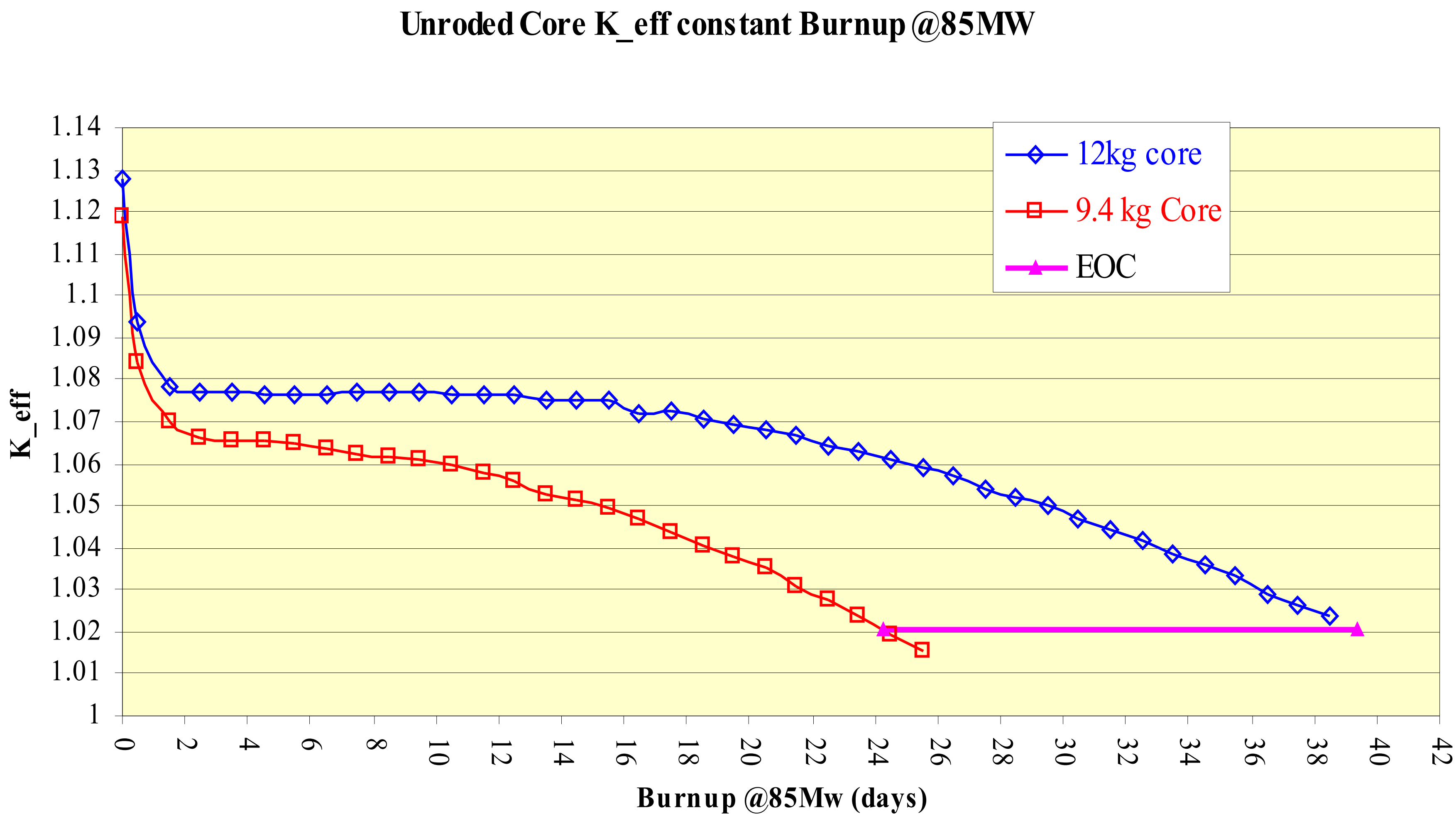
(HFIR costs "50 cents-a-day" to run, consumes about 50 cents of reactivity per day of operation at 85 MW.)

Case number or reference	Final *keff* (col/abs/trk len)	Increase in reactivity	
		(absolute)	(cents)
Cycle-400	1.00863 ± 0.00012	—	—
Case 1—12 beryllium rods	1.01258 ± 0.00013	0.00428	56.32
Case 2—18 beryllium rods	1.01468 ± 0.00012	0.00605	79.61
Case 3—18 beryllium rods PTP	1.01418 ± 0.00012	0.00555	73.03
Case 4—central solid Be reflector	1.02090 ± 0.00023	0.0126	165.79
Case 5—Be reflector over target region	1.02132 ± 0.00013	0.01302	171.32

Application of Model - Fuel cycle and core depletion

- The model can be automatically linked to the Origen code, to perform core depletion studies
- Linkage codes; Monteburns, Aleph, others
- The capability of calculating K-eff, fuel isotopic composition, fluxes, fission rate, and other neutronics parameters at any point in the cycle
- Complete picture throughout the cycle of the effect of any design changes, or improvements to HFIR
- Estimate the fuel cycle length of loading new fuels and enrichments

Application of Model -
Study of increased fuel loading



Complete results will be presented at the 2005 ANS Winter conference

During FY06, low enriched uranium (LEU) fuels will be studied with the MCNP model

- **Will be used to verify results of deterministic HFIR models (VENTURE diffusion theory; ATTILA finite element)**
- **When existing HEU loading "changed" in MCNP model to LEU (20% enriched, same ^{235}U spatial distribution; same control element position), k_{eff} at BOC decreases from 1.008 to 0.930 ($10 loss in reactivity due to ^{238}U)**
- **Criticality can be achieved by removing control elements from the core; comparison with VENTURE shows cycle length reduced from ~24 to ~4 days**
- **With LEU fuel, average U density in "meat" region of plate increases from ~1 g/cc to ~5 g/cc**
- **Re-affirm 1997 conclusion from Argonne studies that U-molybdenum alloy is needed to obtain U densities that could maintain HFIR flux performance with LEU**

Conclusions

- The MCNP model is a 3-D detailed and accurate representation of the HFIR cycle 400
- Benchmark calculations of eigenvalues, neutron fluxes, and reaction rates were performed using the model and compared with other published and or measured values
- Model can accurately calculate reactor parameters with reasonable confidence
- Model input in any region can easily be modified, in order to incorporate design changes, or experiments loading
- Benchmark results are used as a reference to study the effect of new designs, modifications, and experiments