Core Design Studies on a Low-Enriched Uranium Reactor for Cold Neutron Sources at NIST

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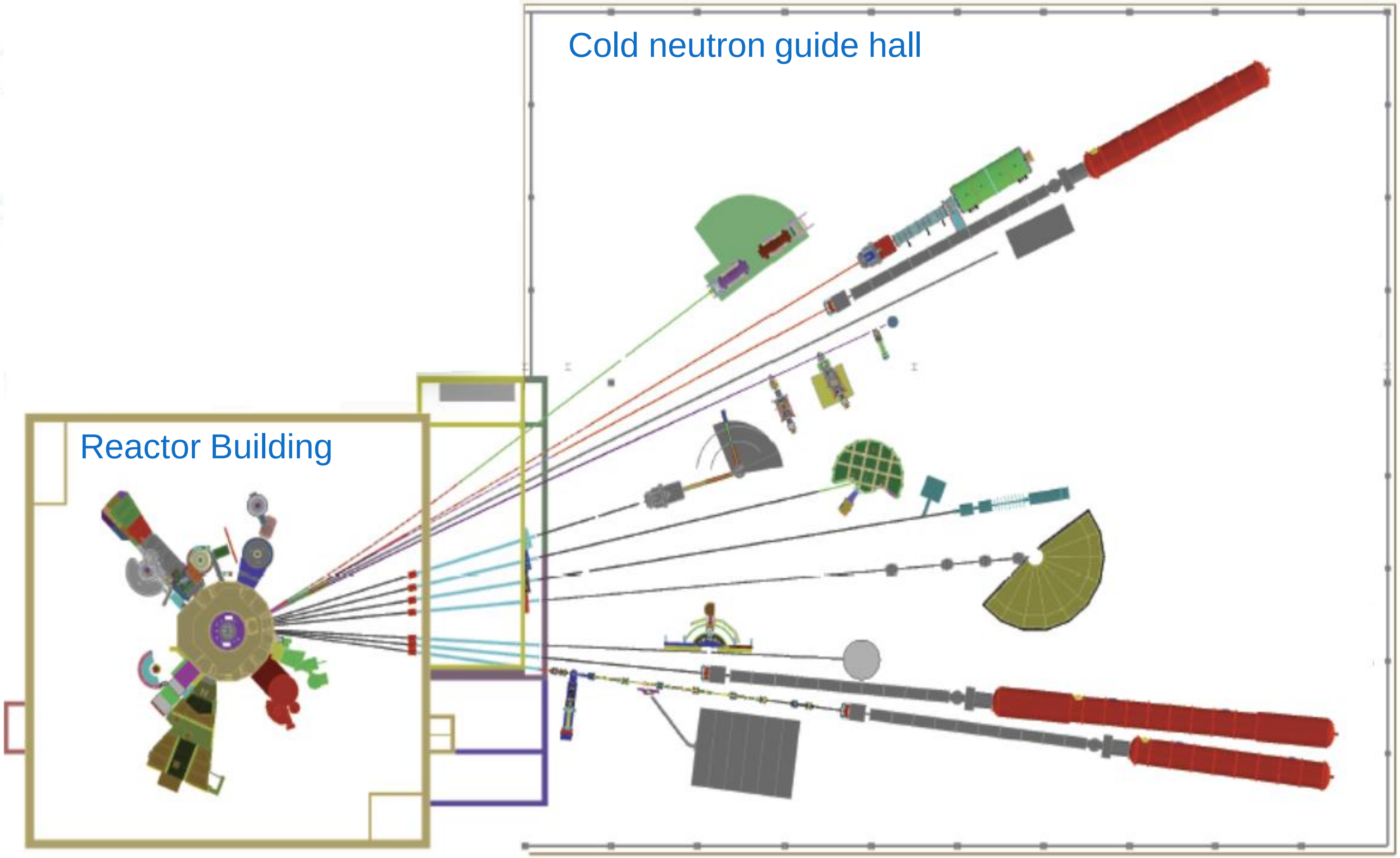
Scientific Utilization of the NBSR



NCNR has 28 instruments for various scientific experiments, 21 of them use cold neutrons (as of Dec. 2015), and hosts over 2,000 guest researchers annually, 70-80% of them are using cold neutrons.

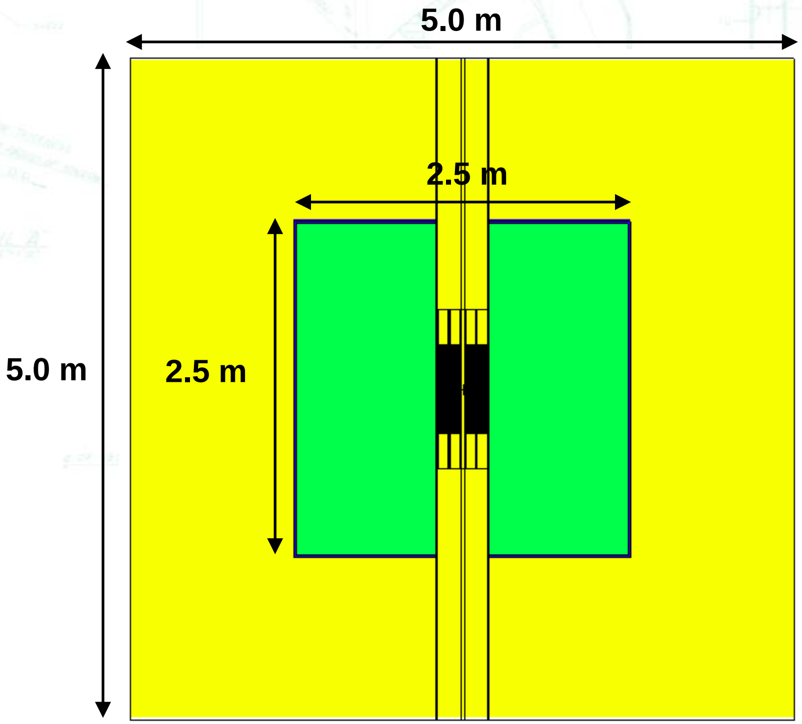
Main Design Parameters of New Reactor

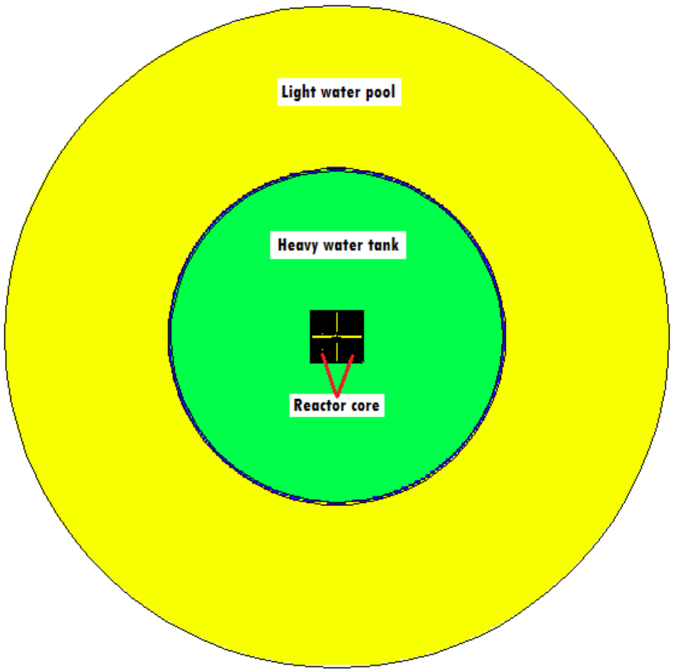
	New Reactor	NBSR
Reactor power (MW)	20 - 30	20
Fuel cycle length (days)	30	38.5
Fuel material	U_3Si_2/Al	U_3O_8/Al
Fuel enrichment (%)	19.75 (LEU)	93 (HEU)

Other Important Considerations:

- Compact core concept is employed in the design
- Principle objective is to provide cold neutron source (CNS)
- At least TWO CNSs are targeted in the new design
- Significantly utilize existing facilities and resources
- Combine latest proven research reactor design features

A Compact Core and 'Tank-in-Pool' Design



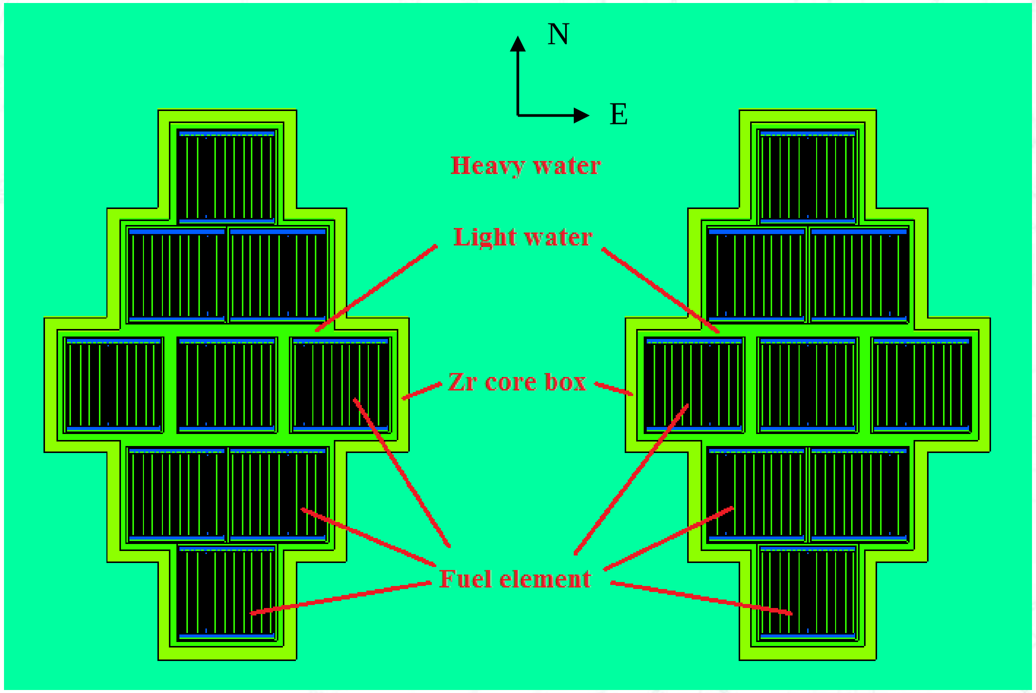


(a) Elevation view **(b) Plan view**

A schematic view of the side-plane (left) and mid-plane (right) of the reactor.

The compact core exploits inverse flux trap (i.e., the thermal flux peaks outside of the core).

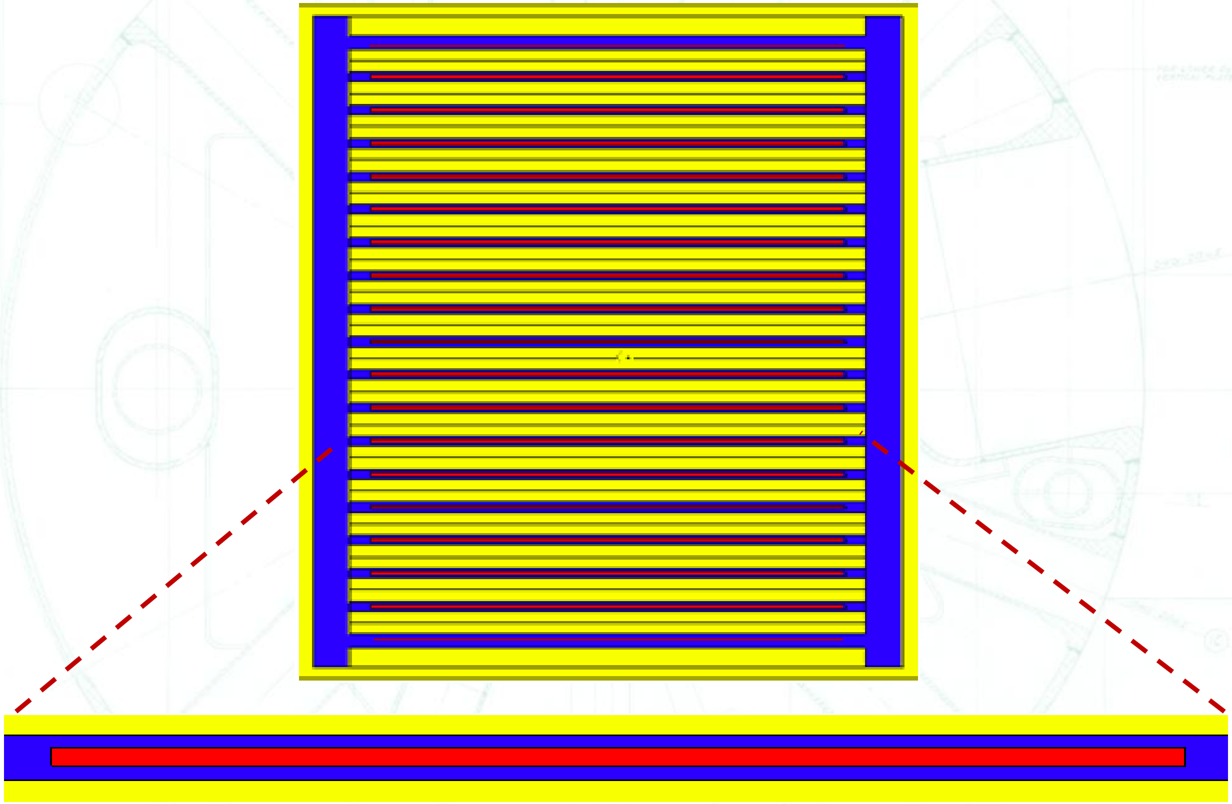
Horizontally Split Core



Fuel element layout in the split core

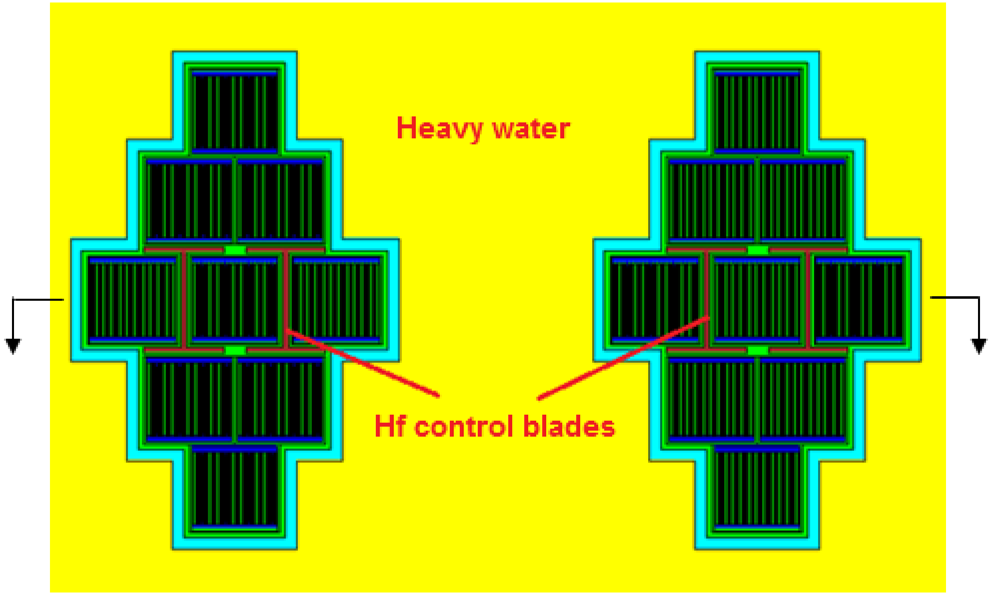
- The fuel element (FE) has similar dimensions as the one in NBSR but no middle gap (active fuel length 60 cm).
- 18 FEs are evenly distributed in two horizontally split regions.
- The side-to-side distance between two core halves is about 19.5 cm.
- The central FEs are slightly separated with 1 cm light water gaps left for control element movement.

The MTR-type Fuel Plate and Fuel Element

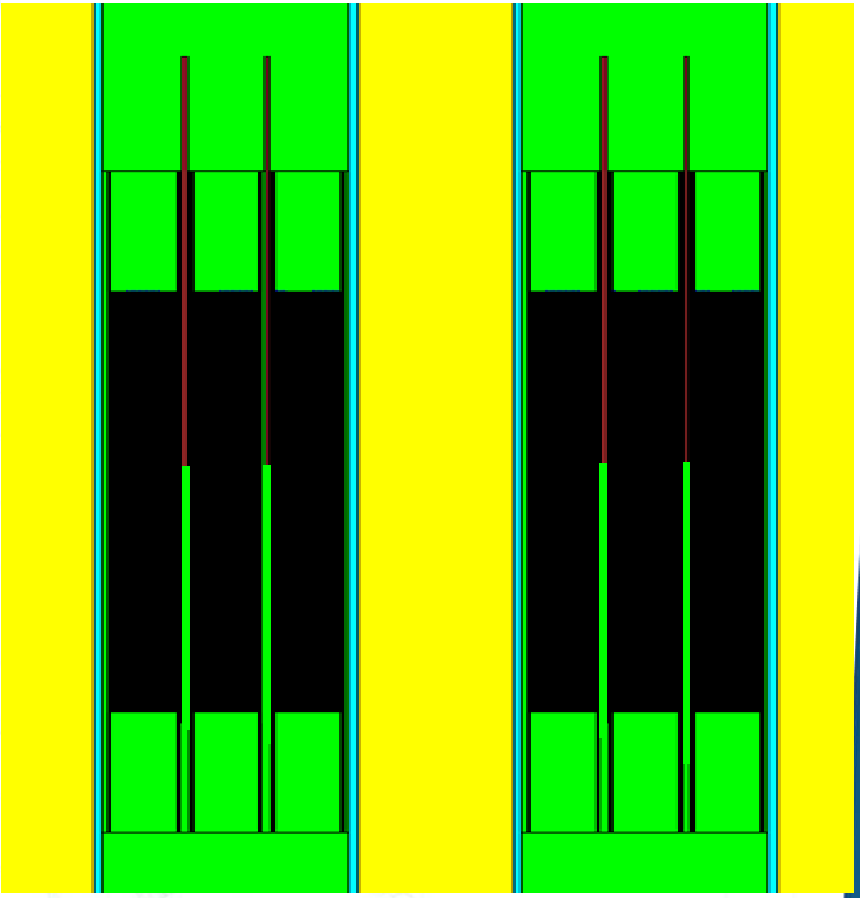


Cross sectional view of the fuel element: 17 fuel plates, 2 end plates and 2 side plates. The U_3Si_2/Al fuel meat is 0.066 cm (26 mil) thick and 6.134 cm wide. The fresh FE has about 399 g U-235.

Arrangement of the Control Elements

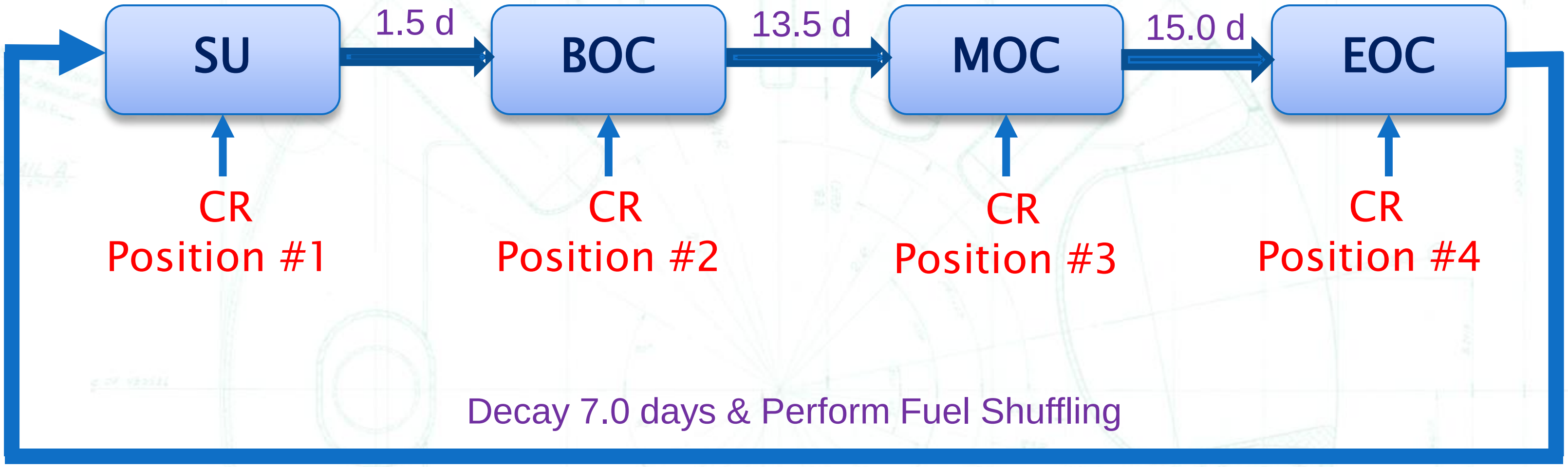


Top view



Side view

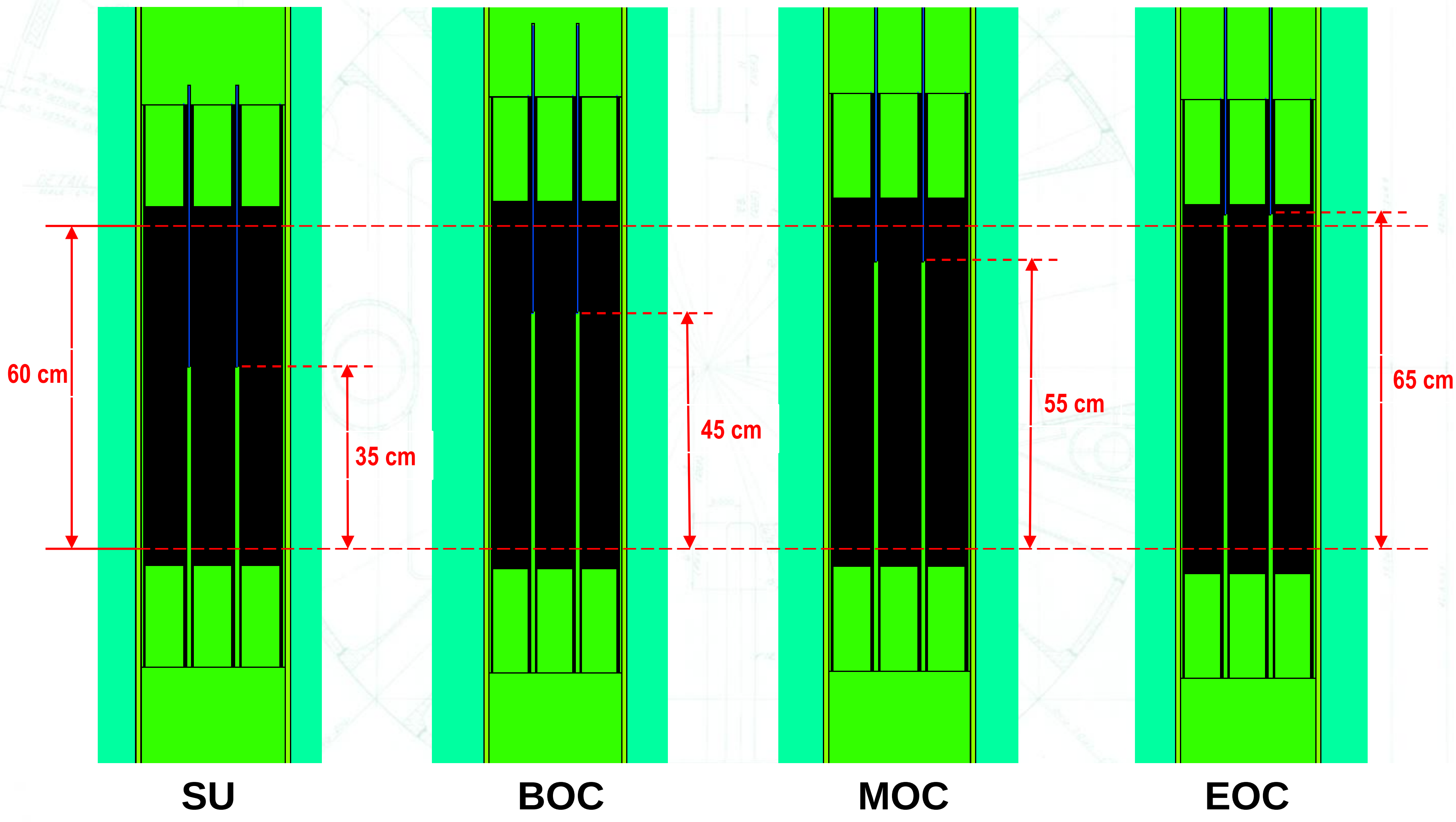
Methodology to Produce Full Cycle Equilibrium Core Using MCNP-6



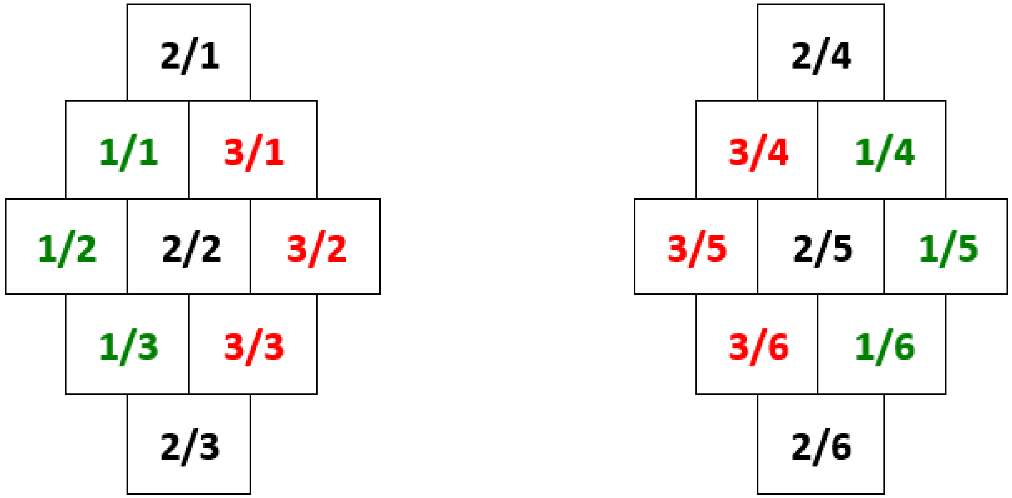
Assumptions:

- Four representative burnup steps (SU, BOC, MOC and EOC) are considered.
- Control element positions are approximated at critical positions for each step.
- The fuel cycle length is fixed at 30 days.
- No transmutation are considered for structure materials (e.g., Al).
- The depletion effect of control material (hafnium) is not taken into account.

CR Critical Positions at Different State

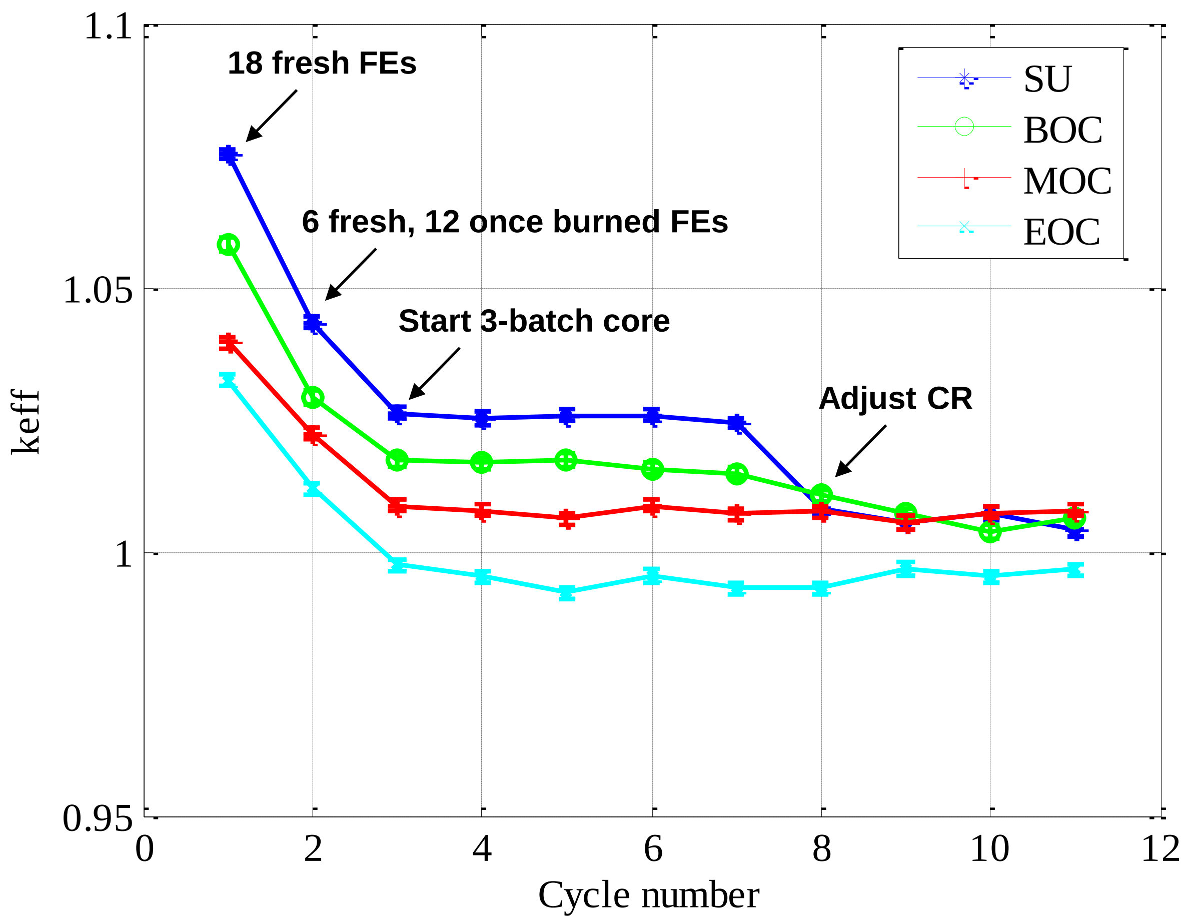


Three-batch Fuel Management Scheme

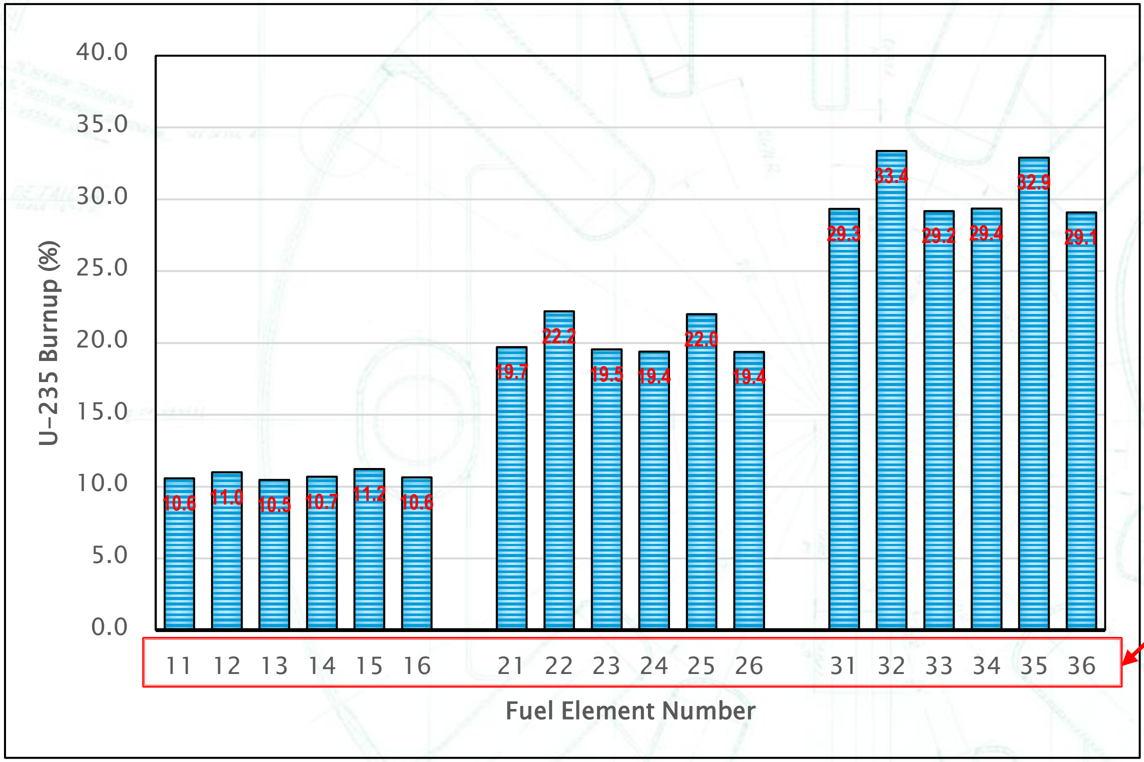


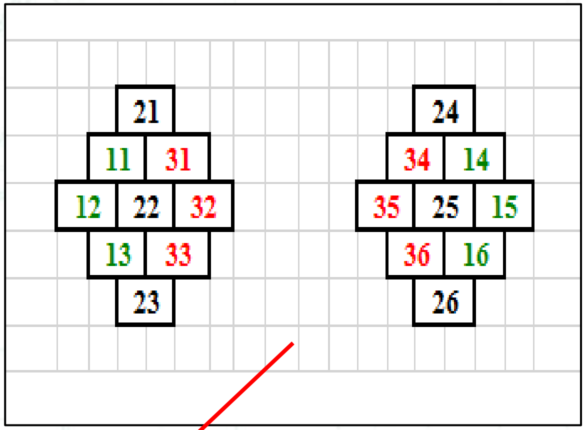
- The **green** color indicates fresh fuel at SU, and the **red** color indicates discarded fuel at EOC.
- The **<u>first</u>** number indicates the batch number, and the **<u>second</u>** number indicates the FE index in the batch.
- For <u>detailed geometry consideration</u>, each fuel element has 6 axial portions, thus the total number of fuel materials considered in the MCNP burnup calculation is 18 x 6 = 108 .
- 6 fuel elements are replaced after the 30-day cycle.

Equilibrium Core Search Procedure – k_{eff}



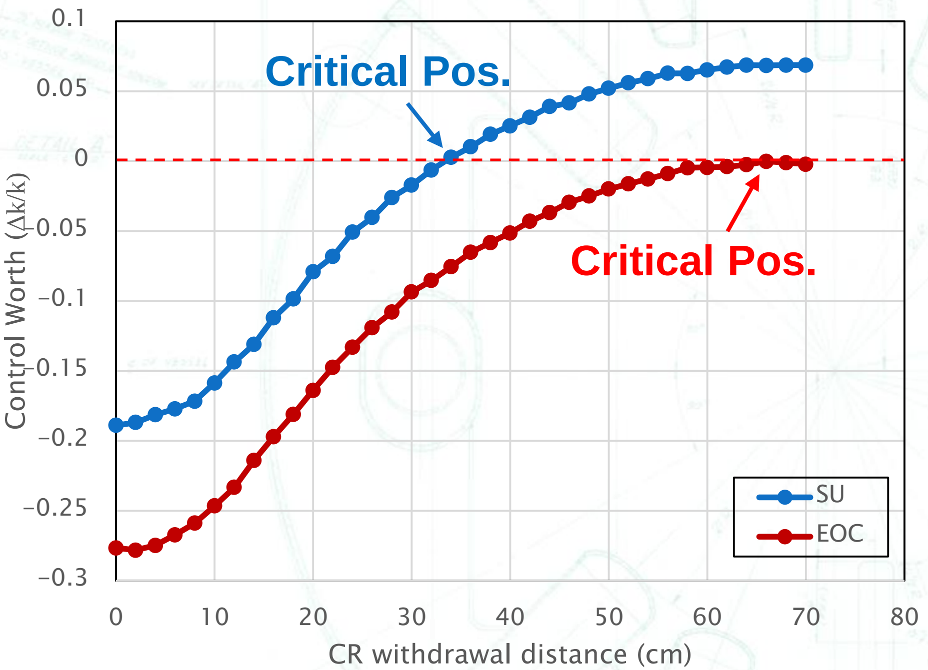
U-235 Burnup at EOC





	1st Batch FEs	2nd Batch FEs	3rd Batch FEs
Avg. Burnup (%)	10.75	20.36	30.53

Control Rod Worth Evaluation for SU and EOC



Control blade worth curve at SU and EOC

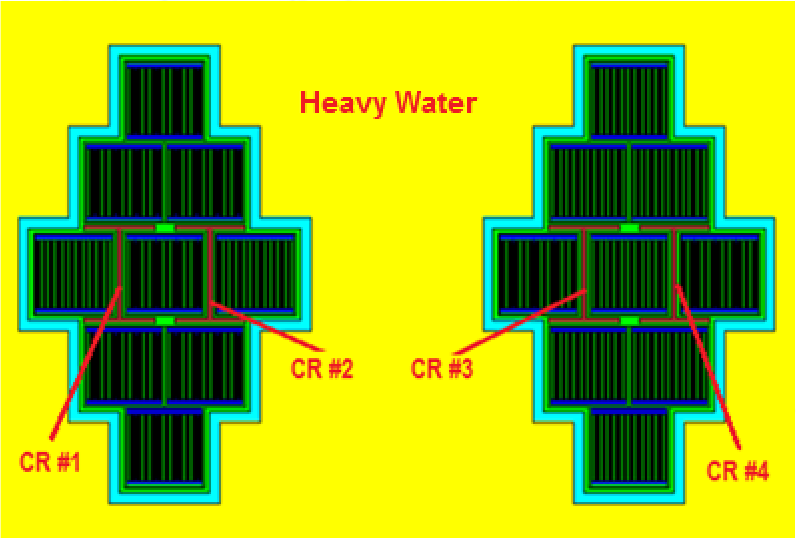
CR Critical Positions

	CR Withdrawal Length (cm)	k_{eff}
SU	34.0	1.00262
EOC	66.0	0.99829

Good agreement with those used in the equilibrium cycle search procedure for SU and EOC !!!

Reactivity (%Δ*k*/*k*) Control Assessment

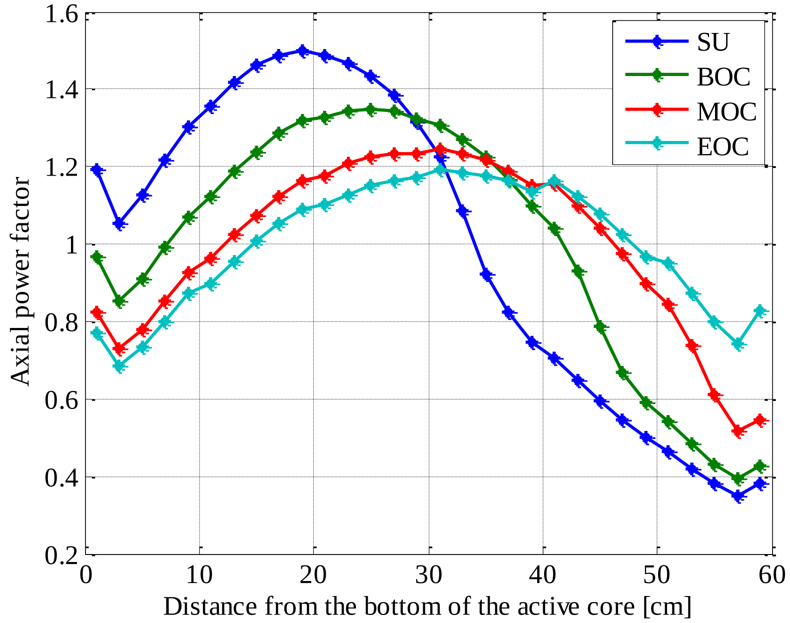
	SU	EOC
Excess Reactivity	6.86	0.00
Total Control Worth	25.74	27.42
Shutdown Reactivity	-18.88	-27.42
Shutdown Margin # 1	-6.60	-14.72
Shutdown Margin # 2	-7.99	-15.83
Shutdown Margin # 3	-7.82	-15.84
Shutdown Margin # 4	-6.42	-14.68



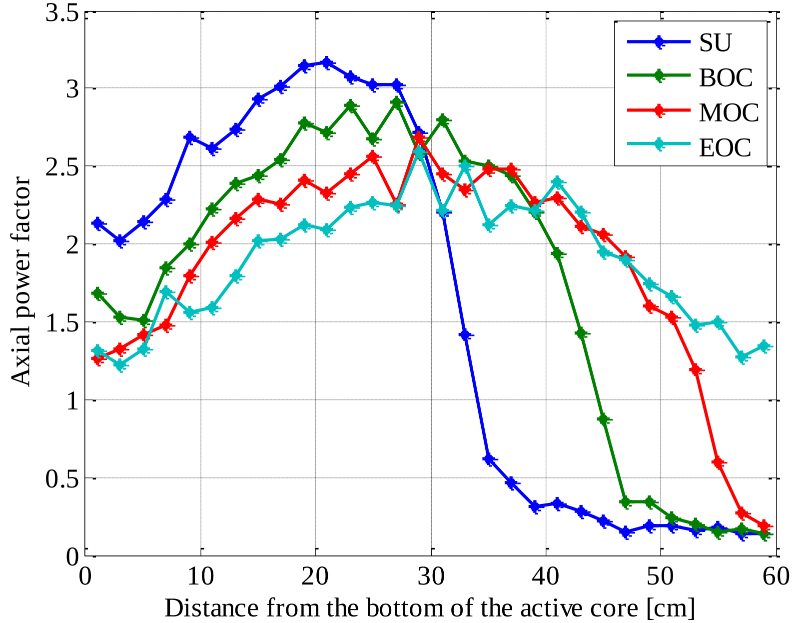
The pre-set reactivity control requirements for a research reactor:

- Excess reactivity cannot exceed **15%** Δ*k*/*k.*
- Total control worth is greater than **25%** Δ*k*/*k.*
- Shutdown margin (negative) is greater than **3%** Δ*k*/*k.*

Axial Power Distribution



Core Average Power



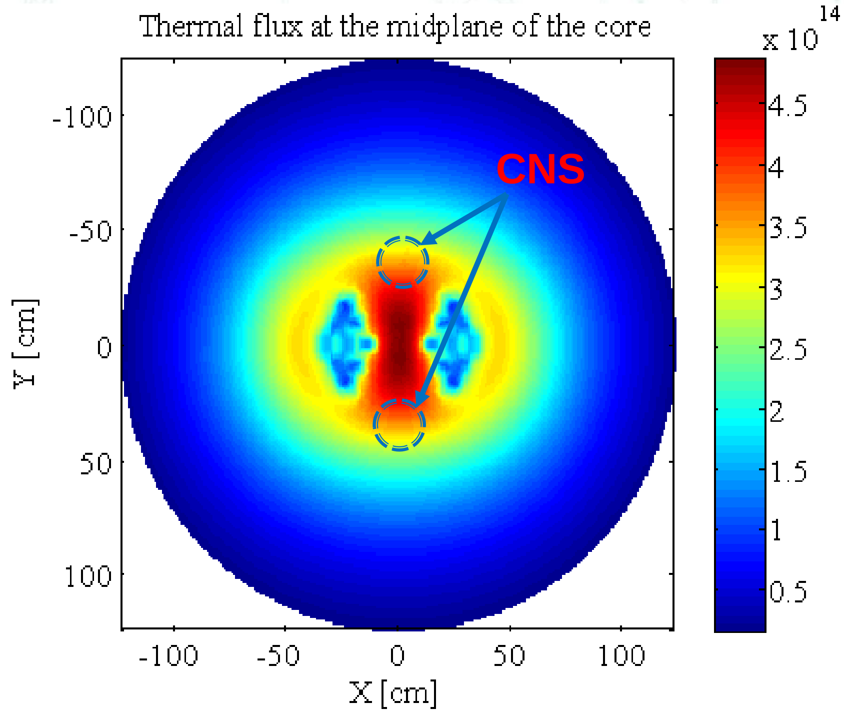
Hottest Stripe Power

Table. Summary of Preliminary T/H Safety Analyses on the SU Core

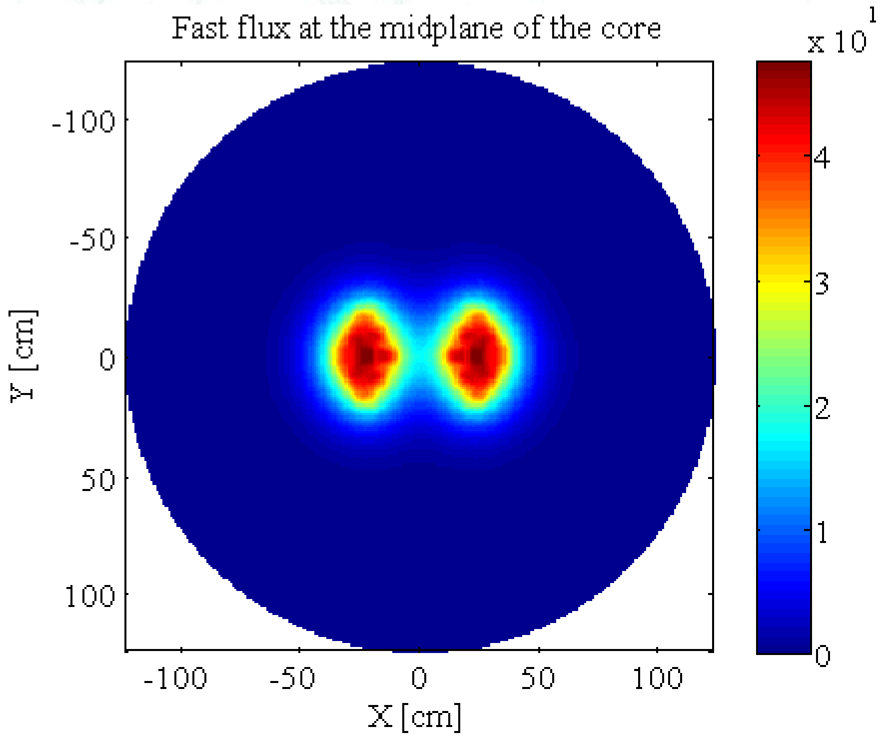
Condition	Limits	SS	MRIA	FLOFA
PCT [°C]	**515**	108	122	139
MCHFR	**1.32**	2.59	2.08	2.02

SS – Steady State; MRIA – Maximum Reactivity Insertion Accident; FLOFA – Fast Loss of Flow Accident.

Top View of the Unperturbed Flux at EOC



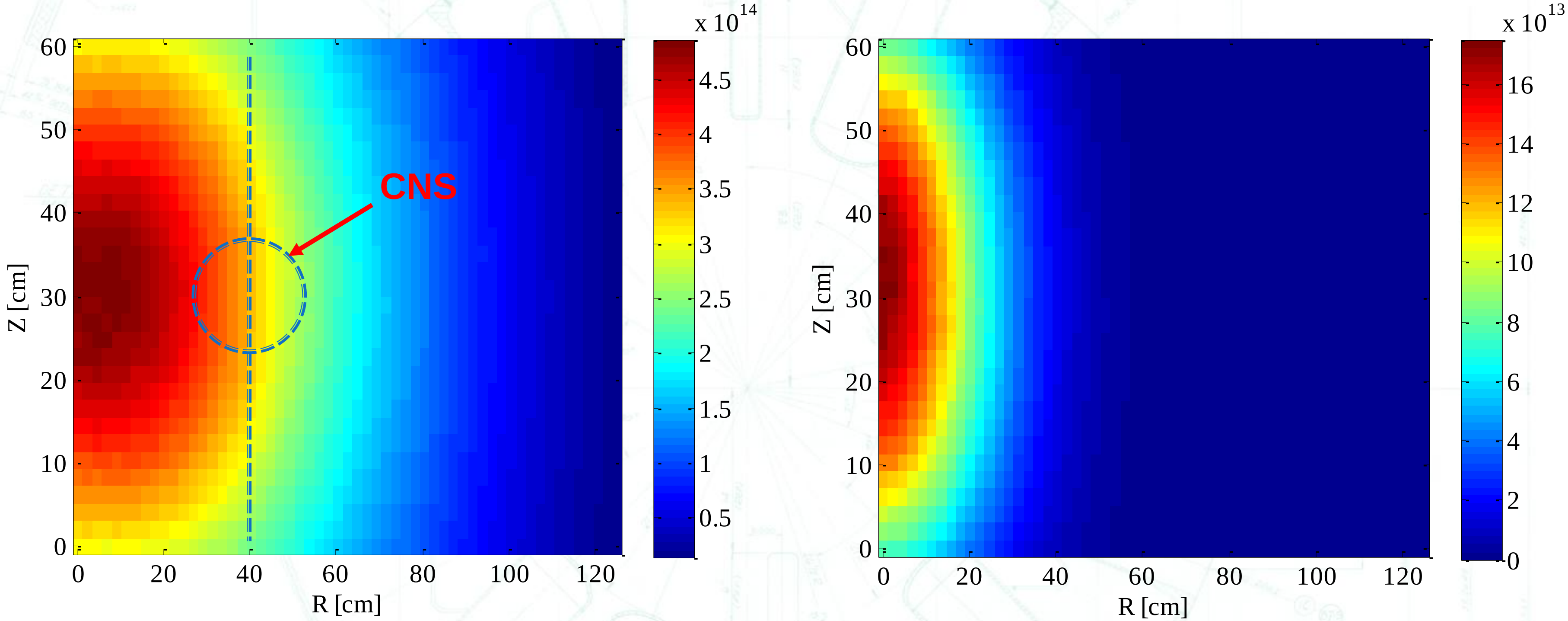
Thermal Flux



Fast Flux

Maximum thermal flux at the core center ≈ 5×10^{14} n/cm^2-s.

Side View of Unperturbed Flux at EOC along N-S Axis

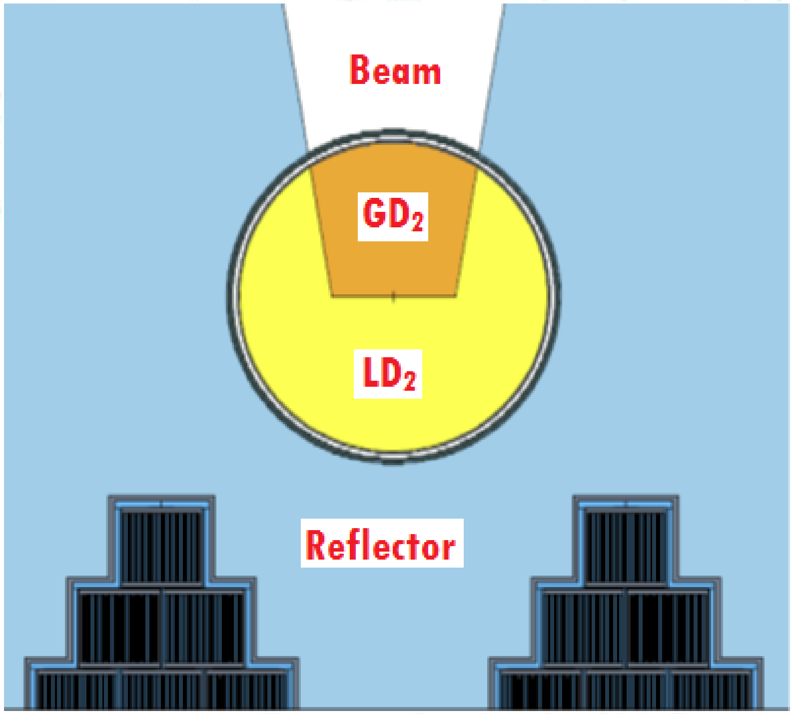


Thermal Flux

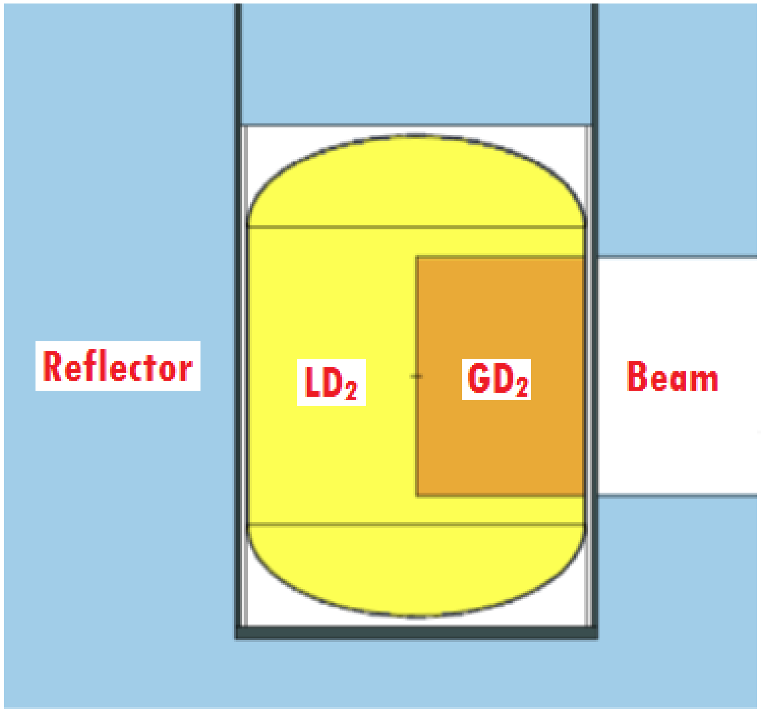
Fast Flux

The accessible thermal flux for CNS ≈ 4×10^{14} n/cm^2-s.

Cold Neutron Source Design (Generic)



Top View



Side View

The distance from the center of CNS to the center of the reactor: 40 cm
The total volume of LD2 in CNS: 20 liter

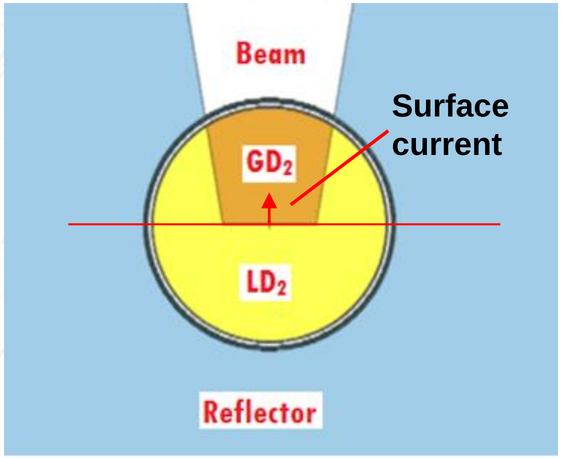
Cold Neutron Performance

SU Results

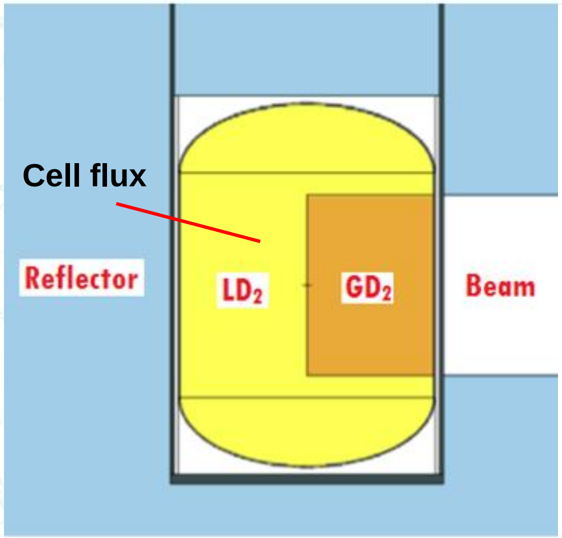
Surface Current at the exit hole (n/cm2-s)			
E (ev)	North CNS	South CNS	NBSR CNS
5.00E-09	2.25E+11	2.26E+11	8.18E+10
Cell flux (n/cm2-s)			
E (ev)	North CNS	South CNS	NBSR CNS
5.00E-09	2.78E+13	2.80E+13	1.80E+13

EOC Results

Surface current at the exit hole (n/cm2-s)		
E (ev)	North CNS	South CNS
5.00E-09	2.18E+11	2.22E+11
Cell flux (n/cm2-s)		
E (ev)	North CNS	South CNS
5.00E-09	2.73E+13	2.73E+13



Top View



Side View

Conclusions

- A feasibility study on a new beam-type research reactor is nearly finalized with the characteristics of low power, LEU fuel, horizontally split core, two CNS, etc.
- A practical multi-batch equilibrium core is generated with 4 representative burnup steps (SU, BOC, MOC, and EOC) using an iterative approach.
- A detailed physics calculation is performed to demonstrate the physics performance characteristics of the core including k_{eff}, 3-D power, 3-D flux, burnup, control rod worth, reactivity assessment, etc..
- The cold neutron flux produced by the new reactor outperforms the NBSR Unit 2 CNS by a factor of ~3.