The Water Ingress Effects on the Reactivity Change of the Conceptual Designed Reactor at NIST

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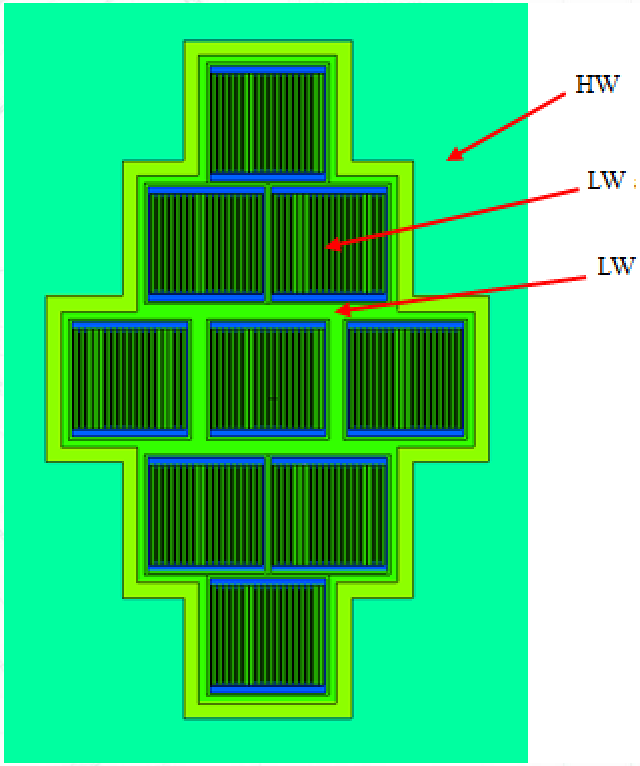
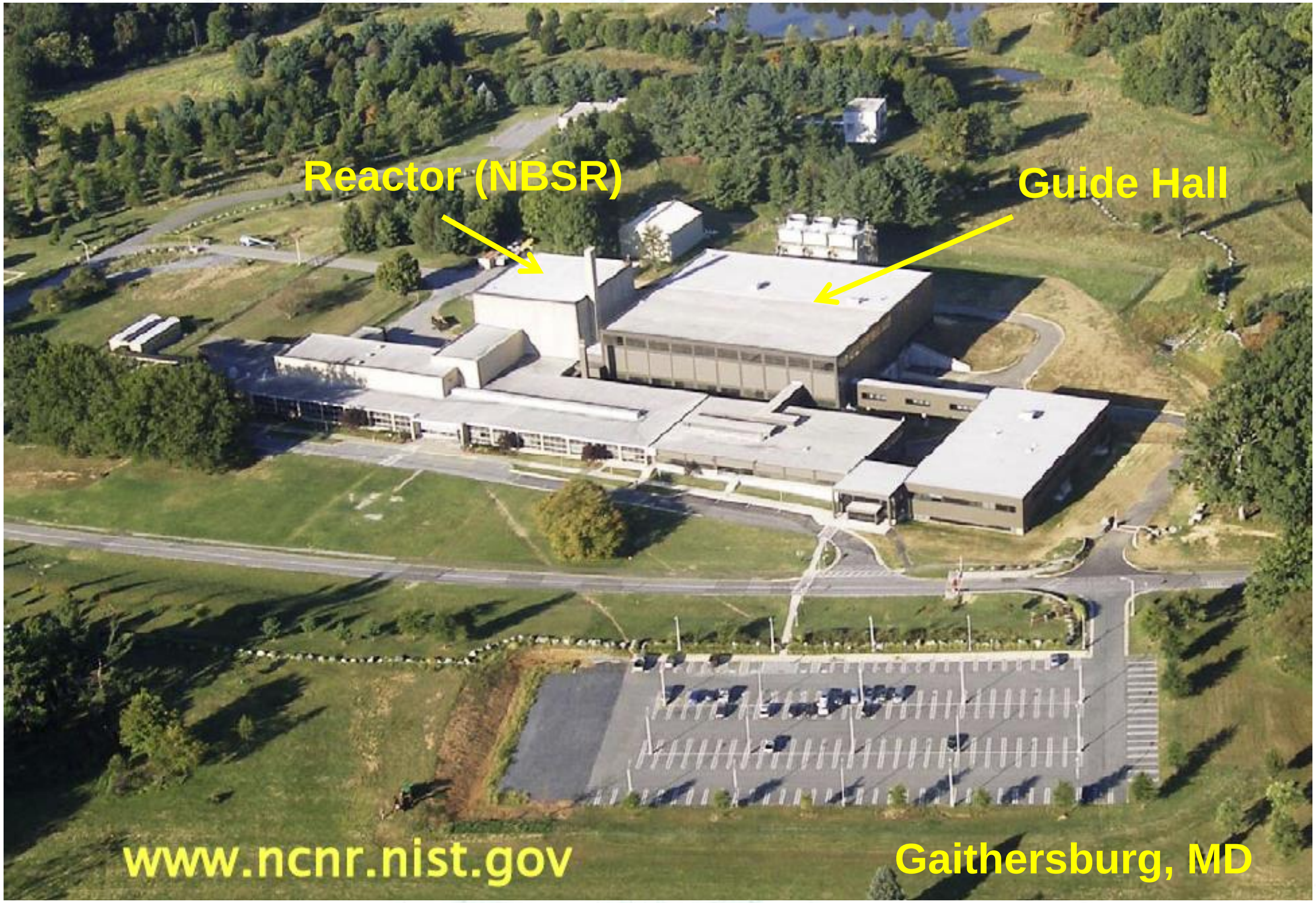
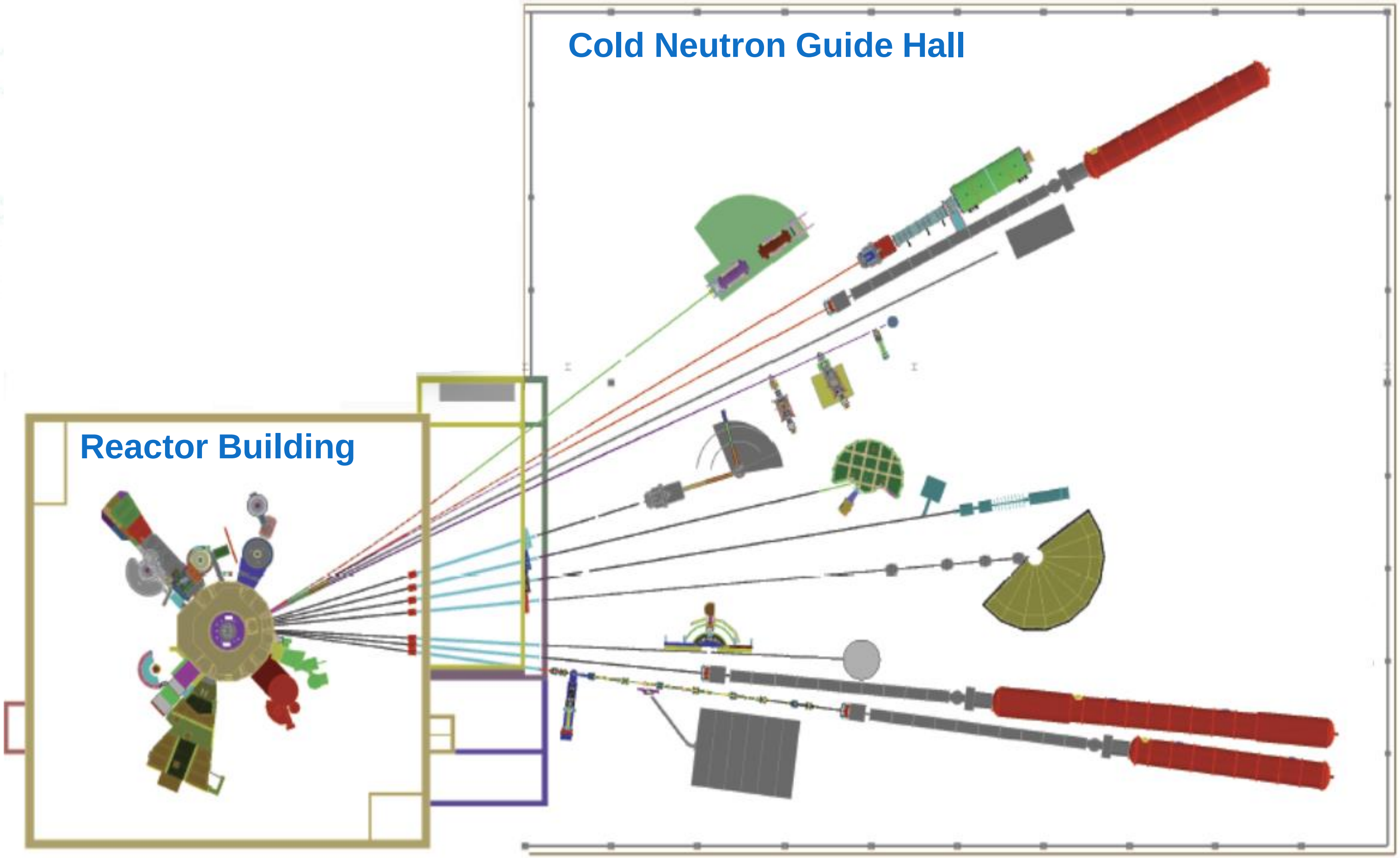


NIST Center For Neutron Research

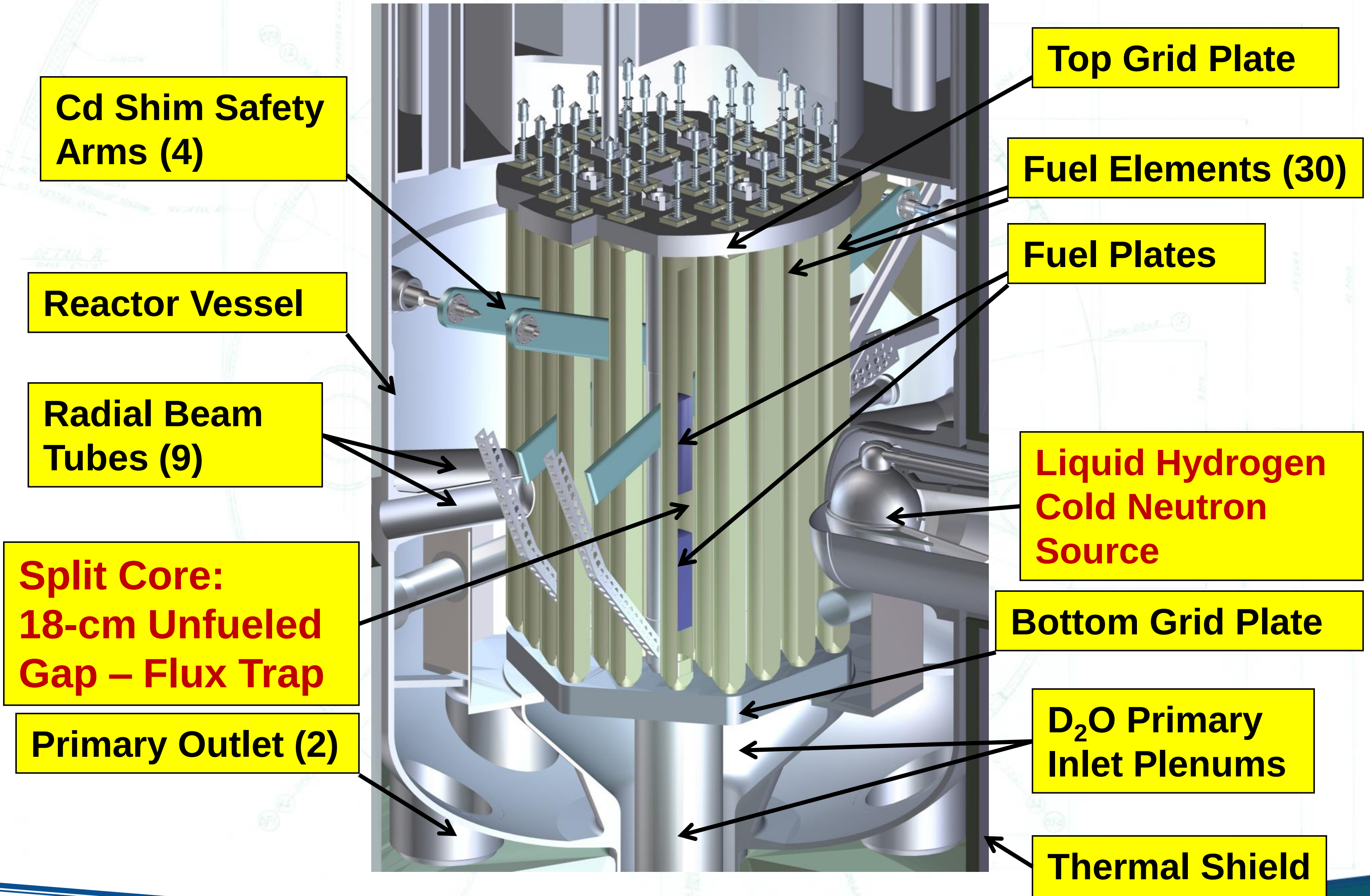


Layout of the Reactor Building and Guide Hall

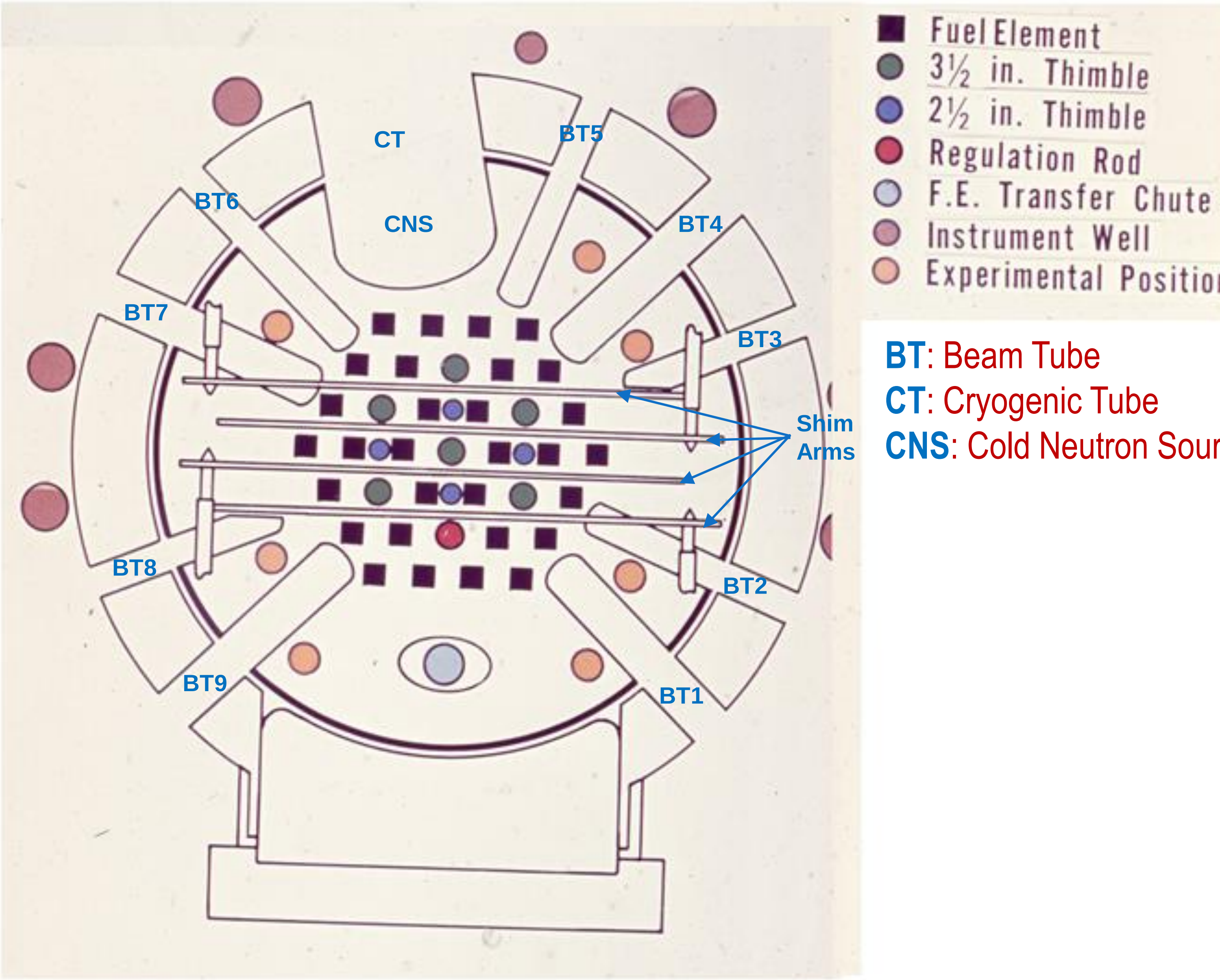


NCNR has 28 instruments for various scientific experiments, 21 of them use cold neutrons (as of Dec. 2015), and hosts over 2,000 guest researchers annually, 70-80% of them are using cold neutrons.

Cut-away View of the NBSR Core



Cross-sectional View of the Mid-plane of the NBSR



BT: Beam Tube
CT: Cryogenic Tube
CNS: Cold Neutron Source

Status of the Present NBSR

- First critical on Dec. 7th, 1967
- Current operating license will go through 2029
- One additional extension may be achievable
- Most likely reach retirement in 2050s

Challenges for Conversion of NBSR to LEU

- LEU U_3Si_2/Al dispersion fuel is not workable
- LEU U-10Mo monolithic fuel is feasible but not manufactured yet - may be 10 years off
- 30% more increase on fuel costs
- 10% reduction on neutron performance

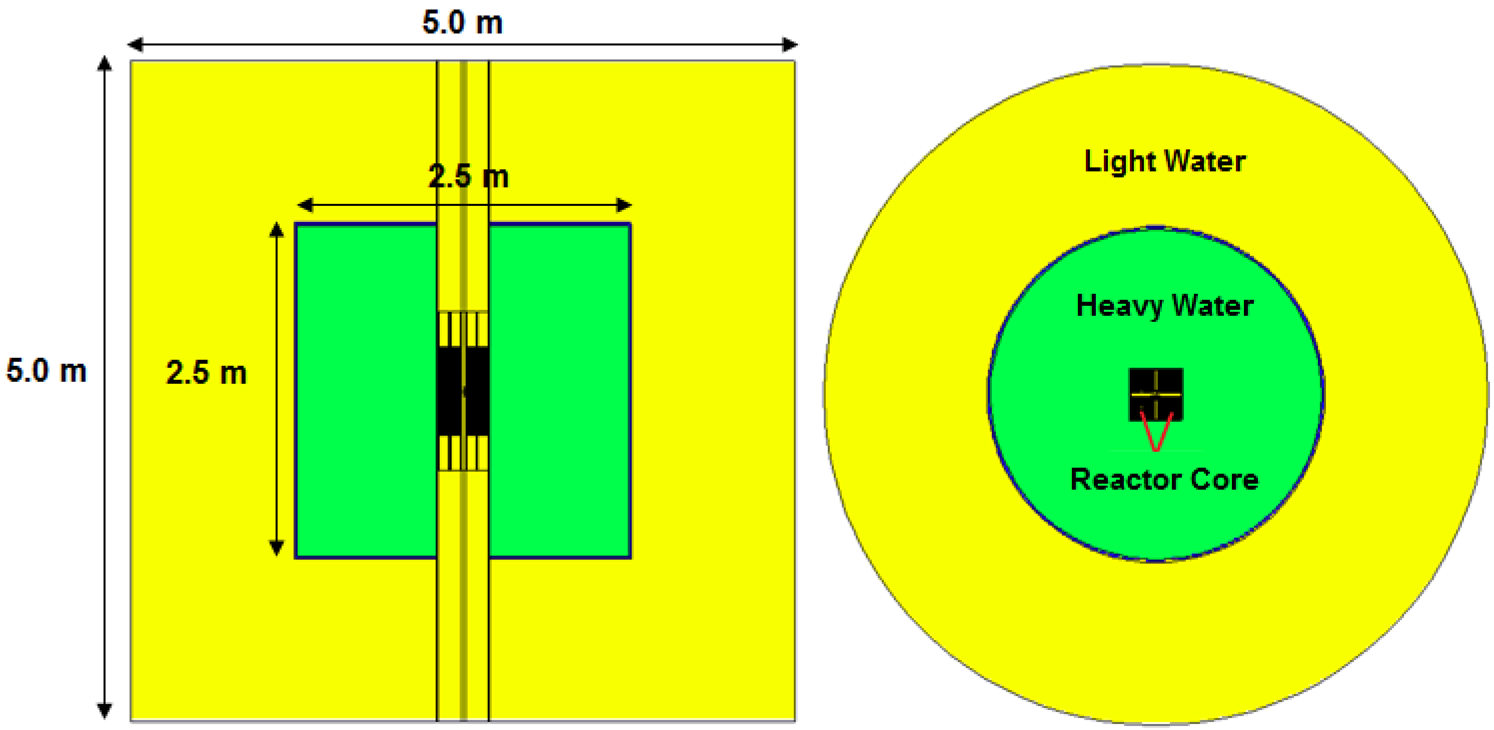
Main Design Parameters of New Reactor

	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' Concept

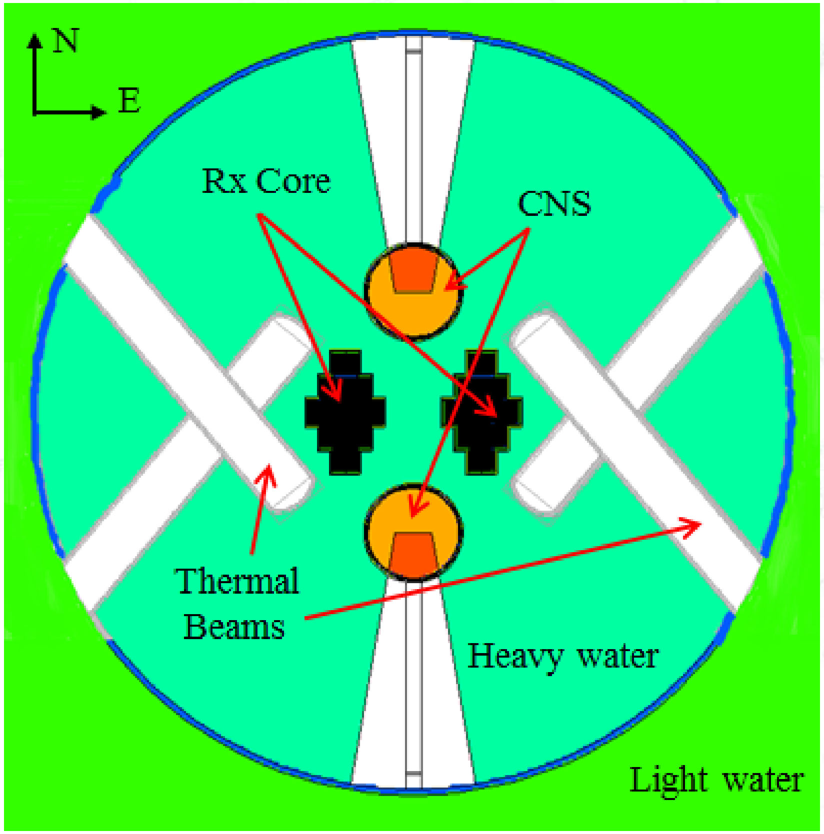


(a) Elevation view **(b) Plan view**

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).

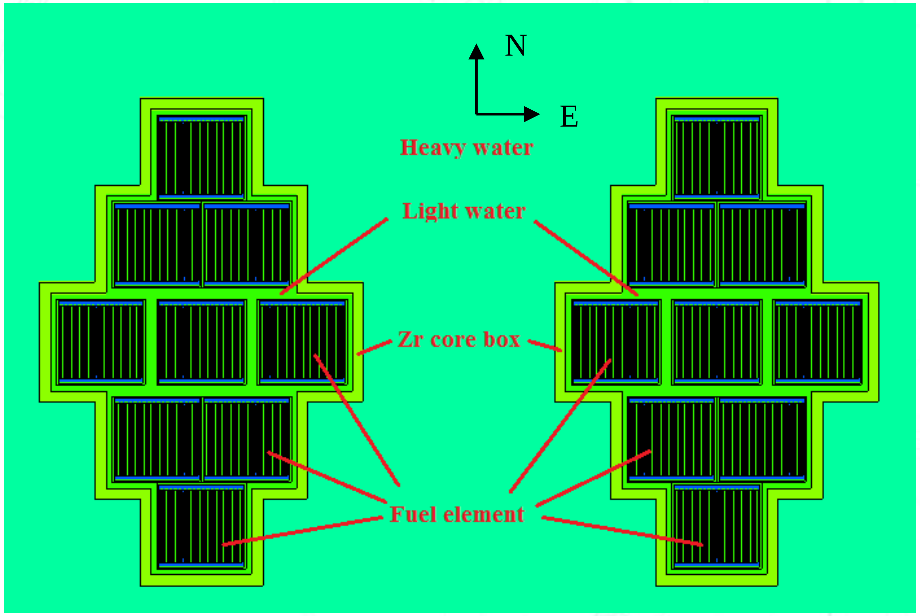
Schematics of the Split-Core Design



Reactor Size (m)	Value
Heavy water tank diameter	2.5
Heavy water tank height	2.5
Light water pool diameter	5.0
Light water pool height	5.0

The mid-plane of the split core reactor. Two cold neutron sources are placed in the north and south side of the core, and four thermal beam tubes are located in the east and west side of the core at different elevations.

Horizontally Split Core With 18 Fuel Elements

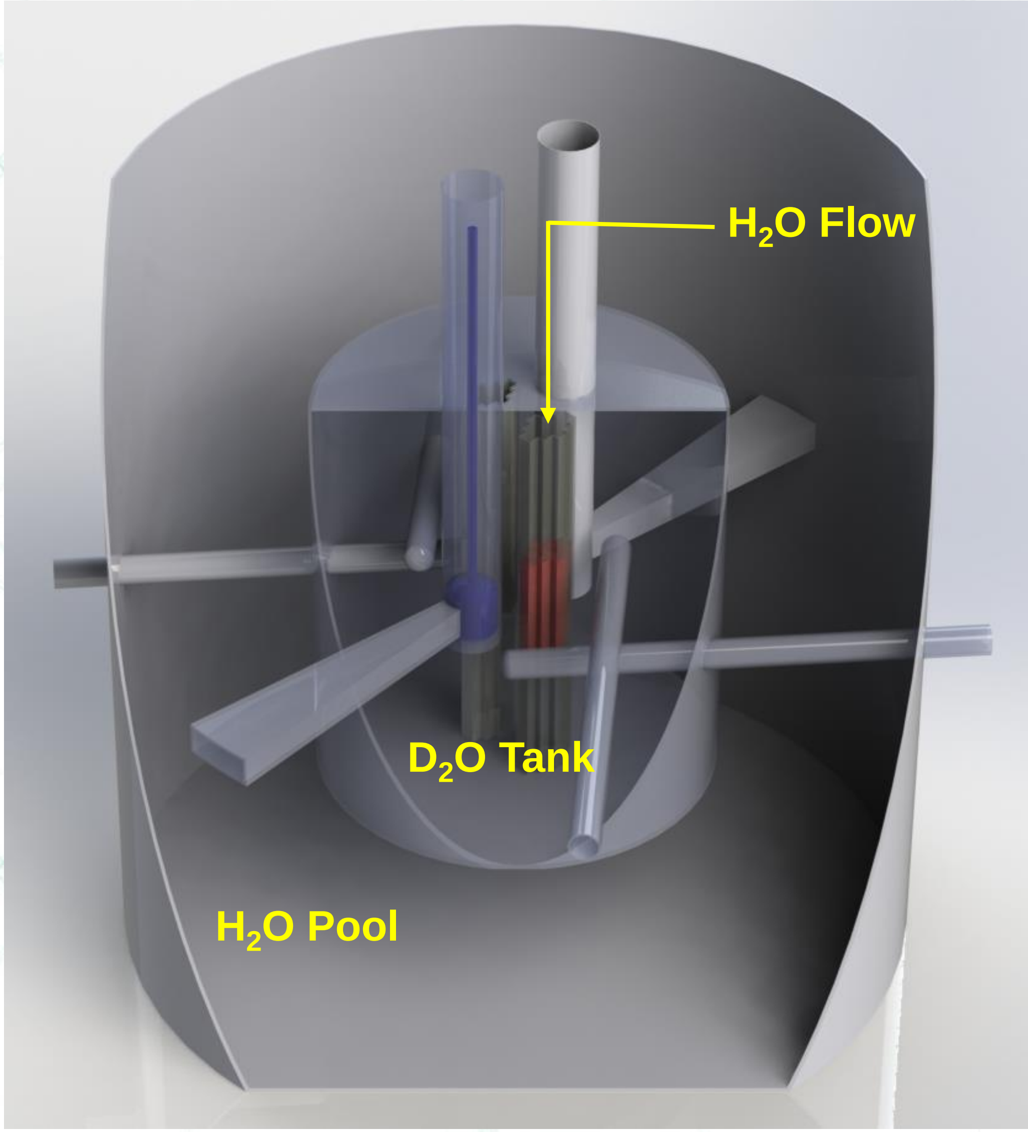


A close view of the horizontally split-core. The core consists of total 18 fuel elements which are evenly distributed into two horizontal split regions.

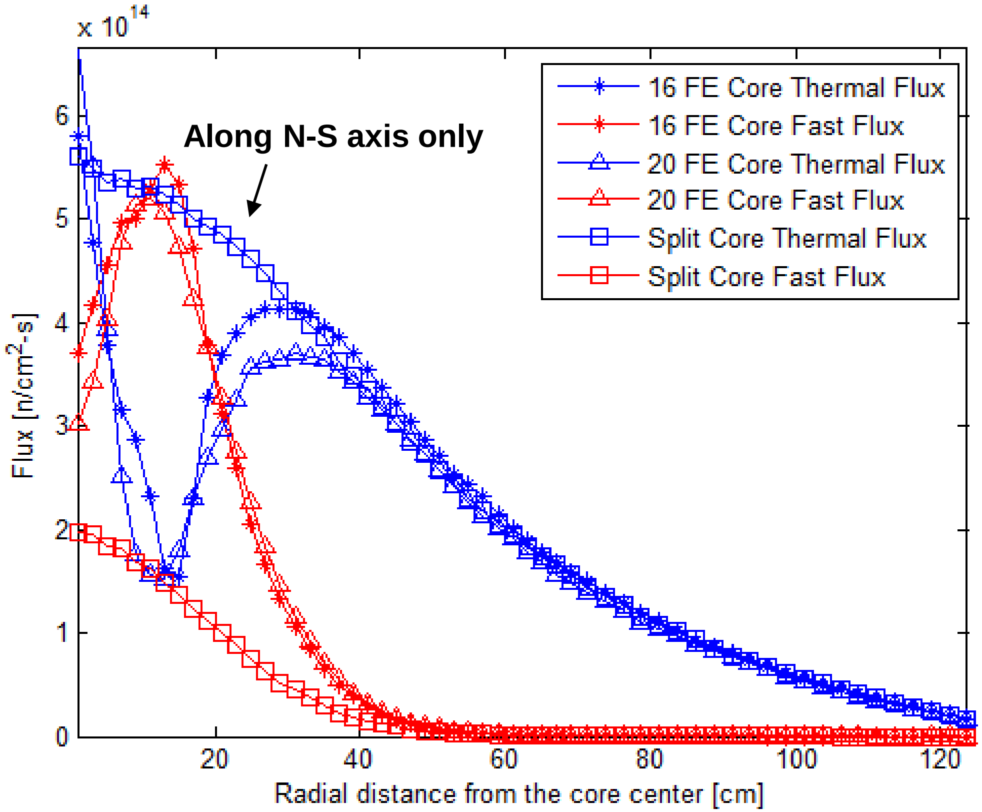
Core Design Information

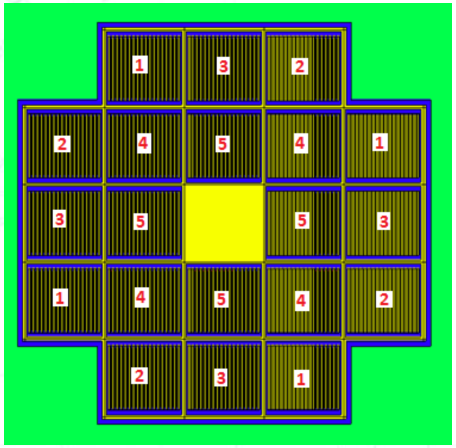
Parameter	Data
Thermal power rate (MW)	20
Fuel cycle length (days)	30
Active fuel height (cm)	60.0
Fuel material	U_3Si_2/Al
U-235 enrichment in the fuel (wt. %)	19.75
Fuel mixture density (g/cc)	6.52
Uranium density (g/cc)	4.8
U-235 mass per fuel element (gram)	399
Number of fuel elements in the core	18

A 3-D View of the Split-Core Design

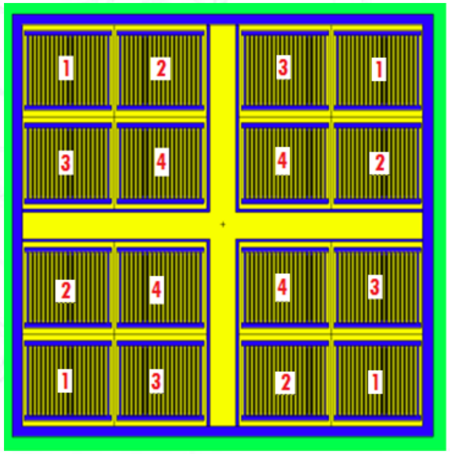


Comparison of Unperturbed Radial Flux at EOC





20 FE Core



16 FE Core

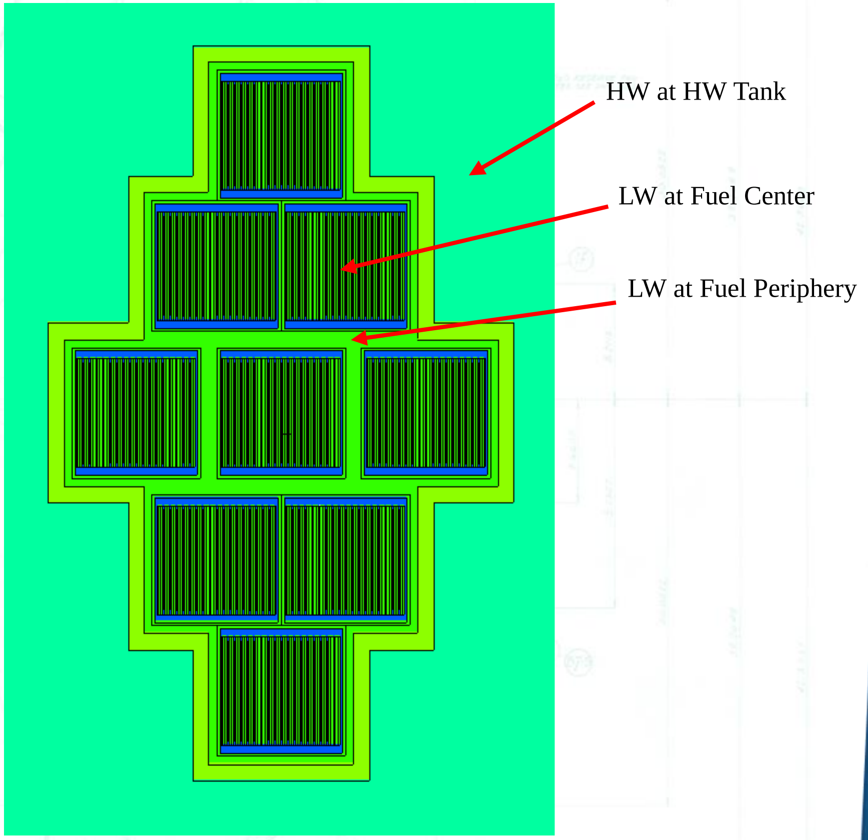
Neutronics Performance Characteristics of the New Reactor

Reactor	NBSR	HFIR	BR-2	OPAL	CARR	FRM-II	NBSR-2
Country	U.S.	U.S.	Belgium	Australia	China	Germany	U.S.
Power (MW_{th})	20	85	60	20	60	20	20
Fuel	HEU	HEU	HEU	LEU	LEU	**HEU**	LEU
Max Φ_{th} ($\times 10^{14}$ n/cm^2-s)	3.5	10	12	3	8	8	5
Quality factor ($\times 10^{13}$ MTF/MW_{th})	1.8	1.2	2.0	1.5	1.3	4.0	2.5

The **Quality factor** is defined as the ratio of maximum thermal flux (MTF) to the total thermal power of the reactor

Water at Difference Locations of the Reactor

- The reactor core is slightly pressurized and surrounded by the heavy water reflector.
- The core is cooled and moderated by light water, which is separated from heavy water with a core box made of Zircaloy.
- Neutronics calculations was performed to determine the effect and trend of the reactivity changes due to water ingress in different scenarios by purposely mixing the waters at three representative places in the reactor.



Neutron Moderating Characteristics of H_2O and D_2O

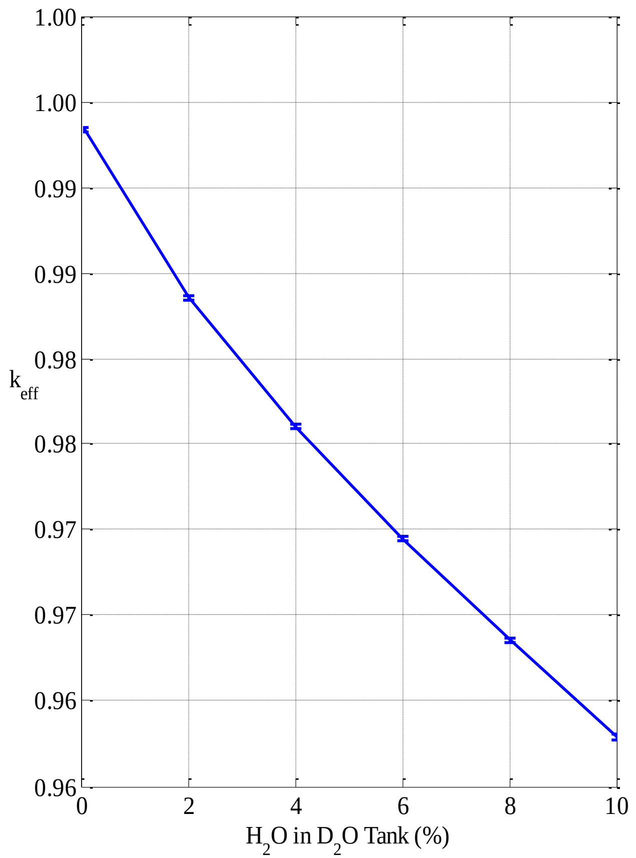
Moderator	H_2O	D_2O
ρ (g/cc)	1.0	1.1
σ_a (barn)	0.66	0.001
σ_s (barn)	103	13.6
Σ_a (cm^{-1})	0.0221	3.31E-5
Σ_s (cm^{-1})	3.4429	0.4498
ξ	0.948	0.57
$\xi\Sigma_s$ (cm^{-1})	3.264	0.256
$\xi\Sigma_s / \Sigma_a$	148	7752

ξ – Neutron average lethargy gain (or average logarithmic energy loss) per collision.

$\xi\Sigma_s$ – Neutron moderating power or slowing down power

$\xi\Sigma_s/\Sigma_a$ – Neutron moderating ratio

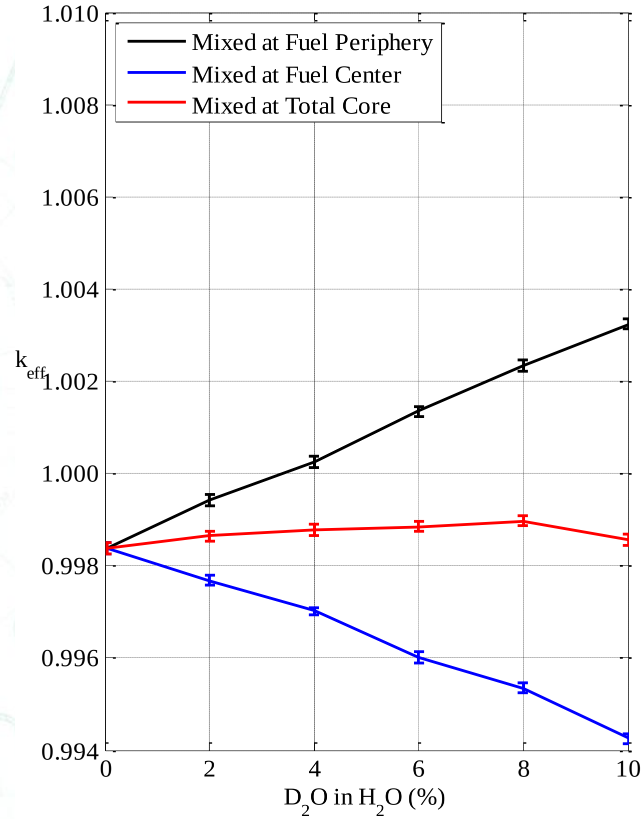
Light Water Ingress in the Heavy Water Tank



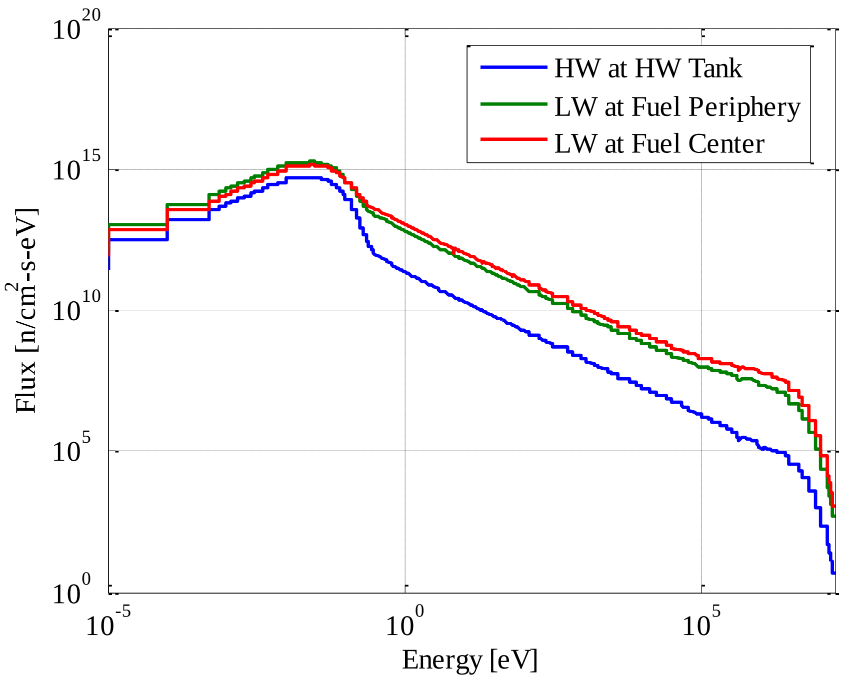
- The reflector tank is filled with D_2O that is assumed to be volumetrically 99.97% pure.
- In the perturbations, the volumetric fraction of the D_2O is reduced in several cases: each case has 2% less D_2O, while the H_2O fraction for each case is increased accordingly to preserve the total volume of water.
- Any amount of light water contamination in the reflector would have a negative effect on the reactivity to the reactor. A nearly linear decreasing trend on reactivity change is observed.

Heavy Water Ingress in the Light Water Region

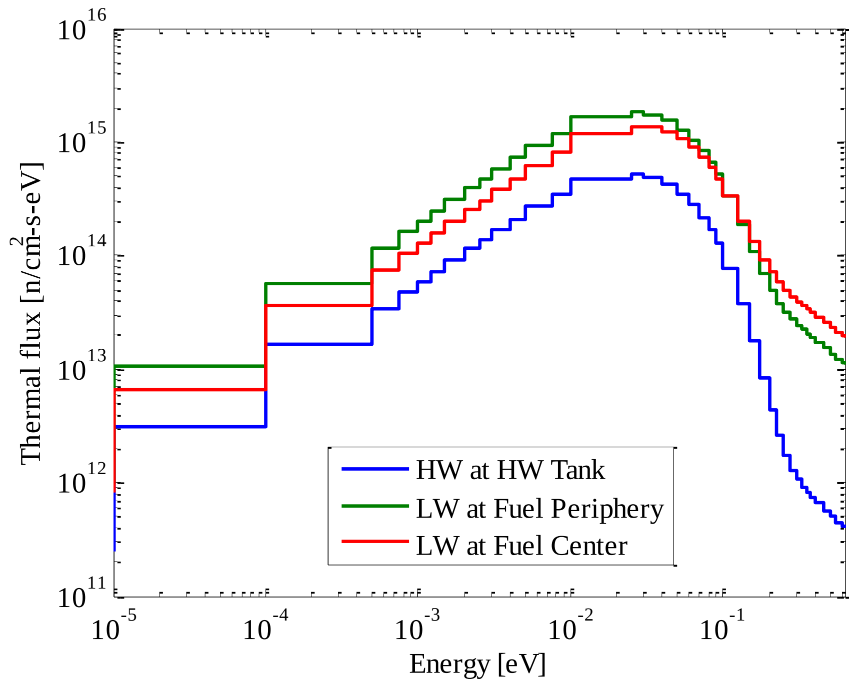
- Focus on those cases for which heavy water leaks into the core regions.
- Examine the water mixing at two different locations in the core: the flowing coolant region (fuel center) and the stationary coolant region between fuel elements (fuel periphery).
- Water mixing in the fuel center provides a negative effect on the reactivity change, whereas water mixing at fuel periphery renders a positive effect.
- The combined effect of water mixing in the light water coolant has slightly positive effect.



Neutron Flux Spectrum at Different Locations



Entire energy range.



Thermal energy range.

Summary

- The split core design employs a 'tank-in-pool' design pattern, in which the core is immersed in a cylindrical heavy water tank and the tank is surrounded by a light water pool.
- The effect on reactivity due to the water mixing in either direction is studied in this paper.
- The results show that light water ingress in the heavy water tank would always cause negative reactivity.
- Heavy water ingress in the coolant at the fuel center provides negative effects, whereas heavy water ingress in the coolant at the fuel periphery renders positive effects, which results a slightly positive effect on the reactivity in the combined case.
- These reactivity effects will be taken into account when designing the primary and reflector cooling systems.

Thank you!