NIST Center for Neutron Research

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A Research Reactor Core Design For Advanced Neutron Source

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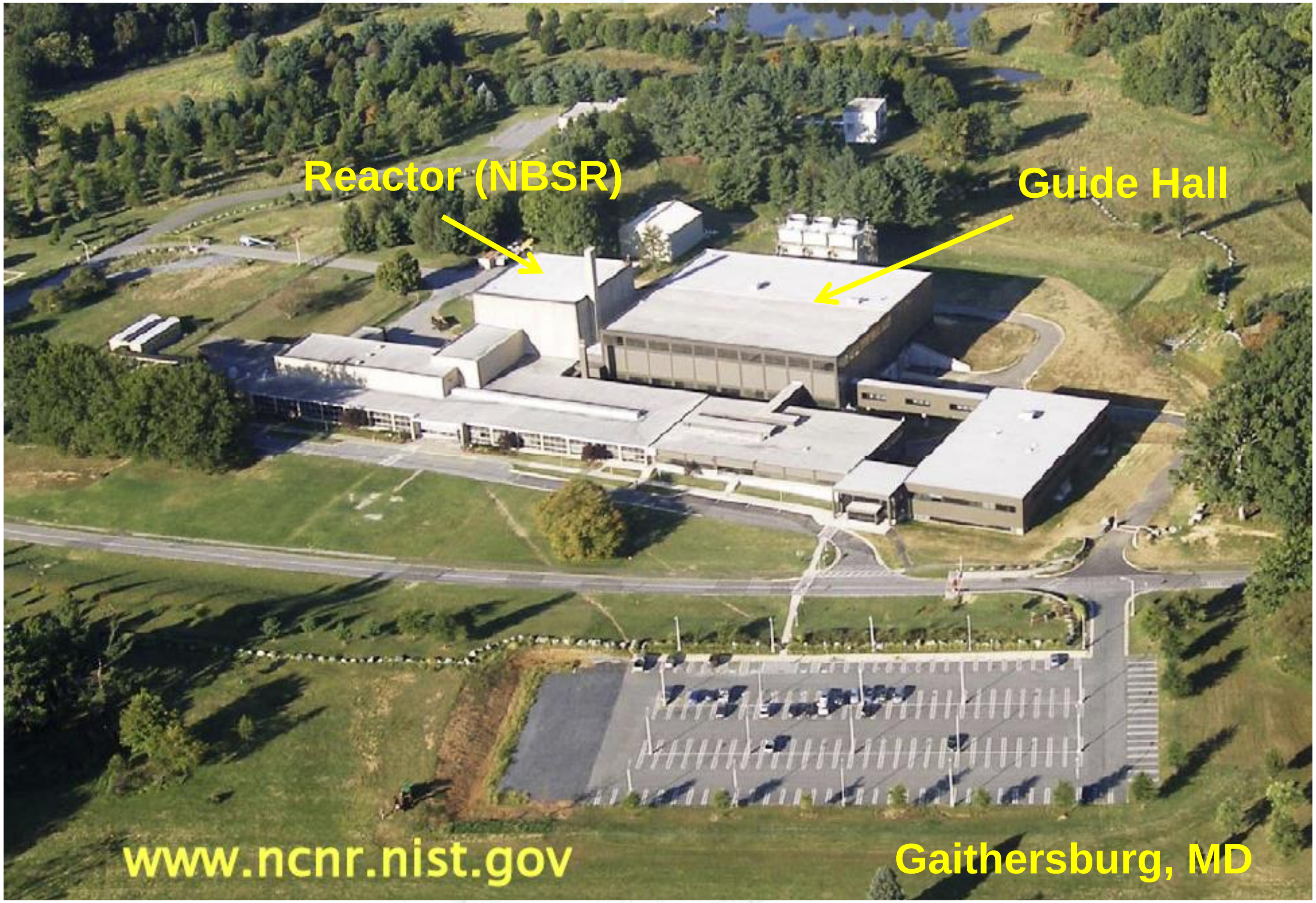
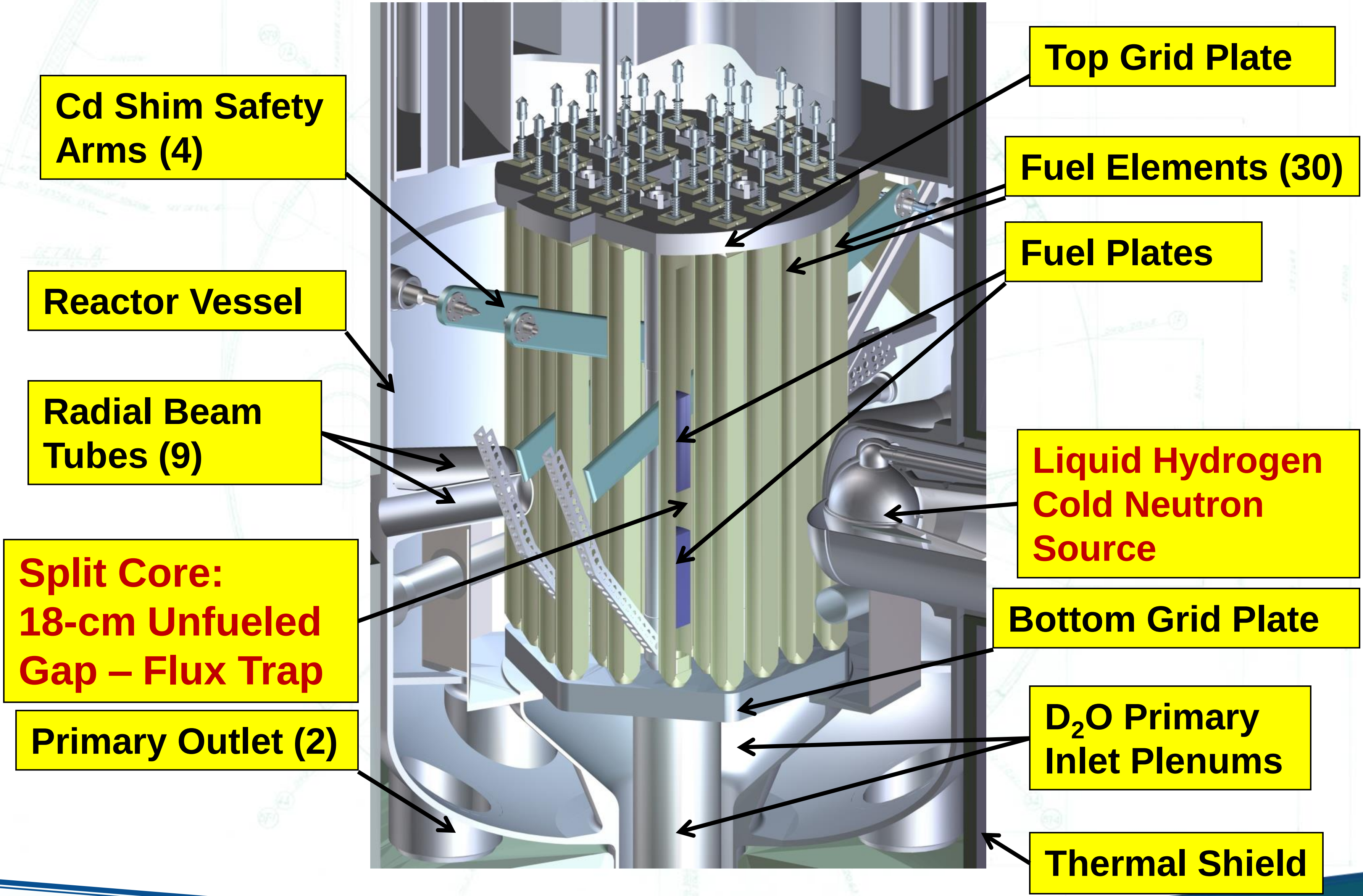
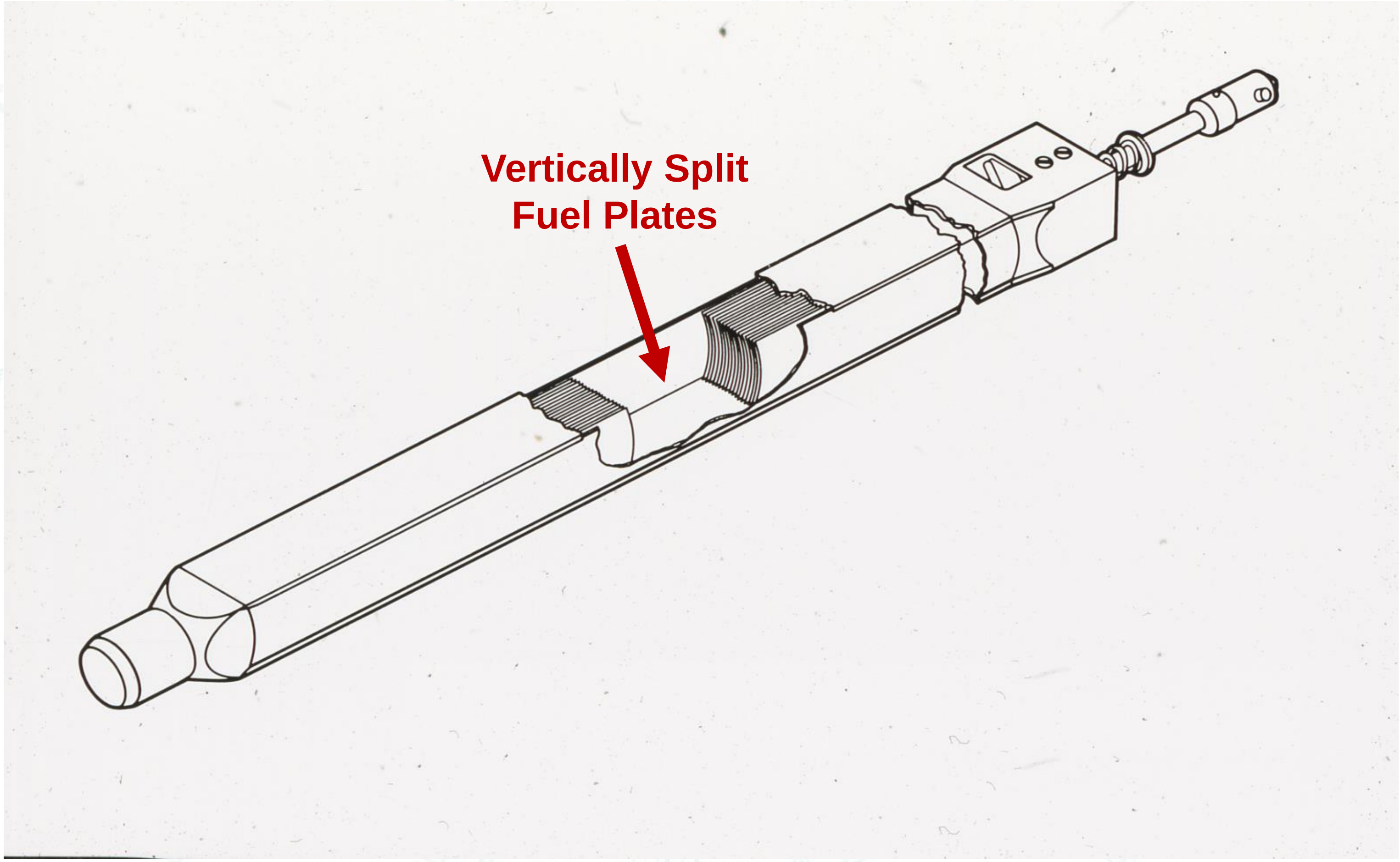


Cut-away View of the NBSR Core



NBSR Fuel Element



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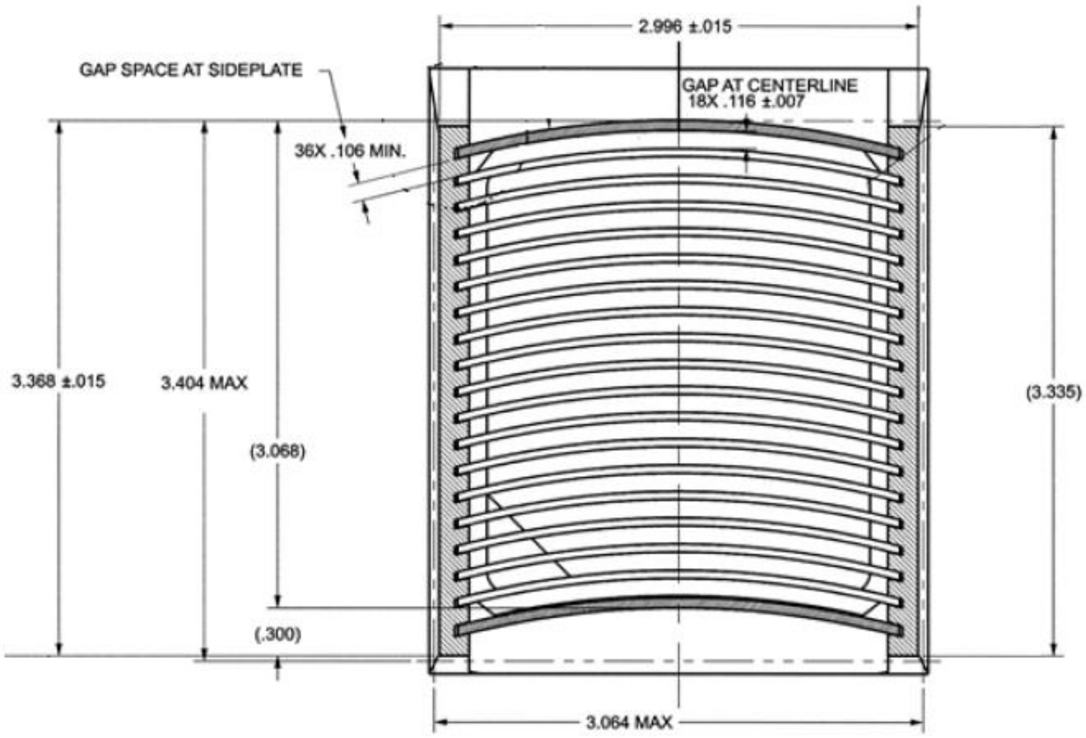
NBSR Fuel Element (Cont.)



(dimensions are in Inches)

- High Enriched Uranium Fuel: 93% $^{235}U_3O_8$ + Al
- 350 g U-235 in fresh fuel element
- 17 fuel plates
- 2 outside plates
- 2 side plates

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

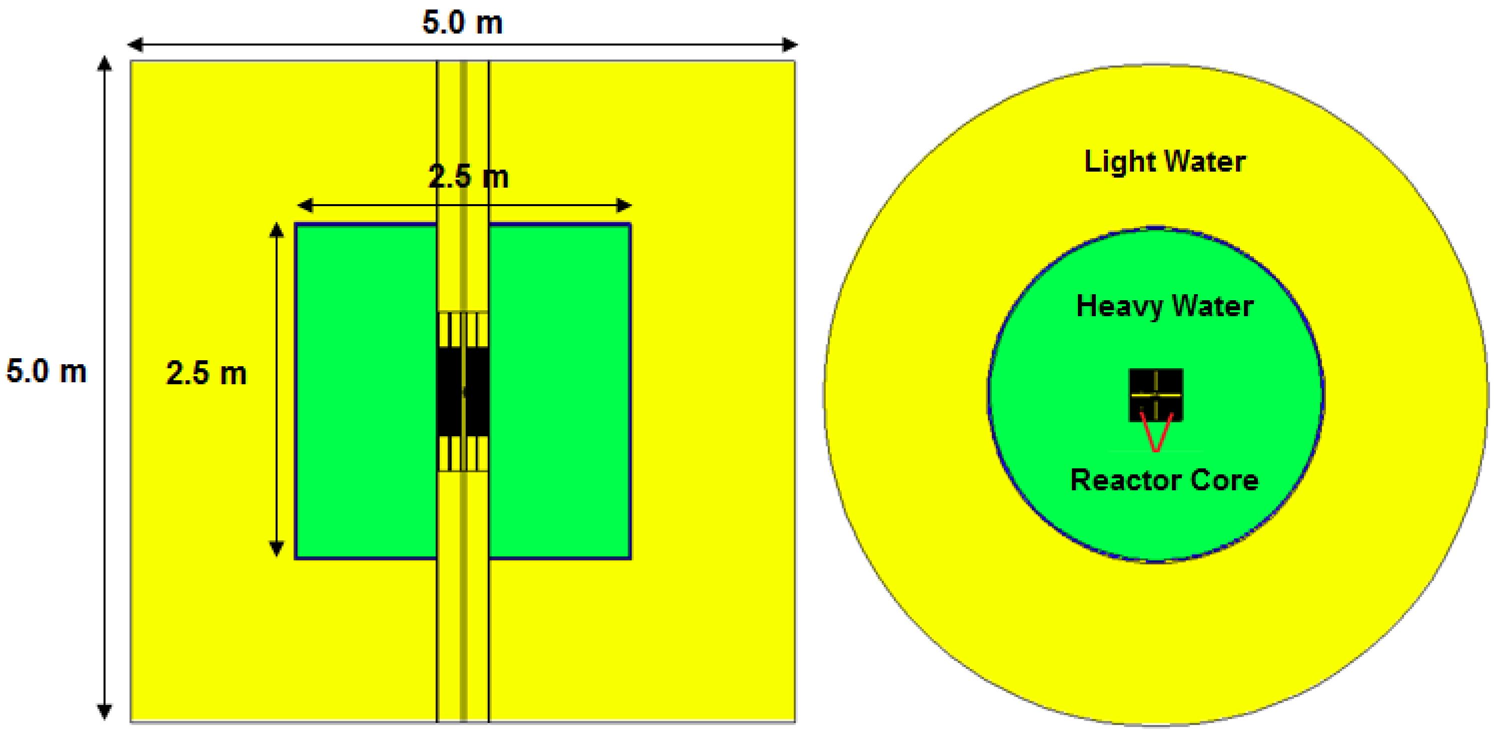
Main Design Parameters of New Reactor

	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' Design

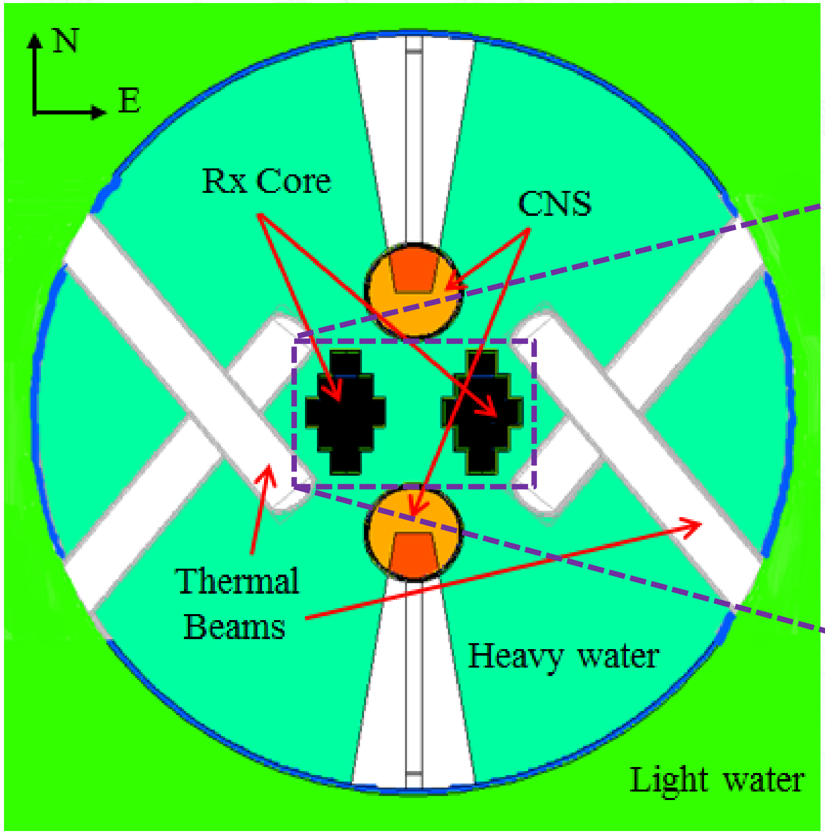


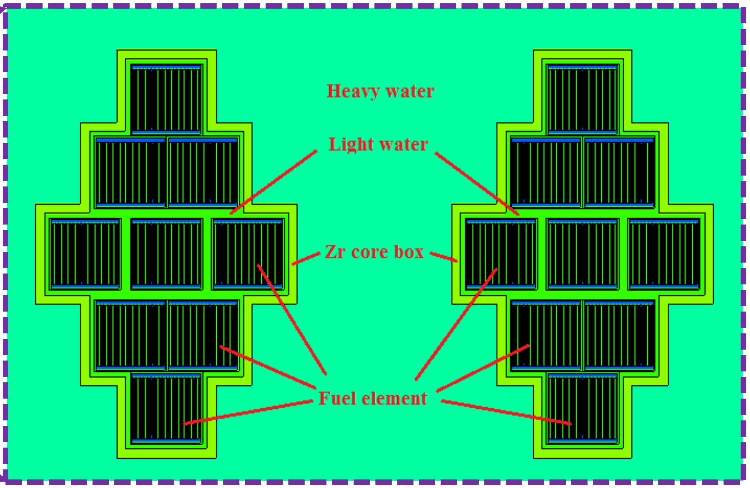
(a) Elevation view **(b) Plan view**

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).

Schematics of the Split-Core Design

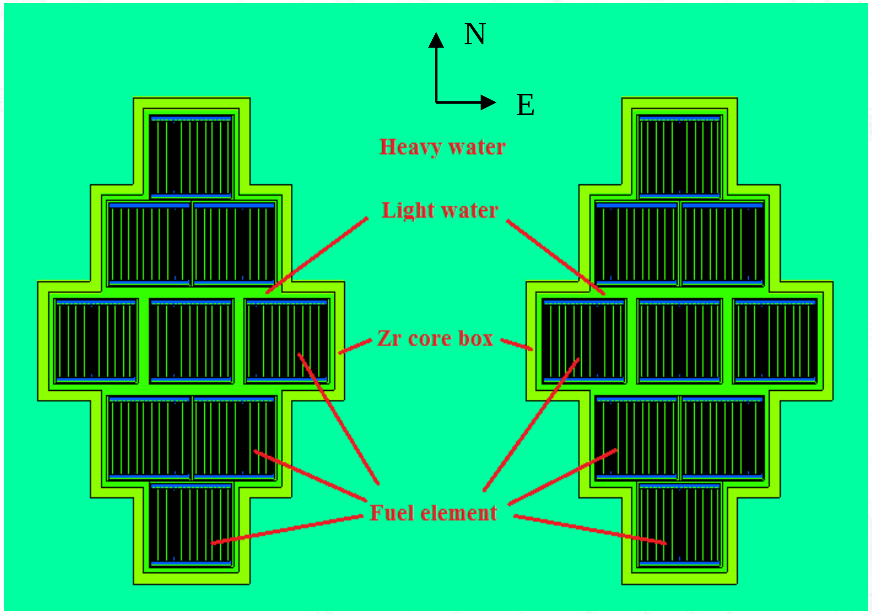




The core consists of total 18 fuel elements which are evenly distributed into two horizontal split regions.

The mid-plane of the split core reactor. Two cold neutron source (CNS) 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



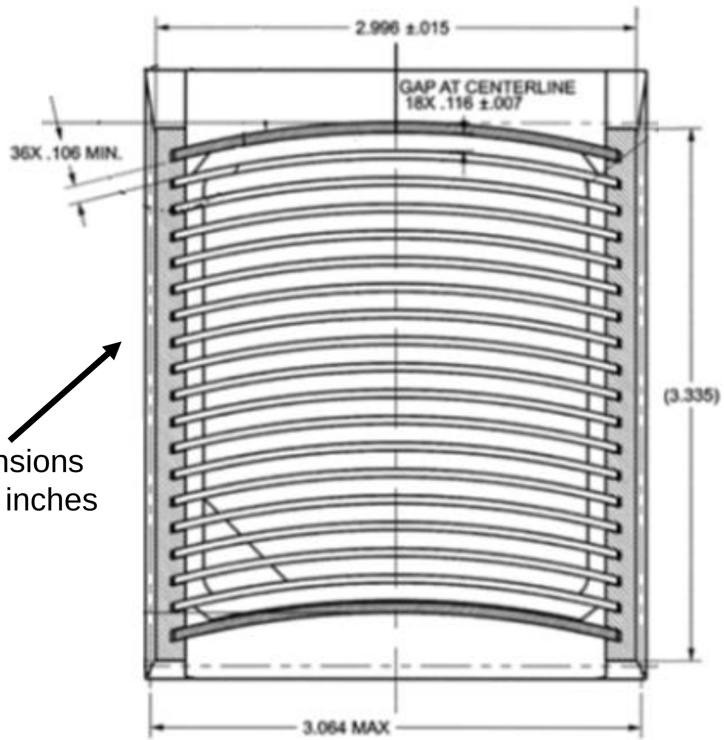
Fuel element layout in the split core

Core Design Parameters

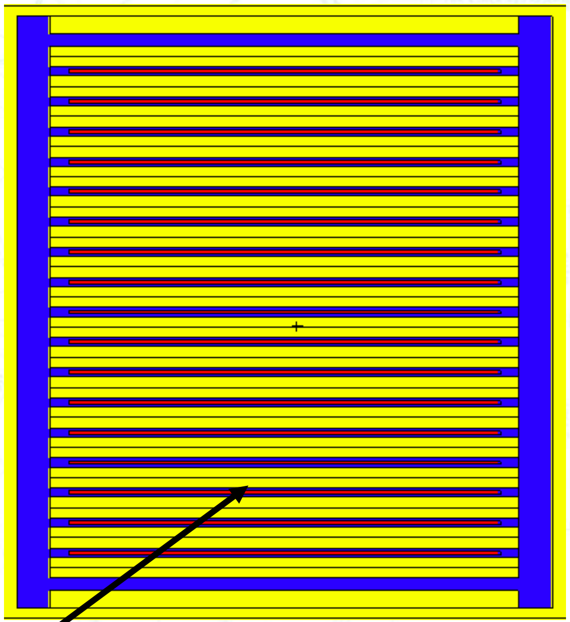
Parameter	Data
Thermal power rate (MW)	20
Fuel cycle length (days)	30
Active fuel height (cm)	60
Fuel material	U_3Si_2/Al
U-235 enrichment in the fuel (wt. %)	19.75
Fuel mixture density (g/cc)	6.52
Uranium density (g/cc)	4.8
Number of fuel elements in the core	18

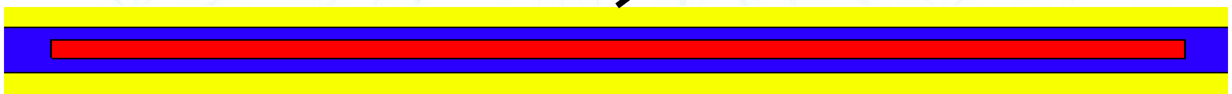
The MTR-type Fuel Plate and Fuel Element

Cross sectional view of the fuel element: 17 fuel plates, 2 end plates and 2 side plates.



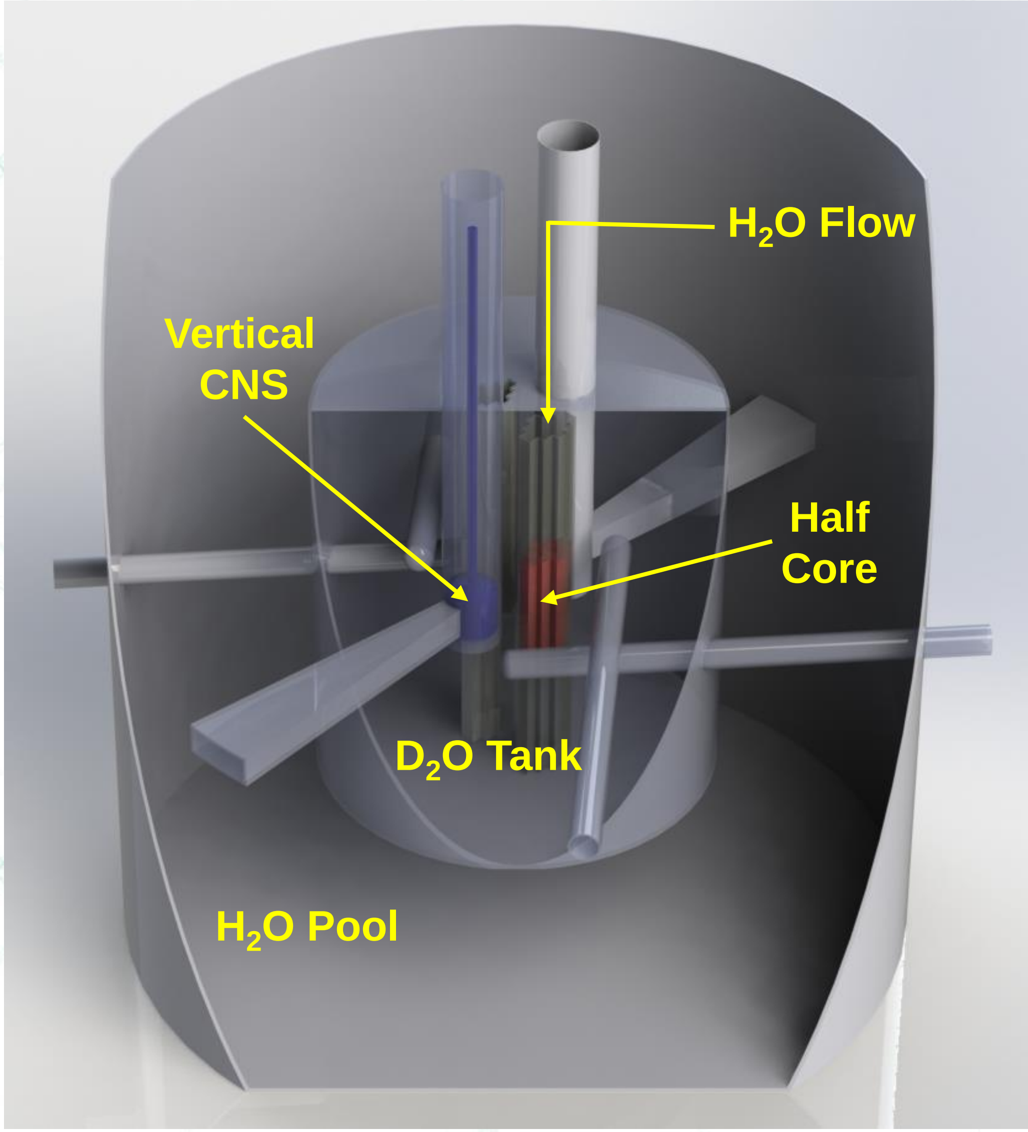
Dimensions are in inches



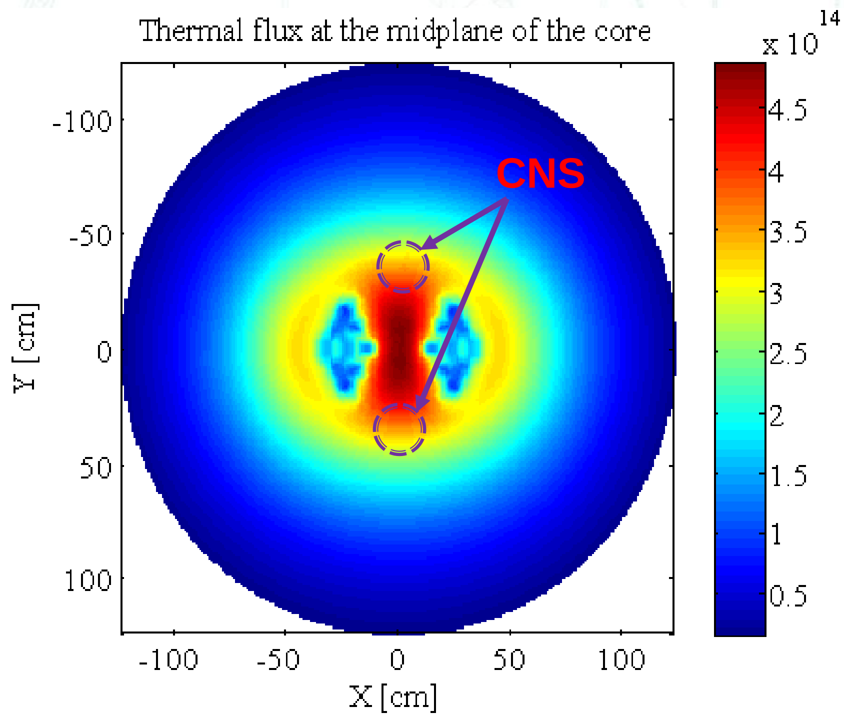


The fuel plate: For the U_3Si_2/Al fuel meat, it is 0.066 cm (26 mil) thick and 6.134 cm wide.

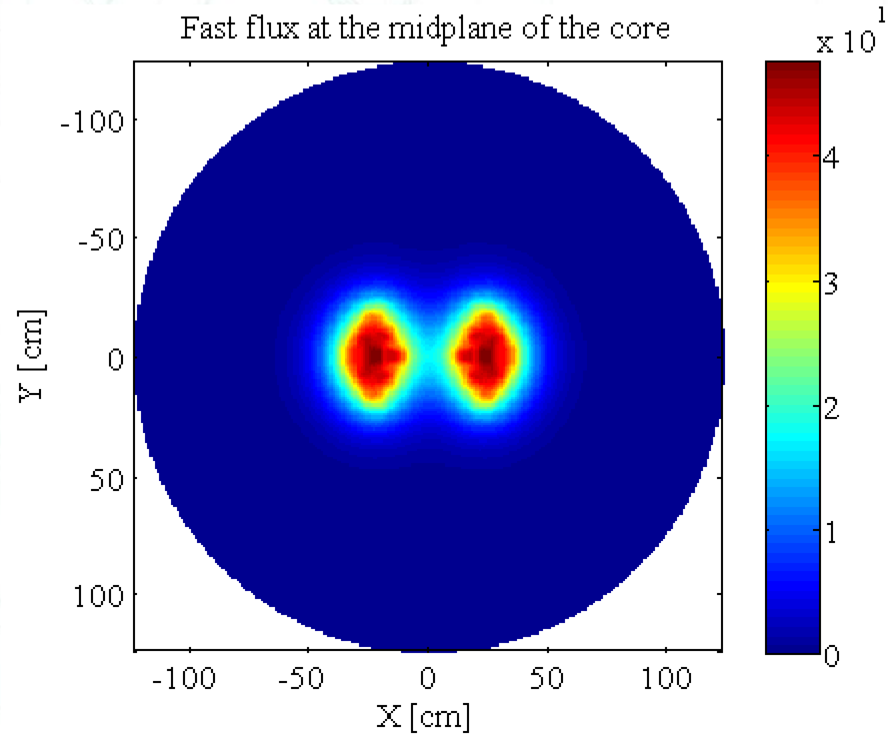
A 3-D Cutaway View of the Split-Core Design



Top View of the Unperturbed Flux at EOC



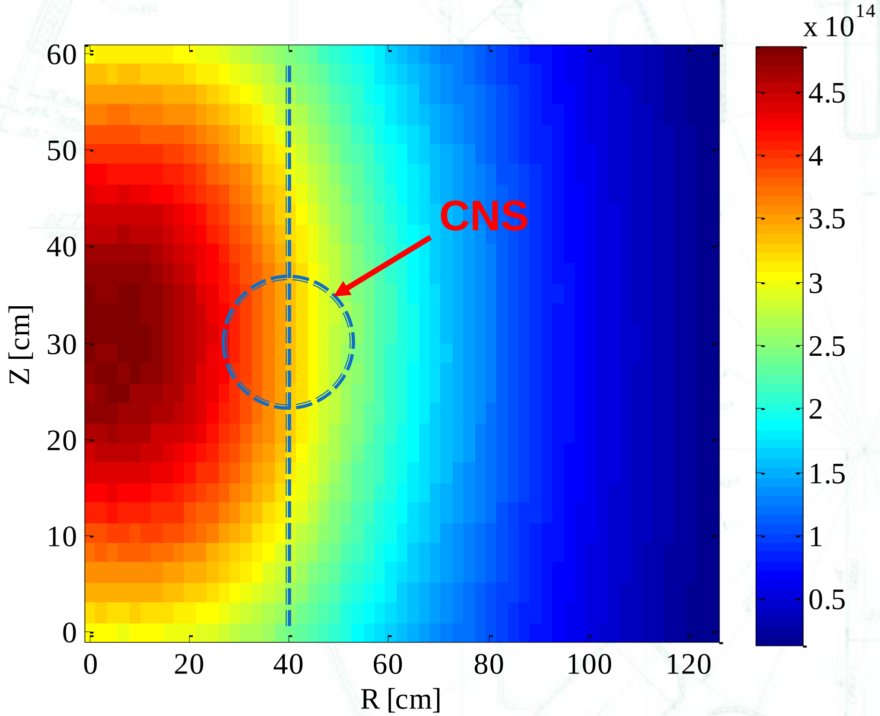
Thermal Flux



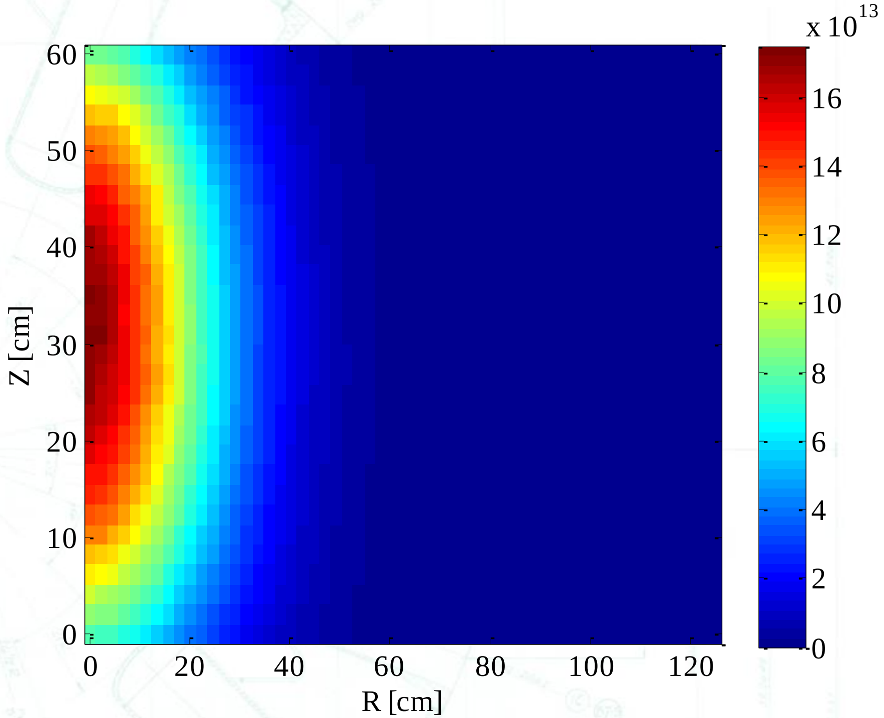
Fast Flux

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

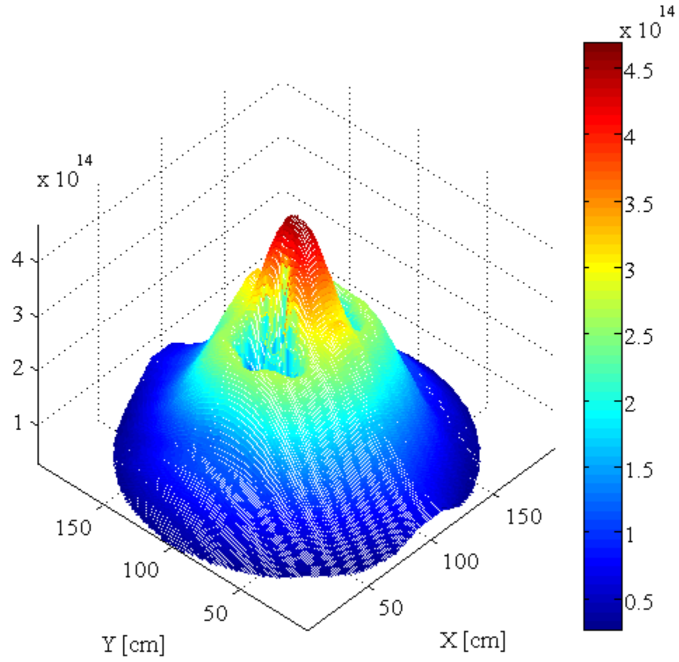
The accessible thermal flux for CNS ≈ 4×10^{14} n/cm^2-s.

Neutronics Performance Characteristics of the New Reactor

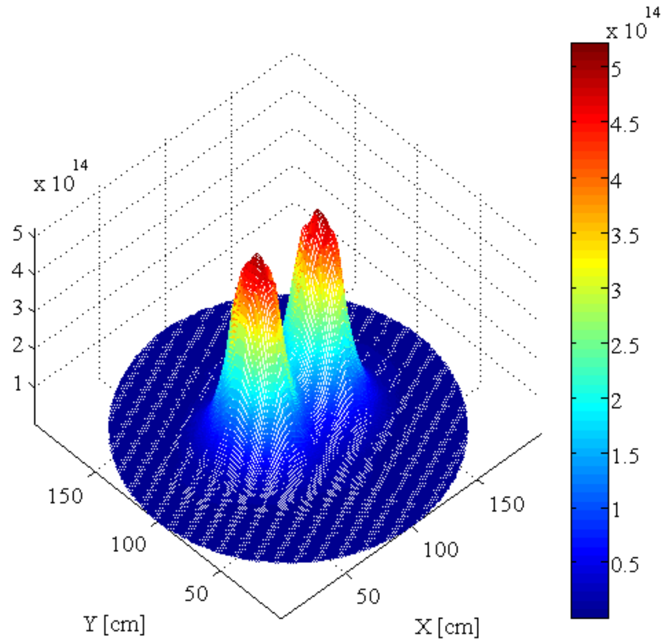
Reactor	NBSR	HFIR	BR-2	OPAL	CARR	FRM-II	NBSR-2
Country	U.S.	U.S.	Belgium	Australia	China	Germany	U.S.
Power (MW_{th})	20	85	60	20	60	20	20
Fuel	HEU	HEU	HEU	LEU	LEU	HEU	LEU
Max Φ_{th} ($\times 10^{14}$ n/cm^2-s)	3.5	10	12	3	8	8	5
Quality factor ($\times 10^{13}$ MTF/MW_{th})	1.8	1.2	2.0	1.5	1.3	4.0	2.5

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

Thermal Flux vs. Fast Flux (EOC)



Thermal Flux



Fast Flux

Thermal Neutron Beams

SU Results

Current at the exit surface (n/cm2-s)				
E (MeV)	TB1	TB2	TB3	TB4
6.25E-07	8.13E+11	8.13E+11	7.99E+11	8.18E+11

Cell flux (n/cm2-s)				
E (MeV)	TB1	TB2	TB3	TB4
6.25E-07	1.47E+14	1.47E+14	1.46E+14	1.47E+14

EOC Results

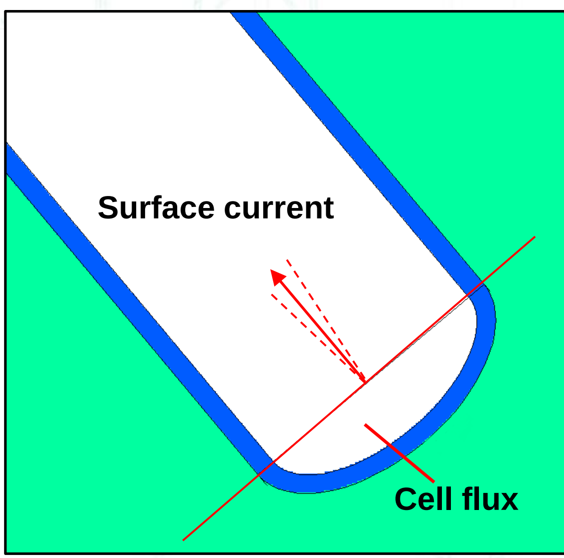
Current at the exit surface (n/cm2-s)				
E (MeV)	TB1	TB2	TB3	TB4
6.25E-07	7.83E+11	7.94E+11	7.84E+11	7.87E+11

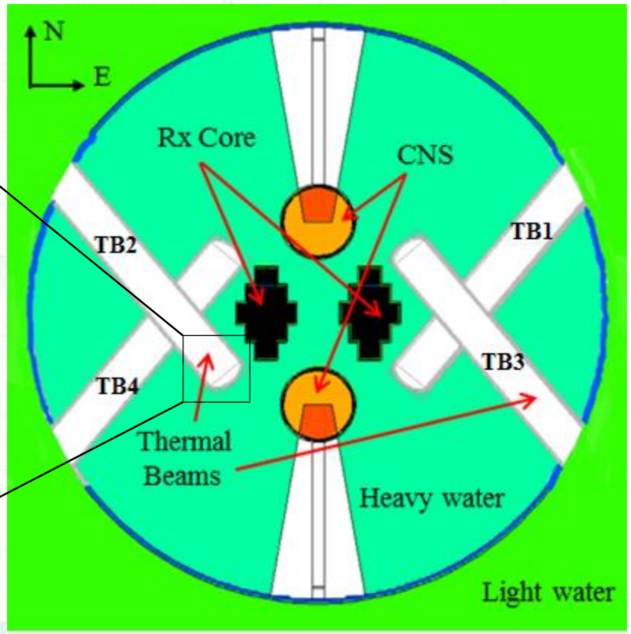
Cell flux (n/cm2-s)				
E (MeV)	TB1	TB2	TB3	TB4
6.25E-07	1.45E+14	1.45E+14	1.45E+14	1.46E+14

NBSR

Surface Current
Thermal Beam
7.7E+11

Cell flux
Thermal Beam
1.45E+14





Cold Neutron Performance

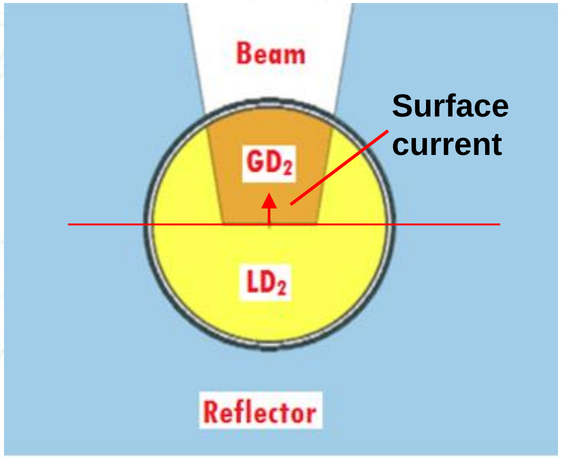
SU Results

Surface Current at the exit hole (n/cm2-s)			
E (MeV)	North CNS	South CNS	NBSR CNS
5.00E-09	5.53E+11	5.68E+11	8.18E+10
Cell flux (n/cm2-s)			
E (MeV)	North CNS	South CNS	NBSR CNS
5.00E-09	7.51E+13	7.57E+13	1.80E+13

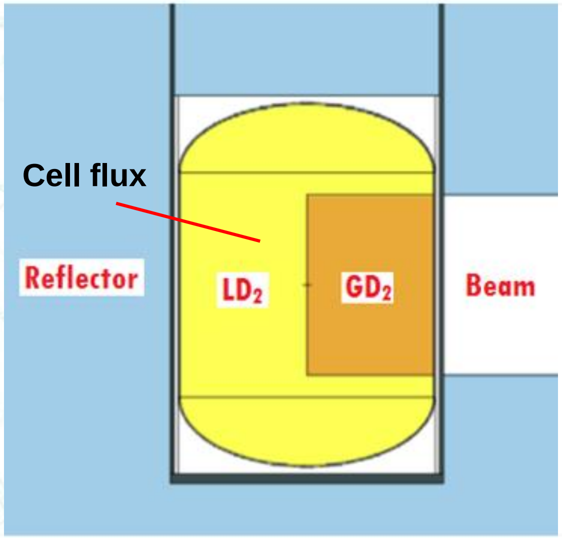
EOC Results

Surface current at the exit hole (n/cm2-s)		
E (MeV)	North CNS	South CNS
5.00E-09	5.44E+11	5.46E+11
Cell flux (n/cm2-s)		
E (MeV)	North CNS	South CNS
5.00E-09	7.35E+13	7.37E+13

The cold neutron flux produced by the new reactor outperforms the NBSR Unit-2 CNS by a factor of ~5.

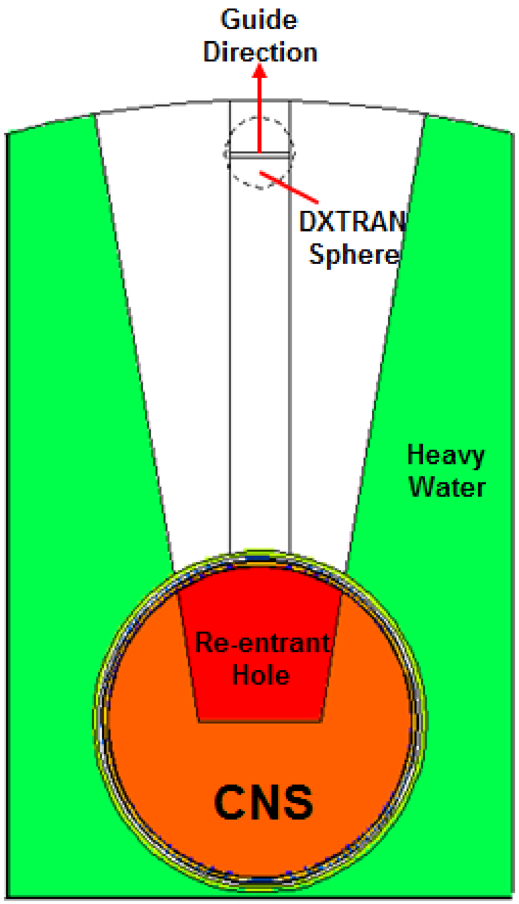


Top View

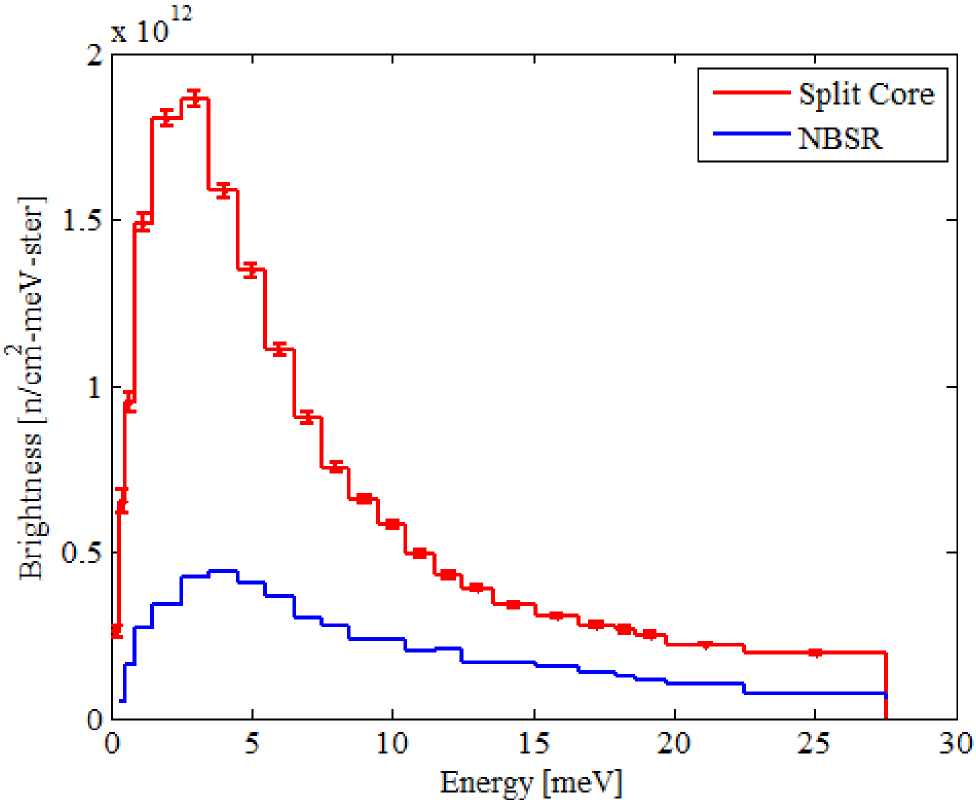


Side View

Cold Neutron Brightness

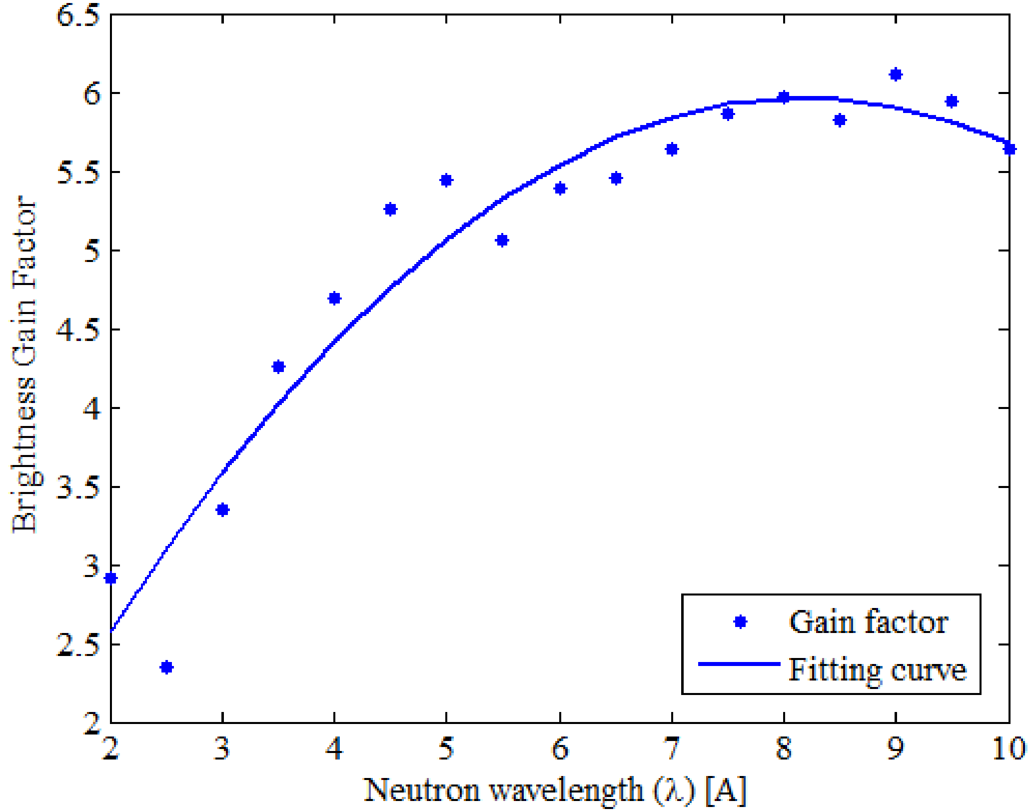


MCNP tally performed for the CNS brightness calculation



Cold Neutron brightness comparison

Expected Gain over NBSR CNS



The cold neutron produced by the new reactor outperforms the NBSR Unit-2 CNS by a factor of ~5 !!!

Conclusions and Future Work

What has been achieved by this time:

- A conceptual core design of a new beam-type research reactor is developed with the characteristics of low power, LEU fuel, horizontally split core, two CNS, several thermal beams, etc.
- Neutronics studies were performed using MCNP6. The maximum unperturbed thermal flux can reach 5.0×10^{14} n/cm^2-s, which indicates the quality factor of the neutron source is 2.5×10^{13} MTF/MW and exceeds nearly all the well-known neutron sources currently operating in the world. The performance of the cold neutron for the new proposed reactor has achieved a gain of a factor of 5 compared to the existing NIST reactor.

What needs to be done in the near future:

- More detailed safety analyses on other design basis accidents such as LOCA need to be investigated by expanding the T/H model to the whole primary loop using more sophisticated safety analyses tools (e.g. Relap5/MOD3.3 code).
- The U-10Mo LEU fuel (a uranium alloy with 10% molybdenum by weight) will be investigated in the next stage to assess the neutronics feasibility and safety performance under the split core concept.