Preliminary Studies on a New Reactor and Cold Neutron Sources at NCNR

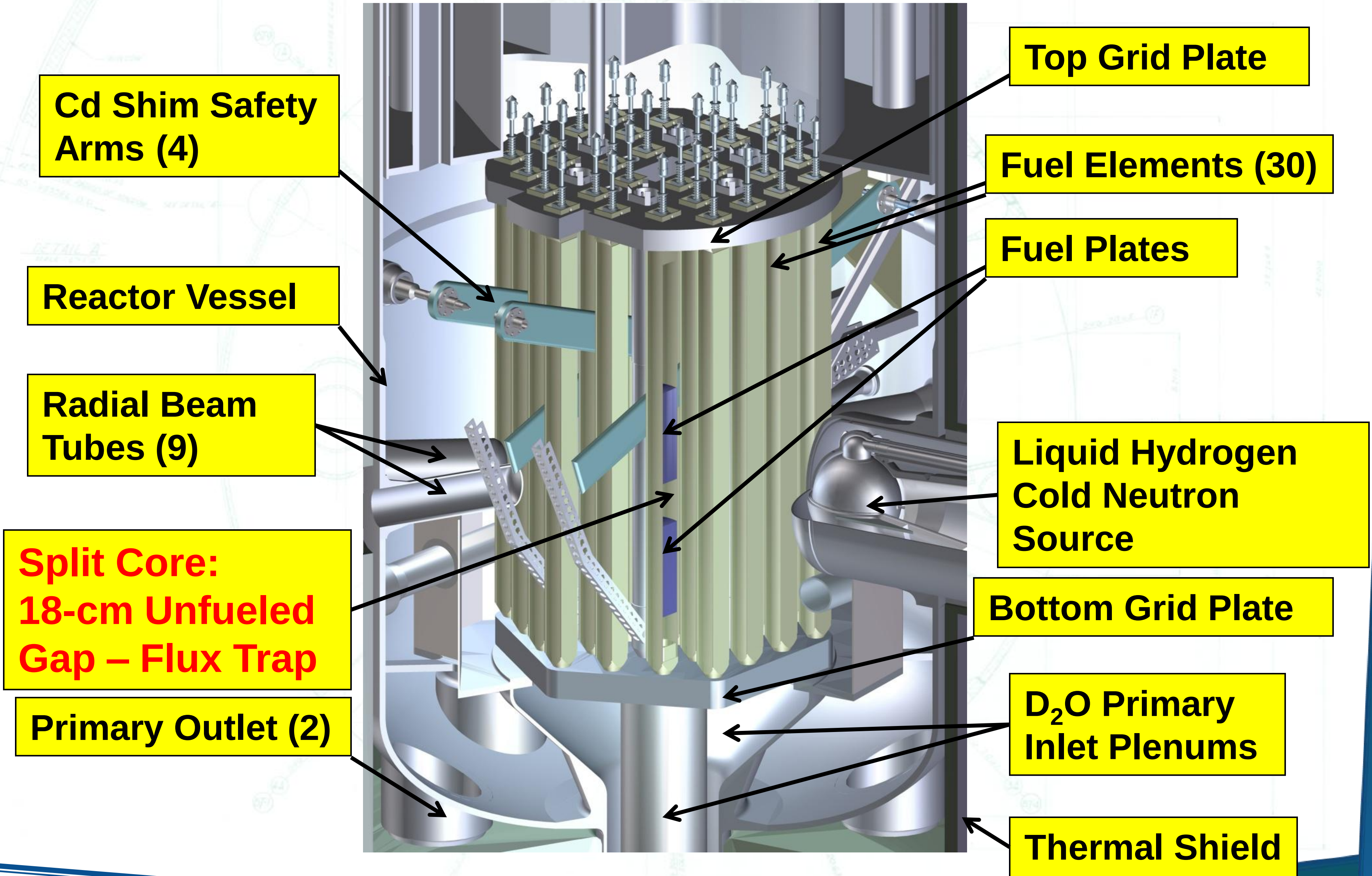
Zeyun Wu, Robert Williams, and Sean O'Kelly

The 16th IGORR/IAEA Technical Meeting,
Bariloche, Argentina
November 17, 2014

Outline

- Introduction
- Design Overview
- Horizontal Split Core Design
- Vertical Cold Neutron Source Design
- Summary

Cut-away View of the NBSR Core



Challenges for Conversion of NBSR to LEU

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

Overview of the NBSR Lifetime

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

Some Key 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 Considerations

- Compact core concept is employed in the design
- Principle purpose is to provide quality neutron source with great priority for 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

The core must be greater than 400 m from the site boundary (red).

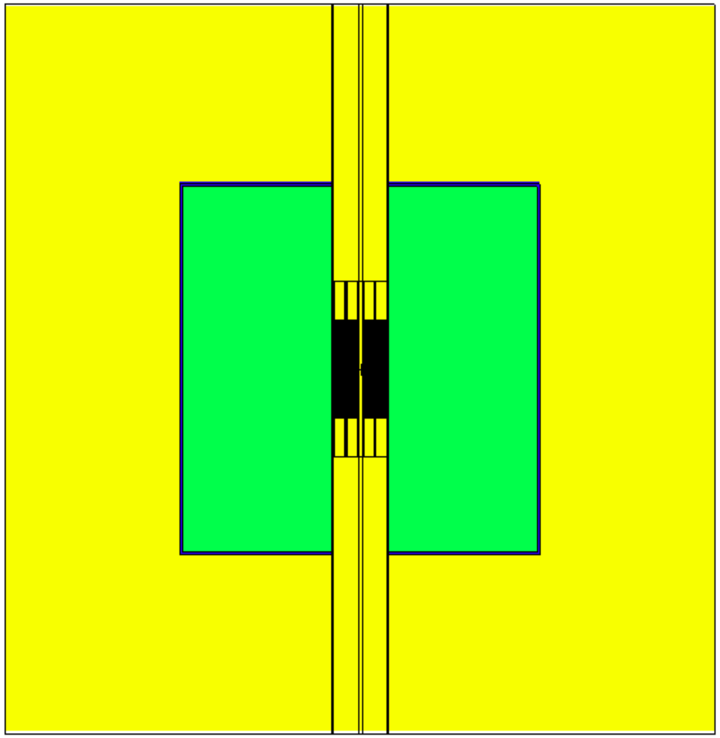
Inverse Flux Trap Principle & *Compact Core* Concept[1]

- Core volume **V** should be made as small as possible at constant reactor power **P**
- The compact core should be surrounded with a moderator (reflector) of high quality and large volume to maximize the thermal flux production
- Reactor power **P** should be chosen as high as possible to obtain a high absolute value of the thermal flux

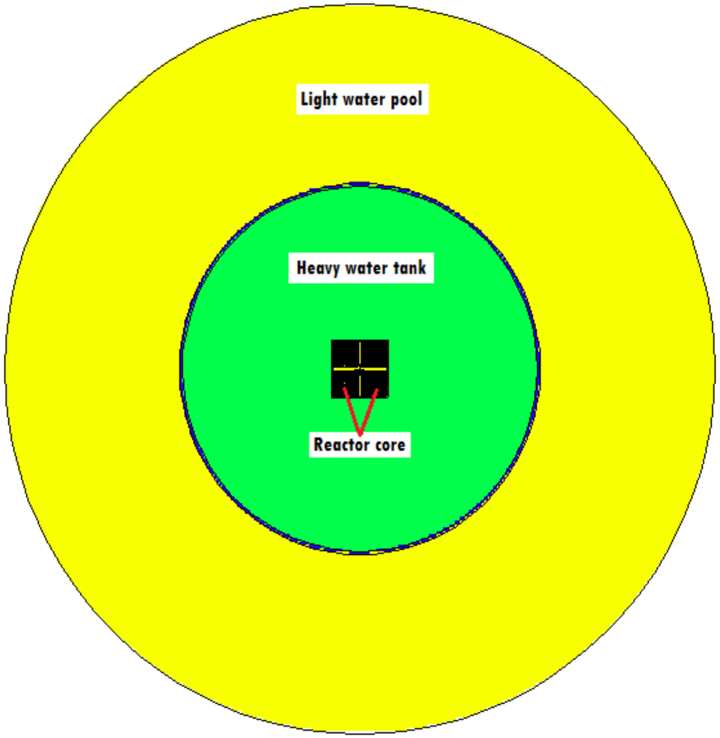
- Some advantages of compact core design
  - High "quality factor" – $\phi_{th}^{\max}/\mathbf{V}$
  - Large "usable volume" – $\mathbf{V_{eff}}$ in the reflector
  - High spectral purity of the thermal neutron flux ϕ_{th}

[1]. K. Boning and P. Von Der Hardt, "Physics and Safety of Advanced Research Reactors," *Nuclear Instruments and Methods in Physics Research* A260 p.239-246 (1987)

Schematics of Compact Core Design



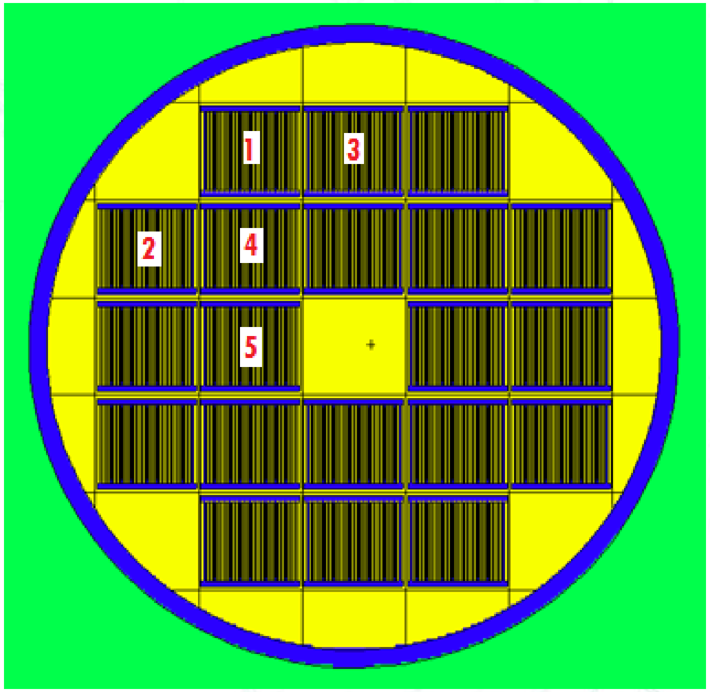
(a) X-Z view



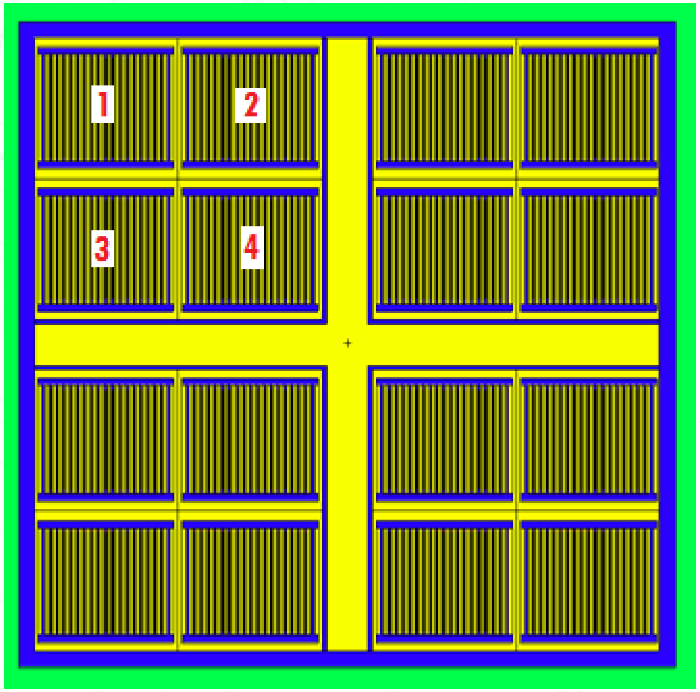
(b) X-Y view

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

Compact Core Examples:



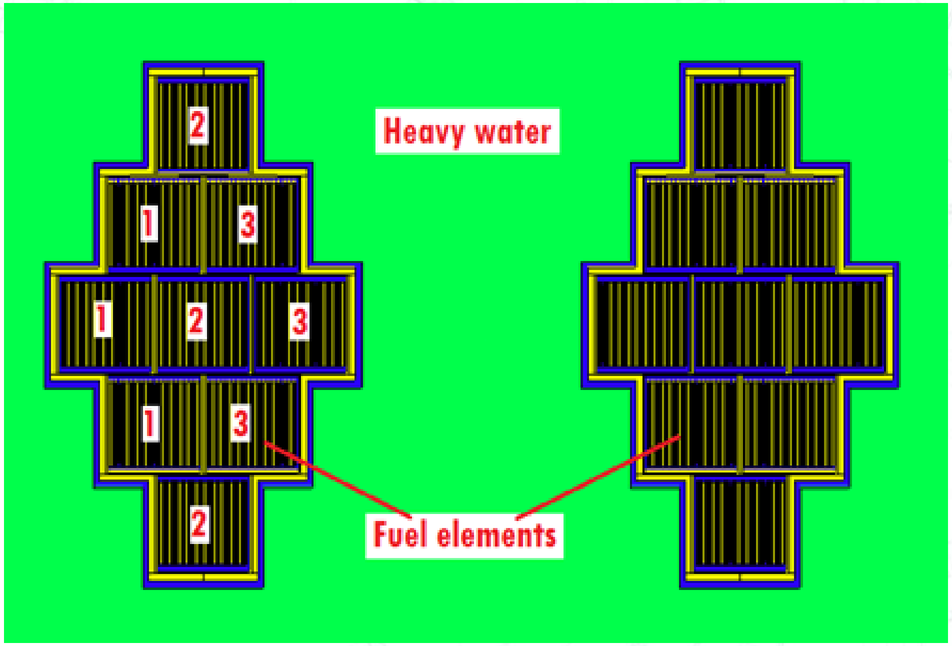
(a) 20 FE Core



(b) 16 FE Core

The 20 FE core is similar to the CARR (China Advanced Research Reactor) core, and the 16 FE core is similar to the OPAL (Open Pool Australian Light-water Reactor) core.

Horizontal Split Core Design

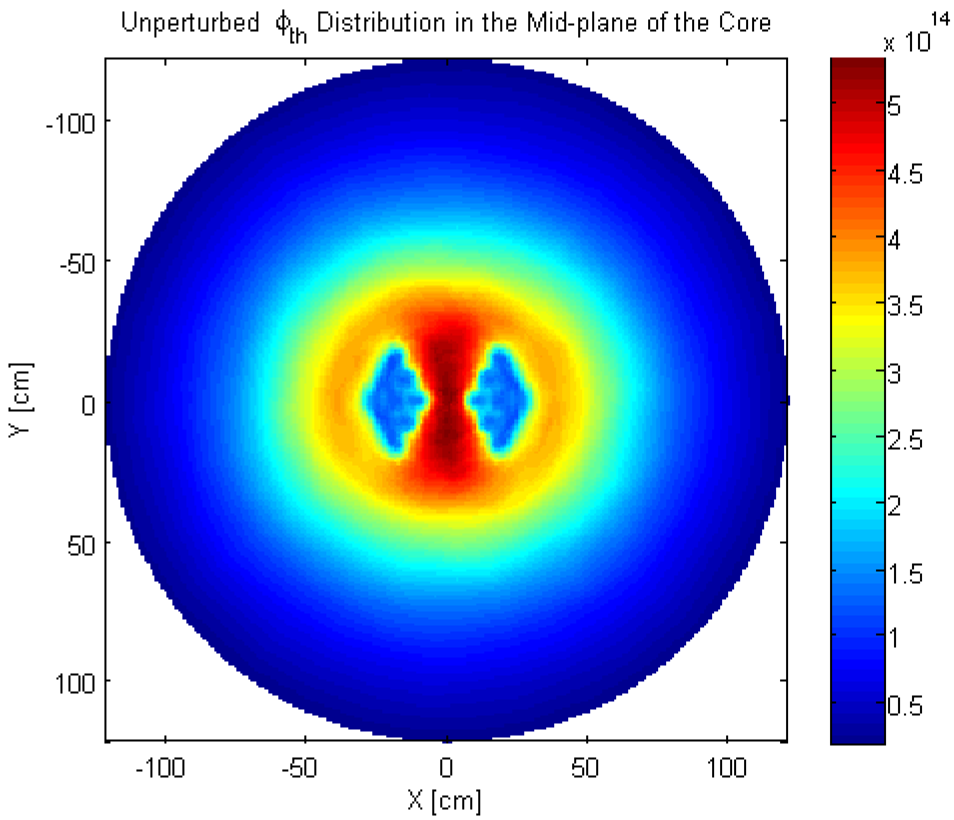


Schematic view of the core

Core design information

Parameter	Data
Power rate (MW_{th})	20
Reactor type	Tank in a pool
Active core height (cm)	60.0
Fuel element lattice pitch (cm)	8.2
Number of fuel elements in the core	18
Core center horizontal gap distance (cm)	19.5
Water gap between box and fuel grid (cm)	0.5
Core box thickness (cm)	0.5
Heavy water tank diameter (m)	2.5
Heavy water tank height (m)	2.5
Heavy water tank thickness (cm)	2.0
Light water pool diameter (m)	5.0
Light water pool height (m)	5.0
Reactor coolant/moderator	Light water
Reactor reflector	Heavy water
Biological and thermal shielding	Light water pool

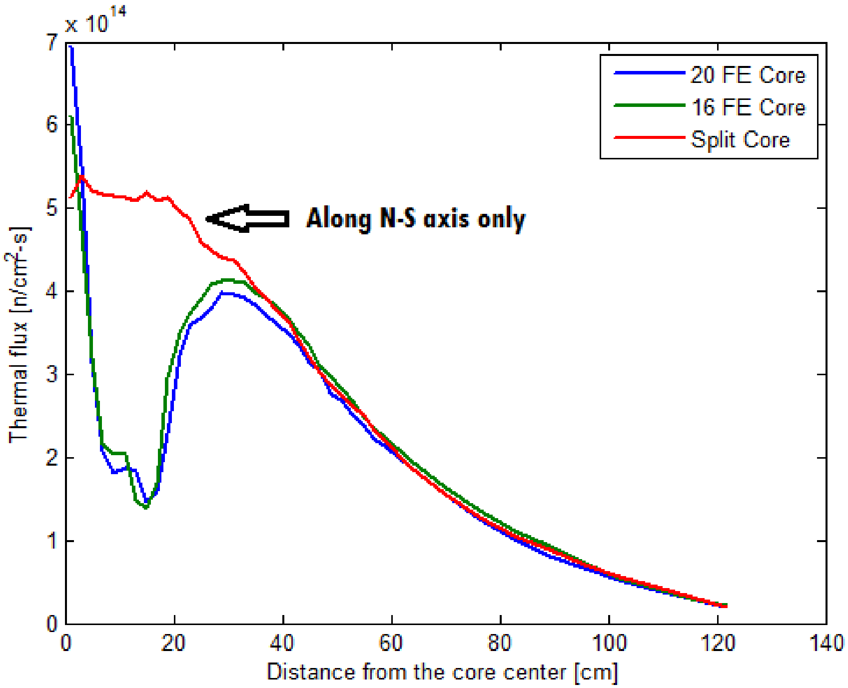
Planar View of Unperturbed Thermal Flux at Equilibrium EOC



Maximum thermal flux occurs in the space between split halves of the core.

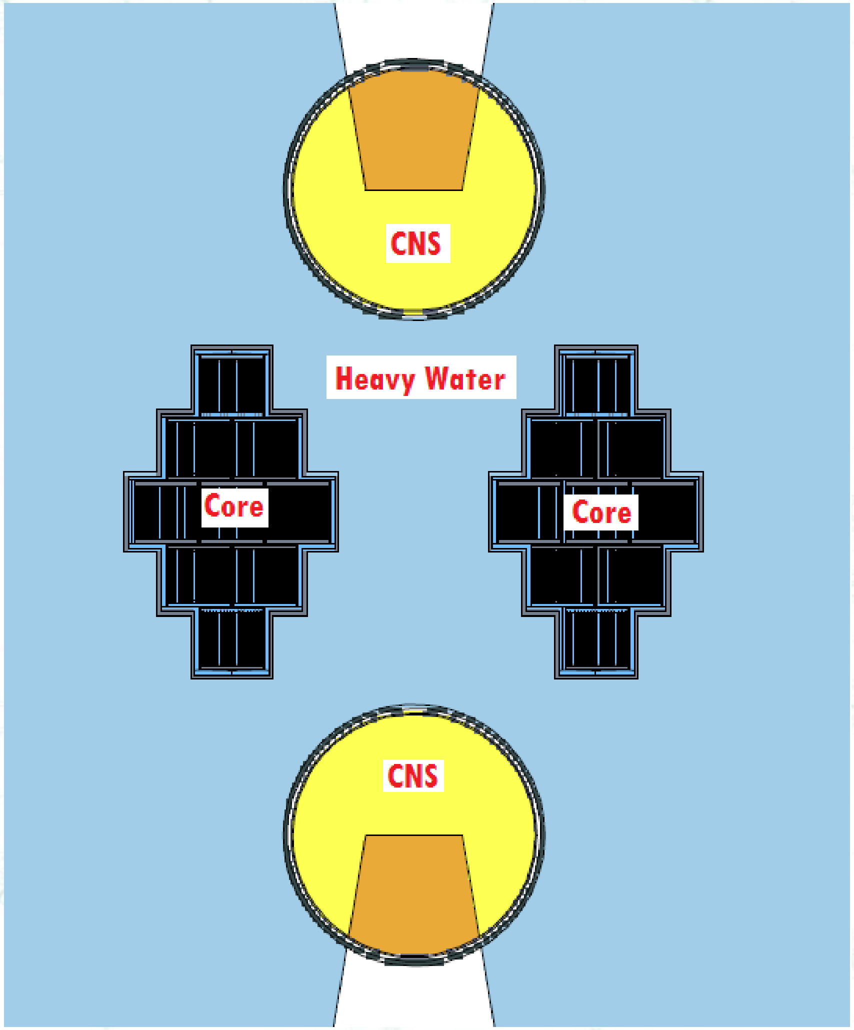
Even outside of core, the thermal flux is 2-3 times existing NBSR beams.

Unperturbed Thermal Flux Comparison

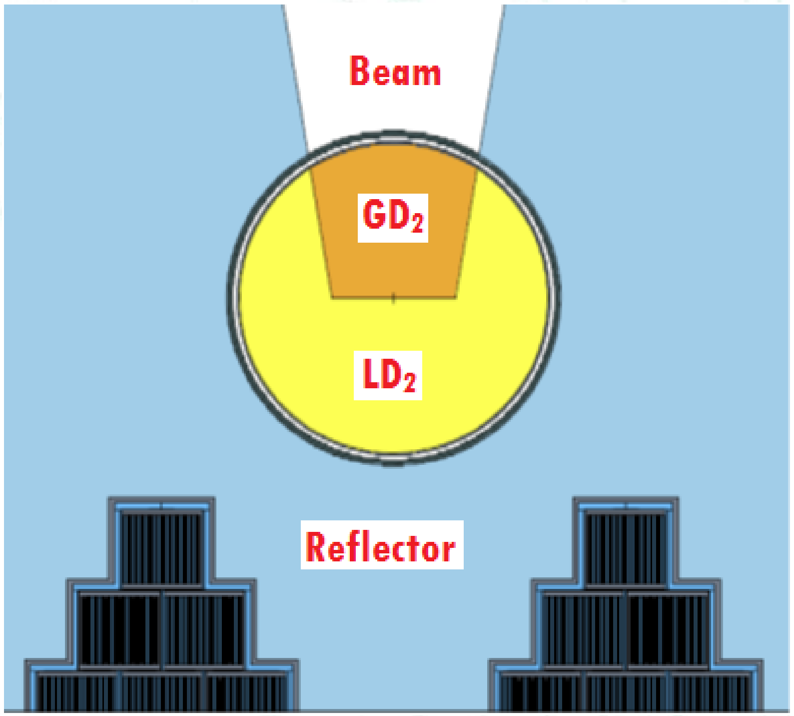


Parameter	Data
Power (MW_{th})	20
Fuel cycle length (days)	30
Fuel material	U_3Si_2
U-235 enrichment (%)	19.75
D_2O tank diameter (cm)	250
D_2O tank height (cm)	250
20 FE core cylinder radius (cm)	24
16 FE Core box side half-length (cm)	18

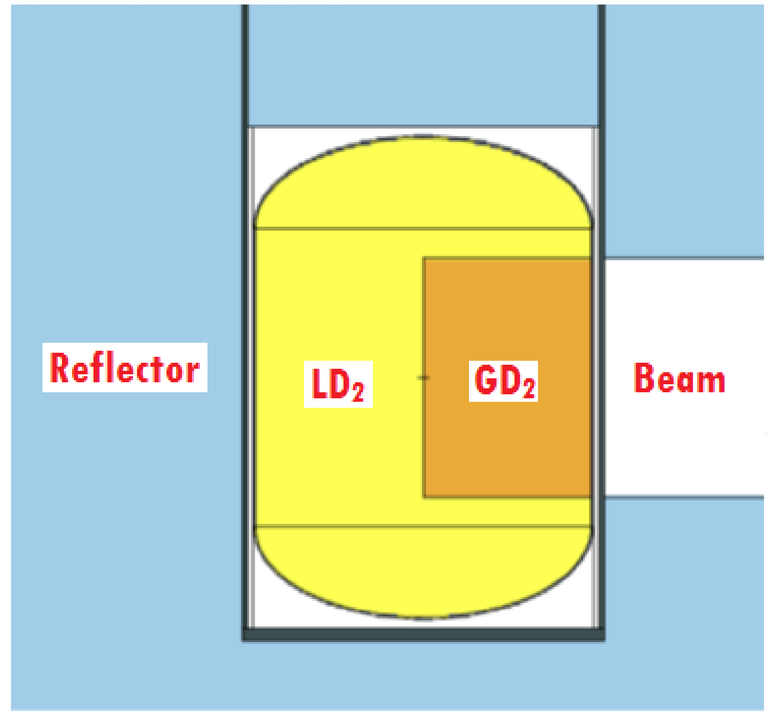
Vertical Cold Neutron Source (VCNS) Placement



Vertical Cold Neutron Source Design (Generic)



Top View



Side View

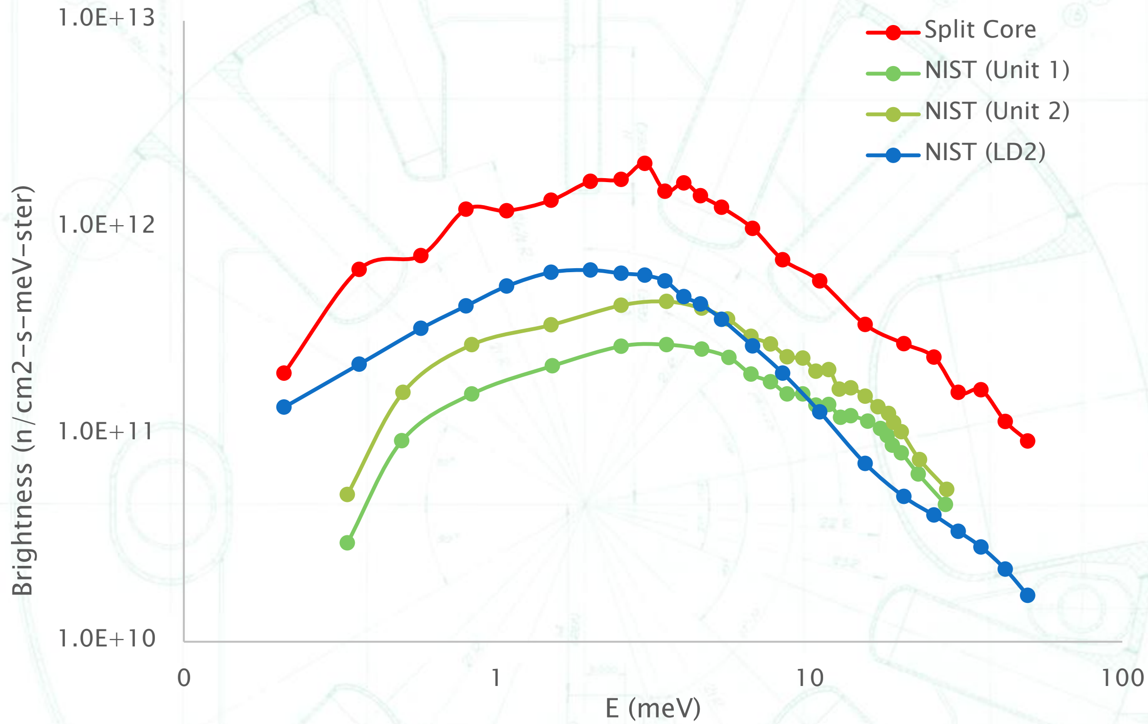
The distance from the center of VCNS to the center of the reactor: 40 cm
The total volume of LD2 in VCNS: 20.68 liter

Heat Load Calculation for VCNS

Component	Moderator – LD2	CNS vessel – Al
Radiation source	Heat (W)	Heat (W)
Neutrons	721	6
Gamma rays	1276	1001
Beta particles	–	906
Subtotal	**1997**	**1913**

- **The total heat load estimated for one VCNS by MCNP simulation is 3.91 kW**
- **The heat load limit is designated as 4 kW for thermo-siphon cooling in this design.**

Preliminary Cold Neutron Performance of VCNS



- The cold neutron (λ> 4 Å) source brightness in the split core is about 4 times that of the existing source at NBSR.
- No effort has yet been made to optimize the source.

Remaining Work on the Split Core Design:

- Thermal neutron beam ports (guides)
- Reactivity control elements
- Detailed fuel inventories, burnup
- Power distribution
- Thermal-hydraulic analysis
- Evaluate accident scenarios

- These engineering constraints will likely reduce the CNS performance.
- We will continue to study the split core design and compare it to more conventional compact cores.

Summary

- A research project on the design of a new LEU fueled beam tube research reactor is underway at NCNR. *The primary objective of the new reactor is to optimize cold neutron beams for instruments.*
- The new reactor will operate at 20 – 30 MW_{th} with a cycle length of 30 days.
- Preliminary neutronics feasibility studies are completed on a horizontal split core design model.
- A vertical LD_2 CNS is also modeled in the reactor using MCNP. *The cold neutron spectrum brightness/MW may be as much as a factor of two above existing sources.*
- *Many engineering constraints need to be evaluated!*