Optimization of a Cold Neutron Source for a Proposed LEU Reactor at NIST

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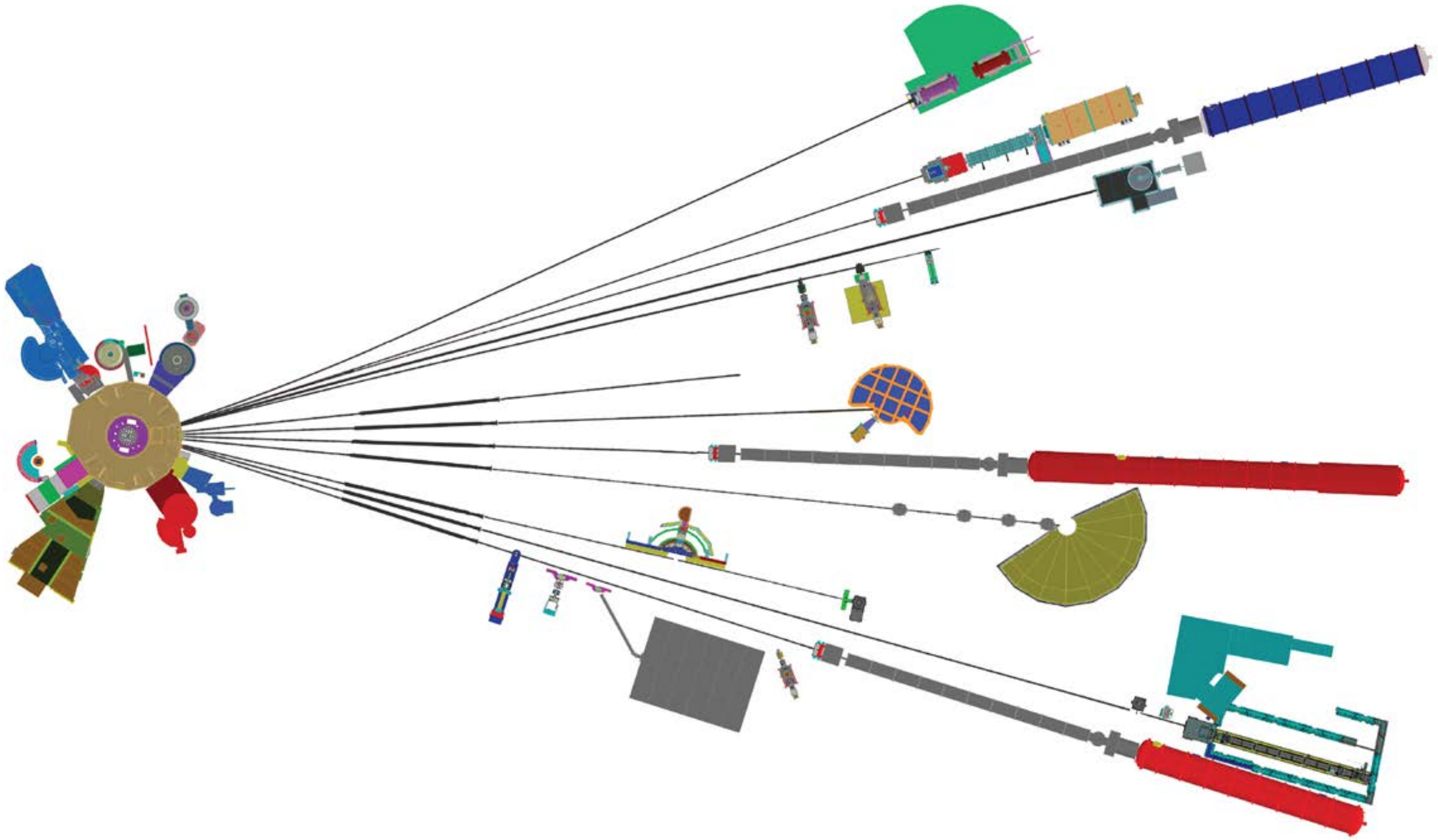
The NBSR



- The lifetime of the **National Bureau of Standards Reactor** (NBSR) will be coming to an end sometime in the middle of this century.
- NCNR hosts over **2,000** researchers annually
- **70%** use cold neutrons in their experiments.
- Feasibility study for a **Low-Enriched Uranium** (LEU) reactor underway

Cold Neutrons

Type	Energy Range	Wavelength Range (Å)
Fast	1 MeV – 20 MeV	.0003 - .0001
Thermal	.025 eV – .625 eV	1.8 - .04
Cold	< .005 eV	> 4

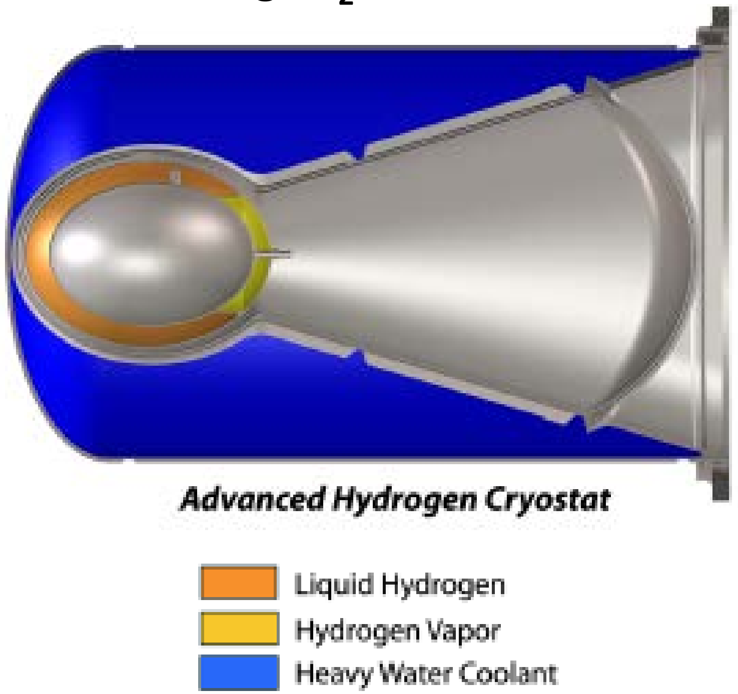
Note: 1 Å = 1 x 10^{-10} m

- Materials with structural spacings on the order of 100 Å have become more prominent in science and technology (Ex. Polymers).
- With their low energy and long wavelength, cold neutrons are better suited for probing these materials.

Producing Cold Neutrons

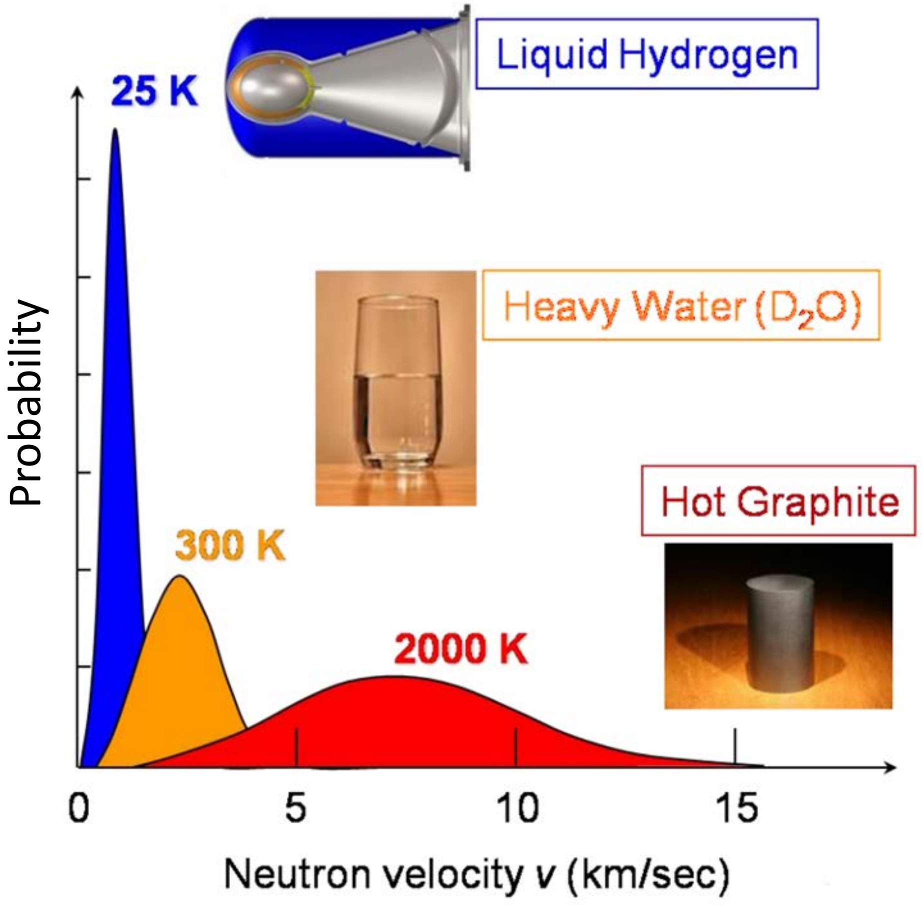
- To increase the production of cold neutrons from a reactor core, a **cold neutron source (CNS)** is used.
- Cryogenically cooled to around 20 K to shift the spectrum of neutrons to lower energies.
- Atoms with low Z (Example: hydrogen or deuterium) make ideal moderators.
- The new CNS design will be filled with liquid Deuterium (2021).

Unit 2 - Existing LH_2 Cold Neutron Source

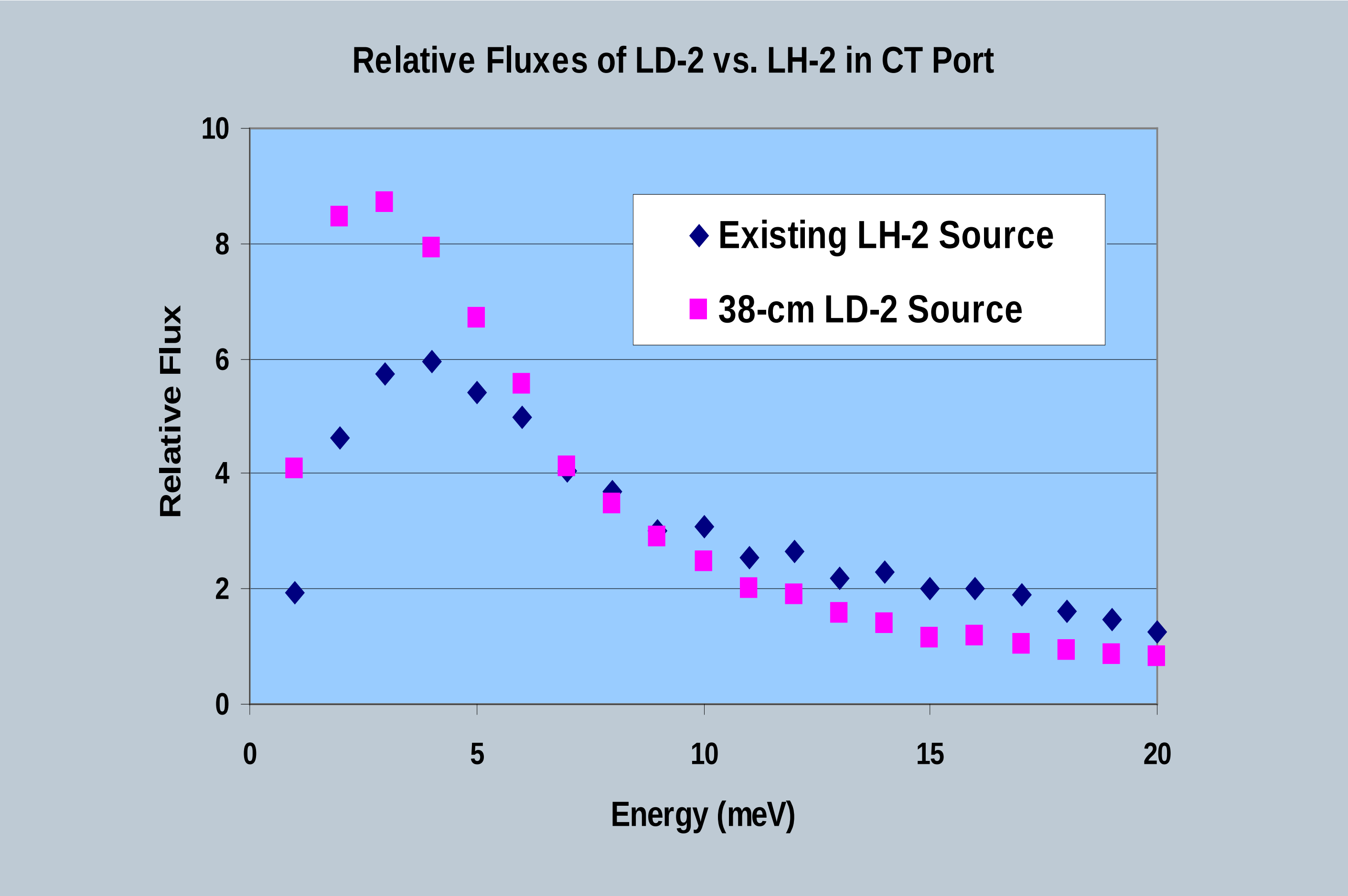


Neutron Moderation

- Neutrons collide with the atoms of the medium they reside in much like air molecules colliding in the room around us.
- Their kinetic energies depend only on the temperature of the surroundings according to the **Maxwell-Boltzmann Distribution**.
    - D_2O Moderator $\approx 300\ K$
    - LD_2 Moderator $\approx 20\ K$

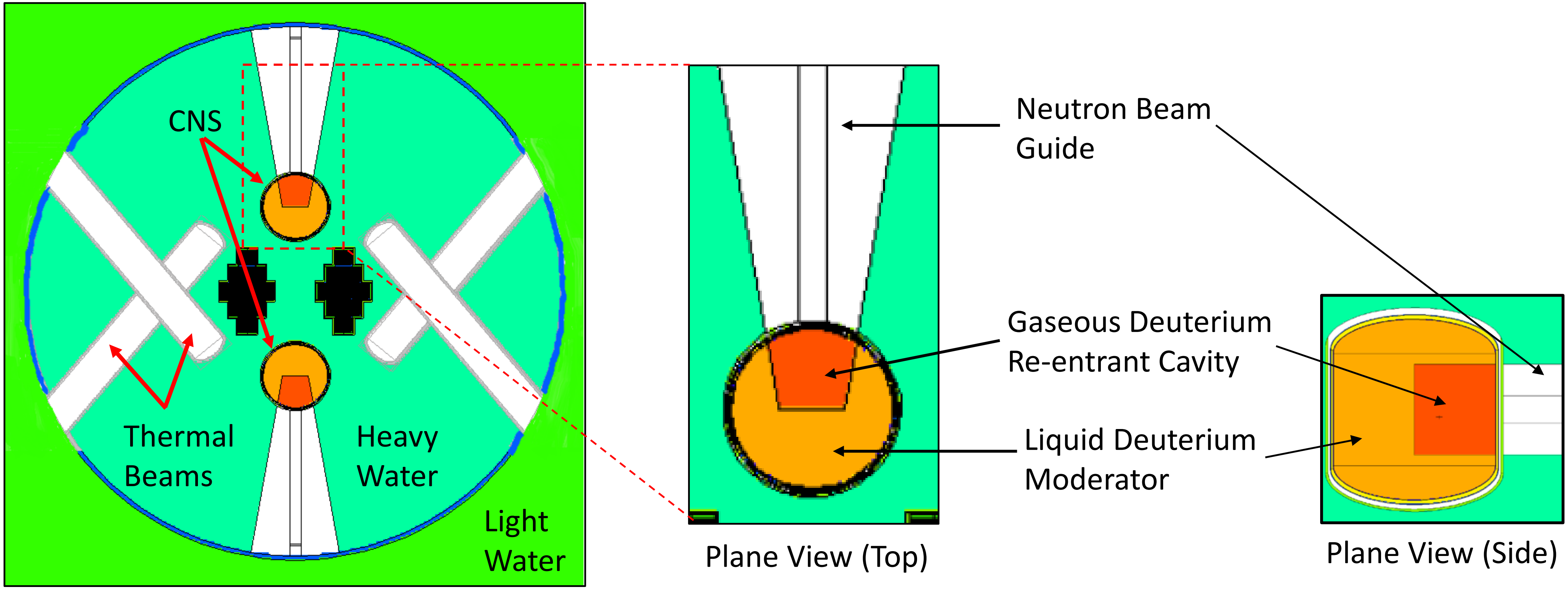


Why Switch to Deuterium?



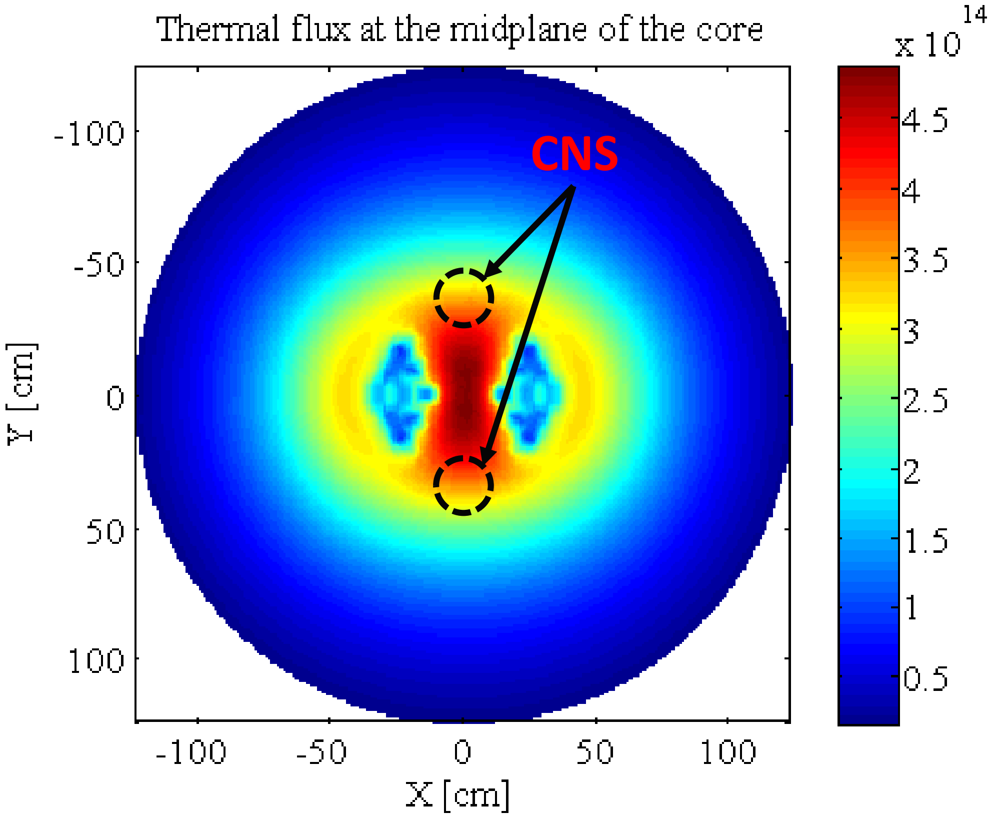
- Spectrum shifts to lower energies.
- Gains of up to 2 for the longest wavelengths.
- Up to a 50% loss at 15 meV (2.5 Å).
- Conversion of NBSR to LEU will result in 10% reduction in thermal and cold neutron beams.
- New CNS/guides intended to make up for this reduction.

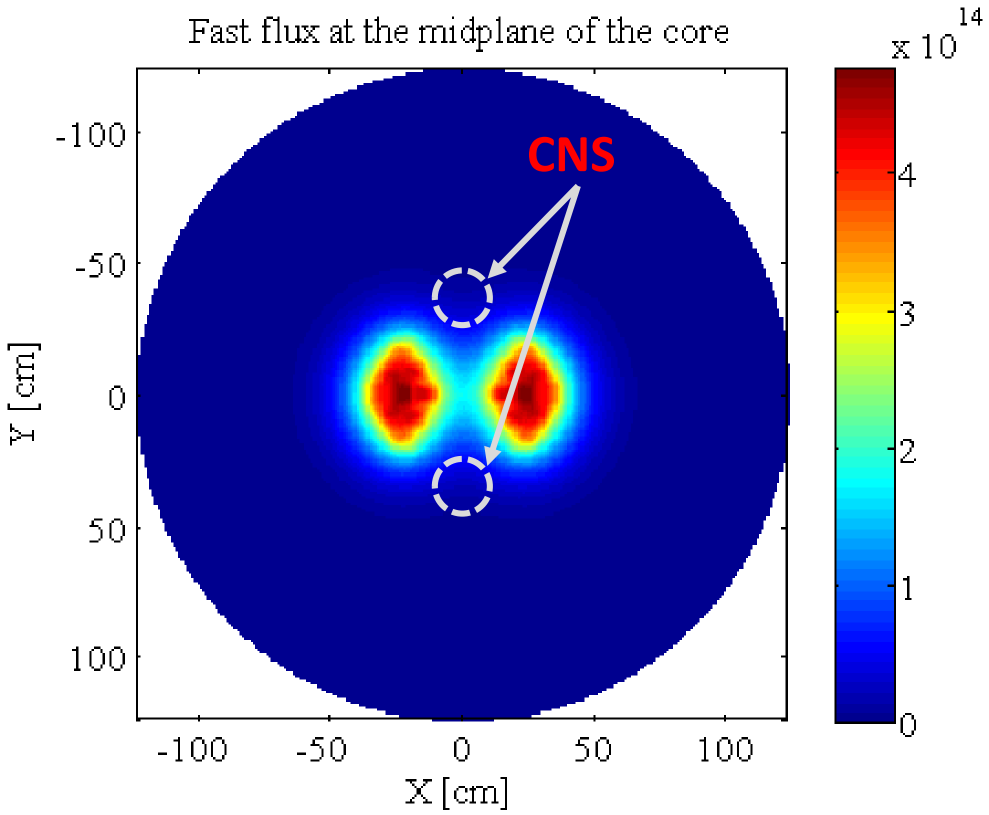
Deuterium Cold Neutron Source for Replacement Reactor



Optimizing the Cold Source Location

- Monte Carlo N-Particle (MCNP) computer simulations were used previously to perform flux calculations on the new reactor design.

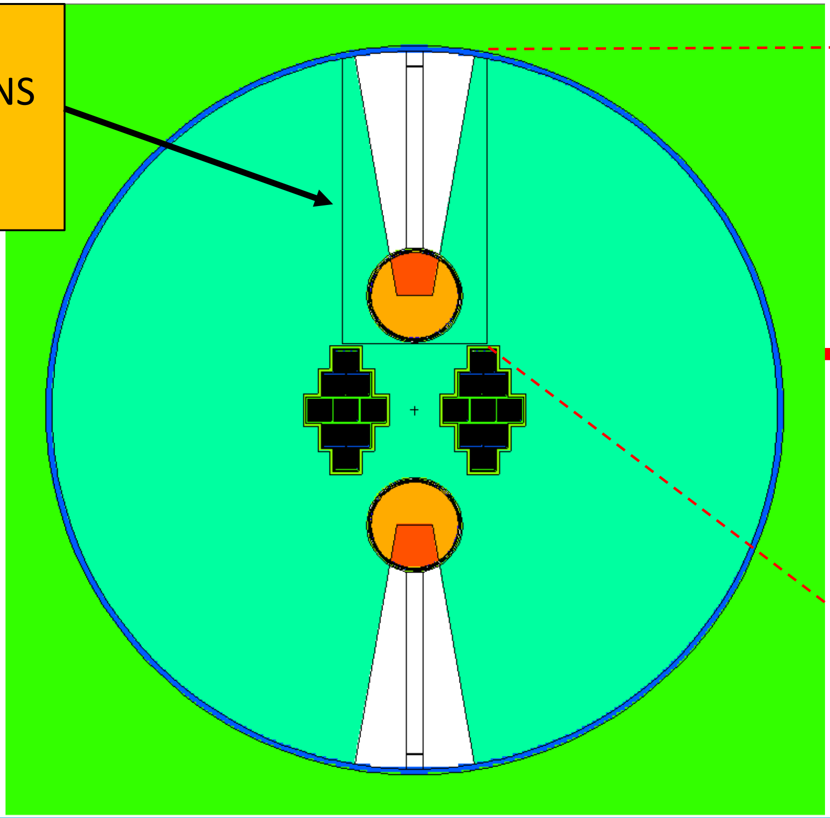


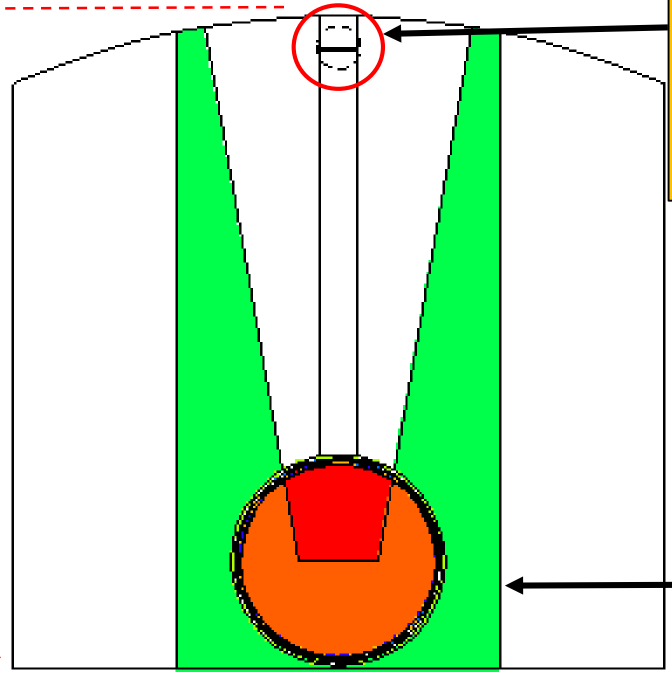


MCNP Neutron Brightness Calculations

- The quantity used to measure the performance of the cold neutron source is the **Brightness**.
  - Units: **n/cm^2-s-meV-ster** or **n/cm^2-s-Å-ster**

A surface source is generated around the CNS using a whole-core criticality calculation.

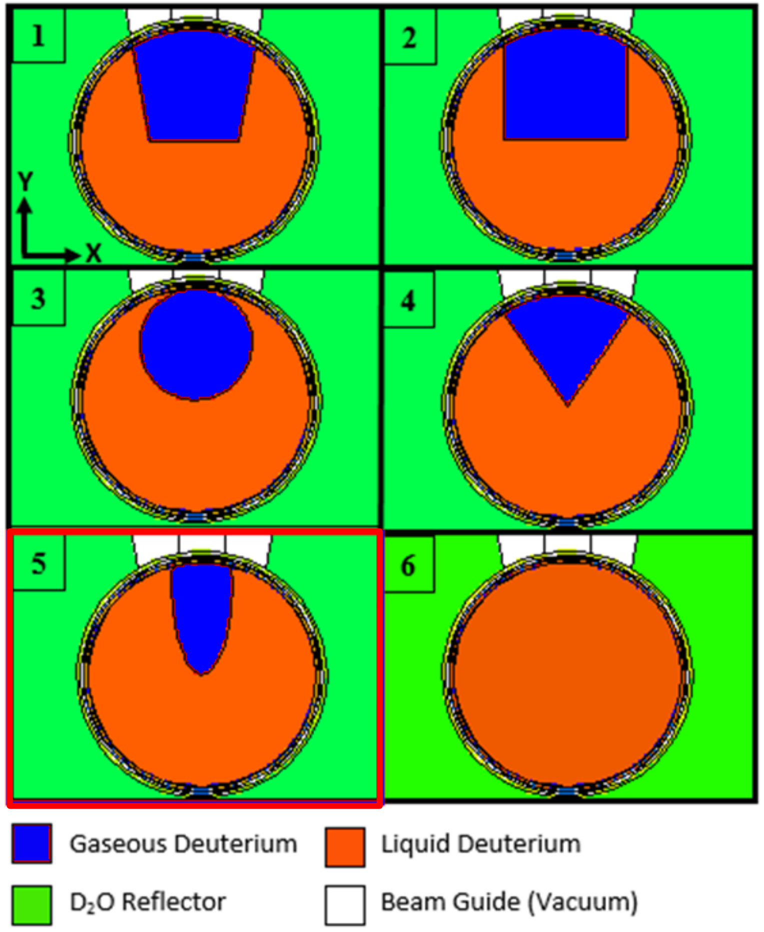




The **DXTRAN** feature is used to force “pseudo” particles to a tally plane at the neutron guide entrance.

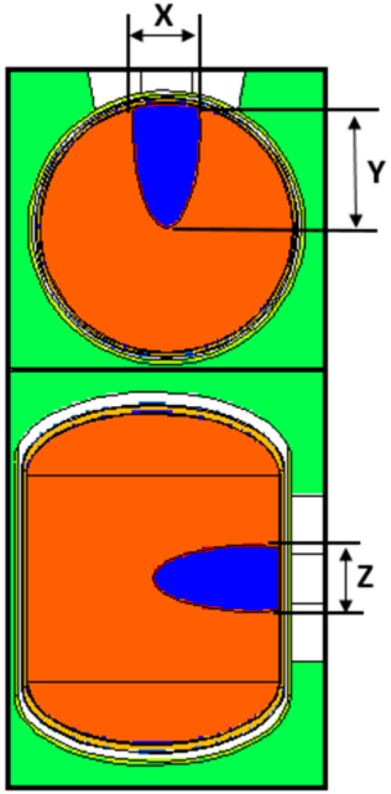
This surface source is used to perform surface current calculations on the CNS.

Optimizing the Cold Source Geometry

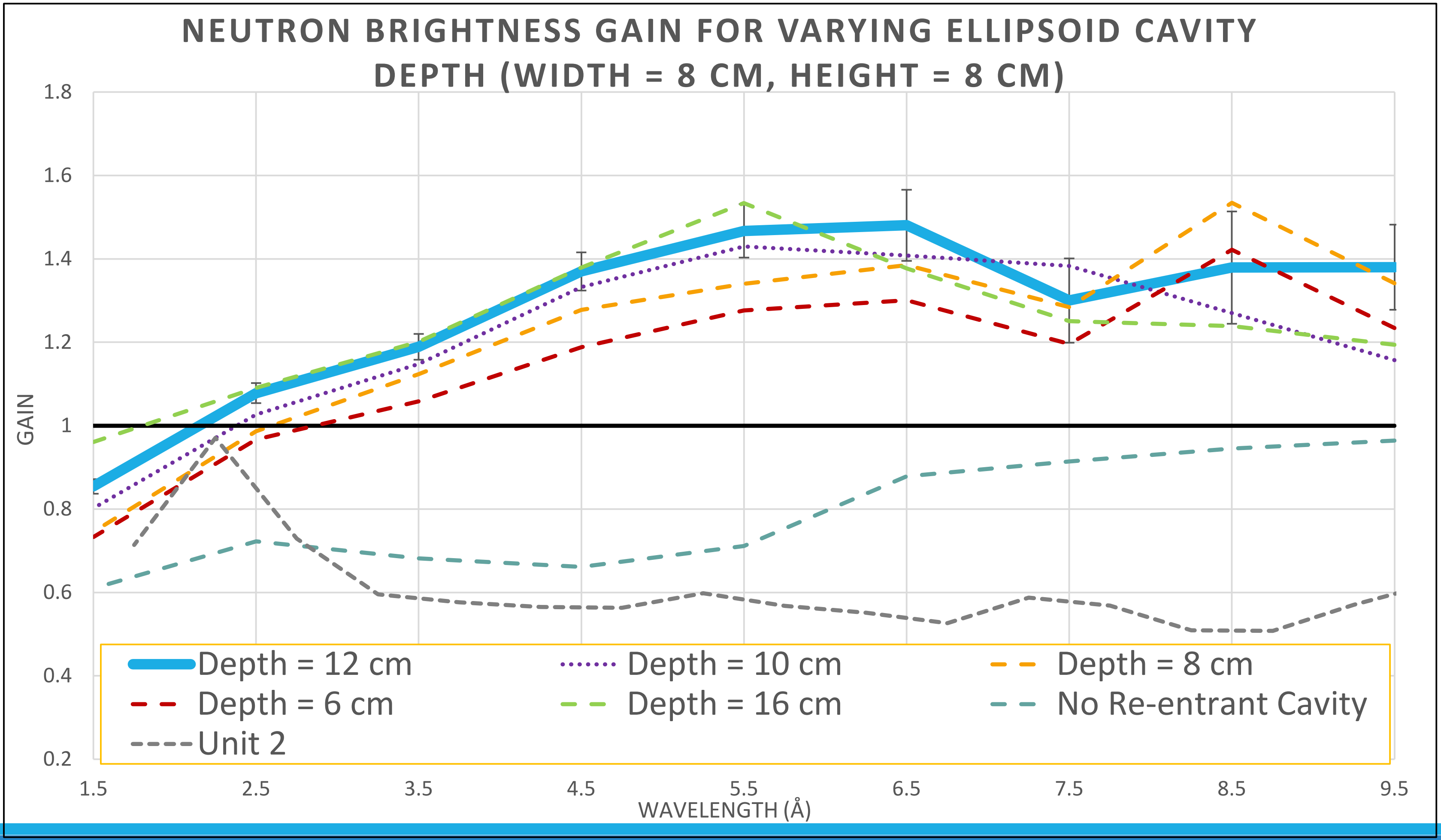


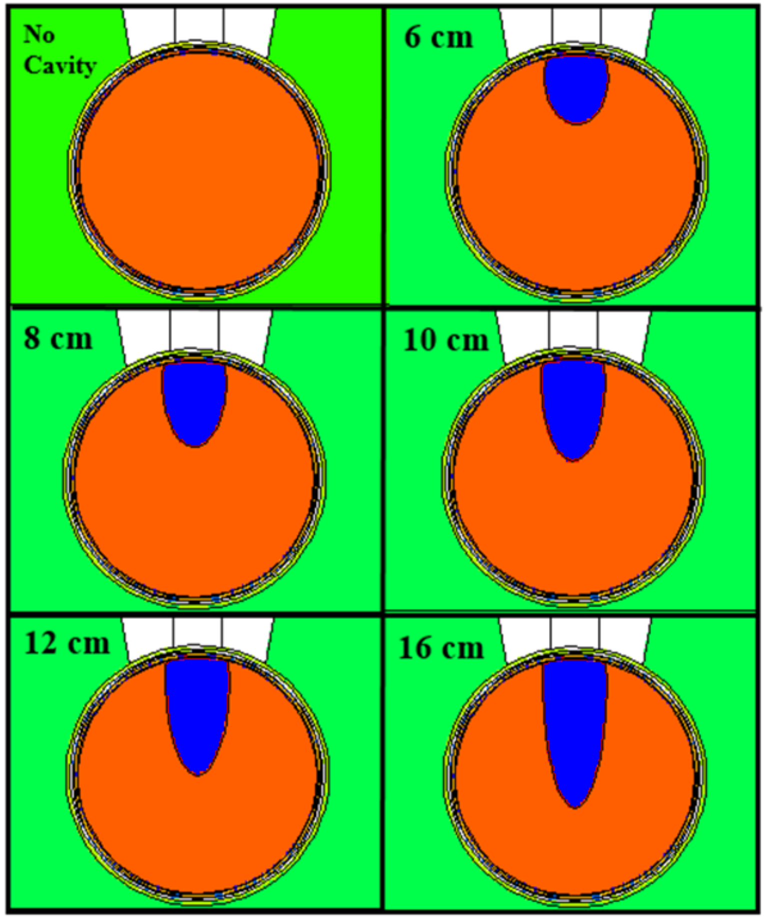
- The effects of changing the size and shape of the re-entrant cavity were investigated using MCNP.

#	Geometry (X x Y x Z) (cm)
1	Original (Trapezoid)
2	16 x 12 x 20 Box
3	Cylinder: d = 15, h = 20
4	38^o Cone (vertex @ center)
5	8 x 12 x 8 Ellipsoid
6	No Re-entrant Cavity



Brightness Gain Compared to the Original Deuterium CNS Design





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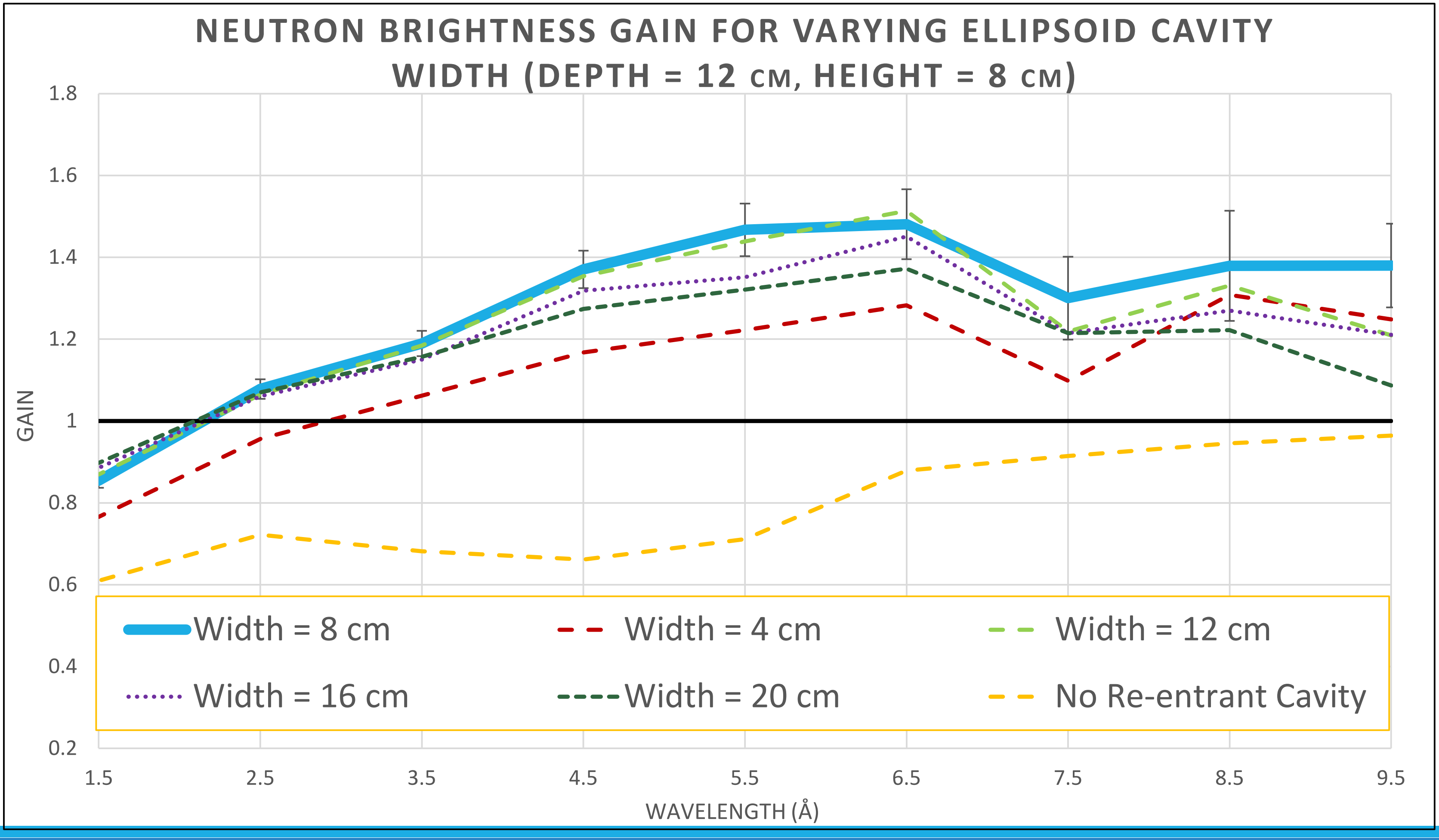

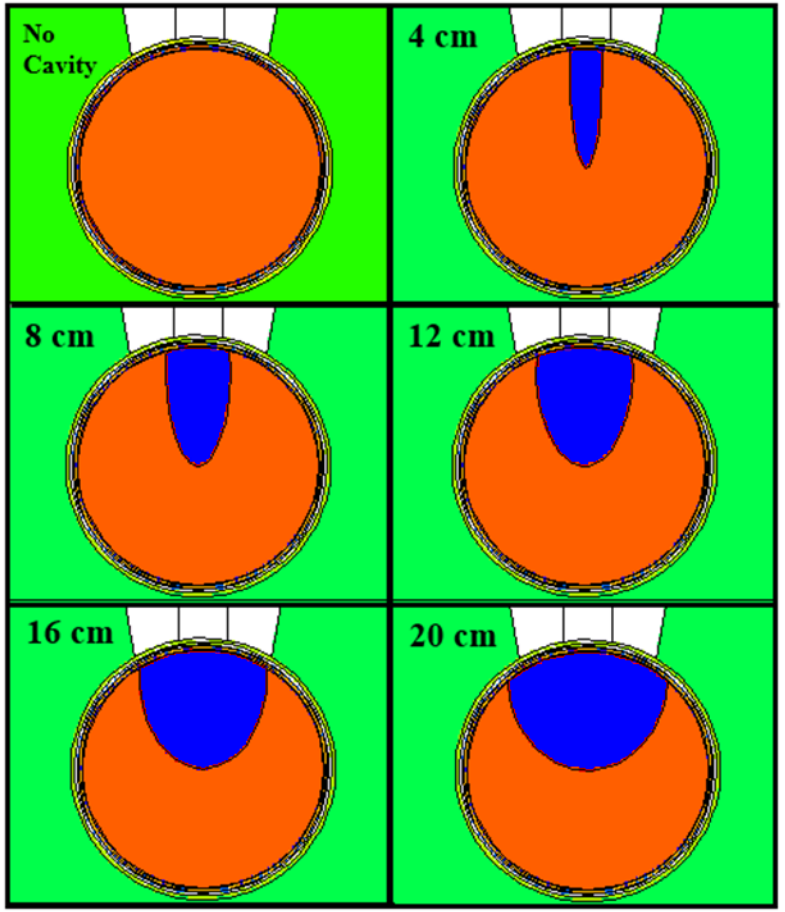

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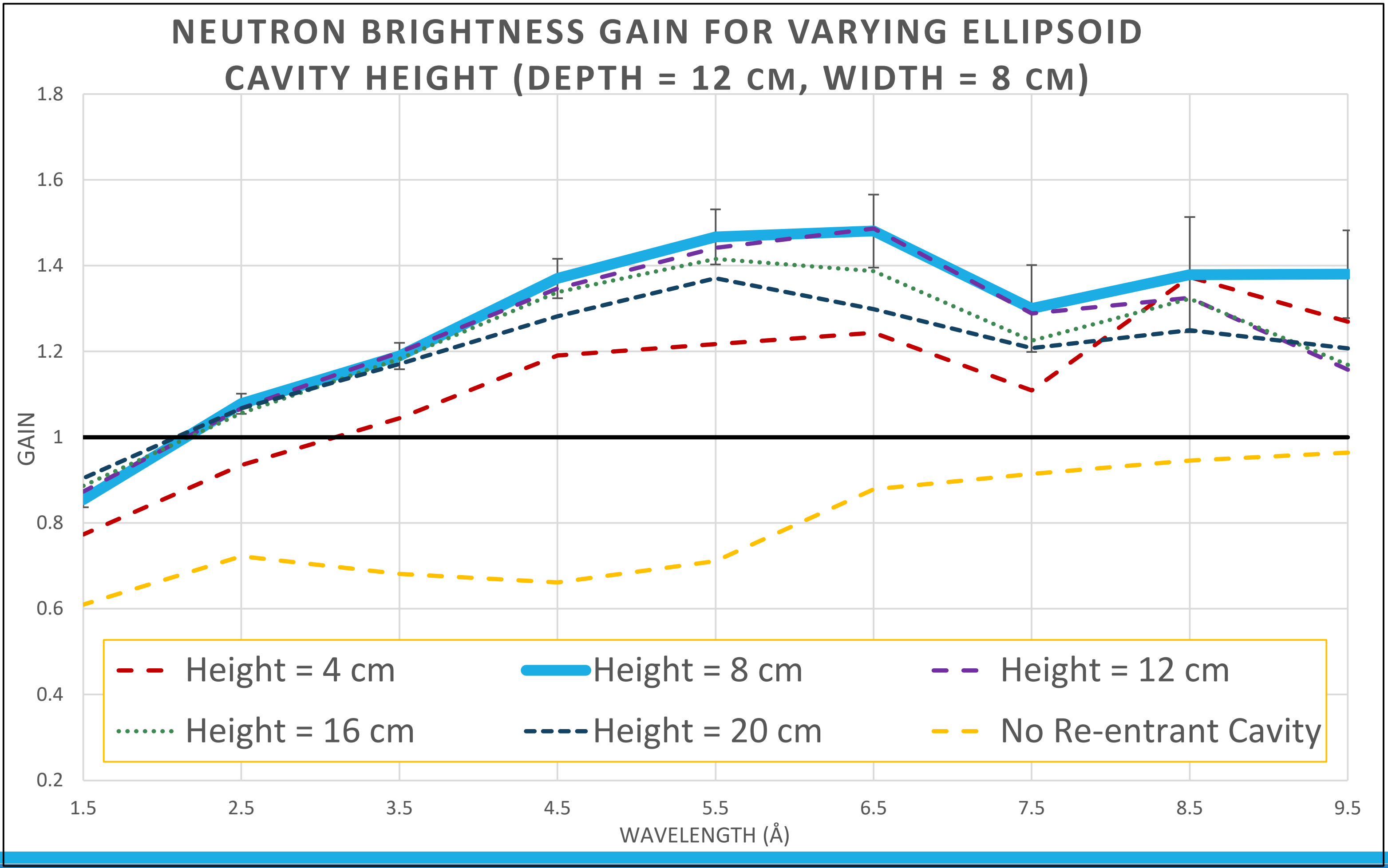
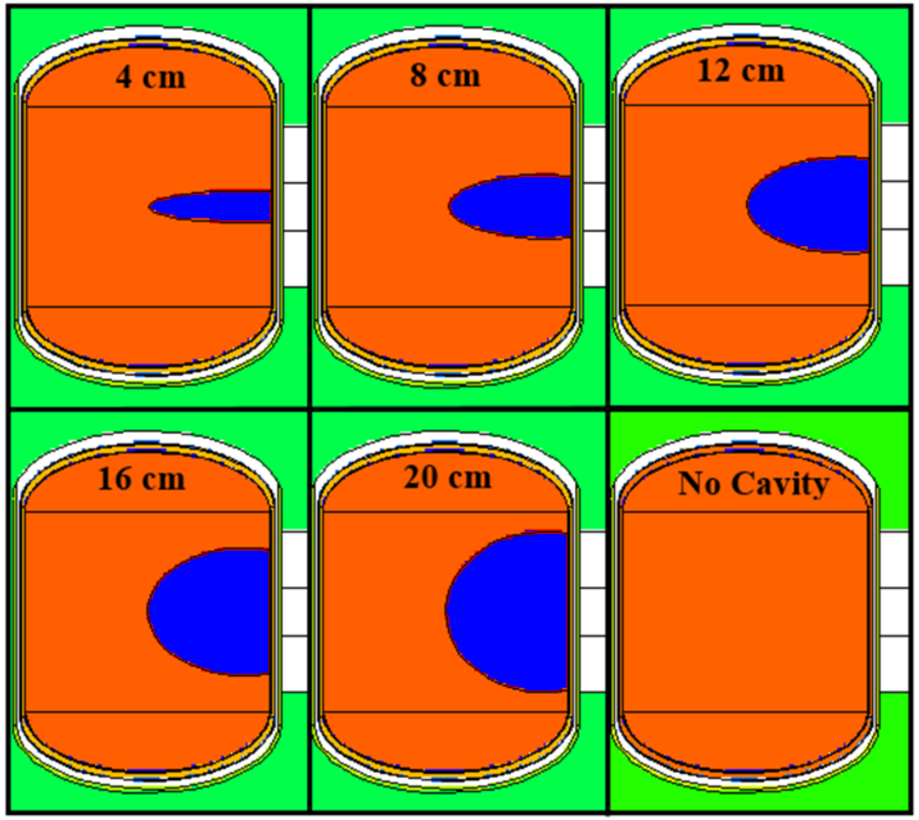




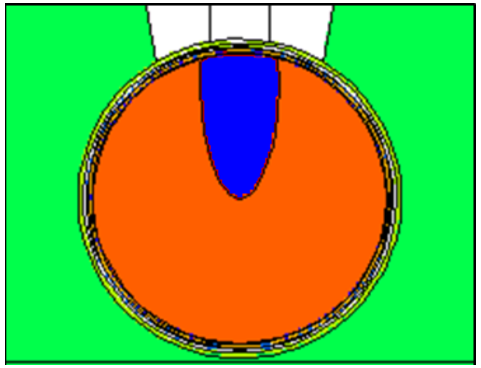
Nuclear Heat Load

- The Deuterium Cold Source is more massive than the existing Hydrogen cold source, meaning it will take on a greater nuclear heat load.
- MCNP used to calculate expected heat deposition rate in the LD_2 and moderator chamber with an (8 x 12 x 8) cm ellipsoid re-entrant cavity .
- A new 7 kW cryogenic helium refrigerator is being installed to account for this threefold increase in heat load.

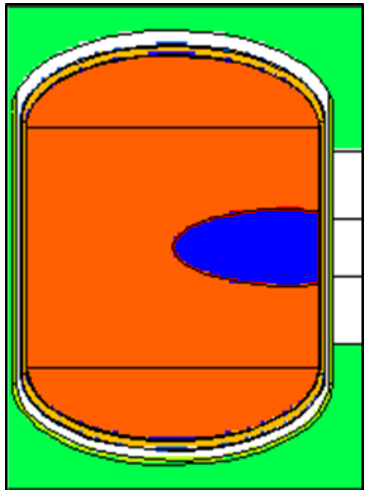
	Deuterium (3806 g)		Aluminum (2280 g)	
Radiation Source	Rate (W/g)	Heat (W)	Rate (W/g)	Heat (W)
Neutrons	0.0716	777	.0081	4
Beta Particles			4.32	679
Gamma Rays	1.53	1465	1.45	741
Subtotal		2242		1424
Total Cryogenic Heat Load = 3666 W				

Conclusion

- An optimized LD_2 cold source is needed to recover the 10% loss in neutron flux due to the switch to LEU fuel.
- The position and re-entrant cavity geometry were optimized to produce brightness gains between 1.3 - 1.5 for the desired range of 4 - 9 Å.
- (8 x 12 x 8) cm Ellipsoid re-entrant cavity consistently performs the best in terms of brightness in the 4 - 9 Å range.



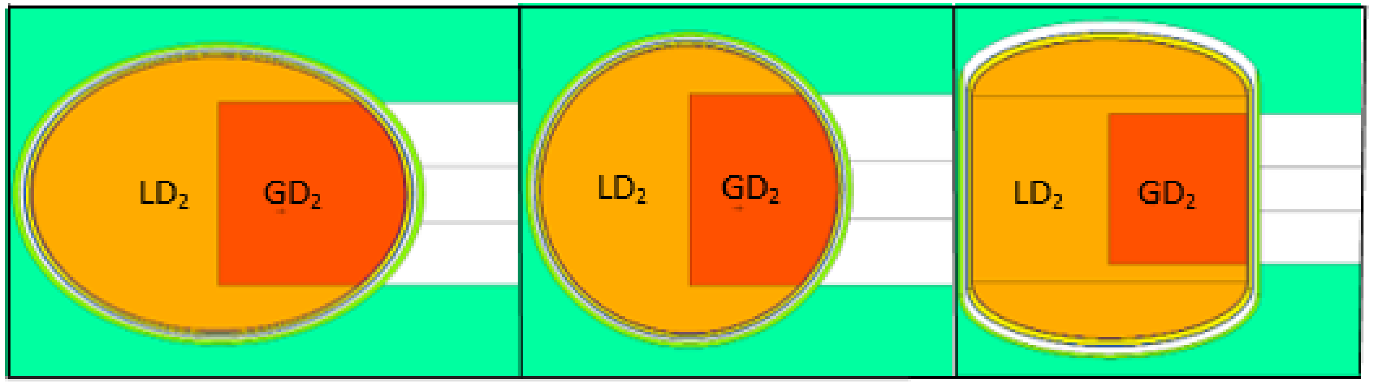
Plane View (Top)



Plane View (Side)

Future Research

- Cold Source re-entrant cavity has been optimized to within a few minor geometrical variations.
- The size and shape of the moderator chamber warrants further optimization research.
- This model must be adapted to the actual beam guide geometry.



Ellipsoid Sphere Annular

Acknowledgements

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