Liquid Deuterium Cold Source Concept for the NIST Neutron Source

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Abstract

The National Institute of Standards and Technology (NIST) Center for Neutron Research (NCNR) houses a reactor serving more than 40% of all cold neutron research needs in the U.S. First critical in 1967, **the National Bureau of Standards Reactor (NBSR) is now more than 50 years old**.

NCNR engineers have initiated a design effort for **a replacement reactor – the NIST Neutron Source or NNS**. The NNS is a 20-MWth light-water cooled and moderated, and heavy-water reflected compact core design.

The NNS will include **two liquid deuterium cold neutron sources (CNS)** to moderate neutrons. These CNS will require new cryogenic infrastructure to operate. Here we describe a preliminary proposed design concept for the NNS cold sources and associated ancillary infrastructure.

NNS Overall Architecture

- NNS is planned to be adjacent to the existing NBSR facility, allowing NBSR to continue operation during NNS construction.
- NNS user facility will provide cold and thermal neutron beams, and several in-core irradiation positions.
- NNS reactor concept proposed design:
  - Open-pool research reactor
  - Nominal power of 20 MW.
  - Light-water-cooled compact reactor core
  - Surrounded by heavy water in a reflector tank.
  - In bottom of reactor pool filled with demineralized light water.
  - Two (2) cold neutron sources.

Cold and Thermal Neutrons

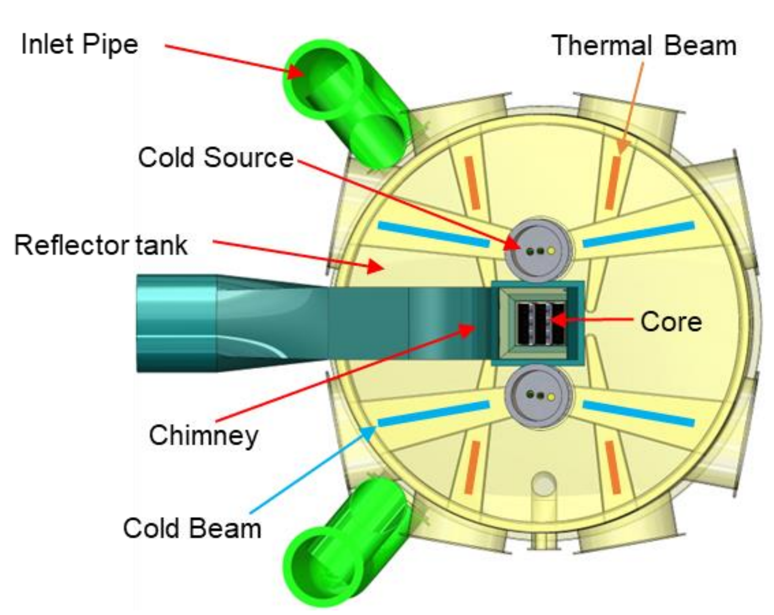
- Thermal neutrons – Room-temperature Maxwellian energy distribution
- Cold neutrons – Maxwellians with lower effective temperatures
- NNS defines cold neutrons as having energies less than 0.005 eV or neutron wavelengths, λ, greater than about 4 Å.

CNS Design and Performance

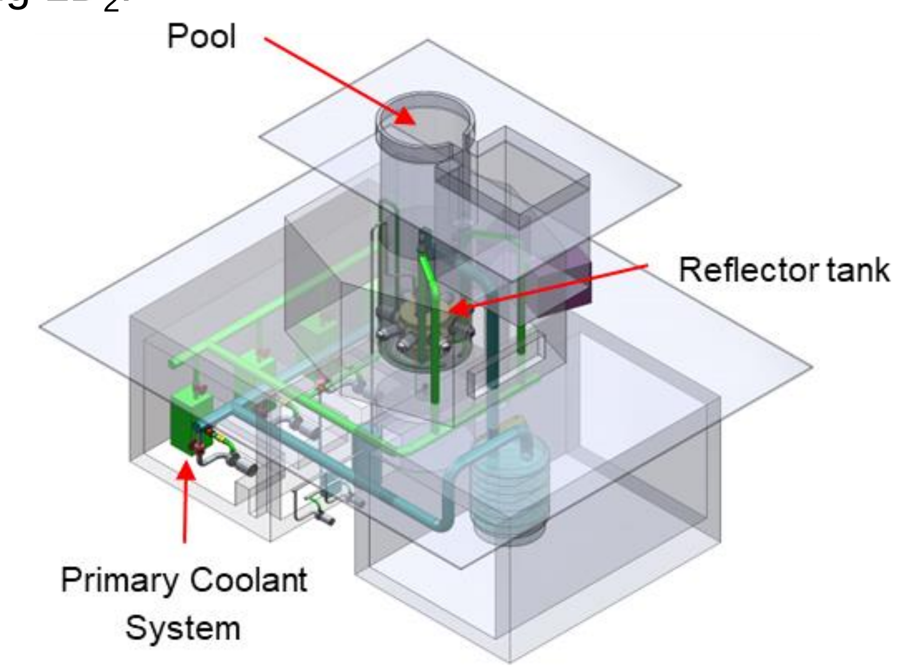
CNS is a cryogenically cooled moderator placed near the peak of the moderator/reflector thermal neutron flux. CNS shifts the thermal Maxwellian neutron flux distribution towards lower energies (lower temperatures).

Proposed NNS CNS model is similar to the OPAL CNS design.

- Liquid deuterium (LD_2) maintained as a single liquid phase in the moderator
- Operates with a thermosiphon instead of a deuterium pump or circulator.
- Single-phase LD_2 maintained in the moderator via a He/D_2 heat exchanger
- Helium with an inlet temperature of about 19 K maintains the LD_2 in the moderator by recondensing boiling LD_2.



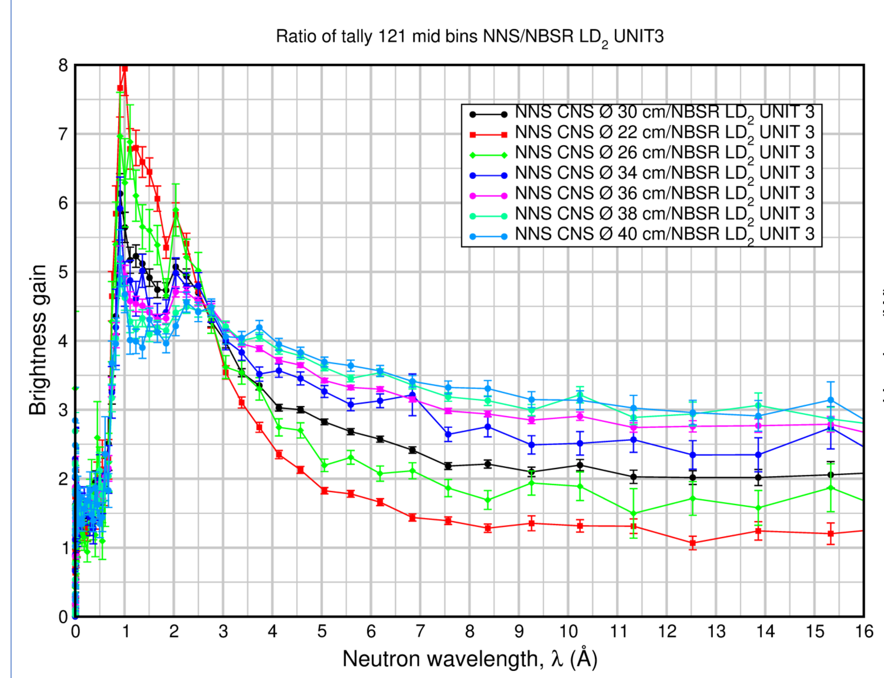
Reactor pool and primary coolant system



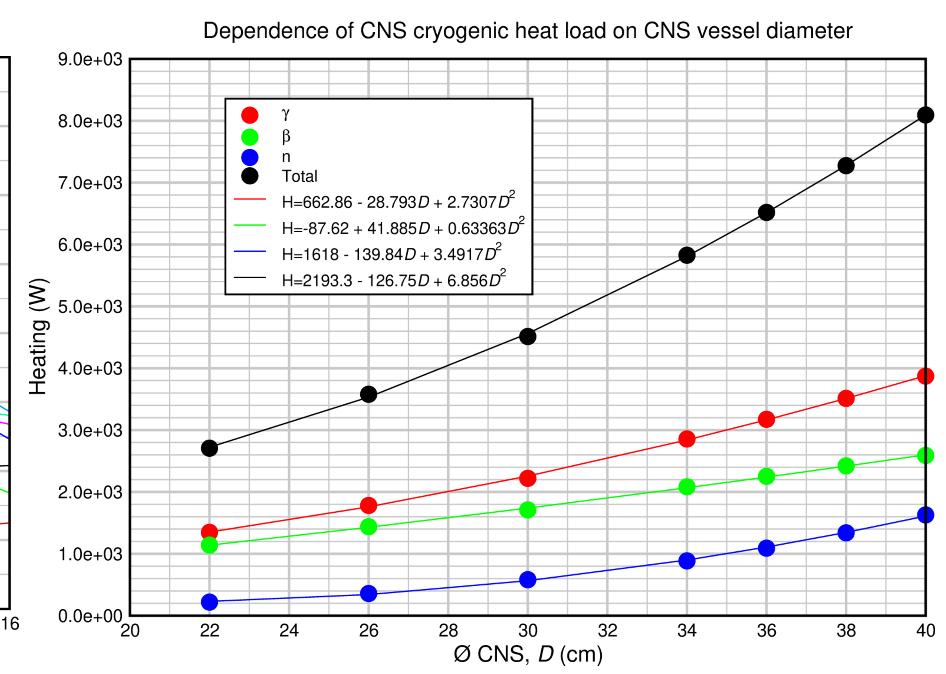
Reflector tank with core, cold sources, and beam tubes

Cold Neutron Source

- Radiation heat load estimated for the CNS is based on a 30 cm diameter LD_2 CNS model. Nuclear heating components include prompt gamma, saturation level ^{28}Al decay β, & neutron heating.
- Dependence of cold source brightness spectrum on the CNS diameter was simulated. Results showed potential for an increase in cold neutron (> 4Å) brightness with moderate increase in vessel diameter.
- Results show how nuclear heat load scales with vessel diameter. *Based on analysis, we consider evaluating the 30-cm and 36-cm moderator cases.*



Simulated cold neutron brightness gains versus CNS vessel diameter



Dependence of the CNS cryogenic system radiation heat load vs. model CNS vessel diameter

CNS System Design

Cold source baseline - two identical LD_2 CNS. NNS initially configured with one cold source, a second cold source added later.

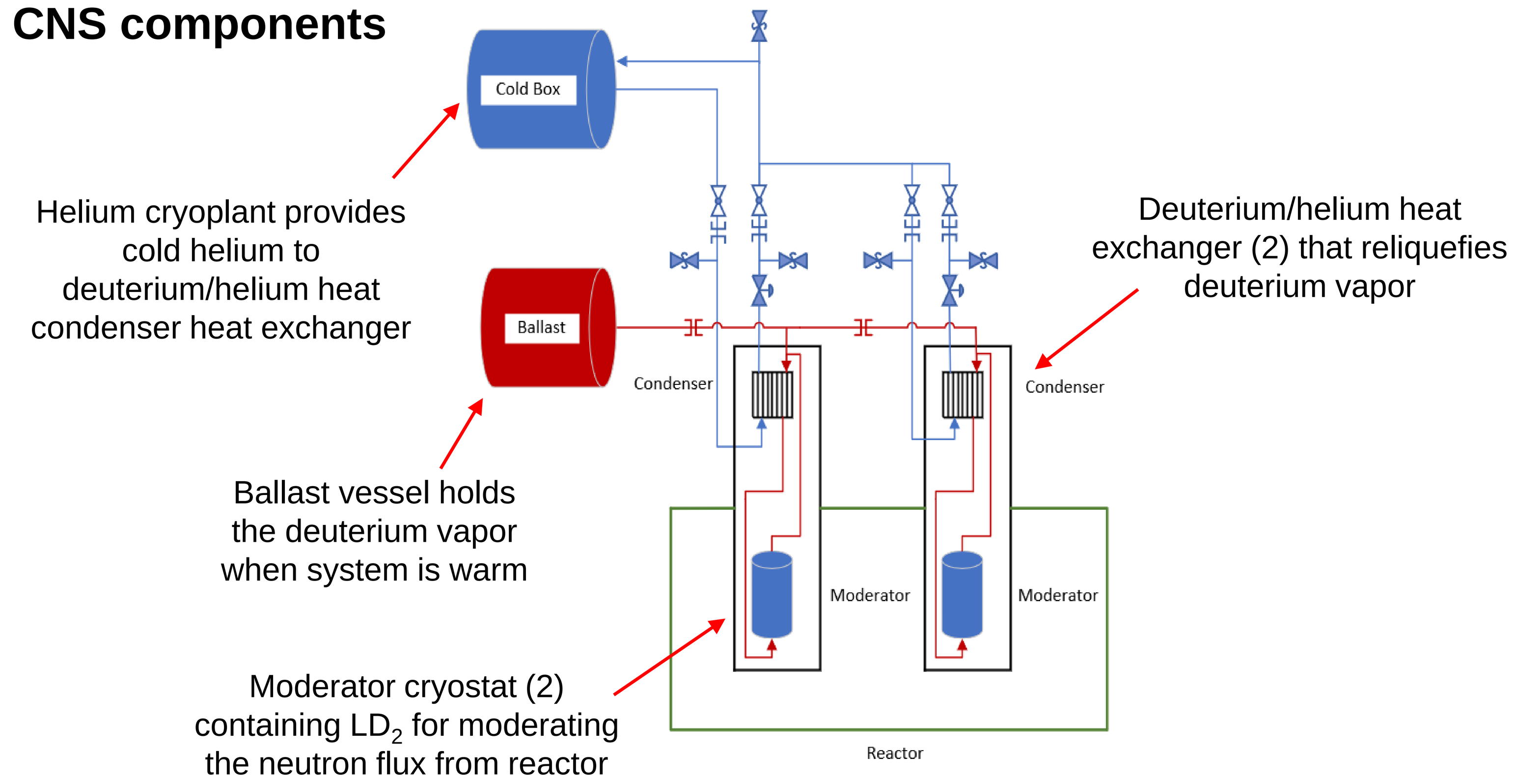
Helium refrigeration configured to support a wide range of CNS heat loads.

The CNS circuit utilizes a thermosiphon design –

- Helium cooled condenser provides LD_2 flow to the moderator
- Heat load to moderator is removed via boiling of liquid and vapor return to the condenser
- Deuterium system has no moving parts
- Entire deuterium inventory is contained in a large volume closed system with no automatic or remotely operated valves or safety relief devices
- During normal operation (LD_2 in the moderator), system pressure is approximately 1 bara
- When system warms up, the system pressure rises to approximately 5 bara

Cold source diameter (cm)	30		36	
Number of cold sources	**1**	**2**	**1**	**2**
Neutronic heat load (W)	4,500	9,000	6,500	13,000
Static heat load $^{(10\%)}$ (W)	450	900	650	1,300
Contingency $^{(15\%)}$ (W)	743	1,485	1,073	2,145
Total heat load (W)	**5,693**	**11,385**	**8,223**	**16,445**

CNS components



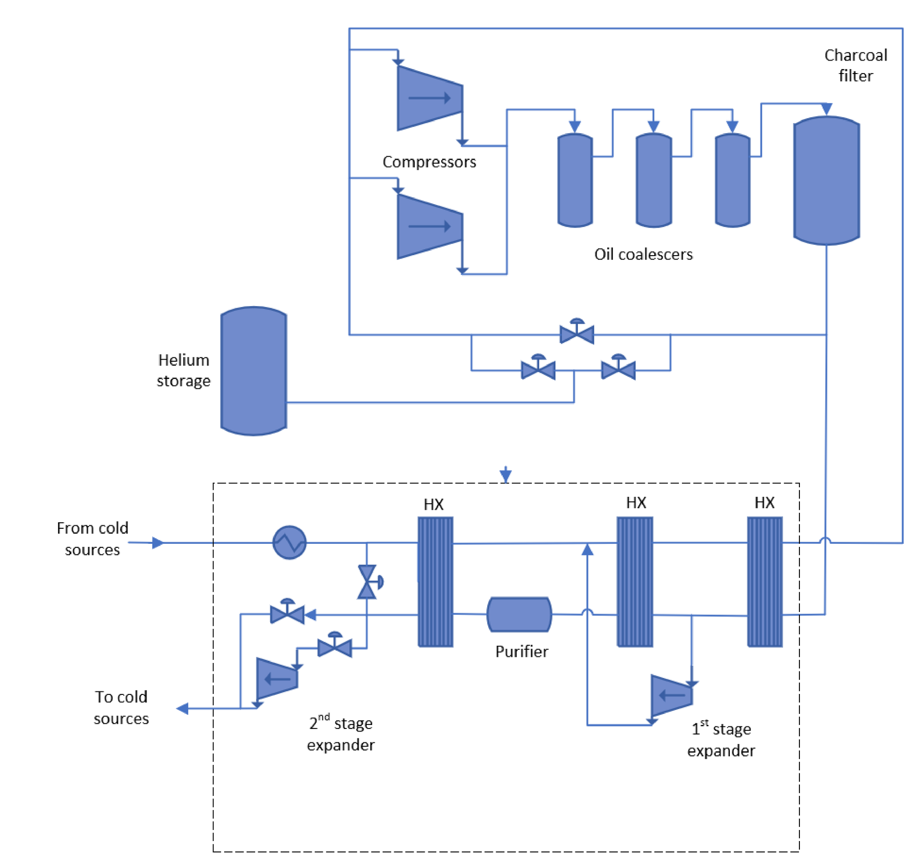
- Helium containment surrounding the entire deuterium system to provide a safety barrier

Helium Refrigeration System

Helium refrigerator features –

- Two warm helium compressor modules (one online, one spare)
- Oil removal skid with coalescing filters and final charcoal oil removal vessel
- Helium gas management controls
- Cold box with expansion turbines, heat exchangers, and He purifier vessel
- Low-pressure helium storage vessel
- Floating pressure / Ganni cycle operation to accommodate varying refrigerator loads

CNS dia. [cm]	Number of CNS	Heat load [W]	HP [bara]	LP [bara]	PR	Flow rate [g/s]
30	2	11,385	15	3	5	790
	1	5,693	7.5	1.5	5	395
36	2	16,445	15	3	5	1,141
	1	8,223	7.5	1.5	5	570



Simplified Process Flow Diagram of helium cryoplant

Summary

- A congressional strategic plan calls for succession planning for the aging NBSR reactor to address the future of neutron science research in the US.
- A replacement reactor will ensure a reliable neutron source in the long term.
- A pre-conceptual design is being developed for a NNS that will satisfy the needs of the neutron science community for the remainder of this century.
- Here we summarize a pre-conceptual CNS and helium refrigerator design that will be integral components of the new NIST Neutron Source.