A Liquid Deuterium Cold Neutron Source for the NIST Research Reactor

Robert Williams, Paul Kopetka and Mike Rowe (retired)
NIST Center for Neutron Research

Outline:

1. Existing LH₂ Cold Source
2. Feasibility of Liquid Deuterium
3. Work Required for Unit 3
The NBSR was designed with a 55-cm diameter cryogenic beam port for a D$_2$O-ice CNS.

1967-1987: No Cold Source

1987-1994: D$_2$O cold source, gain=3

1995-2001: Liquid Hydrogen, gain=6
(Unit 1)
Unit 2: The Advanced LH$_2$ CNS, installed in 2002, nearly doubled the brightness of Unit 1

- 5 liters of LH$_2$ partially surrounded with D$_2$O.
- Heat load is 1150 watts.
- Refrigerator, H$_2$ system and condenser unchanged from Unit 1.
The condenser is located outside the reactor, 2 meters above the source.
The MCNP model of the NBSR was created for CNS development.

The code has generalized geometry and scattering kernels for cold moderators, and **powerful variance reduction techniques** to tally low-probability events ($10^{-6}$).

A surface source was generated from the whole-core criticality calculation for CNS performance calculations.

This source preserves the normalization.

The DXTRAN feature was used to force “pseudo” particles to a current tally plane at the neutron guide entrance.
Can a liquid deuterium source give us another gain over Unit 2?

• There is plenty of room in the CT thimble for a large volume \( \text{LD}_2 \) source.

• Many parameters can be varied to optimize its performance: diameter, length, reentrant hole depth, hydrogen content.

• Varied vessel diameter from 32 to 46 cm; volumes from 20 to 50 liters.

• Goals:
  – Gain factors of 1.5, \( \lambda \geq 4 \) Å, and 2 at 9-10 Å.
  – Heat load small enough for refrigerator.
  – Use thermosiphon and existing condenser piping.
  – Keep it simple and passively safe.
Since the heat load increases linearly with the volume, there is little to gain in performance above 35 liters.

In the 25-30 liter range, a few atom percent of hydrogen enhances the overall brightness, but NOT at the longest $\lambda$.

The best choice appears now to be 38x38 cm, with a 20-cm reentrant hole and 1-2% $H_2$.

Still need more detailed calculations on smaller volumes.
A 38 x 38 cm liquid deuterium source, with a 20-cm reentrant hole, in the CT thimble:

Large volume: 30 liters

7 kg @ 300 kPa will have an expansion volume of nearly 15 m$^3$ (7.5 times our ballast tank)

Calculated heat load of 2200 watts (1.6-mm thick Al wall) will tax our refrigerator.

Boils 6.7 g/s, producing 3.3 liters of D$_2$ vapor per second, close to Unit 2 value.

(It might be possible to cut 400 watts by building a 6-mm Bi shield into the D$_2$O jacket.)
Relative Brightness of a 30-liter LD$_2$ CNS vs. Unit 2, 0 – 20 meV

- Spectrum shifts to lower energies.
- Gain = 1.5 for E < 5 meV.
- Gain > 2 for the longest wavelengths.
- Maxwell-Boltzmann temperature drops from 38 K to 28 K.
- 25% loss at 15 meV (2.5 Angstroms)

(LD$_2$ – solid line)
Gain vs. Wavelength, 2 – 20 Å

Gain: 38-cm LD2, 1% LH2, 20-cm hole

Most work with cold neutrons uses 4 to 10 Å neutrons. There will be a 25 to 100 percent increase over this range.
The LD$_2$ source must also be passively safe, simple and reliable

- A thermosiphon is the simplest way to supply the source with LD$_2$.
  - Cold helium gas cools the condenser below 20 K.
  - Deuterium liquefies and flows by gravity to the moderator chamber.
  - Vapor rises to the condenser and a naturally circulating system is established.
- The system is closed to minimize gas handling (No vents or pressure relief).
- Low pressures: 3 bar warm, 1 bar operating
- All system components are surrounded by He containments.
- Rigorous quality assurance.

(Unit 2 CNS)
Required Work:

- Finalize performance and heat load calculations incorporating “engineering constraints”, such as the minimum wall thickness, and the actual dimensions of the vacuum and He jackets.
- Build and test prototype vessels to check FEA stress analysis.
- Thermal-hydraulic tests of the moisture separator at the top of the moderator chamber.
- Modify the refrigerator for higher temperatures.
- Install a BIG ballast tank (room in C-100?).
- Amend the cold source SAR for a higher inventory.
- Control tritium with hydride storage or recombiner.

Cost: $1 Million  Target Date: 2008-2009
Conclusion

• 2005 marks 20 years since the work began on the D$_2$O cold source.
  – 10$^{th}$ anniversary of the first LH$_2$ source

• Cold source development continues to better serve the neutron scattering community.

• MCNP is a critically important tool in the effort.
Neutron Flux Gains

Gain (compared to no Cold source)

Lamda (A)