The Liquid Deuterium Cold Neutron Source for the NIST Research Reactor

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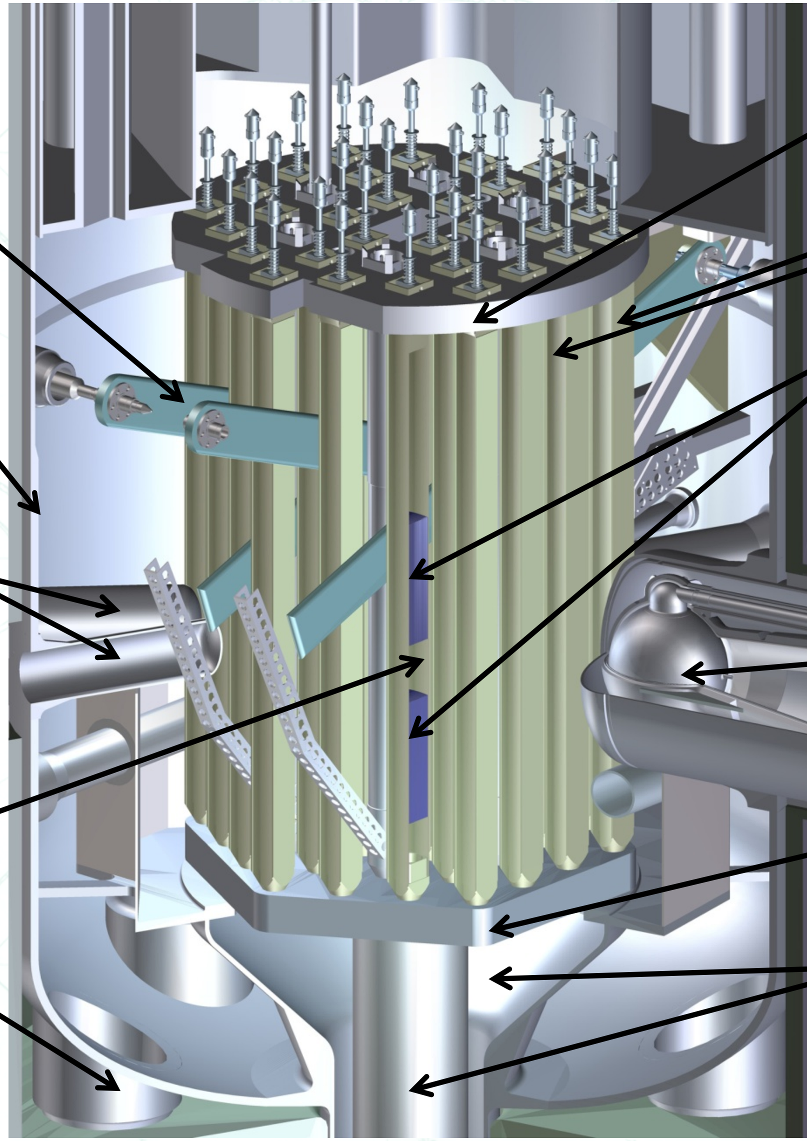
Outline:

- Development of the LH_2 Cold Sources
  - Description
  - Review Process
- The LD_2 Cold Source
  - Overview
  - Status
  - Tritium gas dose conversion factor

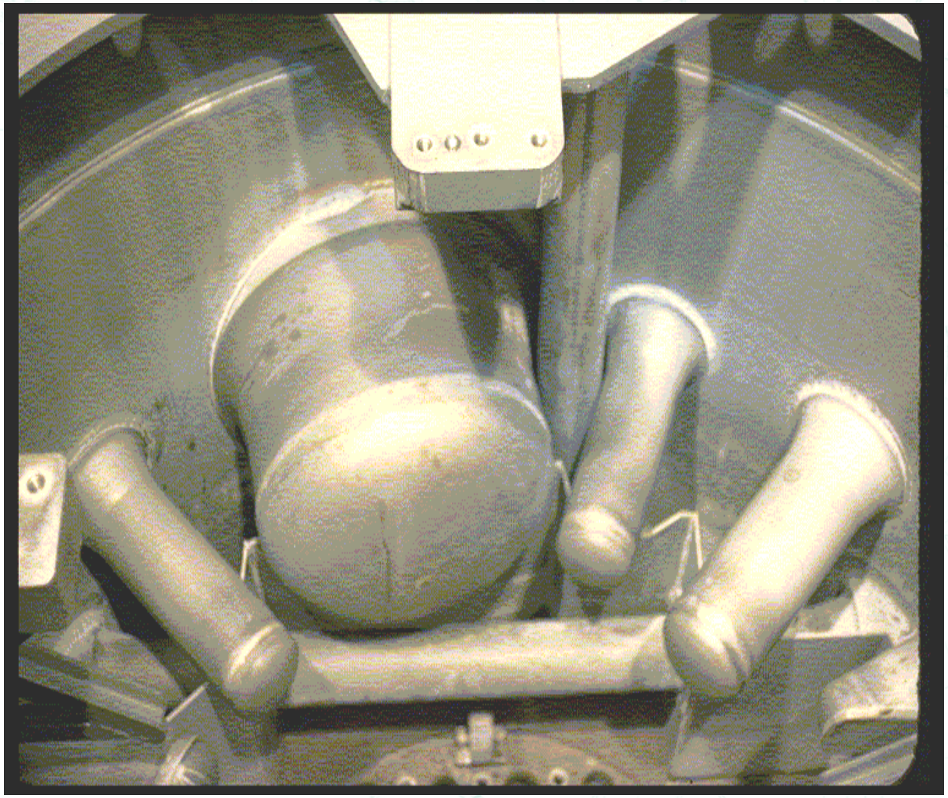
- References:

1. RRFM/IGORR Conference Paper, March 2016, Berlin, Germany.
2. NIST Liquid Hydrogen Cold Source, NISTIR 7352 (2008).
3. ECN 527: Proposal for a Liquid Hydrogen Cold Source in BT-9 (2011).

Cut-away View of the NBSR Core



The NBSR was designed with a 55-cm diameter cryogenic beam port for a D_2O-ice CNS.



History:

1. D_2O Tank (20 years!)
2. D_2O Ice (1987)
3. Unit 1 LH_2 (1995)
4. Unit 2 LH_2 (2002)

Small LH_2 CNS installed in BT-9 (2012).

Review of Hydrogen Source (I)

- **Preliminary Safety Analysis submitted to NRC July 1992**
  - NIST sought opinion as to whether or not a Tech Spec change was needed.
  - NRC had it reviewed by INL team.

- **NRC "We have reviewed…and agree that it does not present an unreviewed safety question." Letter from Theodore S. Michaels, May 17, 1993.**
  - CNS can be installed under 10 CFR 50.59 because it does not increase the likelihood or consequences of accidents previously analyzed, OR present a risk of an unreviewed accident.

Helium containment protects reactor vessel from damage in any credible accident.

Review of Hydrogen Source (II)

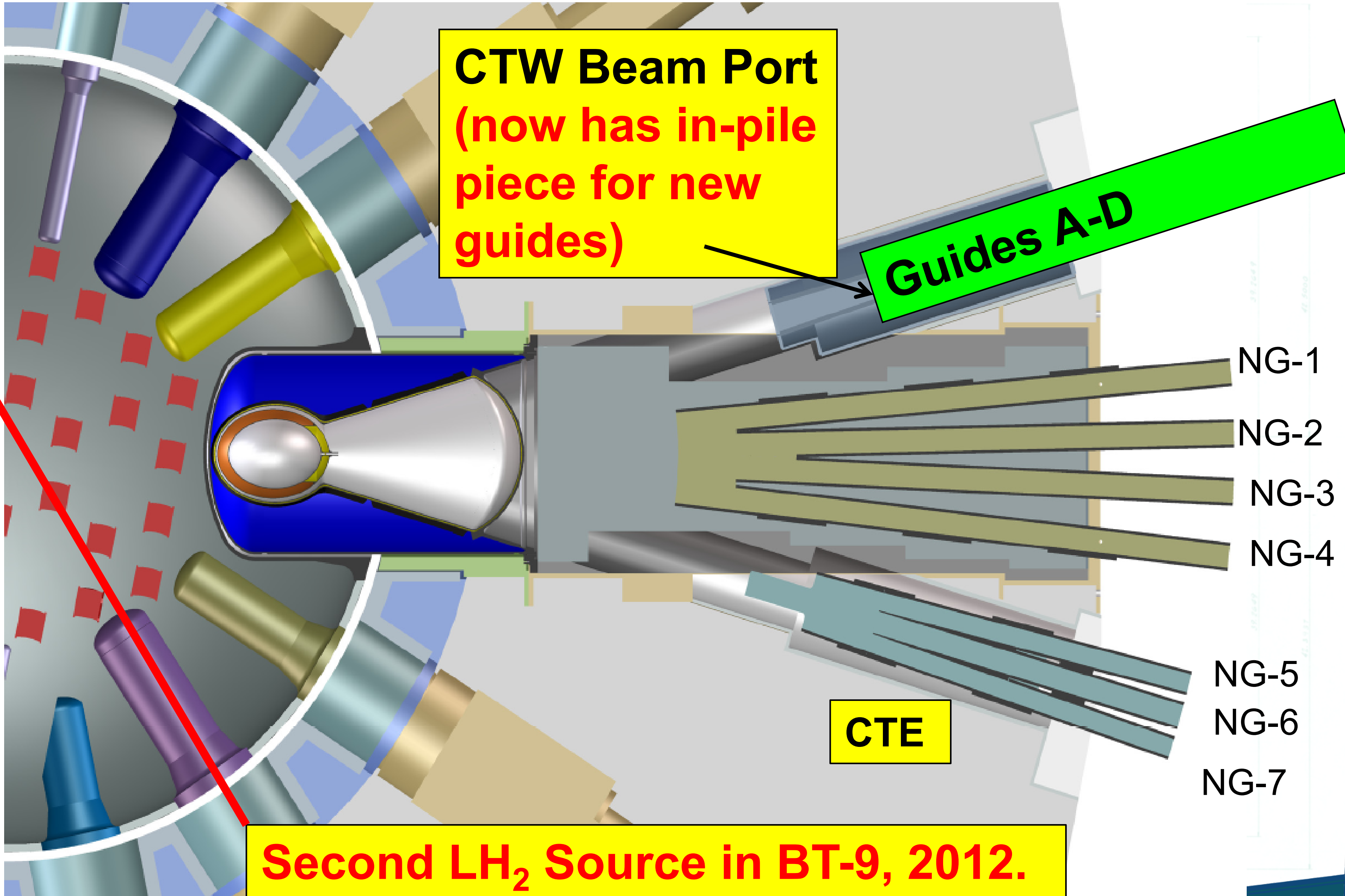
1. External committee of experts (including H_2, CNS)
2. NIST Fire Marshall approved the design and location*.
3. Safety Assessment Committee (Standing External)
4. Safety Evaluation Committee

   Engineering Change Notice (ECN) Process

The LH_2 cold sources have operated safely and reliably over 25 years. We have not lost a gram of hydrogen!

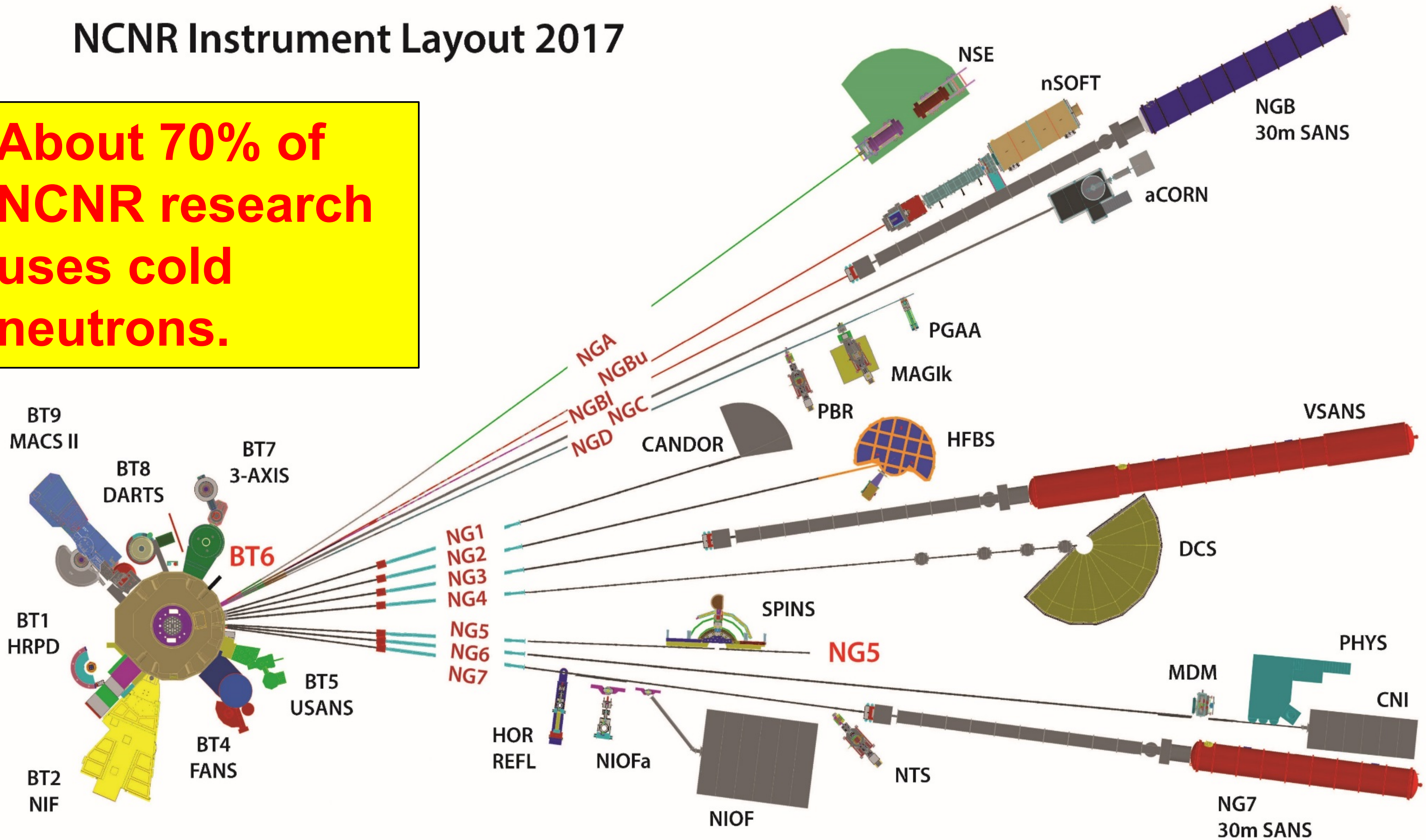
**There was a second review by NIST Fire Marshall in 2012, after the Ballast Tank was moved to D-200.*

Existing LH_2 CNS, Guides



NCNR Instrument Layout 2017

About 70% of NCNR research uses cold neutrons.



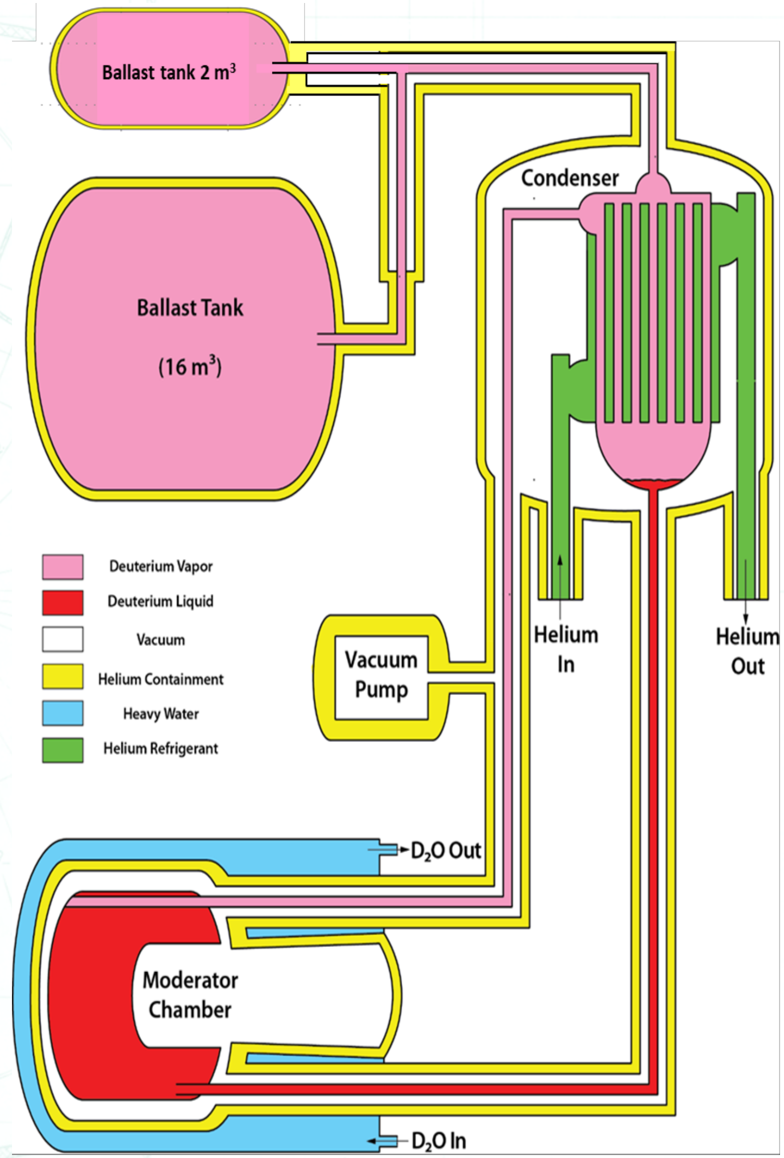
Scientists want more cold neutrons: liquid deuterium cold source.

What's Different about a LD_2 Source?

- A LD_2 source requires a large volume compared to LH_2.
  - Very large LD_2 moderator vessel (35 liters).
  - Maximum D_2 inventory 16 kg (3200 scf)
- Additional Ballast Tank outside the SW corner of the Guide Hall.
- Increased tritium production:
- *About 2.8 kCi at equilibrium (30+ years)*
- The nuclear heat load will be ~4 kW.
  - New 7-kW He refrigerator installed.
  - New and bigger condenser needed.

The LD_2 source must 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 23 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 sealed to minimize gas handling (No vents or pressure relief).
- Low pressures: 4-5 bar warm, 1 bar operating
- All system components are surrounded by He containments.
- Quality Assurance: All welded, He leaks < 10^{-9} cc/s



External Review of Outside Experts May 14-15, 2019

The review committee consisted of the following people:

- *Jamie McAllister, Fire and Facilities Safety, NIST*
- *Bertrand Blau*, Paul Scherrer Institut (PSI), Switzerland*
- *Erik Iverson, Oak Ridge National Laboratory*
- *Weijian Lu*, ANSTO, Australia*

*__Responsible for LD_2 cold sources at their facilities.__

Panel asked to review:

1. **Performance calculations.**
2. **Deuterium safety.**
3. **Operation strategy for two sources, LD_2 and LH_2 at different temperatures/pressures.**
4. **Project status, progress.**
5. **Anything else of concern.**

External Review Panel Findings:

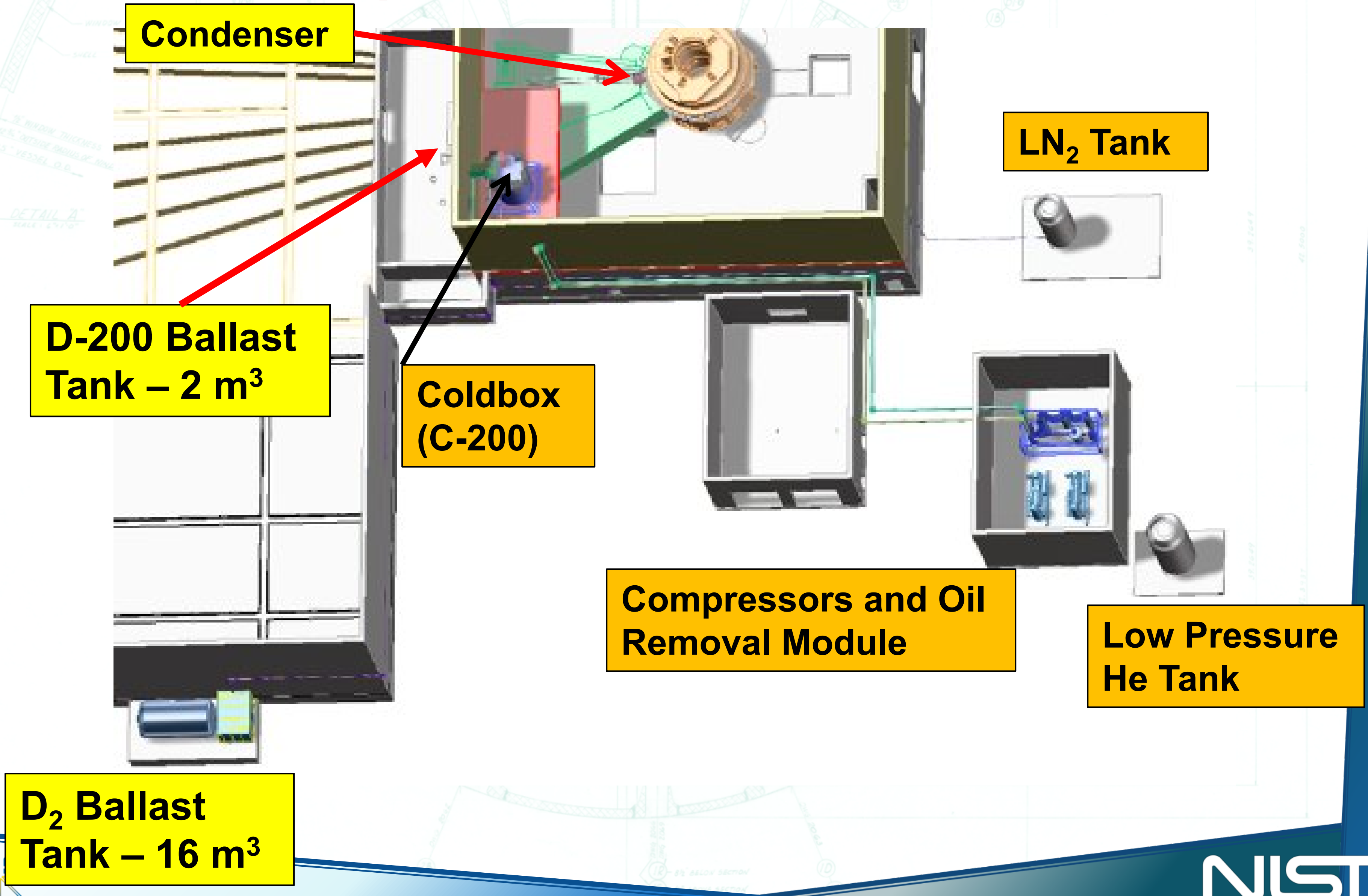
"The project team has already spent considerable effort in ensuring deuterium safety. The committee is confident that this issue is adequately addressed."

"Based on the excellent summary report and comprehensive presentations, the committee believes the project team has the expertise and experience to successfully complete the project and deliver the new LD2 cold source to the neutron user community at NIST."

The panel also made many recommendations:

- NCNR has made much progress in addressing these.
- The new NIST Fire Marshall is currently reviewing the project.
- One open issue is the off-site dose from an uncontrolled release of the deuterium inventory with the expected tritium inventory.

Layout of the 7 kW Refrigerator and LD_2 Cold Source Components



Tritium Gas Dose Conversion Factor

Ballast Tank outdoors, outside confinement building.

- There exists a potential uncontrolled release, however unlikely.
- Physical barriers will be installed to protect the tank and D_2 lines.
- Very expensive: we don't want to lose D_2.
- Danger of fire, explosion a safety concern for NCNR staff.

HotSpot used to estimate off-site (400 m) dose due to tritium release.

- Fire, explosion creates DTO, but effective elevation greatly increased by heat of combustion.
- DT release at ground level causes higher dose at boundary using the conversion factor from 10 CFR 20 (for DTO).
- BUT dose conversion factor for DT is 10,000 times smaller than for DTO (ICRP Publication 30).

More realistic maximum dose calculation for DT is 0.05 mrem.

How do we get there?

Discussion (I)

The LAR is a request for a 20.1302(c) adjustment to the Part 20 App B DAC for DT gas to enable the DOE methodology based on ICRP 66, which amends ICRP 30 to include DT inhalation research by Peterman (1985).

Hotspot is the DOE methodology.

Uses ICRP 30 as amended by ICRP 66 for DT calculations

1. **ICRP 66 references Peterman (1985) to claim that 100% conversion of DT to DTO in the lungs is unrealistic.**
2. **This contradicts Part 20 App B guidance for HT submersion.**

10 CFR 20 enables us to make "adjustments" like this.

1. **The LAR is for NRC approval to adjust Part 20 App B, the inhalation DAC for tritium.**
2. **10 CFR 20.1302(c) states we can ask for this adjustment "to take into account the actual physical and chemical characteristics of the effluents (e.g., aerosol size distribution, solubility, density, radioactive decay equilibrium, chemical form)."**

Discussion (II)

We used Hotspot to look at:

1. a gas release (as DT),
2. a leak w/ standing flame (yielding 100% DTO), and
3. a sudden detonation (yielding 100% DTO)

These are the only credible scenarios because the DT -> DTO reaction is exothermic but slow, and DT is buoyant and highly diffuse in air.

All three cases produce less than the 10 mrem EPA limit at the fence boundary (well bounded by MHA).

Extra Slides

Installation

Removal of Unit 1

Installation of Unit 2

Status Update

- Major components received, tested:
  - *LD_2 condenser assemblies, ballast tank, refrigerator.*
- Refrigerator installed and in service:
  - *Vendor default left much work for NCNR, contractors.*
  - *Cooling capacity > 7 kW @ 18 K.*
  - *Placed in service in January 2018.*
- Procurement of cryostat assembly
  - *Activity suspended in 2013, resumed 2015.*
  - *Contract for engineering analysis, prototypes nearly complete.*
  - *Started final fabrication phase – 2 years.*
- **Installation target: *2023!***

Reactor Safety

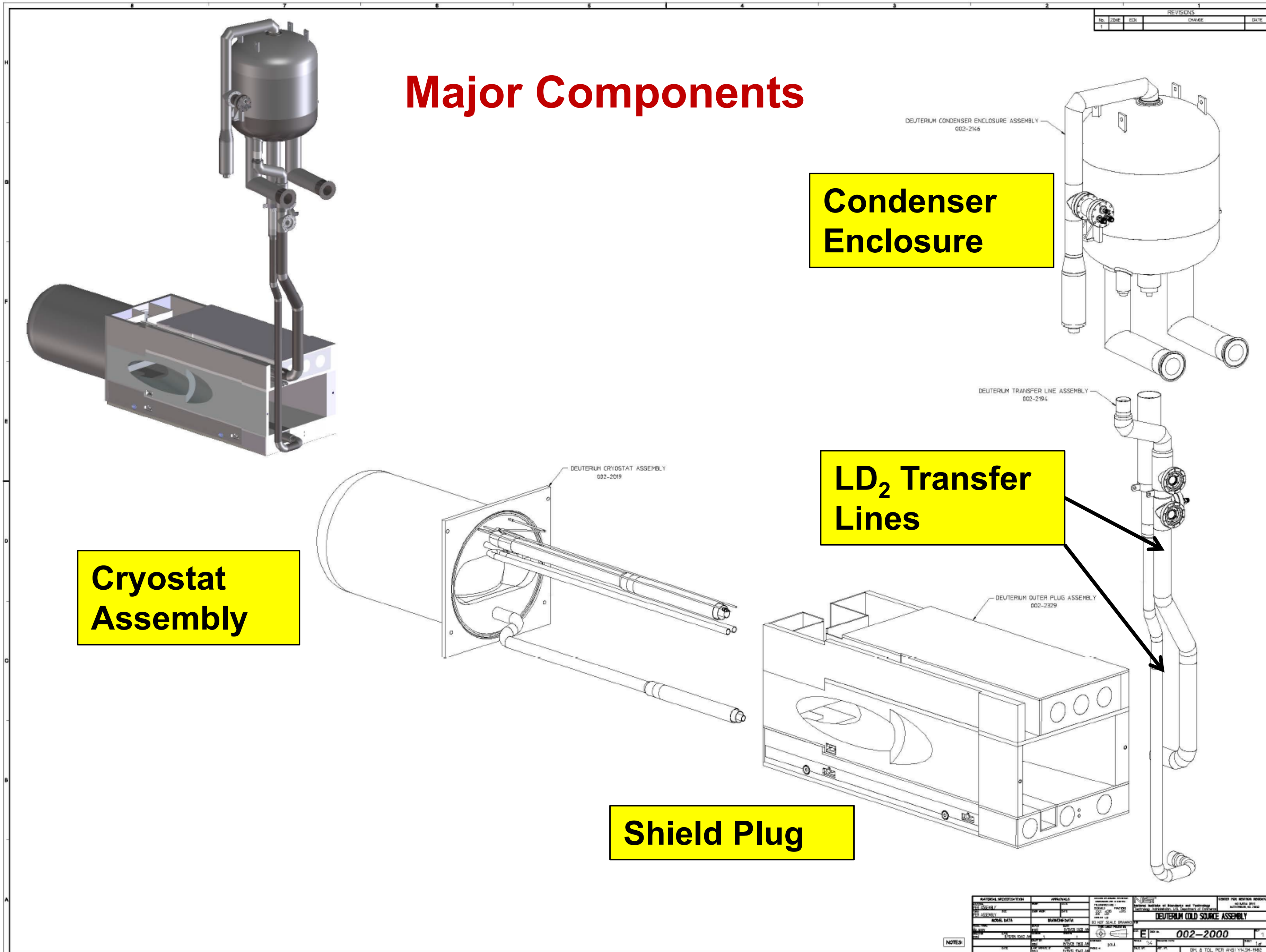
- System is welded throughout, with no connection flanges.
- **Quality Assurance:**
  - All welds within biological shield are X-rayed and helium leak tested, leak $< 10^{-9}$ STP cc/sec
  - All components outside biological shield are also leak tested and protected from damage by shielding or mechanical structures
  - Final pressure tests as per ASME code
- All components that are ***or could be*** filled with H_2 are surrounded by monitored He or N_2 containment vessels.

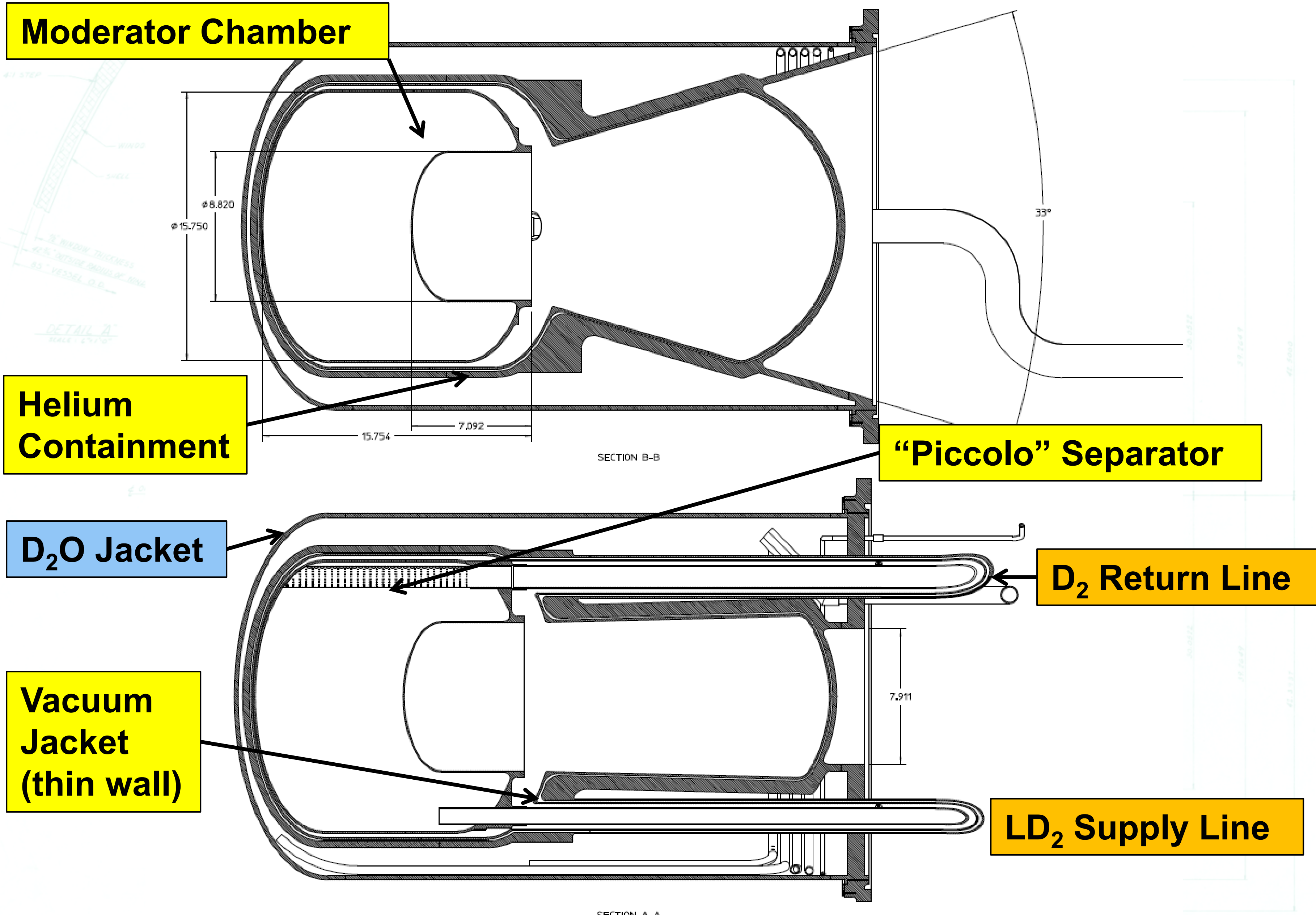
A massive leak of hydrogen in C-100 while the system is operating is not a credible accident.

Personnel Safety

- The greatest danger of a H_2 release is when protective shields are removed or H_2 is being added or removed.
- H_2 is removed from the source and condenser if they are exposed for maintenance activity (*needed only seven times since 1995*).
- H_2 monitors exist to warn personnel in these instances (alarm at 10% LFL).
- H_2 handled only by trained personnel according to long-established procedures.

Major Components





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Future Cold Source Layout