A Liquid Deuterium Cold Neutron Source for the NIST Research Reactor – Conceptual Design

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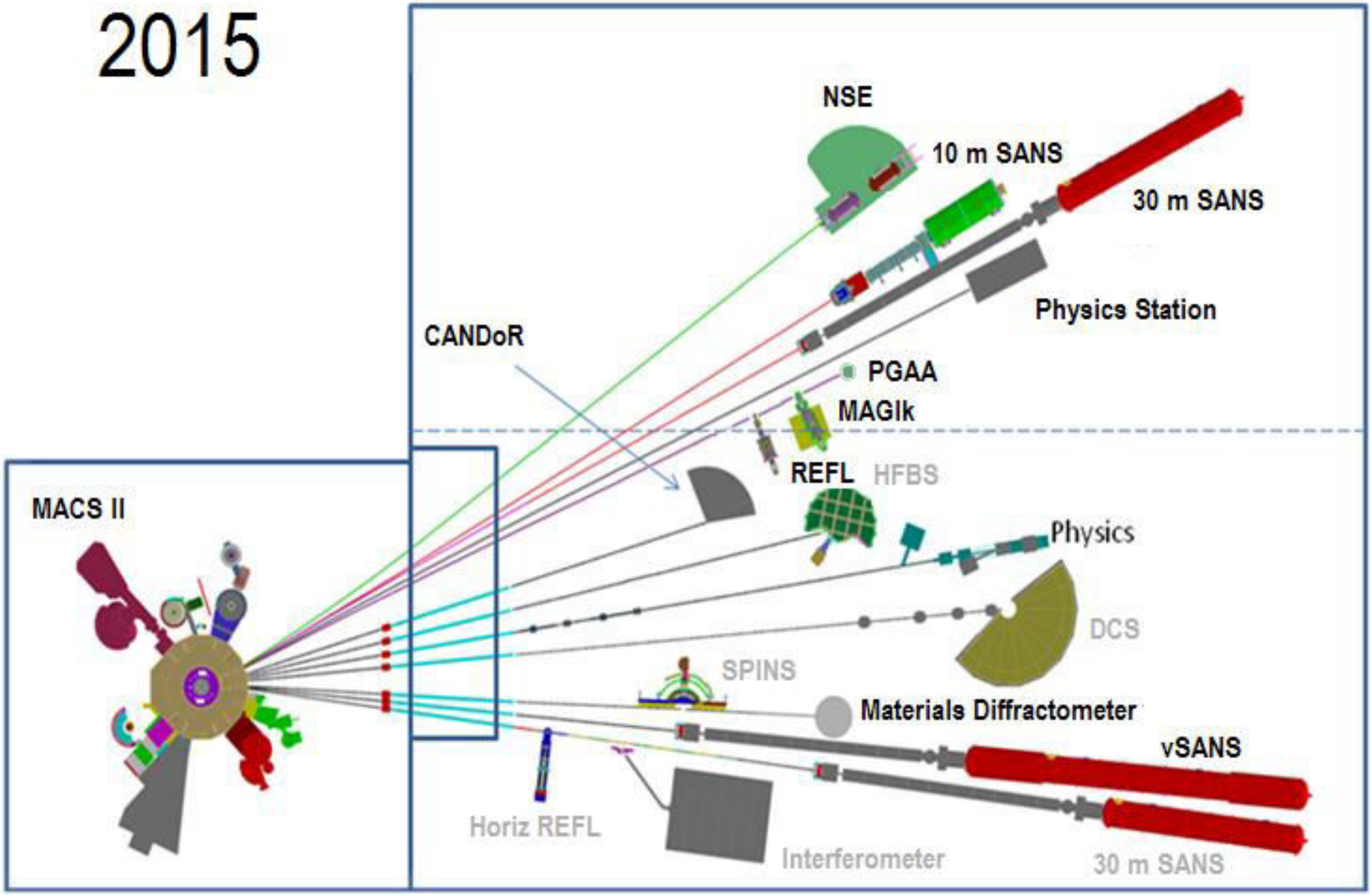
Outline:

- What's new at NIST?
- Existing Liquid Hydrogen Cold Source
- Performance and Heat Load Calculations for the planned LD_2 Source
- Design Overview, Status
- Conclusion

Major Expansion of Cold Neutron Facilities

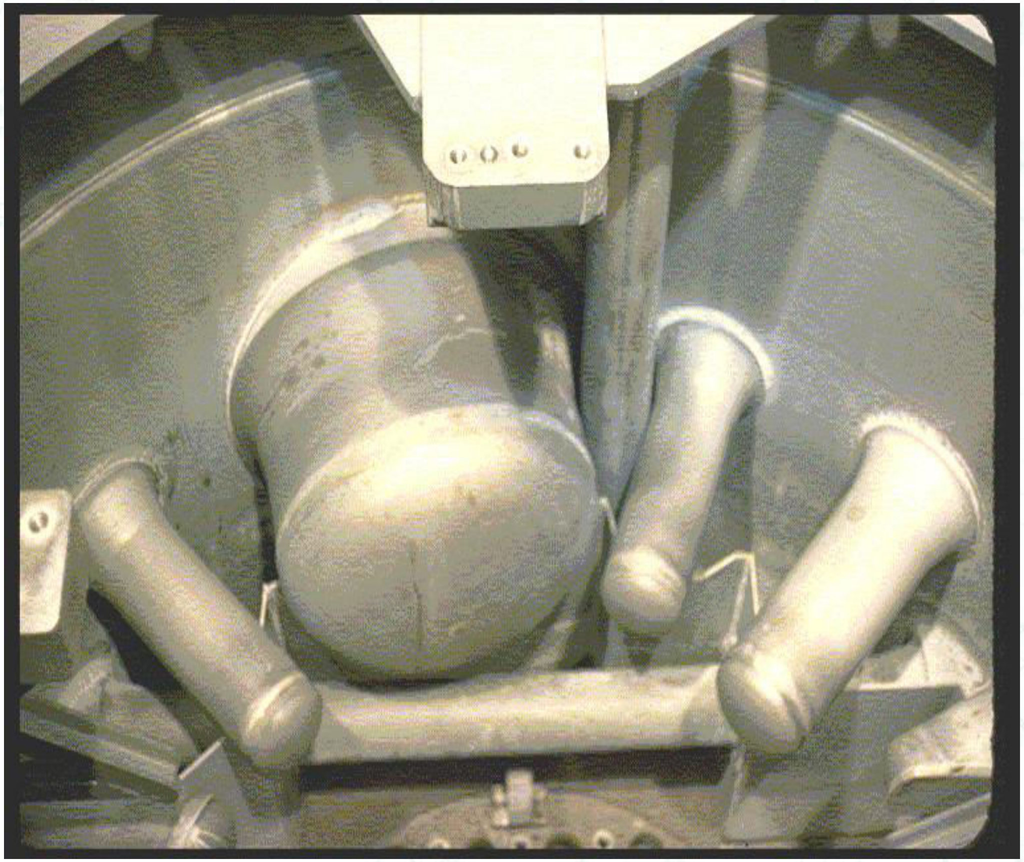
- New Guide Hall and Support Building – 2011
  - Nearly doubled the size of the Guide Hall
  - Five additional guides installed, now 12 guides
  - Several new instruments available to users
- Second LH_2 Cold Source installed in BT-9
  - Operational since April 2012
  - More intense source for MACS-II
  - Cooled by existing refrigerator
- Additional Facility Upgrades:
  - Cold Neutron PLC Upgrade
  - Thermal Shield Cooling System
  - Secondary Cooling Pump Building
  - Fuel Storage Pool Liner

2015



Bold indicates new or re-located, upgraded instruments.

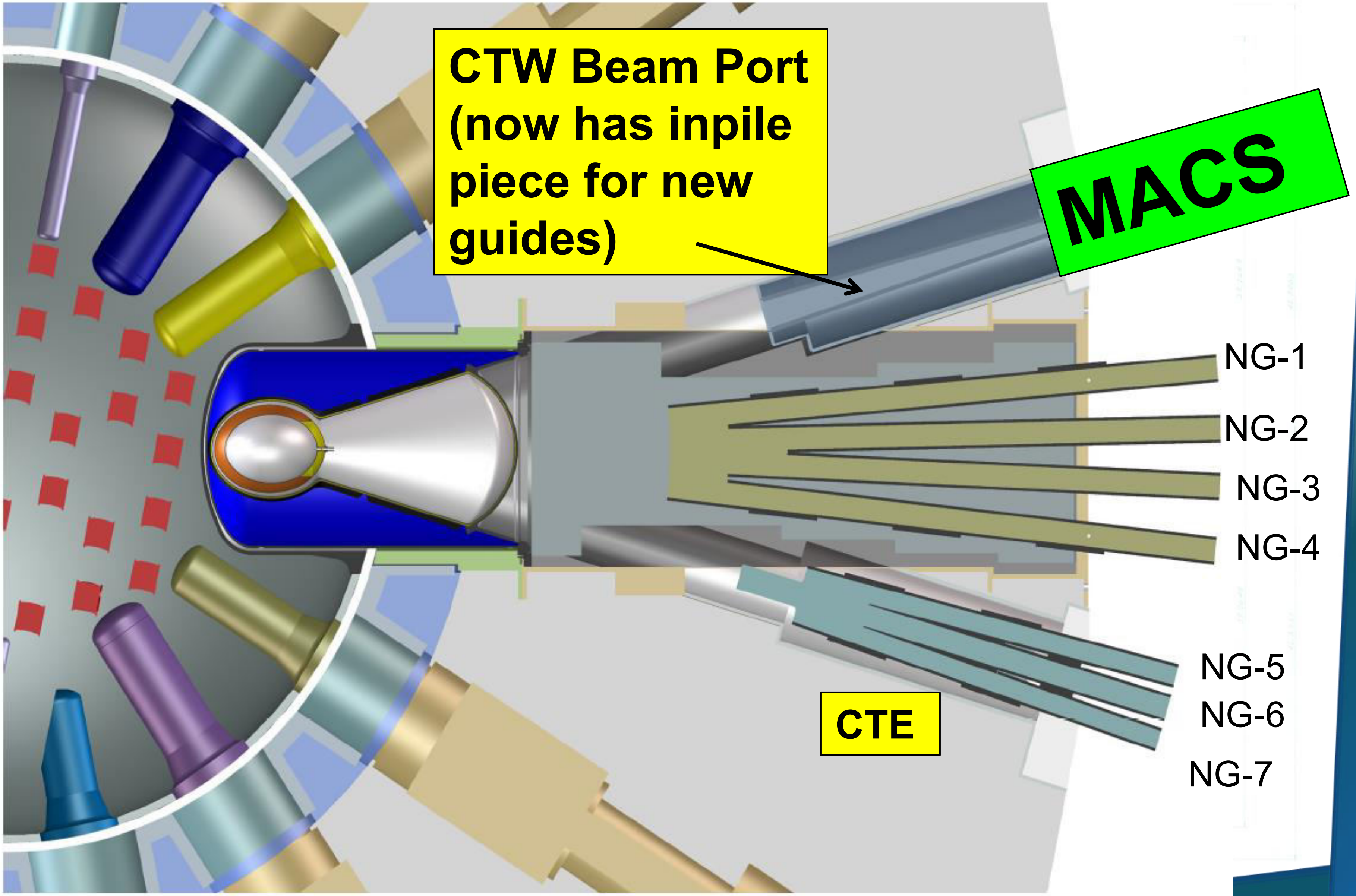
The NBSR was designed with a 55-cm diameter cryogenic beam port for a D_2O-ice CNS.



History:

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

Existing LH_2 CNS, In-pile Guides as of April 2011



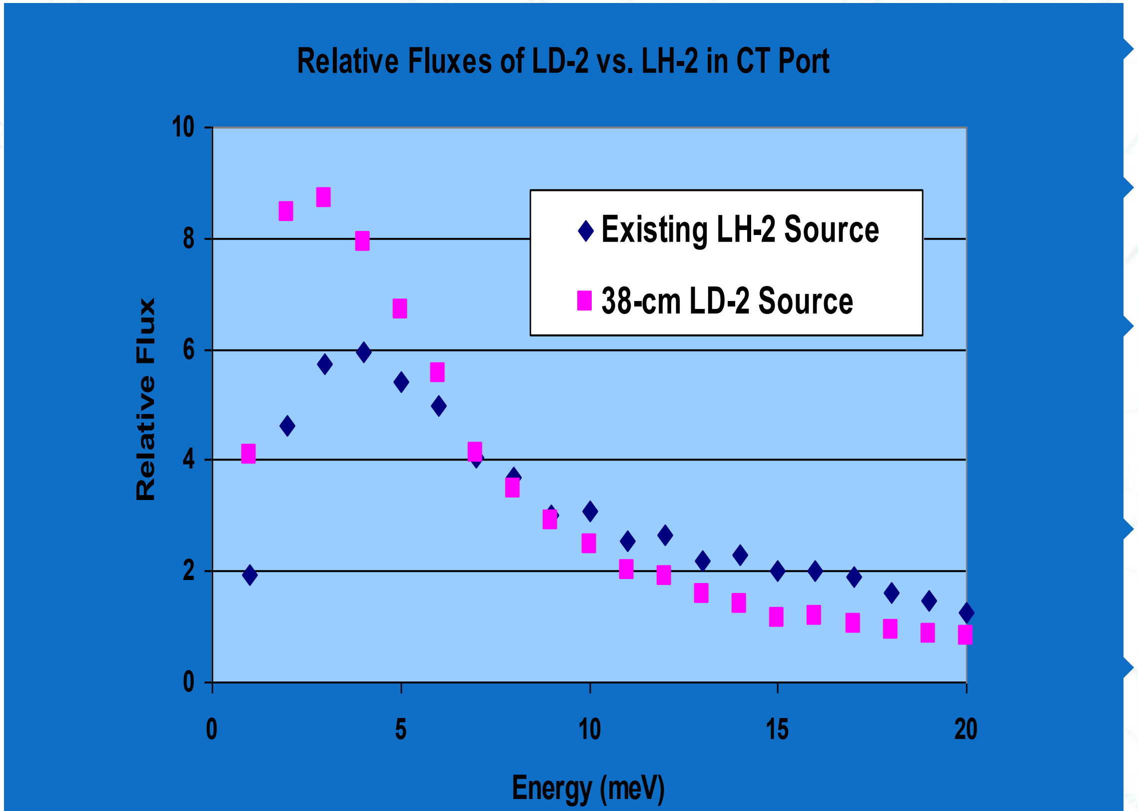
Why Upgrade To Deuterium Cold Source

Deuterium absorption cross section is 500 times less, but
deuterium scattering cross section is 10 times less,
therefore,
higher intensity cold neutron beam.

Affect Of Deuterium On System Design

Volume of liquid deuterium in cryostat is 7 times
greater,
therefore, larger ballast tank, greater heat load and,
larger refrigerator capacity required.

What is to be gained with deuterium?



Φ(E) vs. E, 0 – 20 meV

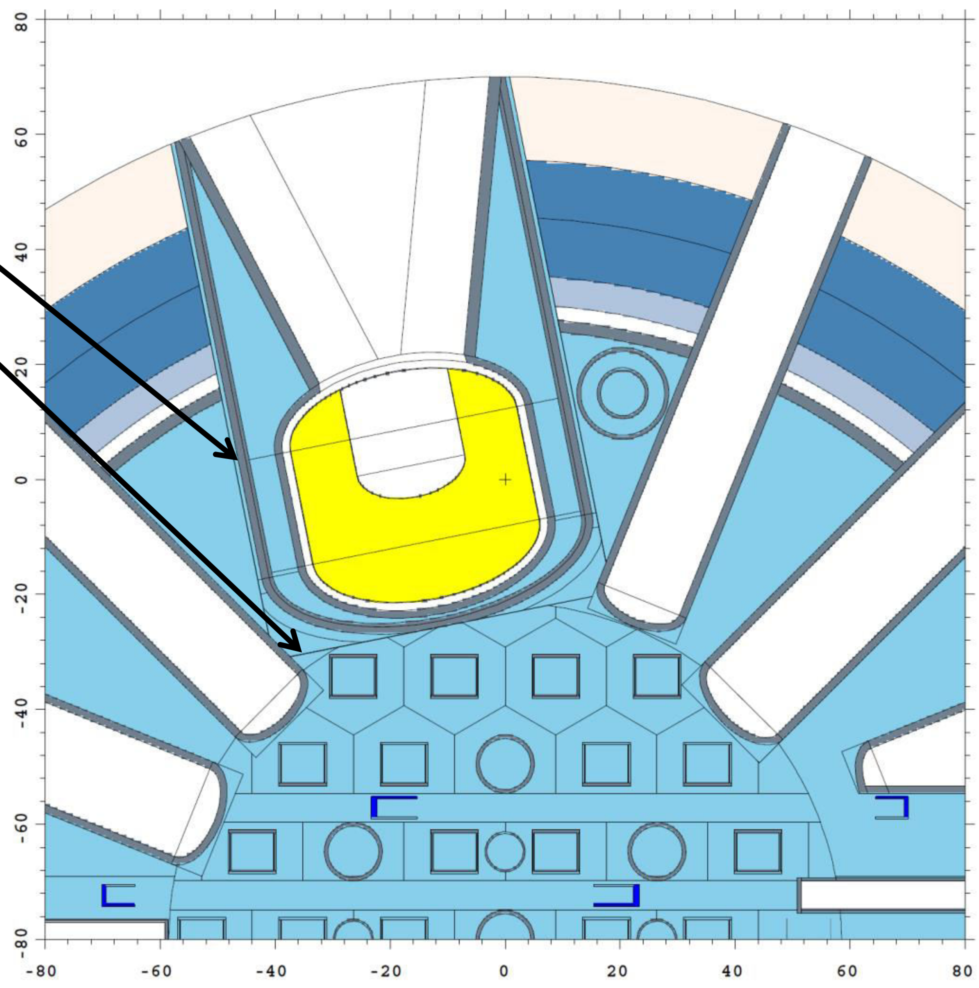
- Spectrum shifts to lower energies.
- Gain of 2 for the longest wavelengths.
- Maxwell–Boltzmann temperature drops from 40 K to 30 K
- Large volume, low absorption.
- Up to 50% loss at 15 meV (2.5 Angstroms).

Feasibility of a LD_2 Source

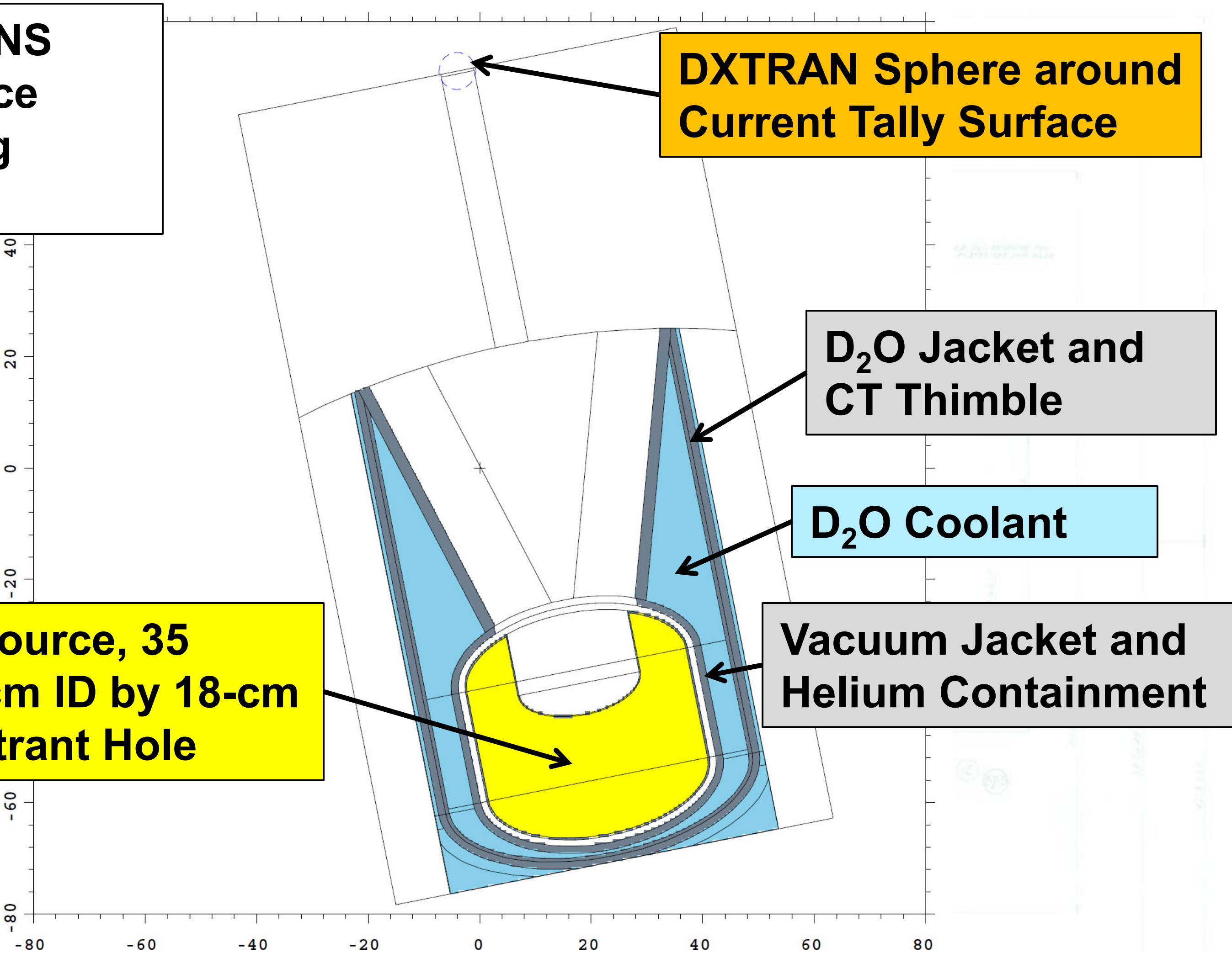
- A LD_2 source requires a large volume compared to LH_2.
- The CT thimble in the NBSR has ample room for a very large LD_2 moderator vessel (30–50 liters).
- The nuclear heat load will be ~4 kW.
- New 7-kW He refrigerator being installed
- Support from DOE National Nuclear Security Administration:
  - Conversion of NBSR to LEU will result in 10% reduction in thermal and cold neutron beams.
  - CNS, new guides is mitigation strategy.

Gain Calculations: MCNP Model of the 40x40 cm LD_2 Source in the NBSR CT Port

Surface Source generated on cylinder surfaces



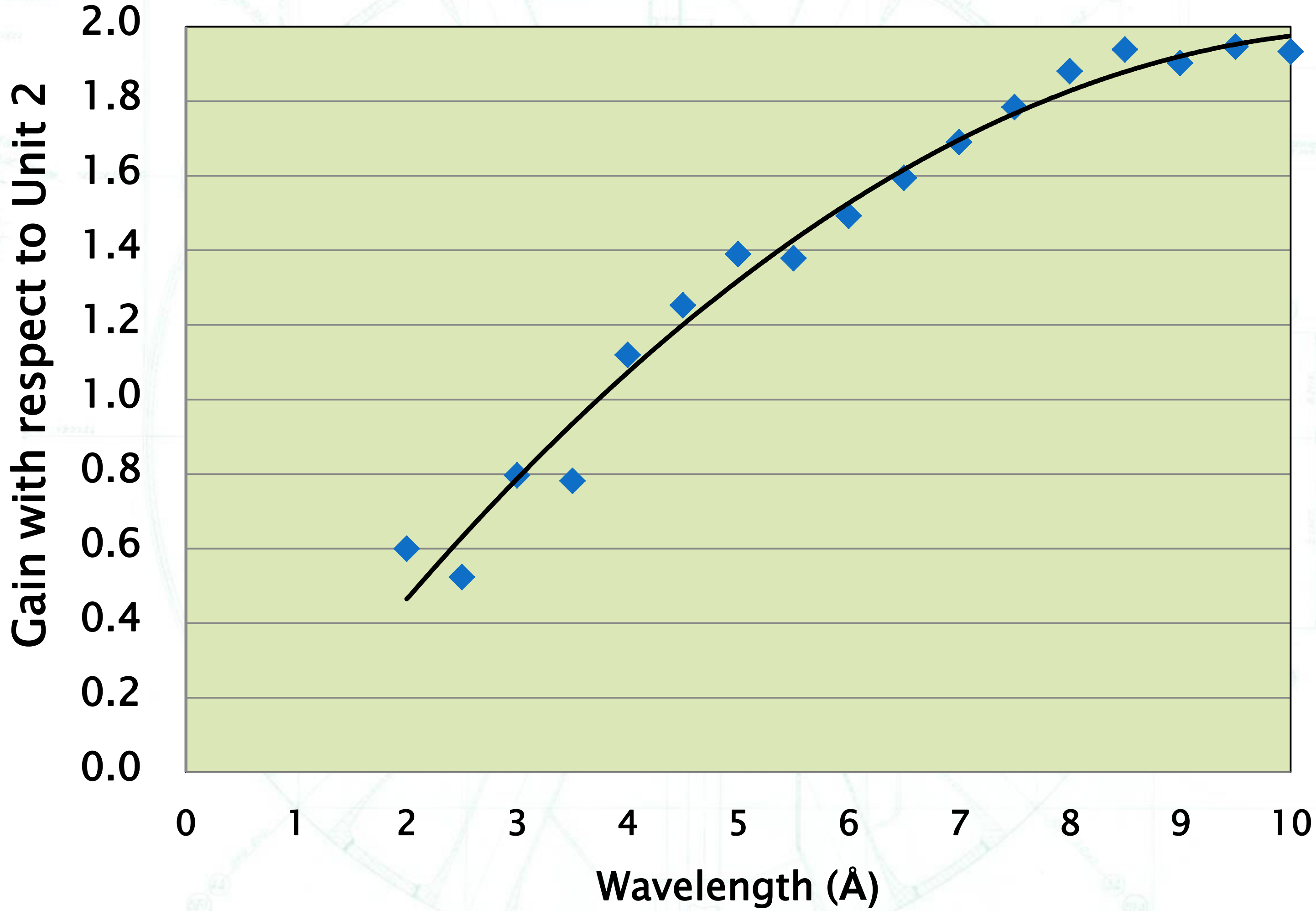
MCNP model of CNS region uses surface source for starting neutrons



Parameters Affecting Performance:

1. **Volume:** 400 mm x 400 mm, 35 liters LD_2
2. **Reentrant Hole Depth:** 180 mm
3. **Reentrant Hole Diameter:** 220 mm
4. **Void Fraction (depends on heat load):** Assume a void fraction of 13% (about half of Kazimi Correlation for pool boiling) based on mockup measurements, *including ILL horizontal source*.
5. **Ortho/Para Content:** 76% ortho-LD_2 based on measurements at PSI.
6. **S(α,β) Scattering Kernels:** The newly released MCNP6.1 includes "continuous" energy/angle thermal neutron scattering cross section data.

Expected Gains with Respect to Existing LH_2 Source



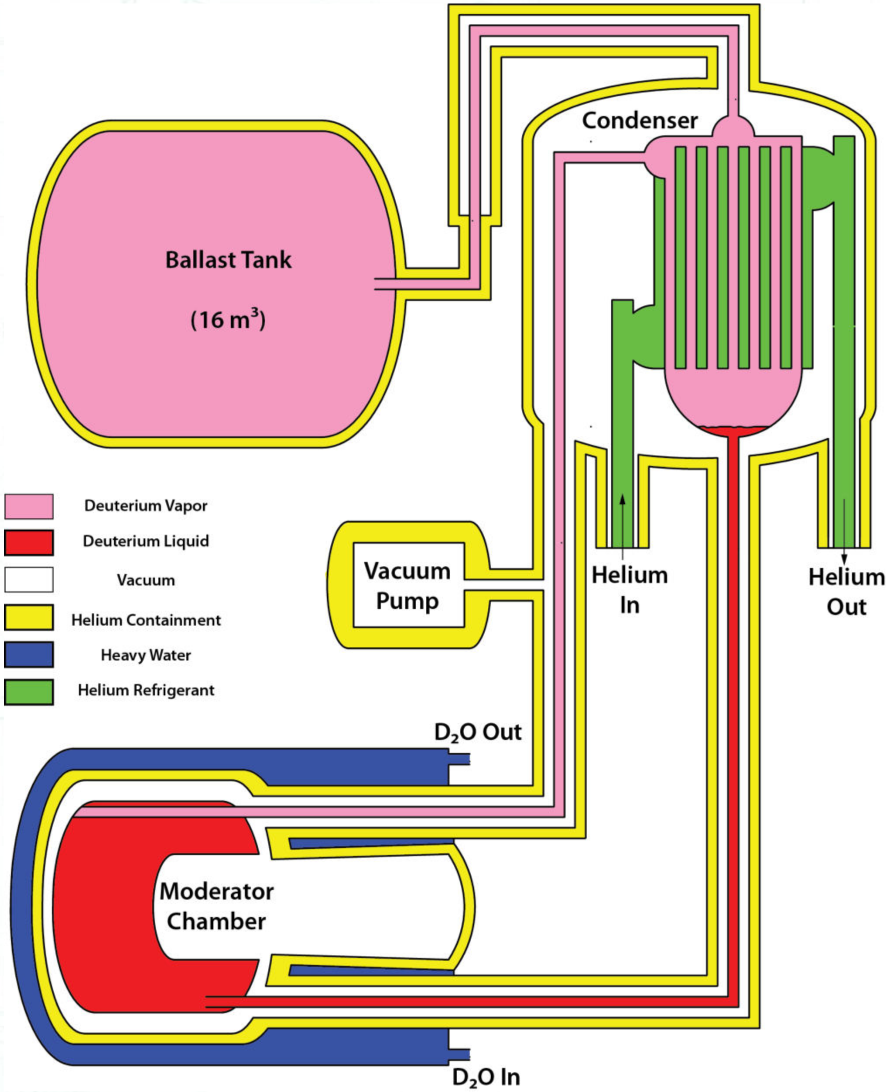
Nuclear Heat Load Calculation:

	Deuterium 5160 g		Aluminum 7155 g	
Radiation Source	Rate (W/g)	Heat (W)	Rate (W/g)	Heat (W)
Neutrons	0.0851	440	0.0008	6
Beta Particles	–	–	0.0793	567
Gamma Rays	0.204	1053	0.215	1538
Subtotal		1493		2111
Total Cryogenic Heat Load = 3604 W				

Note that LD_2 boils at 23 K at 100 kPa, 25 K at 150 kPa.

The LD_2 source must also be passively safe, simple and reliable

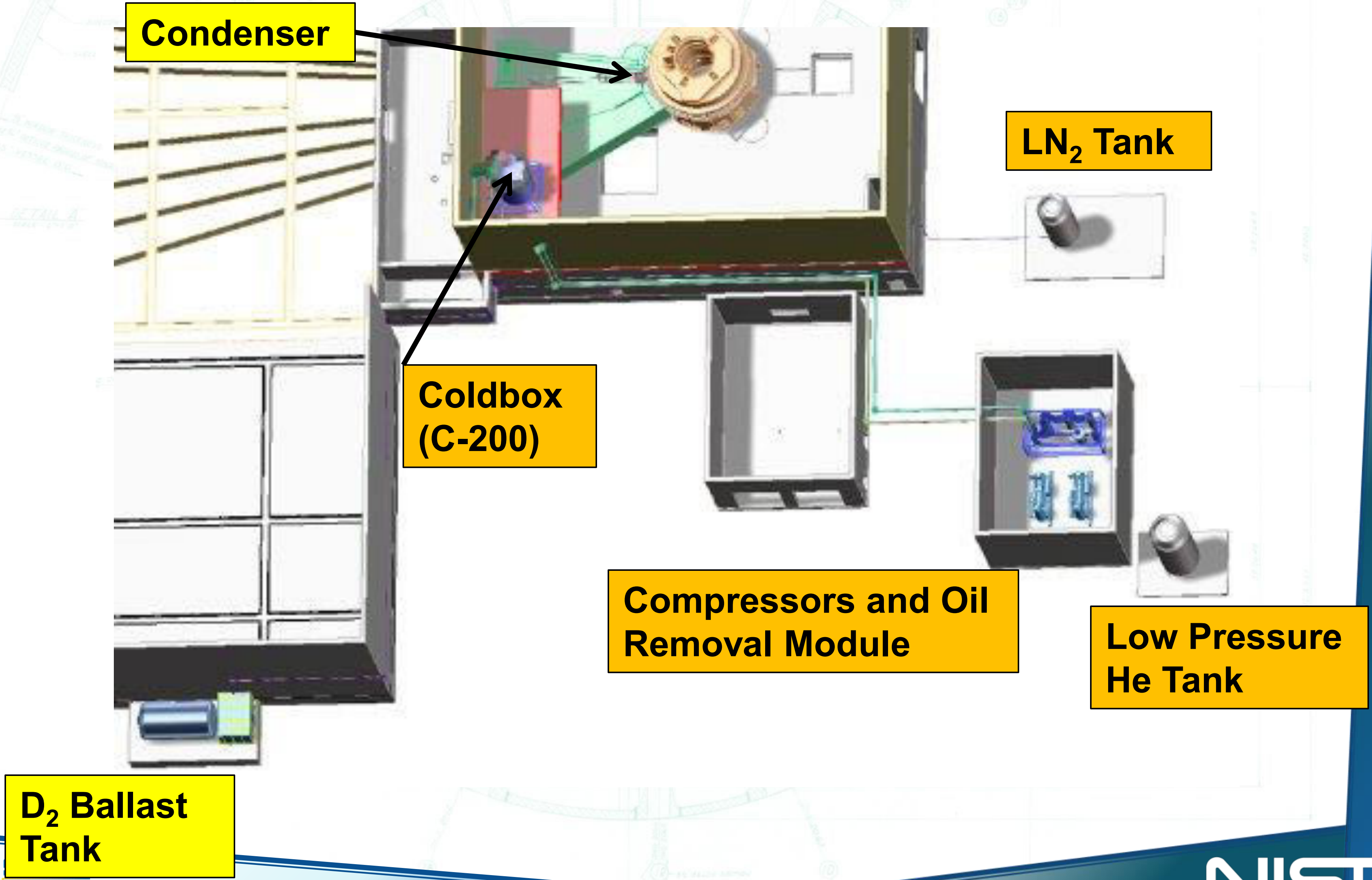
- A thermosiphon is the simplest way to supply the source with LD_2.
  - Cold helium gas cools the condenser below 23 K.
  - Deuterium liquefies and flows by gravity to the moderator chamber.
  - Vapor rises to the condenser and a naturally circulating system is established.
- The system is closed to 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.



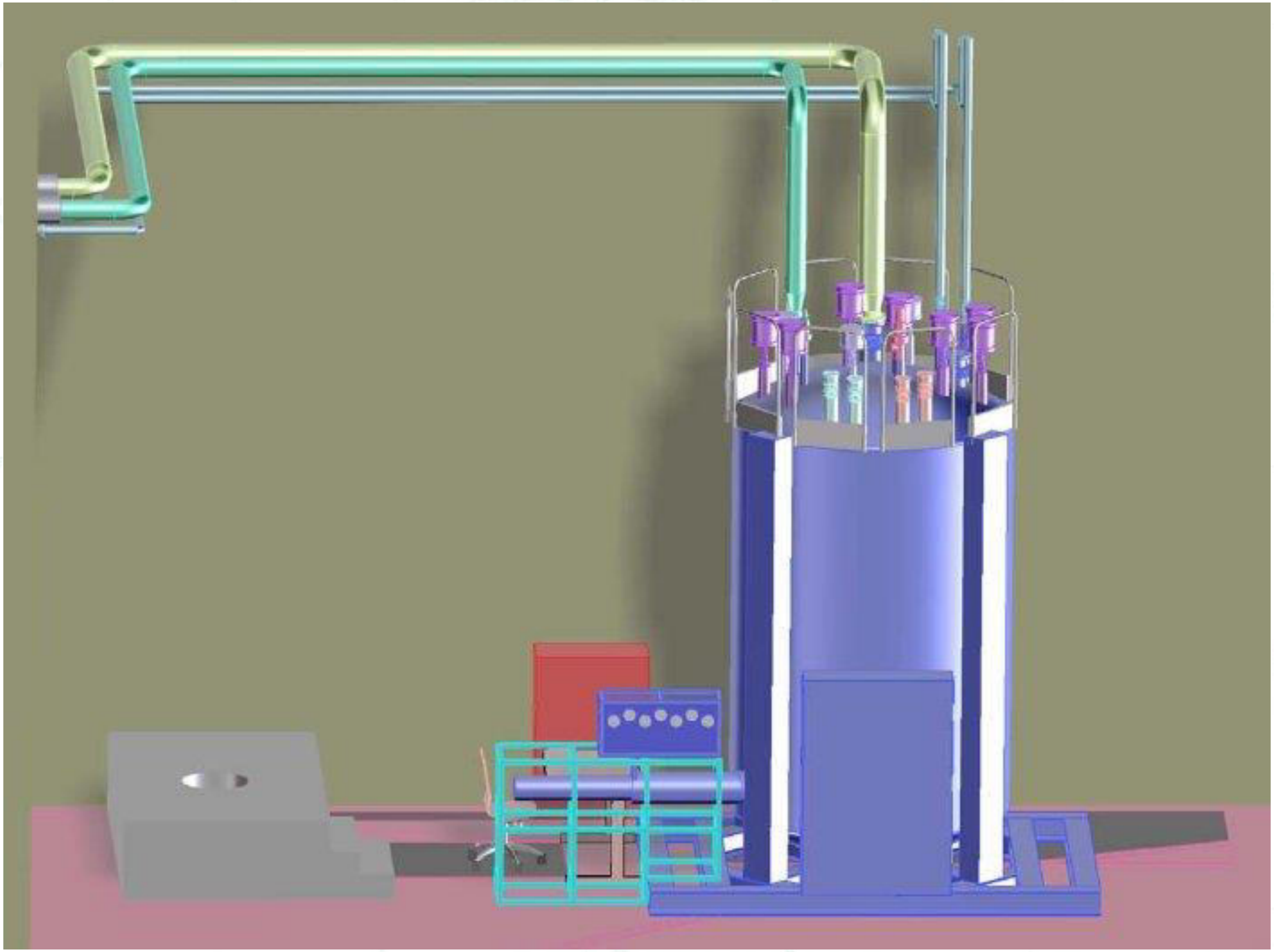
System Components, Status:

- Horizontal LD_2 source is similar to one at ILL, just larger. Thermal hydraulics modeled using data from the mockup of the ILL source. *(complete)*
- 6000 W LD_2 condenser mounted on the reactor face, ~ 2 m above the cryogenic beam port. *(received)*
- 16 m^3 ballast tank for operation at 100 – 150 kPa, 400 – 500 kPa warm. *(expected this fall)*
- Refrigerator installation in progress. *(completion expected April 2014)*
- Procurement of the cryostat assembly and condenser containments in progress. *(~ 2 years)*
- **Installation target: 2016!**

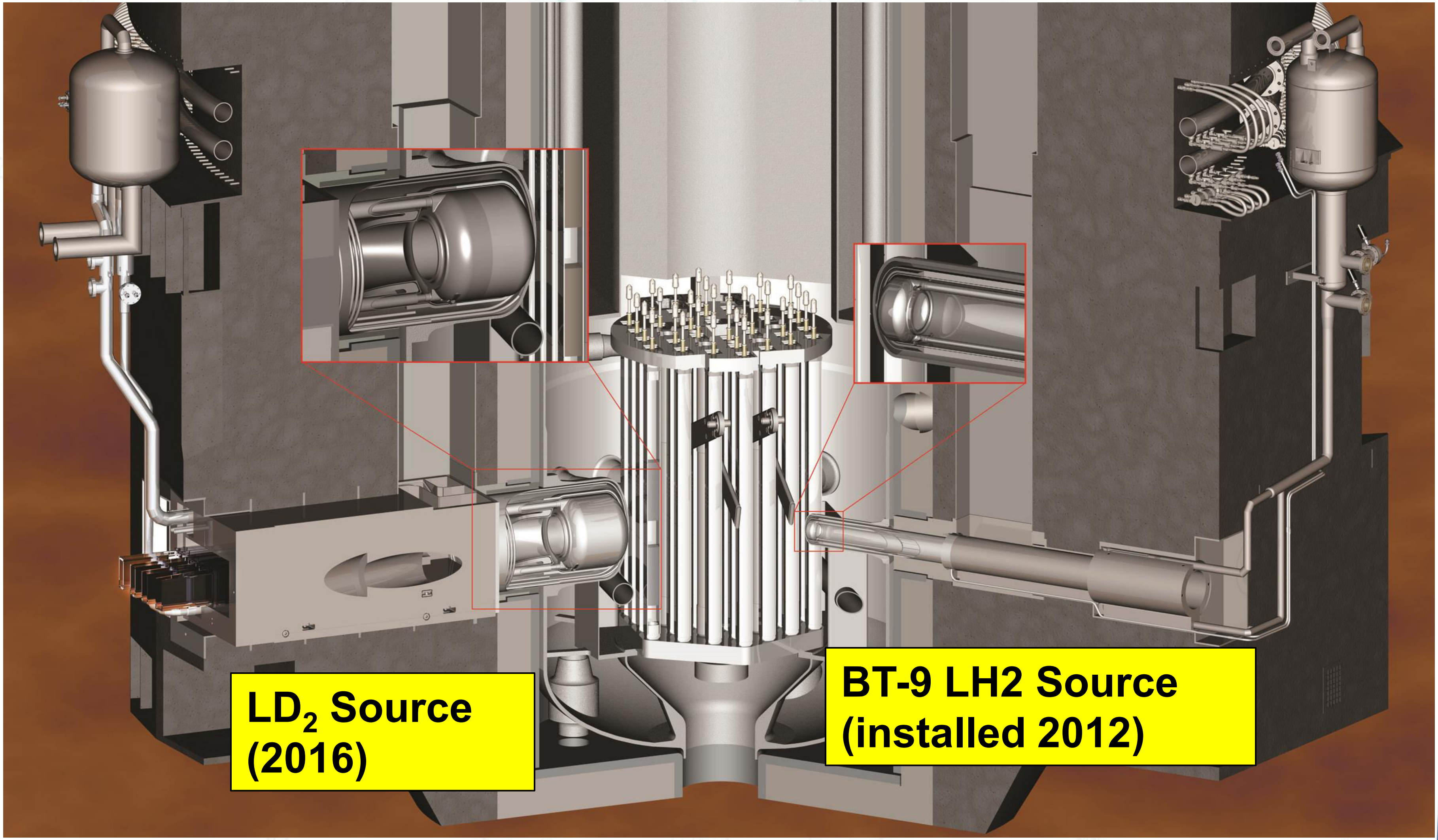
Layout of the 7 kW Refrigerator and LD_2 Cold Source Components



New Refrigerator Model



Future Cold Source Layout



Maximum Hypothetical Accident for Liquid Hydrogen Cold Source

- The Initiating Event is a guillotine break of the vacuum lines allowing air to rush in and freeze on the LH_2 vessel.
- The LH_2 vessel ruptures and there is a detonation when the worst combination of oxygen and hydrogen is present.
- Rupture and Ignition are assumed with no reasonable, credible scenario.

- The overly conservative MHA ‘Unnecessarily Limits the Design’ of the Liquid Deuterium Cold Source.

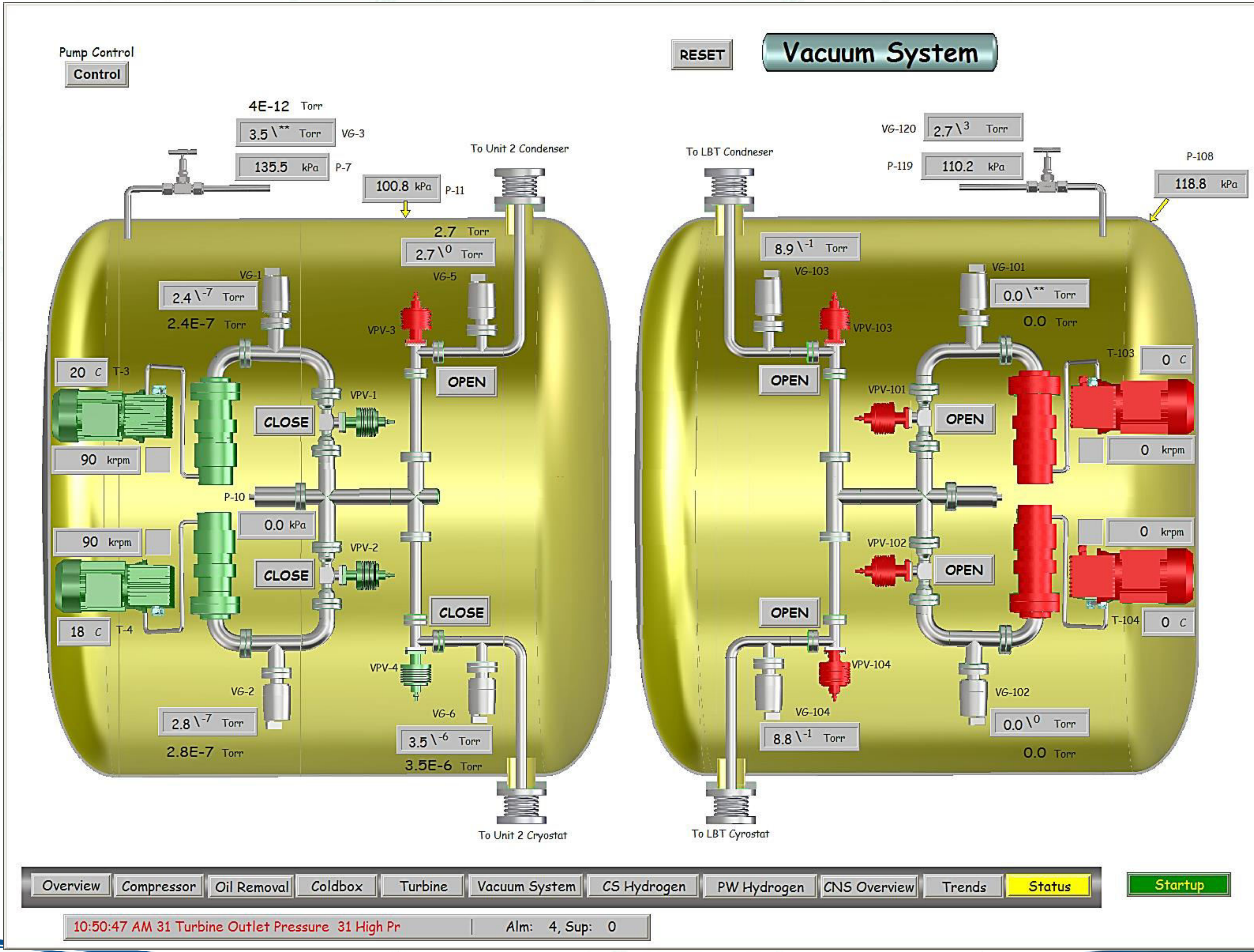
Maximum Hypothetical Accident for Liquid Deuterium Cold Source

- The Initiating Event is a failure of a vacuum pump which allows all the air inside the vacuum enclosure to rush in and freeze on the LD_2 vessel.
- The LD_2 vessel ruptures and there is a detonation when the worst combination of oxygen and deuterium is present.
- Rupture and Ignition are assumed with no reasonable, credible scenario.

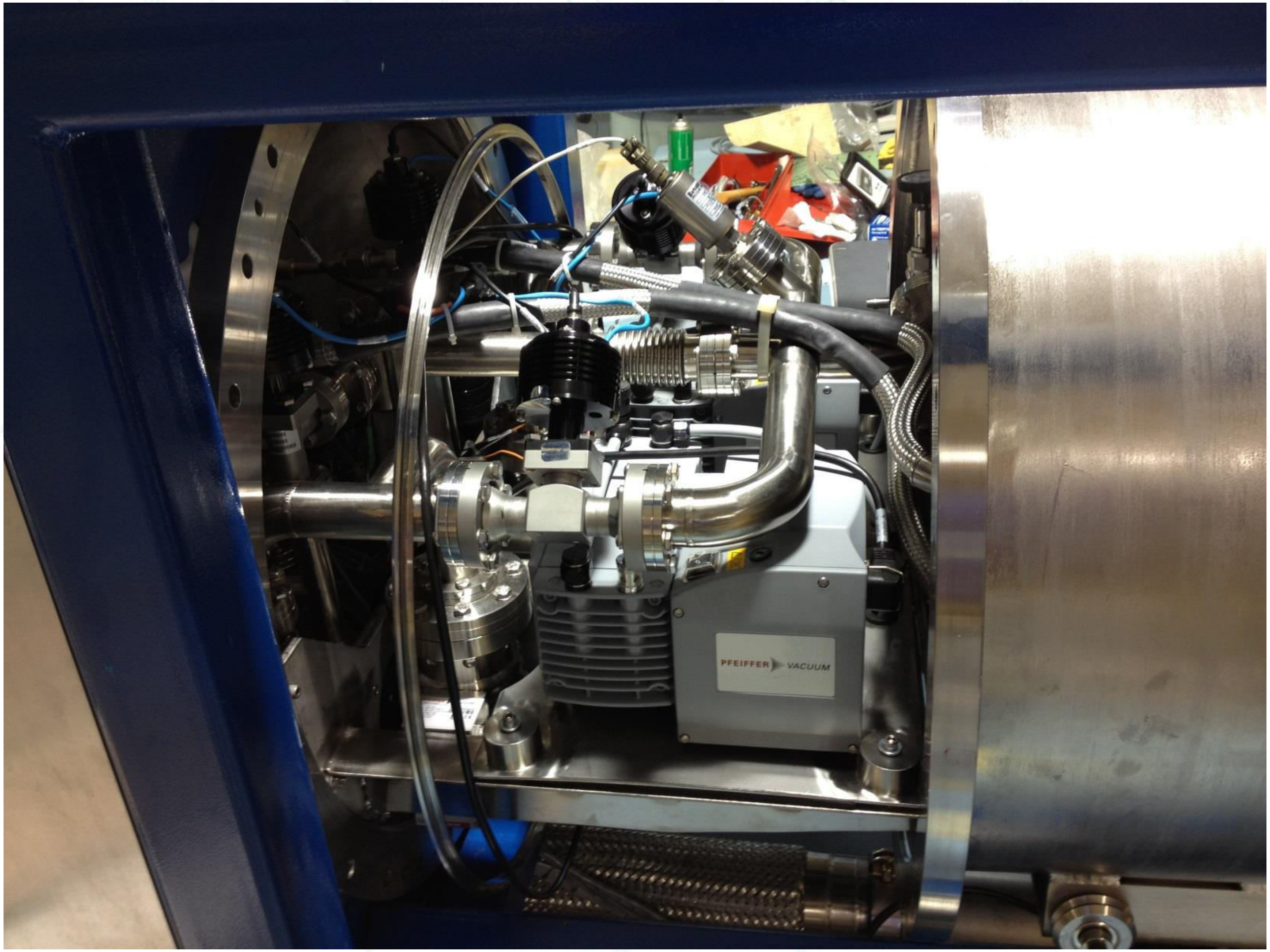
- The overly conservative MHA 'Unnecessarily Limits the Design' of the Liquid Deuterium Cold Source.

Implementation of New Maximum Hypothetical Accident

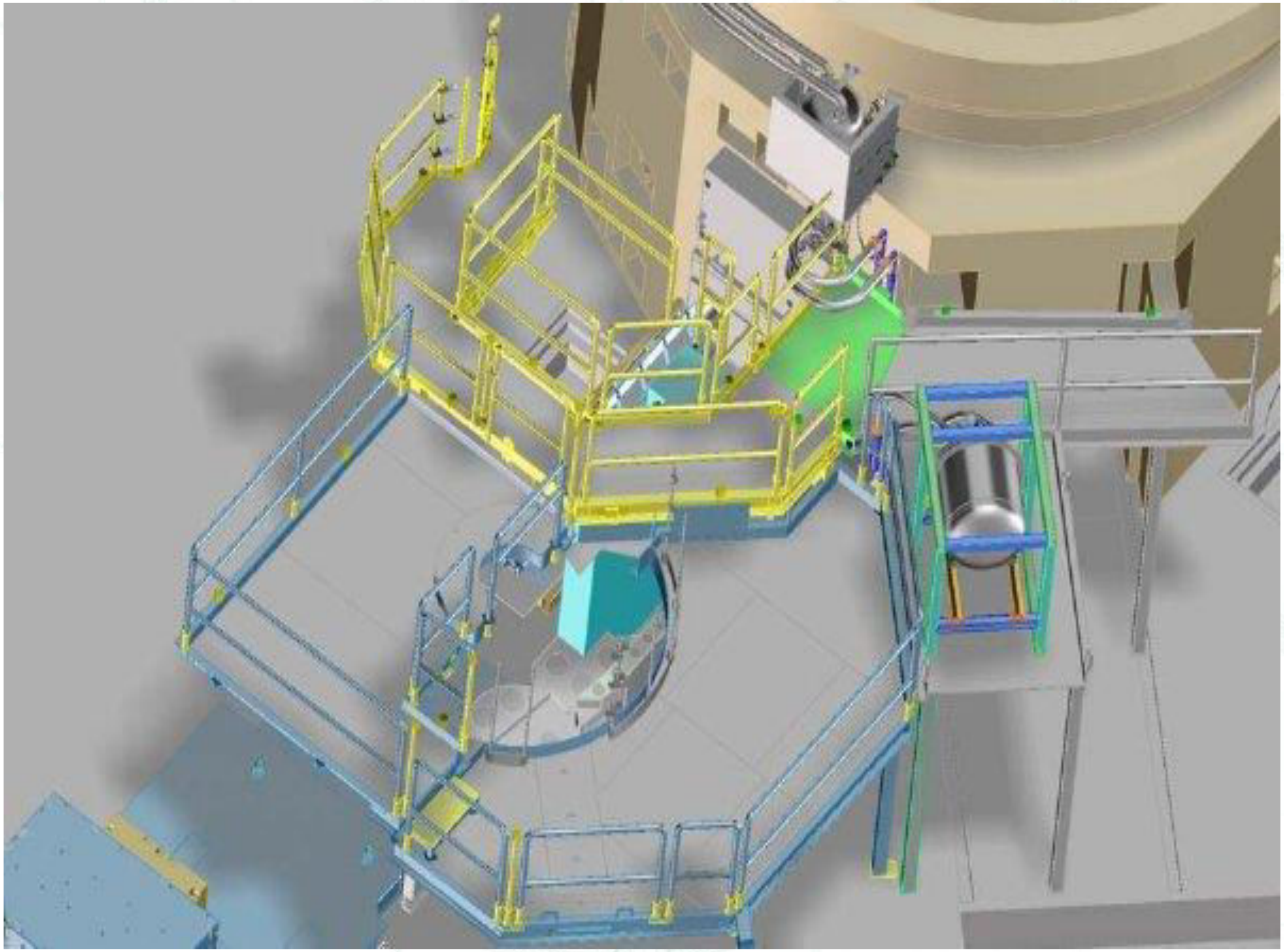
- Change existing MHA used for the liquid hydrogen cold source for the new liquid deuterium cold source.
- Install a separate BT-9 cold source vacuum system.
- Modify the existing vacuum system to make a guillotine break impossible.
- Changes will be completed before the Installation of the new deuterium cold source.


Pump Control
Control
RESET
Vacuum System
4E-12 Torr
3.5 ** Torr VG-3
135.5 kPa P-7
100.8 kPa P-11
To Unit 2 Condenser
2.7 Torr
2.7 \0 Torr
VG-5
VG-1
2.4 \-7 Torr
2.4E-7 Torr
VPV-3
OPEN
20 C T-3
VPV-1
CLOSE
90 krpm
P-10
0.0 kPa
90 krpm
VPV-2
CLOSE
CLOSE
18 C T-4
VPV-4
VG-2
2.8 \-7 Torr
2.8E-7 Torr
VG-6
3.5 \-6 Torr
3.5E-6 Torr
To Unit 2 Cryostat
To LBT Condneser
VG-120 2.7 \3 Torr
P-119 110.2 kPa
P-108
118.8 kPa
8.9 \-1 Torr
VG-103
VPV-103
VG-101
0.0 ** Torr
0.0 Torr
OPEN
T-103
0 C
VPV-101
OPEN
0 krpm
0 krpm
VPV-102
OPEN
OPEN
T-104
0 C
VPV-104
VG-102
VG-104
0.0 \0 Torr
8.8 \-1 Torr
0.0 Torr
To LBT Cyrostat
Overview
Compressor
Oil Removal
Coldbox
Turbine
Vacuum System
CS Hydrogen
PW Hydrogen
CNS Overview
Trends
Status
Startup
10:50:47 AM 31 Turbine Outlet Pressure 31 High Pr
Alm: 4, Sup: 0

Vacuum System

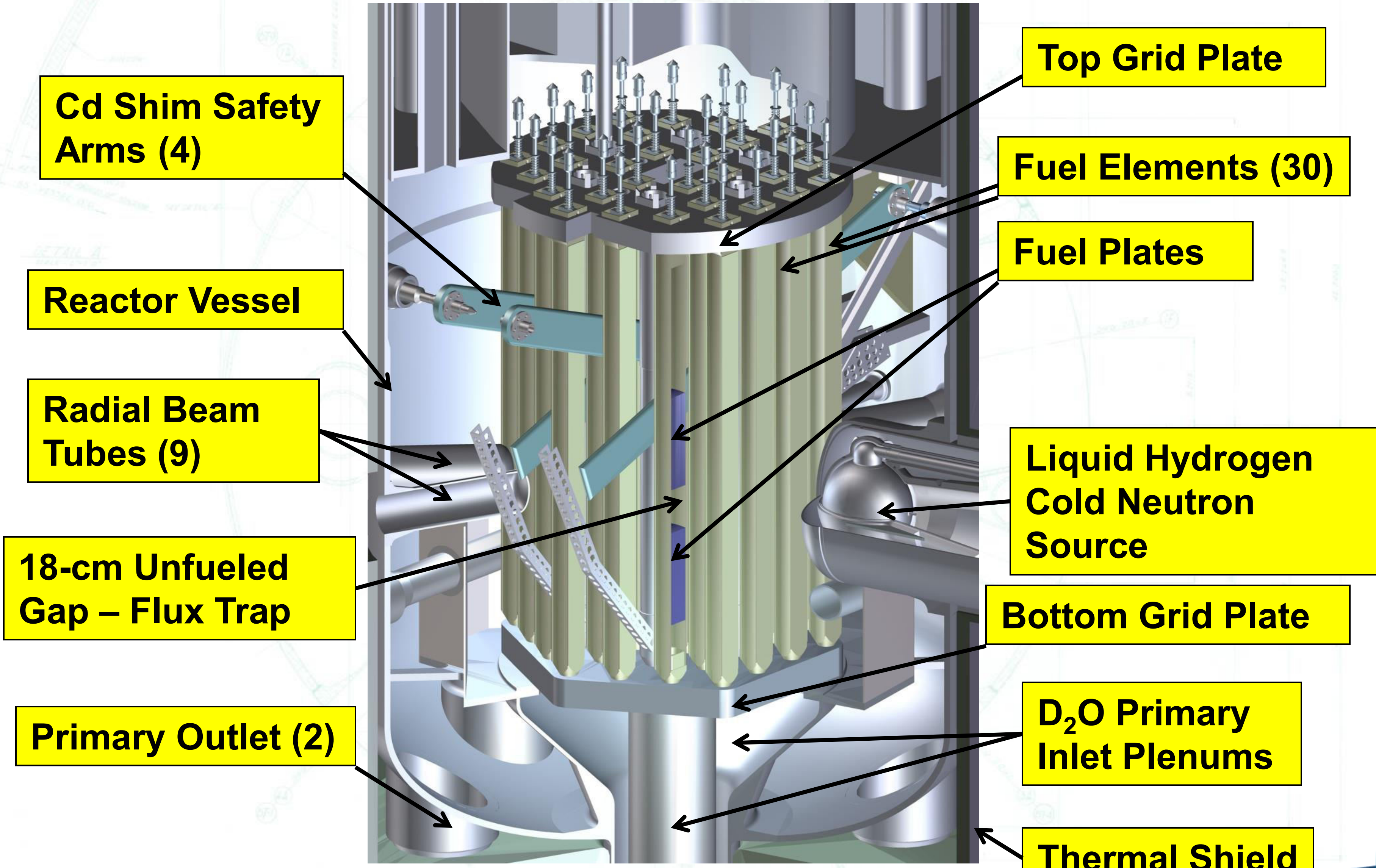


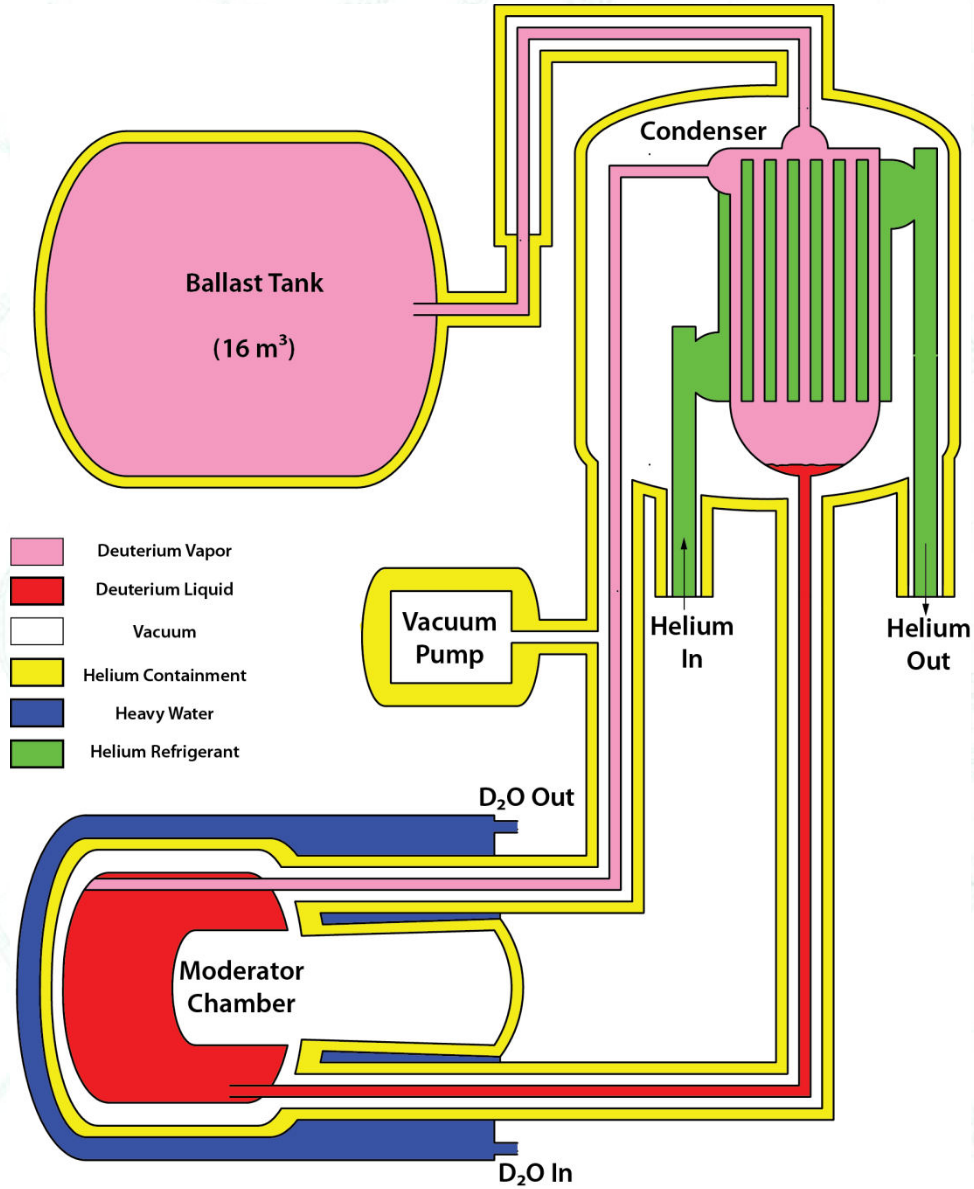
Proposed PW Vacuum Skid Location



QUESTIONS?

Cut-away View of the NBSR Core




Ballast Tank
(16 m³)
Condenser
Deuterium Vapor
Deuterium Liquid
Vacuum
Helium Containment
Heavy Water
Helium Refrigerant
Vacuum Pump
Helium In
Helium Out
D₂O Out
Moderator Chamber
D₂O In