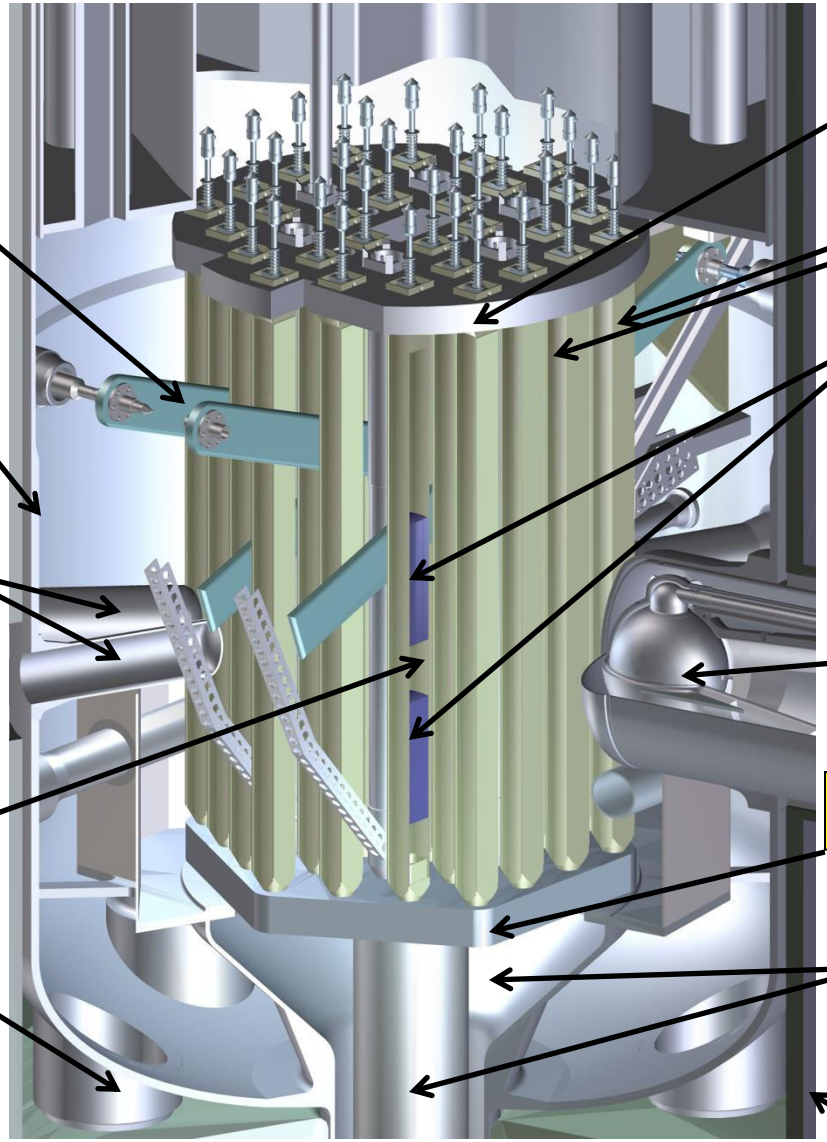
LESSONS LEARNED FROM HELIUM REFRIGERATOR PROJECT

The 20 MW NBSR Reactor was designed with a 55-cm diameter cryogenic beam port. The existing Liquid Hydrogen Cryogenic (Cold Source) was installed 2002. The next generation, Liquid Deuterium Cryogenic (Cold Source) will be installed in 2021 and operational in 2022. As part of this project a new larger Helium Refrigerator was required. A contact was awarded to build the new Helium Refrigerator, but before completion, the company noticed the government that they would not be able to meet the deadline and not long after filed for bankruptcy. It was decided that NCNR would complete the Refrigerator using contractors and the internal work force. The new Helium Refrigerator started operating Jan 2018 supplying cold helium to the existing cold source condensers

Cut-away View of the NBSR Core



Cd Shim Safety Arms (4)

Reactor Vessel

Radial Beam Tubes (9)

Split Core: 18-cm Unfueled Gap – Flux Trap

Primary Outlet (2)

Top Grid Plate

Fuel Elements (30)

Fuel Plates

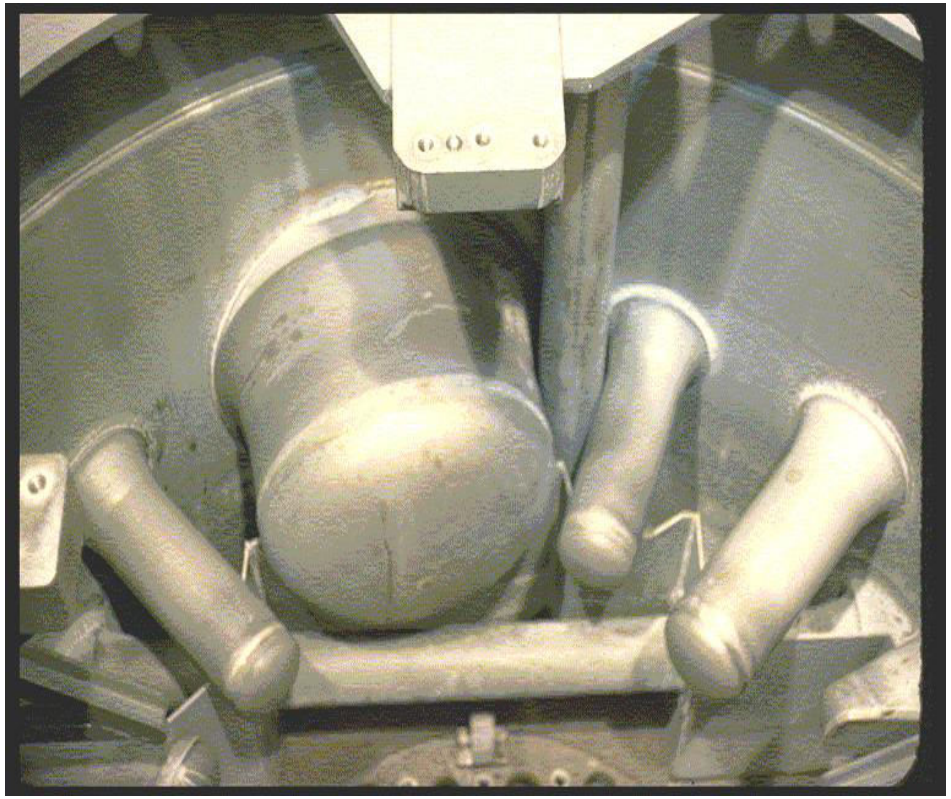
Liquid Hydrogen Cold Neutron Source

Bottom Grid Plate

D_2O Primary Inlet Plenums

Thermal Shield

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

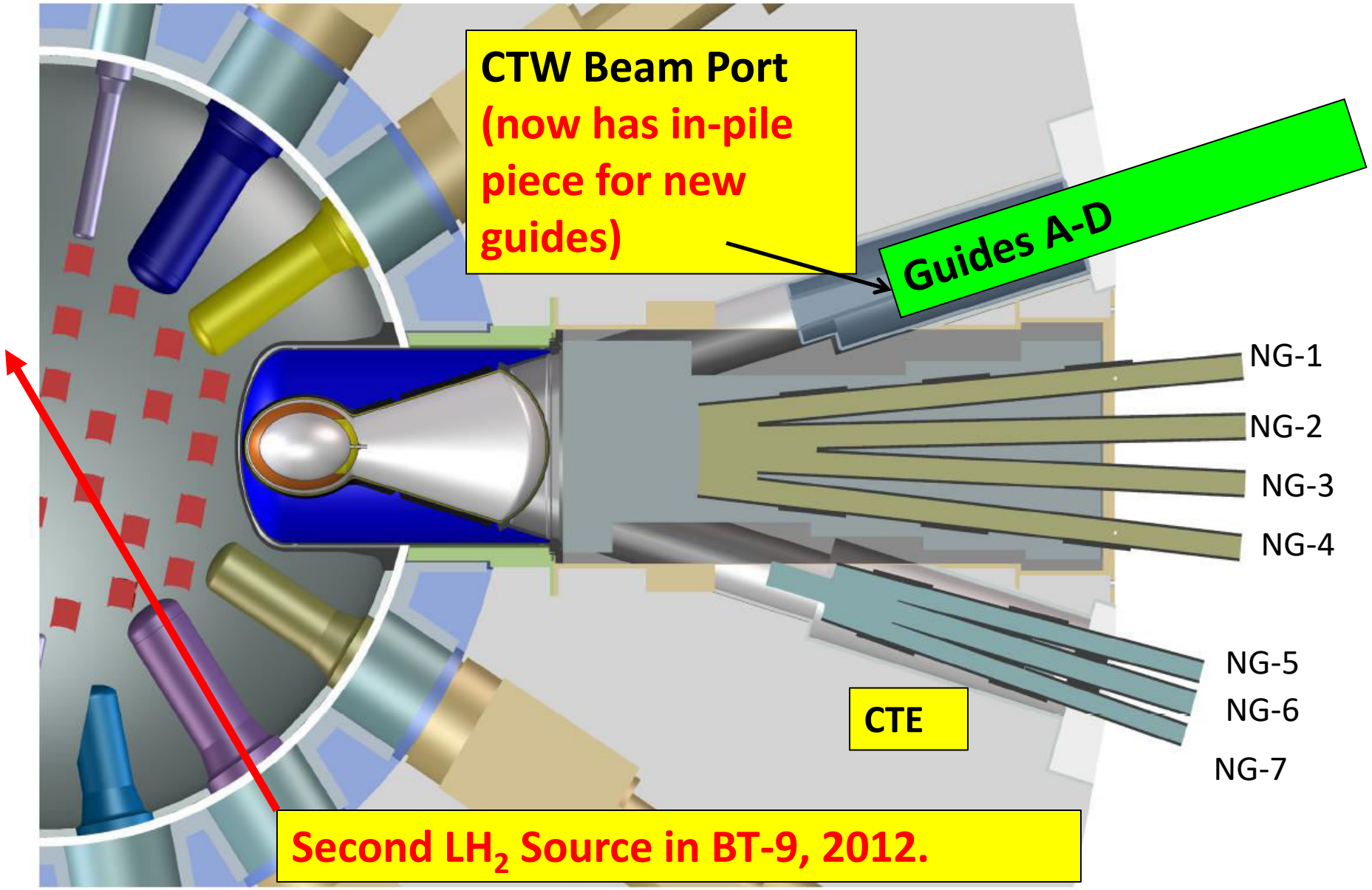


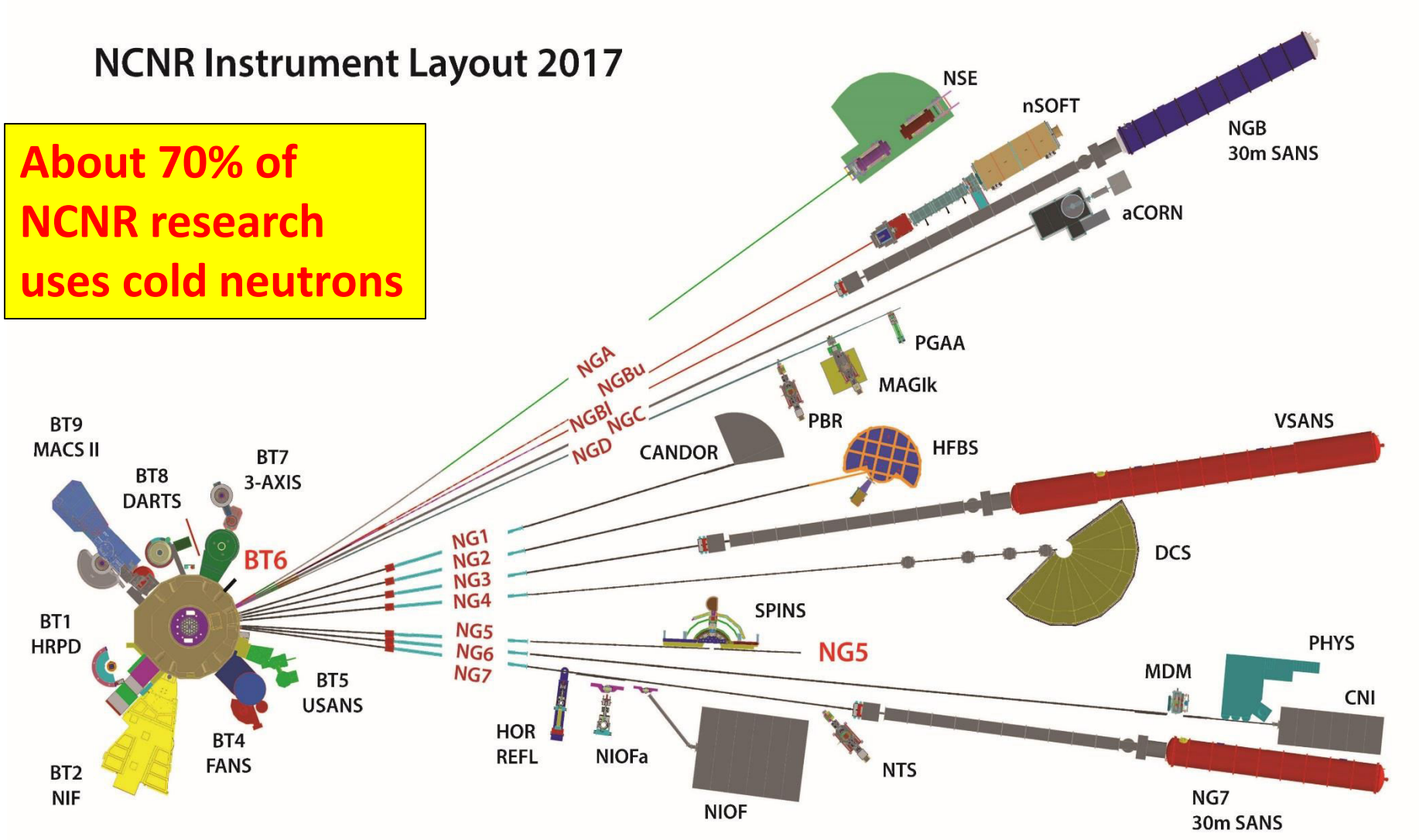
History:

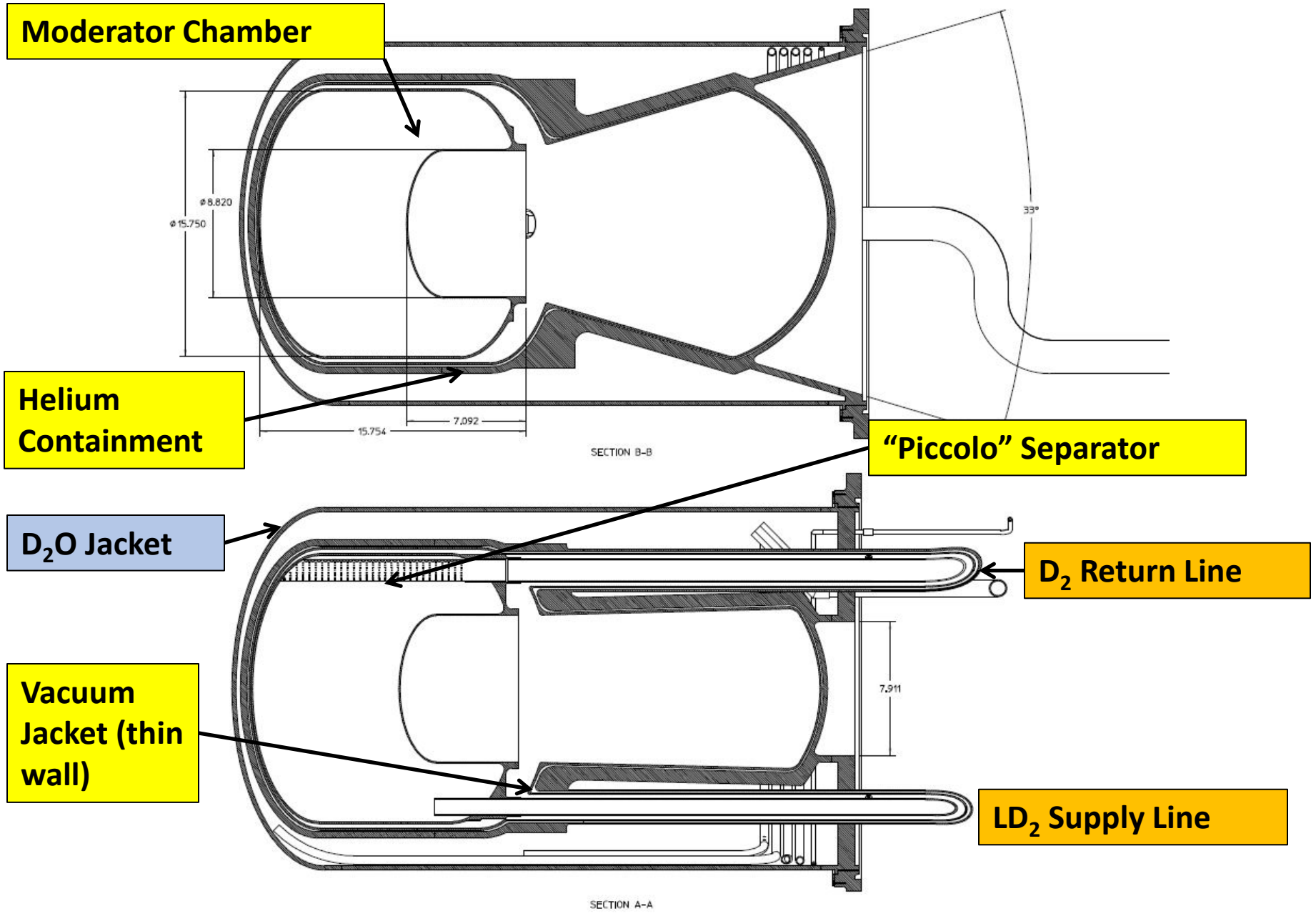
1. D_2O Tank (20 years!)
2. D_2O Ice (1987)
3. Unit 1 LH_2 (1995)
4. Unit 2 LH_2 (2002)
5. Unit 3 LD_2 (2022)

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

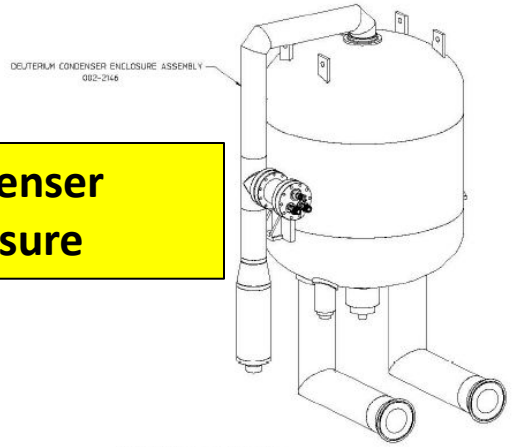
Existing LH_2 CNS, Guides



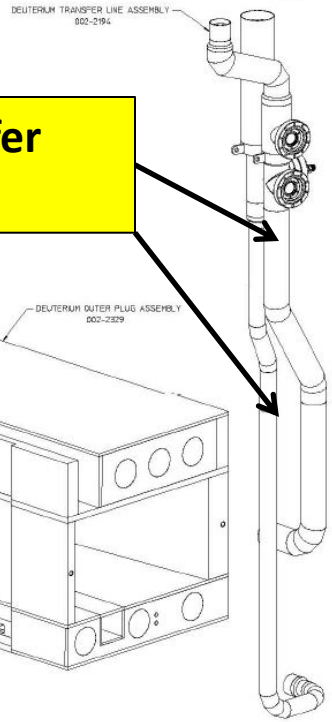

NCNR Instrument Layout 2017
About 70% of NCNR research uses cold neutrons
NSE
nSOFT
NGB
30m SANS
aCORN
PGAA
MAGIk
PBR
CANDOR
HFBS
VSANS
DCS
SPINS
NG5
PHYS
MDM
CNI
NTS
NG7
30m SANS
NIOF
NIOFa
HOR
REFL
NGA
NGBu
NGBl
NGC
NGD
NG1
NG2
NG3
NG4
NG5
NG6
NG7
BT9
MACS II
BT8
DARTS
BT7
3-AXIS
BT6
BT1
HRPD
BT5
USANS
BT4
FANS
BT2
NIF


Moderator Chamber
Helium Containment
"Piccolo" Separator
D_2O Jacket
D_2 Return Line
Vacuum Jacket (thin wall)
LD_2 Supply Line
ø 8.820
ø 15.750
33°
15.754
7.092
SECTION B-B
7.911
SECTION A-A

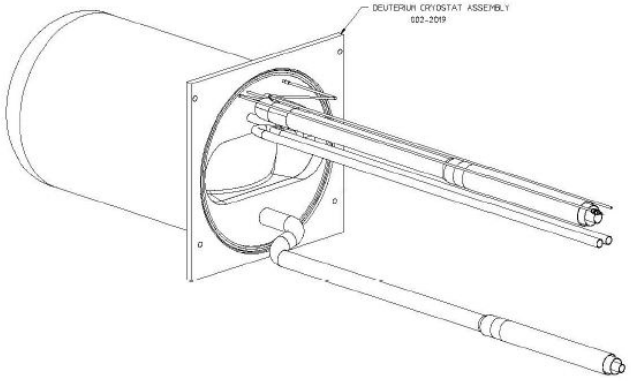
Major Components



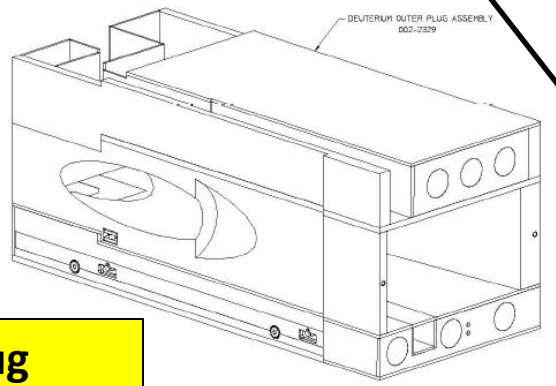
Condenser Enclosure



LD_2 Transfer Lines

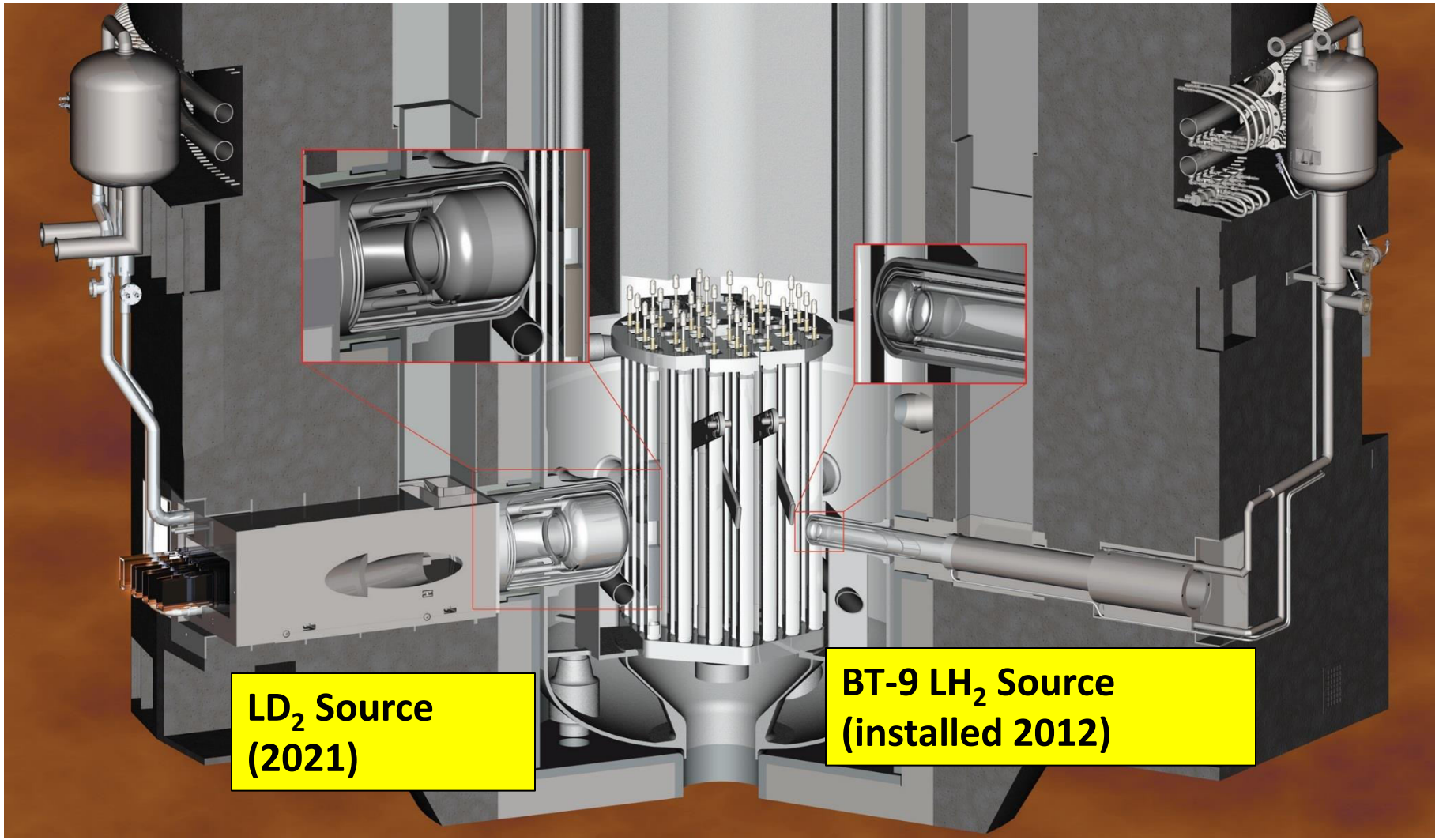


Cryostat Assembly

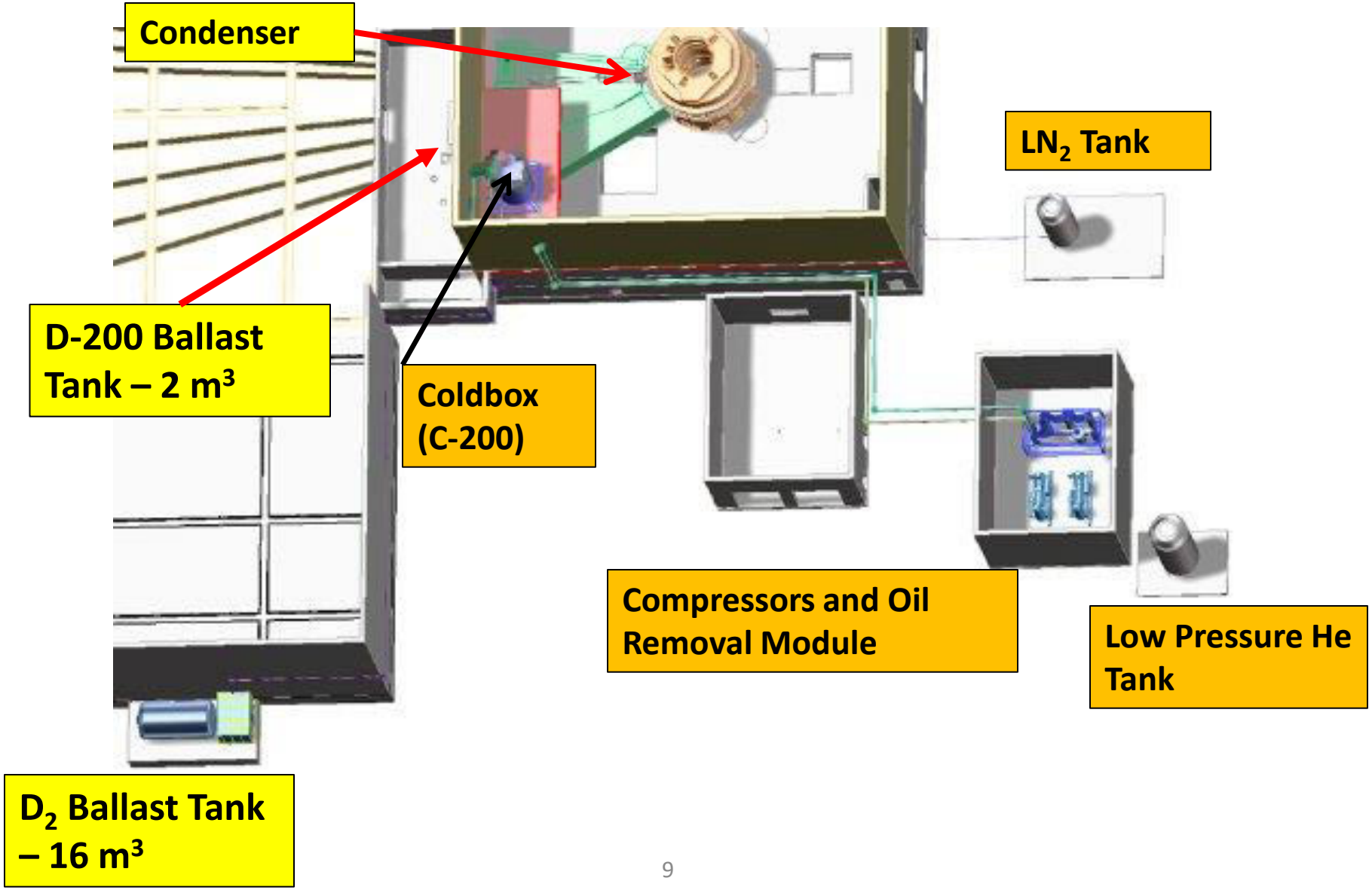


Shield Plug

Future Cold Source Layout



Layout of the 7 kW Refrigerator and LD_2 Cold Source Components



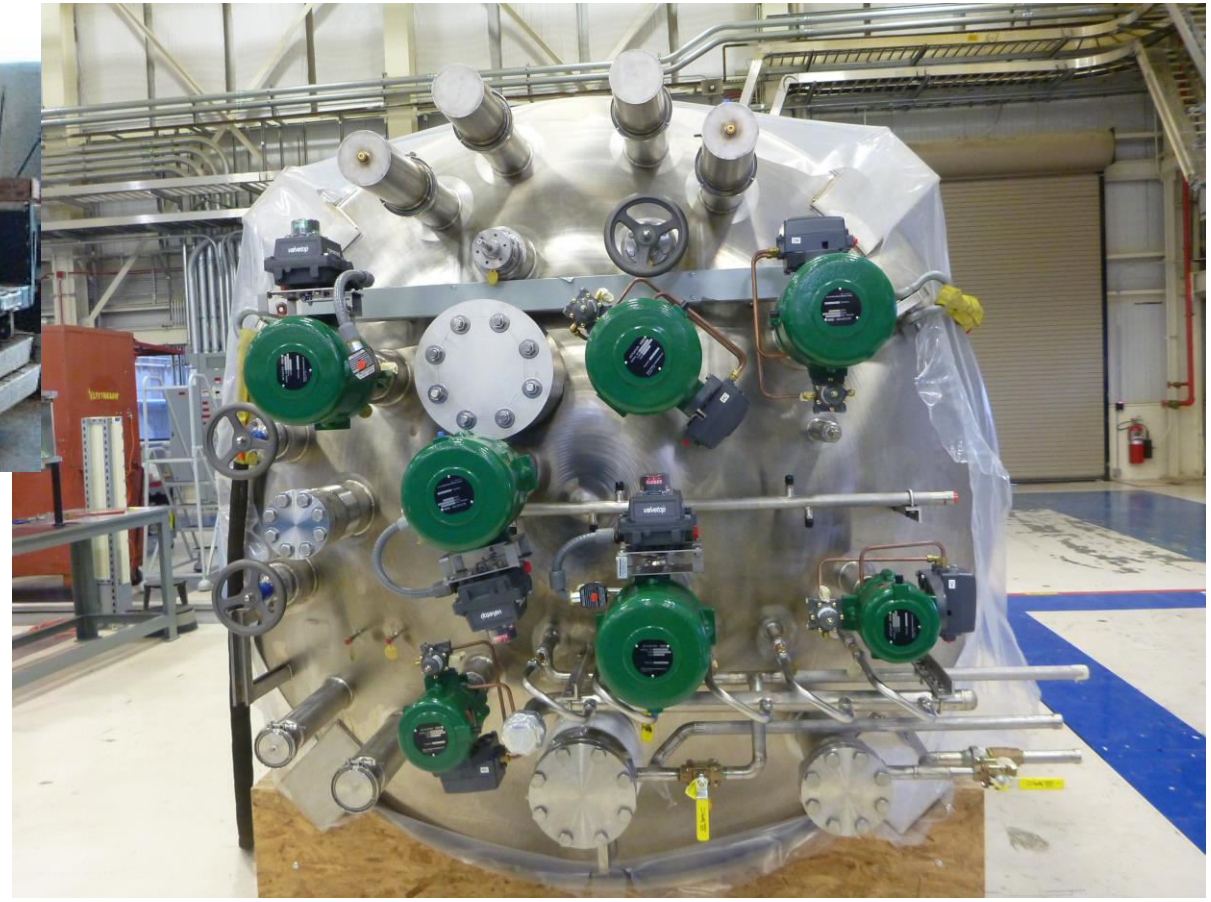
7000 WATT HELIUM REFRIGERATOR PROJECT

- 5 Million Dollar Contact Award, April 2012
- Expected Delivery/Operation, June 2014
- Vendor Notifies Government of Project Delay, Jan 2014
- Vendor Files for Bankruptcy, Sept 2014
- Vendor Contract Terminated, March 2015
- Government Estimates 2 Million Dollars to Complete Project
- Decision Made to Perform as Much Work In House as Possible
- System Operational Jan 7, 2018

IKEA, Helium Refrigerator

Some Assembly Required

Top of Enclosure complete, Majority of plumbing and wiring done while laying on side in Guide Hall.



Coldbox Enclosure Completed and Shipped to NCNR, Oct 2014

Support feet were made, Coldbox set up vertical, Coldbox moved up to C200.

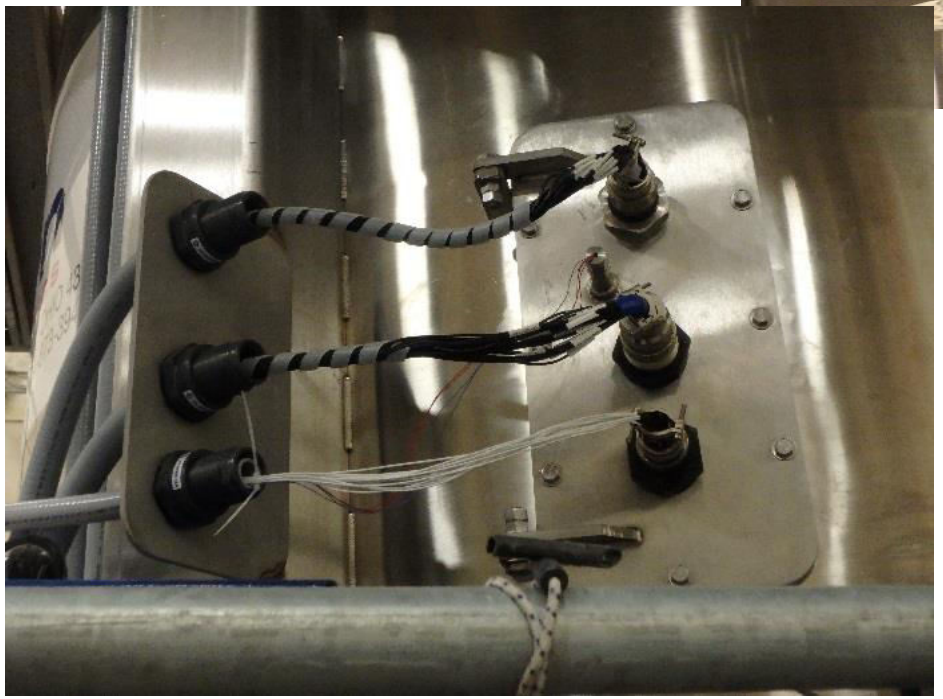
Temporary Scaffolding Installed, work continued on Plumbing and Wiring.

Support Frame made, Coldbox Attached in place in C200.

Received PLC Panel April 2015, 80% completed.

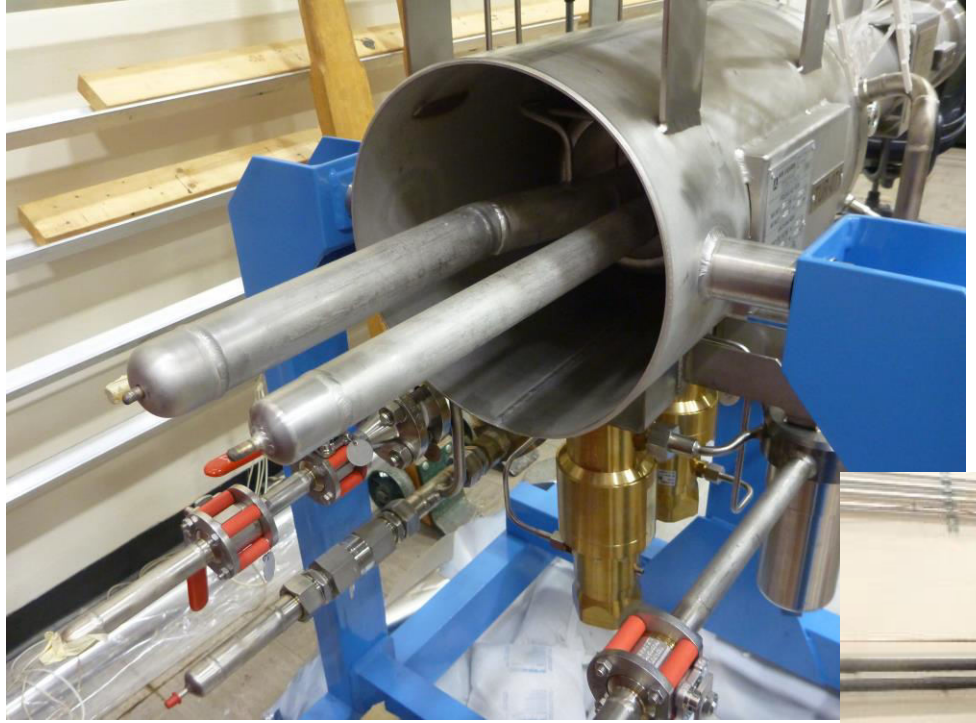
Attached PLC Panel to Coldbox Enclosure, continued filed wiring and PLC programming.

Coldbox Enclosure Interface for Silicon Diode Temp and Heaters' Continued Filed Wiring and PLC Programming.



Completed Pressure Transmitter Panel, Plumbing, Field wiring and PLC Programming.

UPS and Transformer Installed, Power connected to PLC Panel

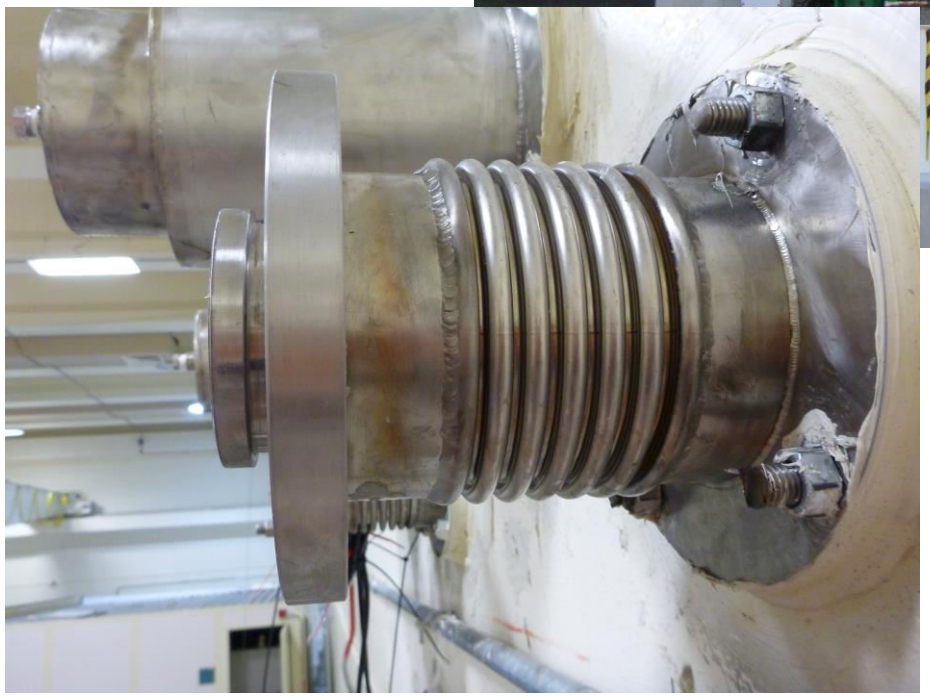


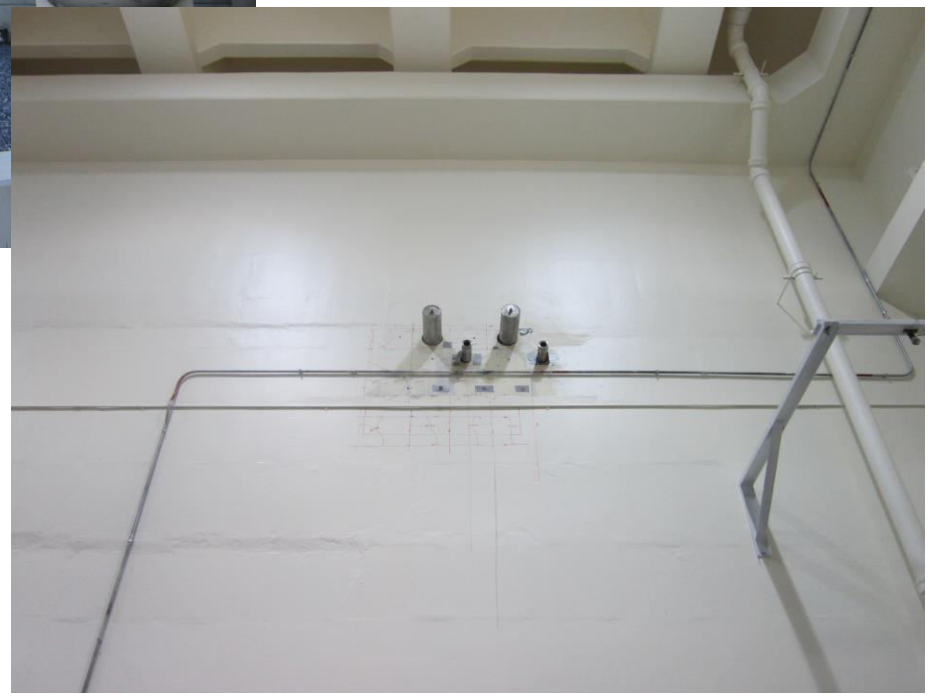
Installed Turbine Assembly,
Continued plumbing, field wiring and PLC programming.

Received Turbine Assembly from Air Liquide, August 2014.

Loading Molecular Sieve into Purifier

Eden completed the Wall Penetrations before Default.





CONNECTING COMPRESSOR, TANKS, ETC TO COLDBOX

Helium Piping and LN2 Piping outside Confinement

Helium Supply and Return Piping, Helium Makeup Piping and Electrical Cabling Installed

Helium Reserve Tank, Connection to Oil Removal Skid and Connection to High Pressure Makeup Tanks, Received Nov/2015.

Connection to Existing High Pressure Helium Makeup Tanks

6000 Gallon LN2 Supply Tank, Installed Jan/2016.

Connection Piping for LN2 Tank and Emergency Shutoff Valve, Installed Aug/2016.

480V/4160V Step-up Transformer and Power Cables received Feb/2014

Plumbing and Electrical Cabling

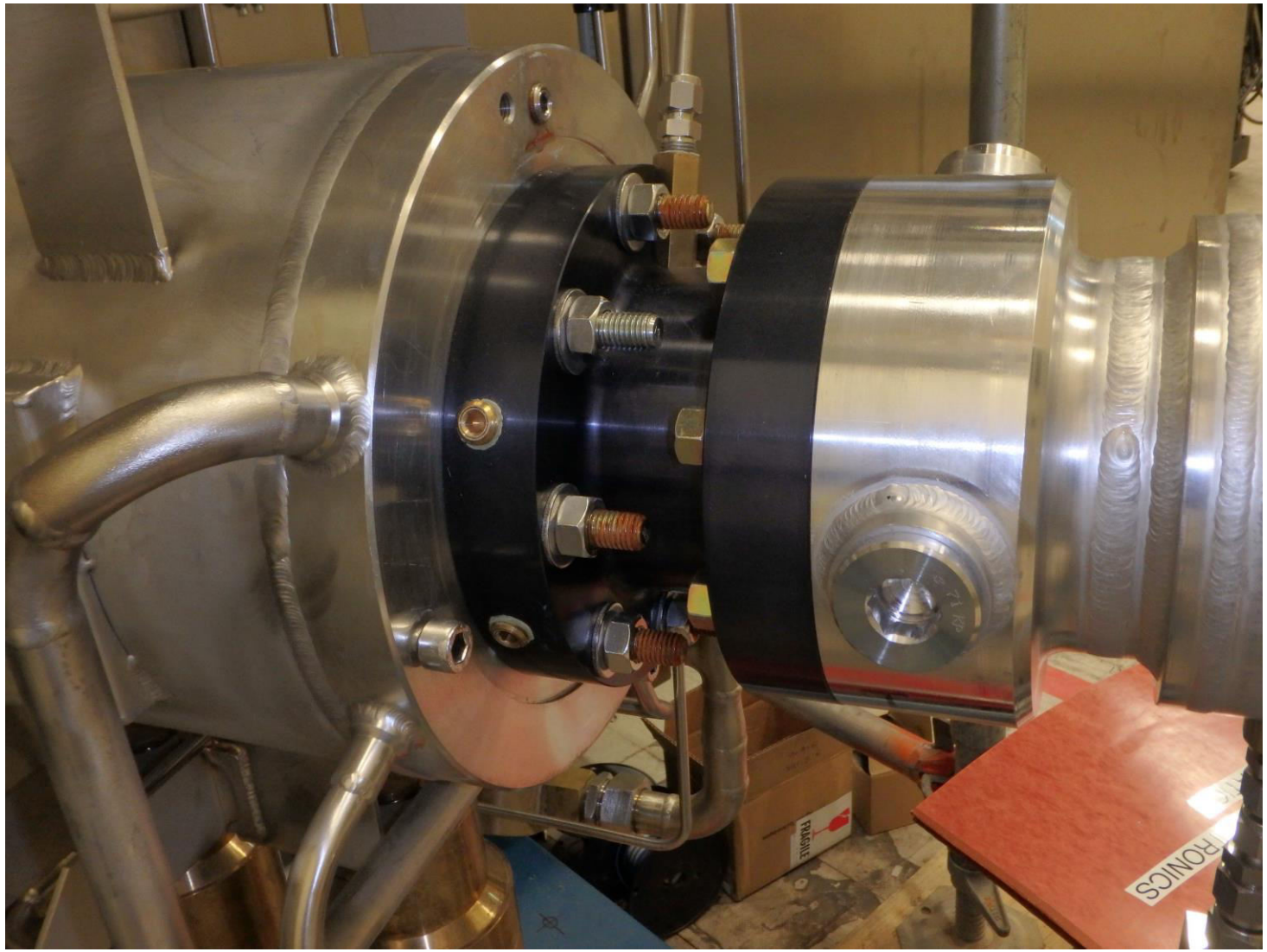
Oil Removal Skid, delivered Mar/2014

JJ Crewe Compressor Skids, Received Feb/2014.

Plumbing and Wiring Completed and Successful Start of Compressors, Sep/2016. Required resetting the Soft Starter and Adjusting of Network Protective Switch.

Completed the Arc Flash Study, allowed to continue testing Jul/2016.

TURBINE INSTALLATION, SYSTEM STARTUP AND CONNECTION TO COLD SOURCES



Installed Turbine, Started the Refrigerator, reaching 14K, Oct/2018.

Drilled holes in Floor for Helium Load Lines, Dec/2016.

Catwalk Installed around Coldbox, Aug/2017.

Purifier Heater Element Replacement, Oct/2017

New Load Lines Installed and Connected to Existing Load Lines Nov 2017

TimeLine:
Jan/2014, Eden Acknowledges inability to finish Project.
Feb/2014, J.J. Crewe Shipped Compressor Skids And Step-up Transformer.
Mar/2014, Eden Shipped Oil Removal Skid.
Apr/2014, Witnessed Leak Testing of Coldbox Internal piping and HXs.
May/2014, Eden Shipped Bearing Reserve Tank and LN2 Piping.
Aug/2014, Air Liquide Shipped Turbine Expander Assembly.
Sep/2014, Eden Files for Bankruptcy.
Oct/2014, Eden Shipped Coldbox.
Dec/2014, Purchased Coldbox PLC Enclosure
Mar/2015, Eden Contract Terminated.
Mar/2015, Purchase 18,000 Gal Helium Storage Tank.
Apr/2015, Purchased 23,000 SCF High Purity Helium
Apr/2015, Received Coldbox PLC Enclosure.
Apr/2015, Task Order Helium Gas Piping.
Apr/2015, Purchase 23,000 SCF High Purity Helium
May/2015, Purchase Molecular Sieve.

Timeline(cont)
Jun/2015, Purchase Compressor Startup Services.
Aug/2015, Purchased 6000 Gal LN2 Tank.
Nov/2015, Installed 18,000 Gal Helium Storage Tank
Dec/2015, Purchase Coldbox Vacuum System.
Dec/2015 , Received High Purity Helium and Filled System
Jan/2016, Installed 6000 Gal LN2 Tank
Apr/2016, Purchased LN2 Transfer Line.
Apr/2016, Received Molecular Sieve.
Mar/2016, First Attempt to Start Compressors.
Jun/2016, Helium Piping Installation Complete.
July/2016, Complete Arc Flash Study.
Aug/2016, Installed LN2 Transfer Line.
Sept/2016, Successful Start of Compressors.
Oct/2016, Installed Coolbox Vacuum System.
Oct/2016, Purchased Coldbox Catwalk.
Nov/2016, Substation Network Protective Switch Reset.

Timeline(cont)
Dec/2016, Drill Load Lines Holes in Floor.
Jan/2017, Initial Fill LN2 Tank.
Feb/2017, Purchased Helium Load Lines.
Jul/2017, Received new Helium Load Lines.
Aug/2018, Operated Refrigerator to LN2 Temperature.
Aug/2017, Install Coldbox Catwalk
Aug/2017, Helium Gas Analysis
Oct/2017, Turbine Install and System Startup.
Oct/2017, Replacement of Purifier Heaters
Nov/2017, Install New Load Lines.
Dec/2017, Cold Source PLC Module Switchover.
Jan/2018, Operational, First Cooldown of Cryostats.