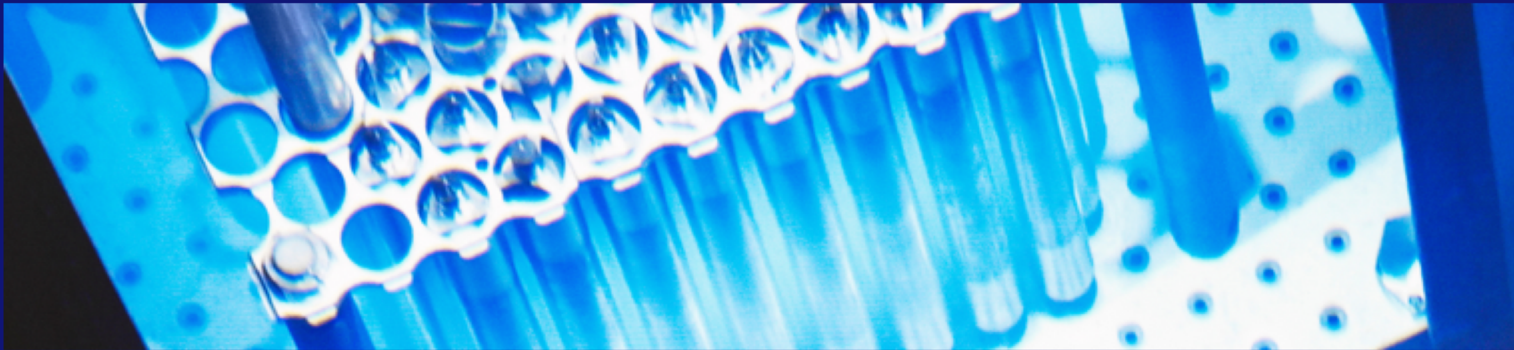


BREAZEALE Nuclear Reactor 69 1955 2024

Design, Installation, and Performance of a Third Generation Mesitylene Based Cold Neutron Source at the Penn State Breazeale Reactor

Daniel Beck and Kenan Unlu
Penn State Radiation Science and Engineering Center

TRTR 2024
September 30, 2024 - Albuquerque, New Mexico

PennState College of Engineering | RADIATION SCIENCE & ENGINEERING CENTER

Outline

- **Radiation Science and Engineering Center**

  Breazeale Nuclear Reactor/Brief History

  Current Activities

- **Cold Neutron Source**

  Design features

  Installation and Performance

Radiation Science & Engineering Center

In 1990, Penn State established the Radiation Science and Engineering Center (RSEC), a university-wide facility to promote research, education, and varied applications of radiation science and nuclear engineering.
The RSEC falls under the Vice President for Research and the College of Engineering at Penn State.

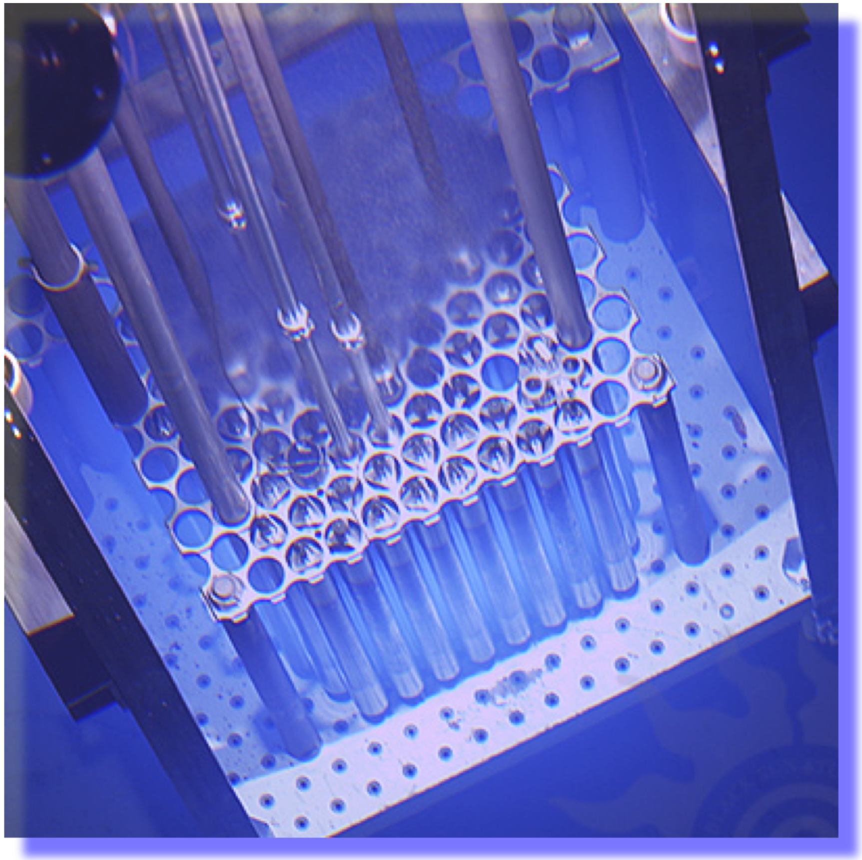
69
1955 2024
BREAZEALE
Nuclear Reactor

Radiation Science & Engineering Center

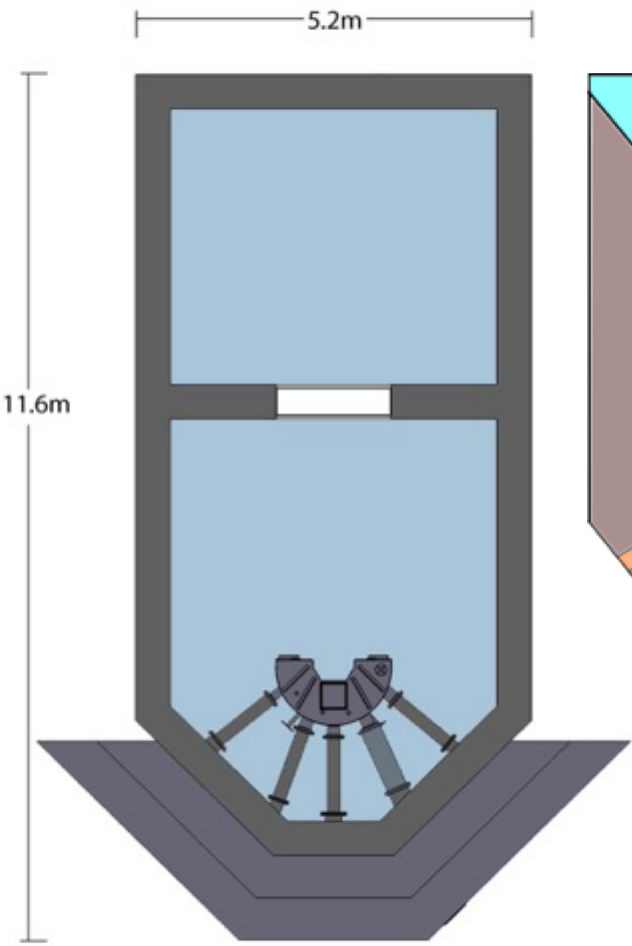
- Breazeale Nuclear Research Reactor
  1 MW TRIGA
  3×10^{13} n/cm^2 sec thermal neutron flux at core center

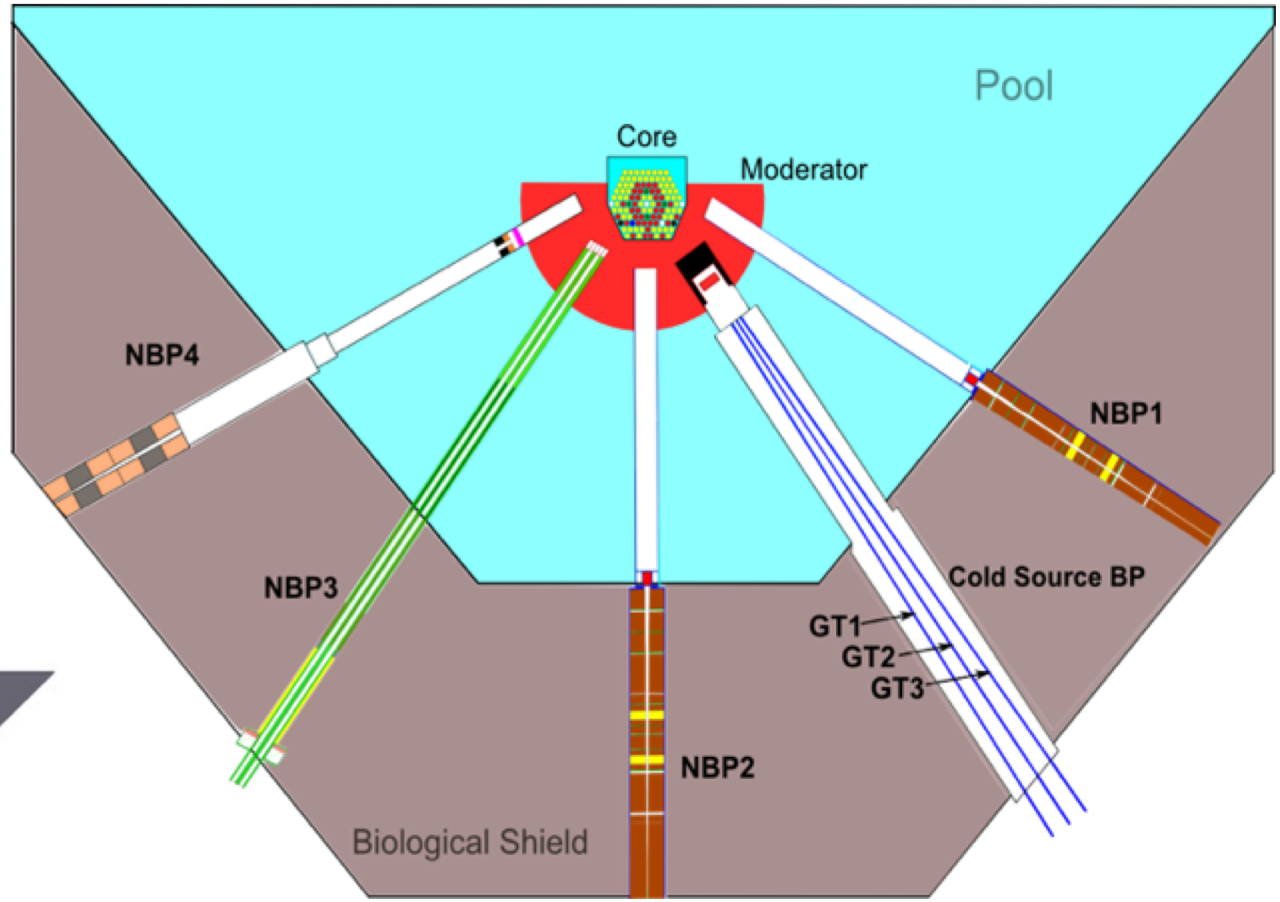
- Gamma Irradiation Facilities
  In-Pool irradiators
  Gamma Cell 220 Dry Irradiator
  (6,000 Curie Co-60, 0.5 MRads/hour)

- Hot Cells
- Radiation Detection & Measurement Labs
- Neutron Beam Laboratory
- Radionuclear Applications Laboratory
- Radiochemistry Laboratory
- Nuclear Security Education Laboratory

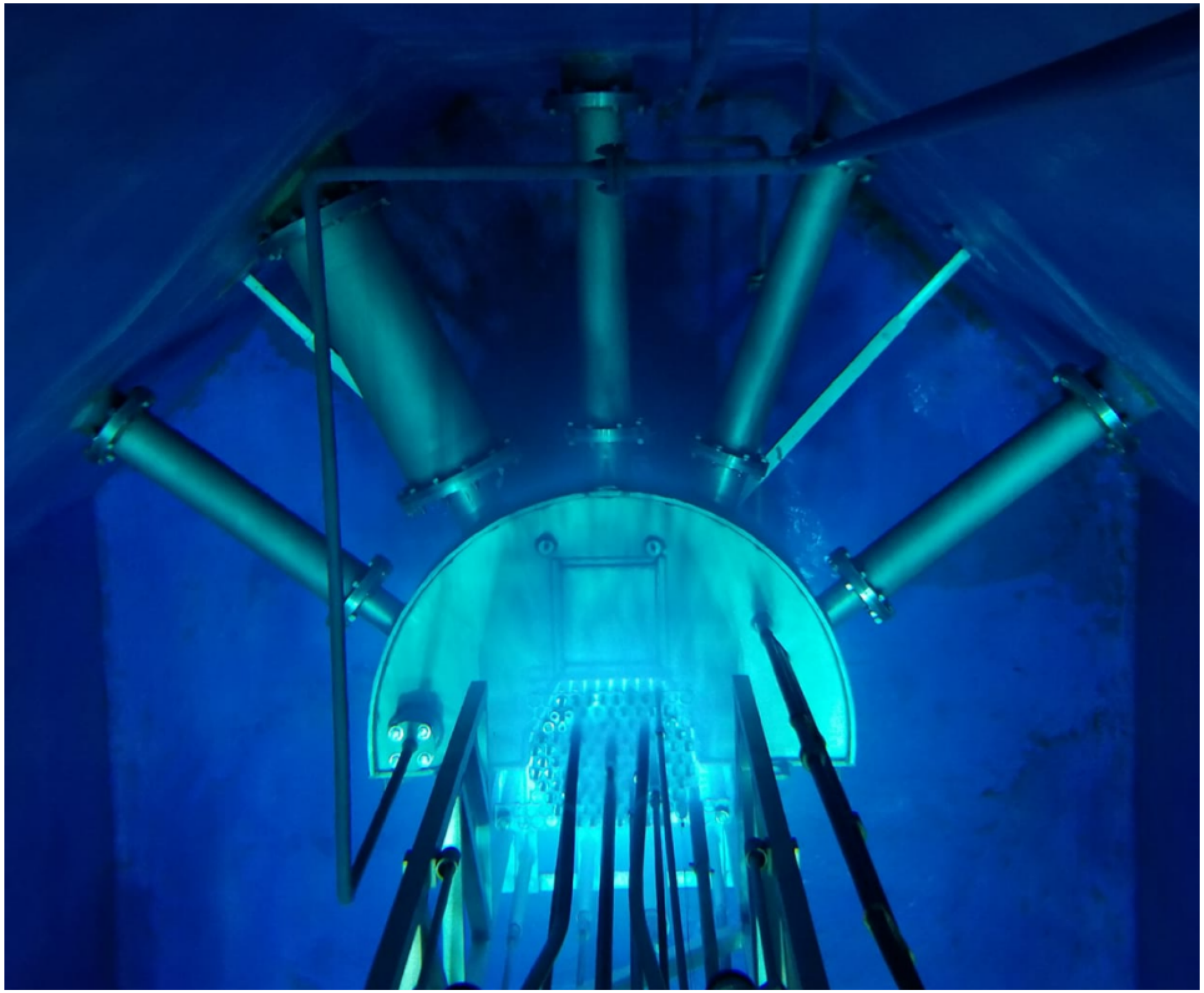


PSBR New Neutron Beam Ports

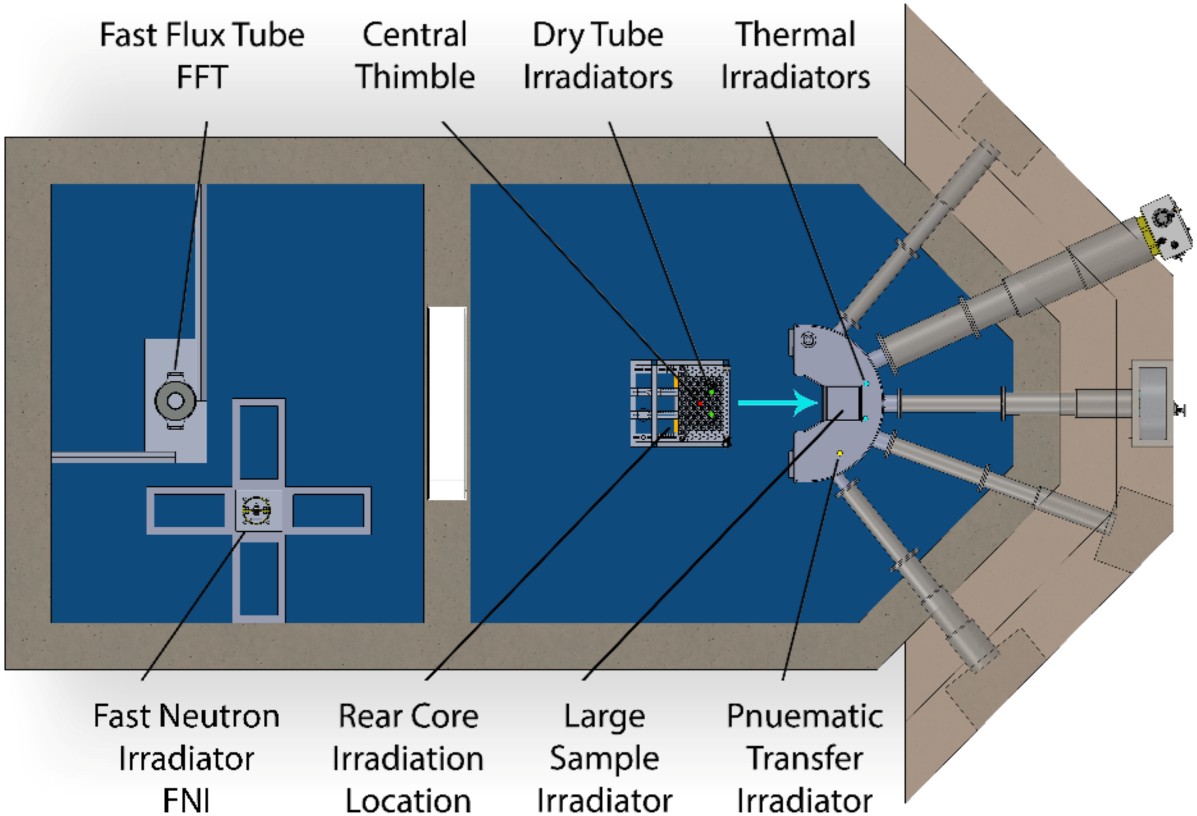




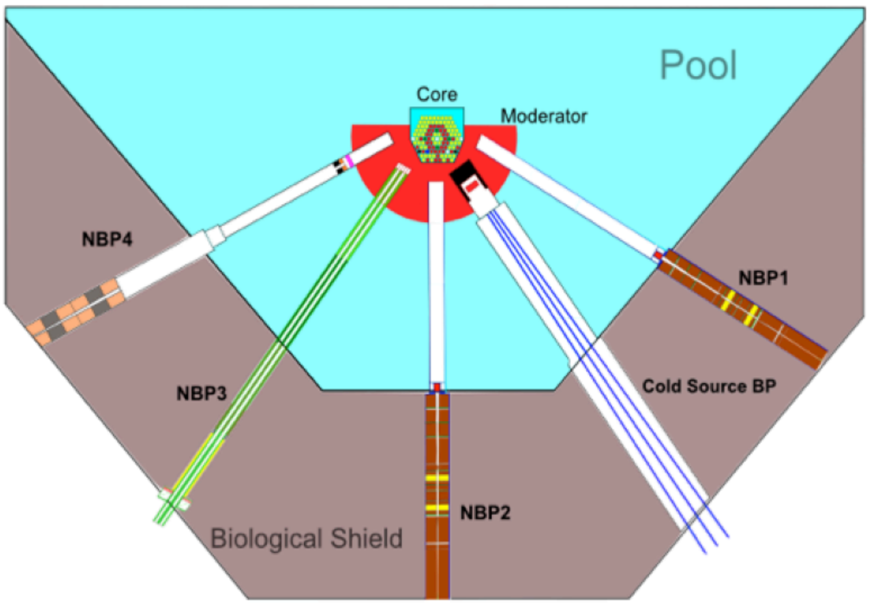
PSBR New Core/Moderator Assembly and New Beam Port Installations (2018)



PSBR New Neutron Beam Ports



PSBR New Neutron Beam Ports



NBP1 : Triple Axis Student Spectrometer (Epithermal Beam Facility)

NBP2 : Thermal Neutron Beam Port for Exploratory Research Projects

NBP3 : Neutron Transmission (Service Activities)

NBP4 : Neutron Imaging Facility

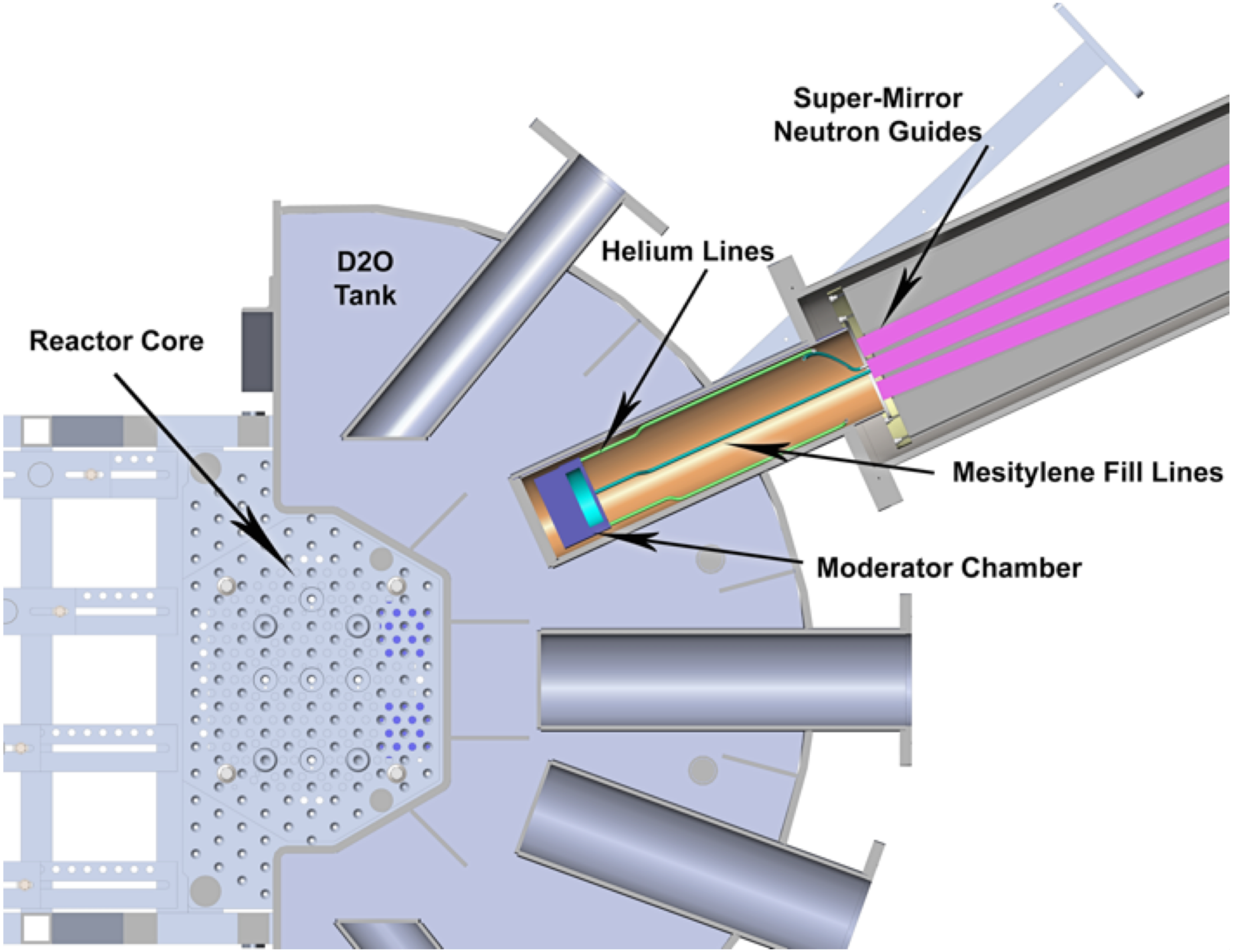
GT1 : Small Angle Neutron Scattering

GT2 : TOF Neutron Depth Profiling

GT3 : Prompt Gamma Activation Analysis

RSEC Expansion (2022)

PSBR Cold Neutron Source (2019)



PSU – Cold Neutron Source

A third generation of mesitylene moderated university research reactor cold neutron source (CNS) is designed, built, and being installed at the Penn State Breazeale Reactor.

- 10 cm diameter, 2.5 cm thick mesitylene moderator chamber
- Moderator Chamber is placed into D_2O Tank very close to the reactor core (~30 cm)
- Cryomech Helium Cryorefrigerator with Cryomech AL325 Cold Head with capacity 60 W at 20 K
- Cold Helium Circulating System integrated into Cold Head
- Triple in-pile straight neutron guides close to the moderator chamber (~ 40 cm)
- Three curved out-of-pile supermirror guides with a beam bender extend to experiment locations.

Cold Neutrons

Energy	1 - 5 meV
Velocity	440 - 980 m/sec
Wavelength	9 - 4 A^o

- Neutron guides transport neutrons without normal $1/r^2$ loss
- Curved neutron guides lower background by attenuating line-of-sight radiation
- Lower kinetic energy increases reaction rates
- Longer wavelength allows increased size scale for material structure studies

Cold Neutron Applications

- Neutron focusing research (neutron optics)
- Prompt Gamma Activation Analysis
- Neutron Imaging
- Neutron Depth Profiling
- Neutron Scattering/Diffraction Experiments

    SANS spectrometer
    Powder diffractometer
    Reflectometer

Moderating Materials

Physical properties of some moderating materials

Moderator	Boiling Point (K)	Freezing Point (K)	Density (gr/cm^3)	Σ_a for 5 meV neutrons (cm^{-1})	Σ_s for 5 meV neutrons (cm^{-1})
Hydrogen	20.4	14.0	0.071 (liq)	0.030	2.7
Deuterium	23.6	18.7	0.140 (liq)	0.002	0.50
Methane	111.6	89.0	0.415 (liq)	0.045	4.1
Mesitylene	437.0	228.3	0.865 (liq) 0.928 (sol)	0.040	3.8

Mesitylene

$C_6\ H_3\ (CH_3)_3$

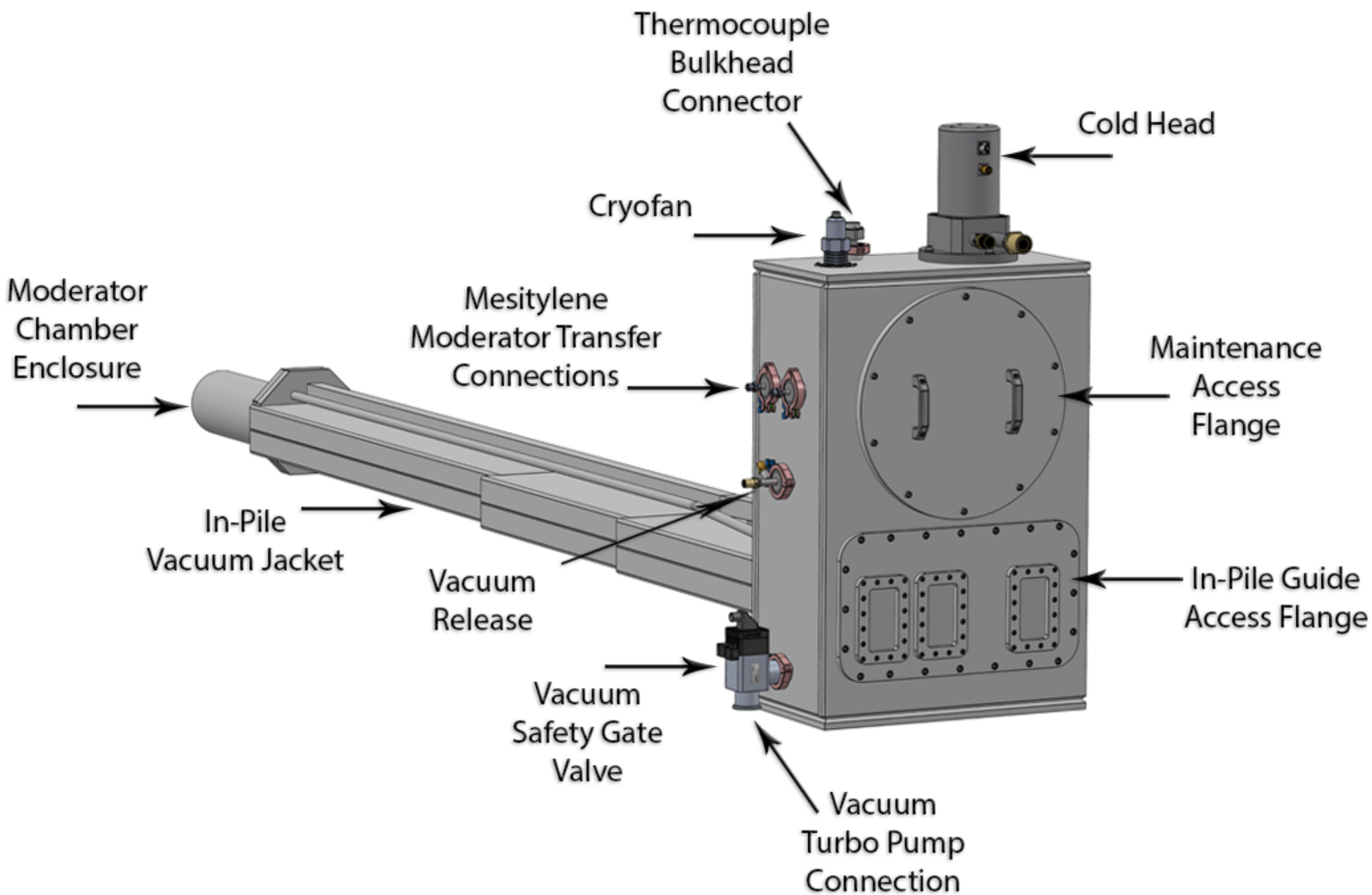
1, 3, 5 - trimethylbenzene

Freezing point	:	228.3 K
Boiling point	:	437.0 K
Ignition point	:	823.0 K
Density	:	0.865 gr/cm^3 (liq)
		0.928 gr/cm^3 (sol)

Mesitylene Properties

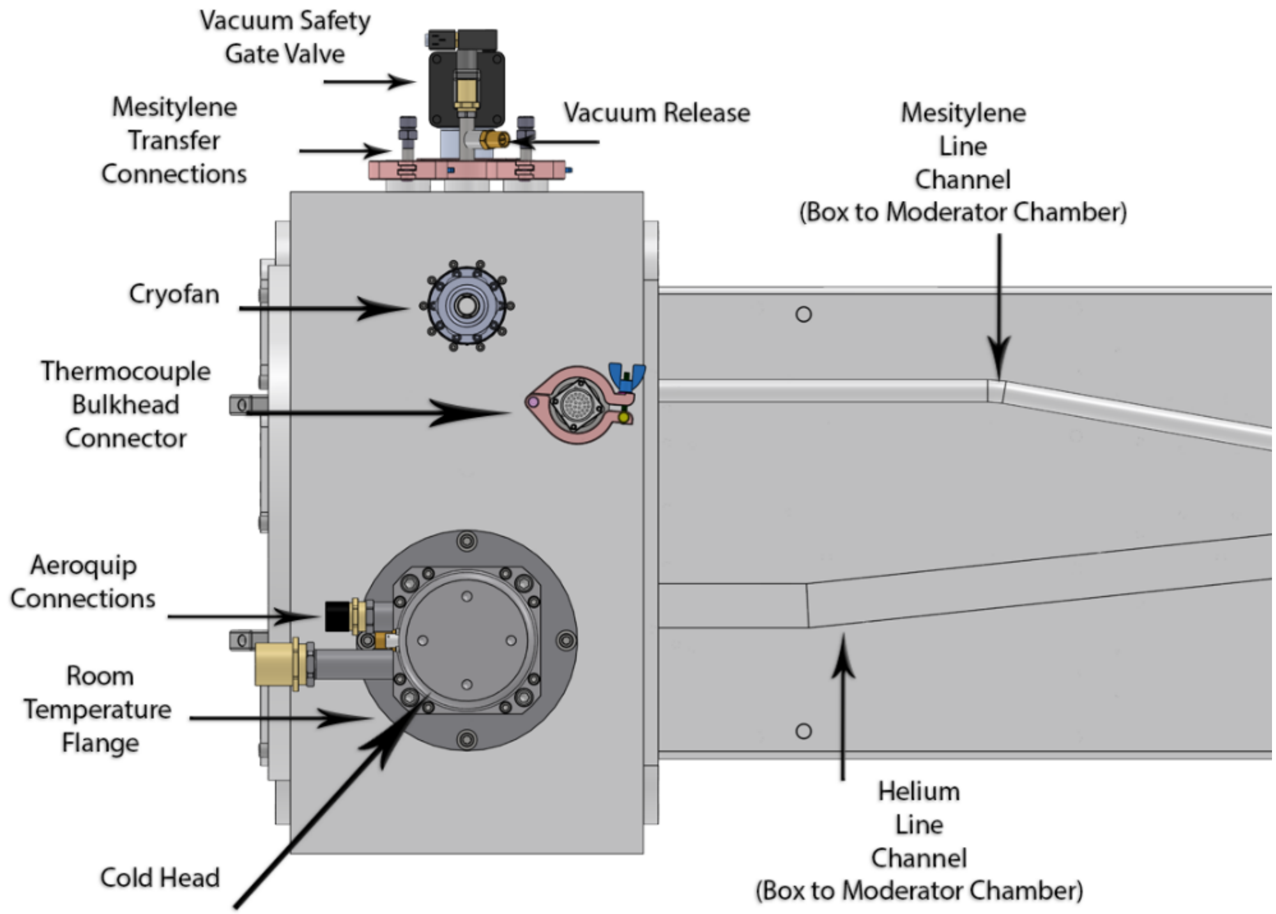
- hydrogenous
- liquid at room temperature
- can be left free-standing at room or cold temperature. Not present a hazardous fire situation (i. p. = 823 K)
- causes no increase in pressure like other moderators due to change in state from solid or liquid to gas
- has energy loss mechanism to allow moderation to very low energies (low potential barrier to rotation)

PSU-CNS Assembly



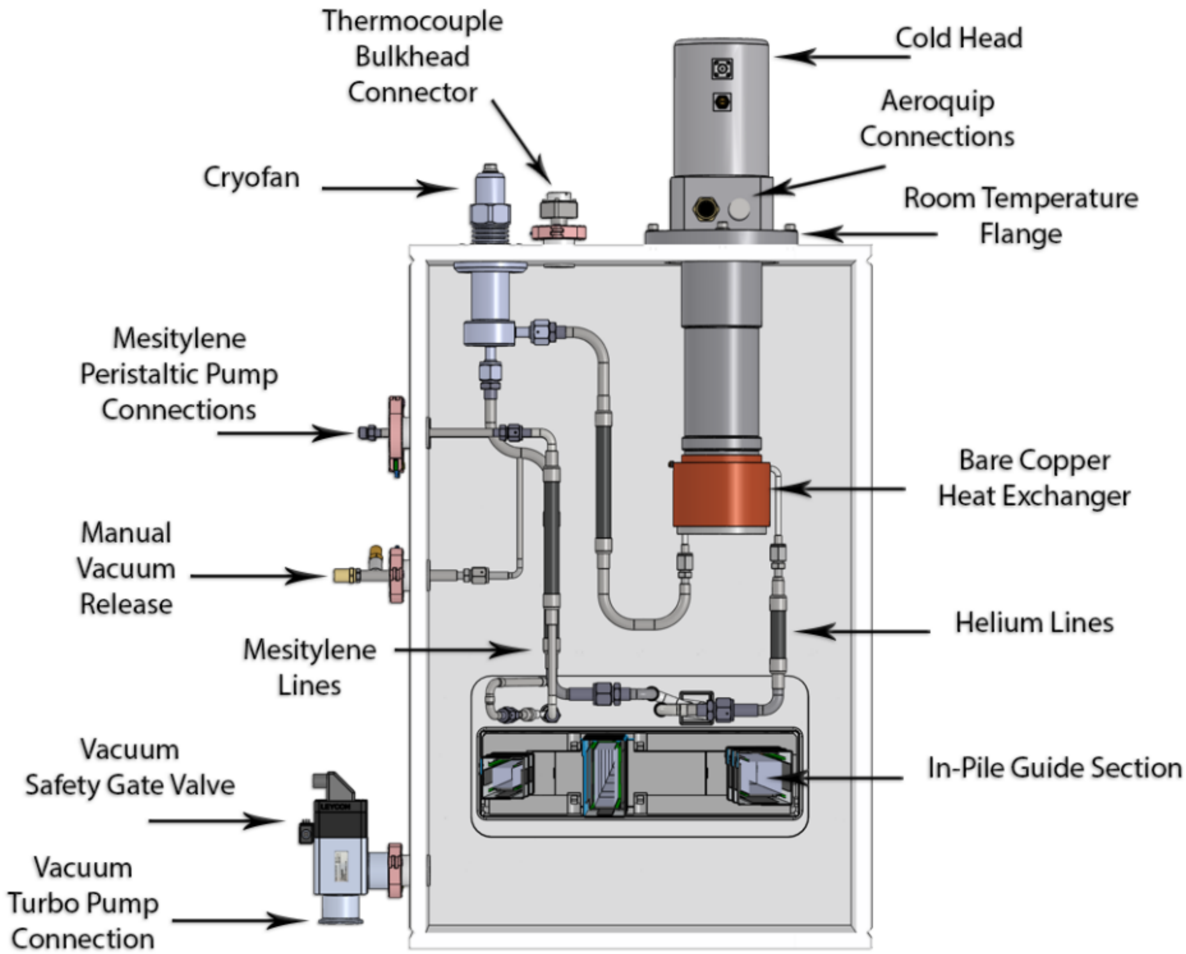
PSU-CNS Assembly

Cold Box Top View

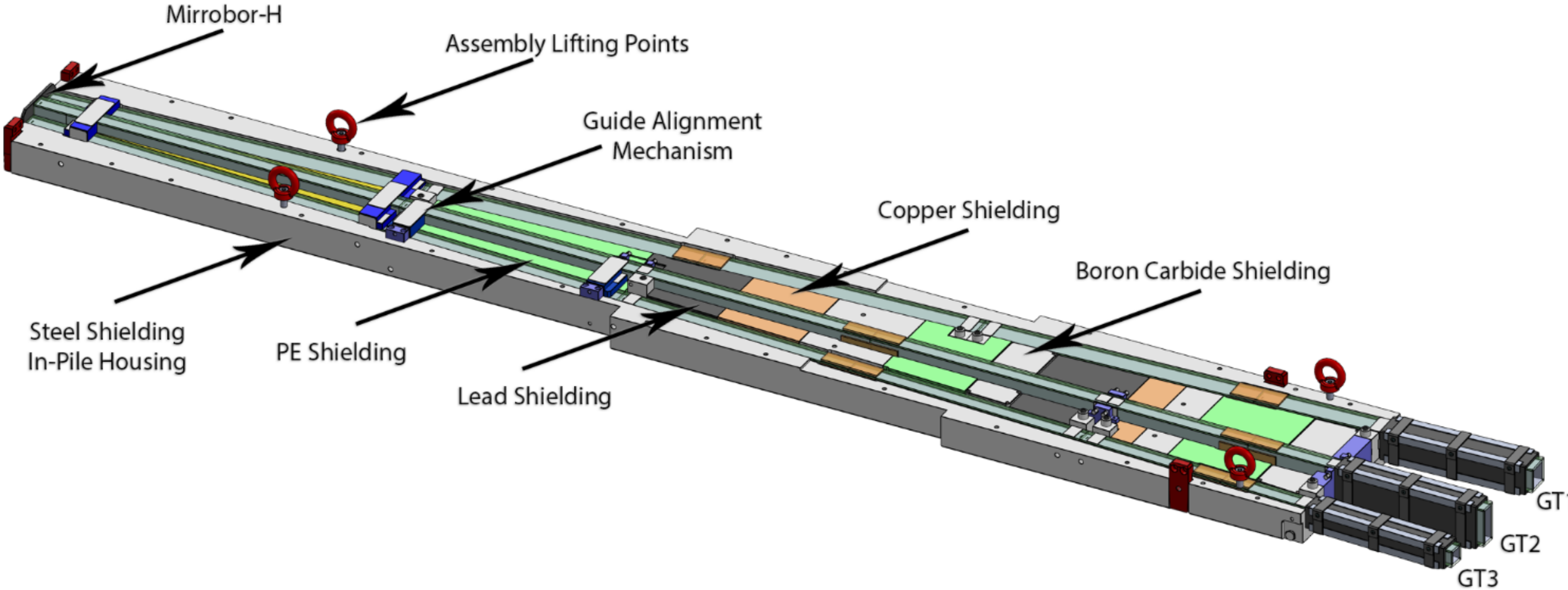


PSU-CNS Assembly

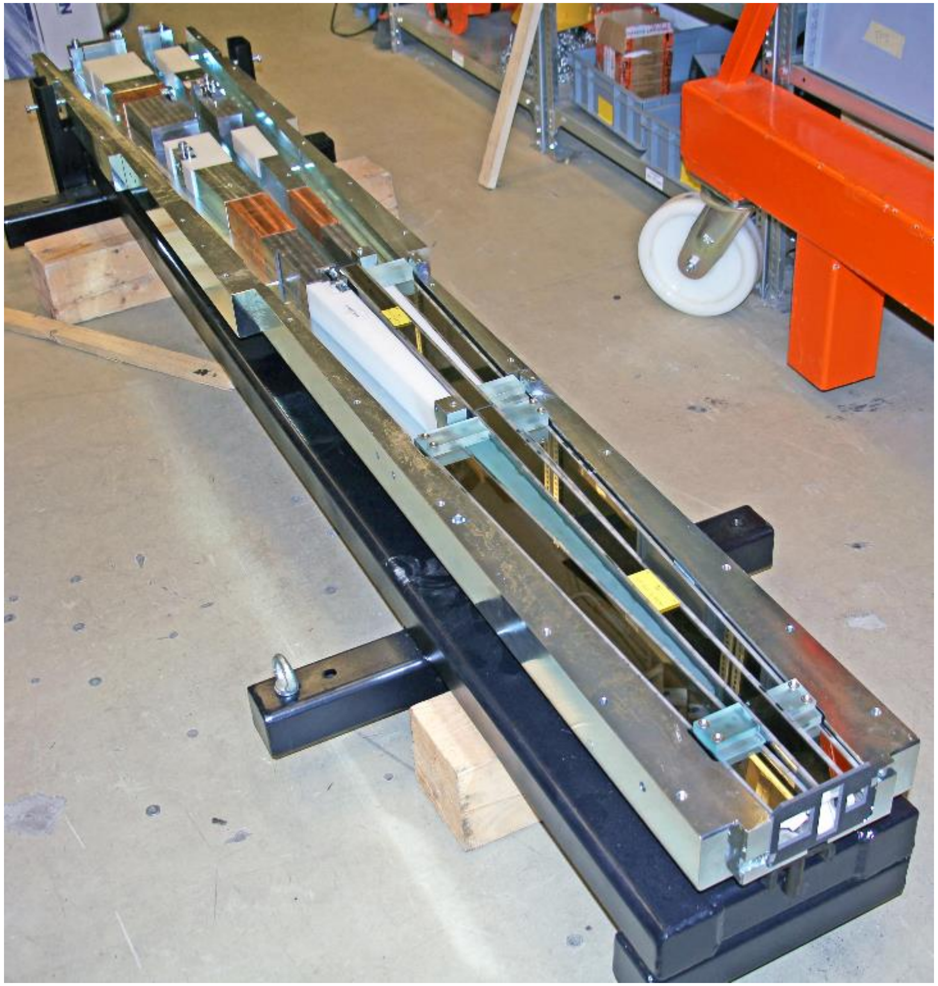
Cold Box Front Face Removed



PSU-CNS In-pile Guide Assembly



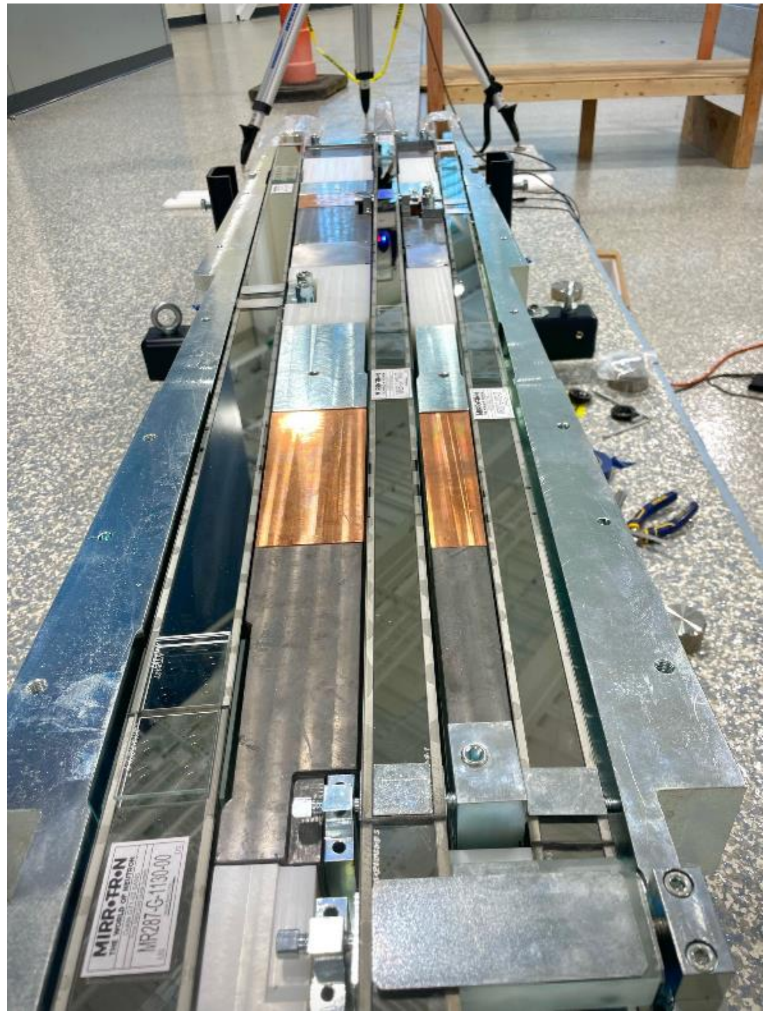
In-pile Supermirror Guides



In-pile cold neutron guide assembly – Fabrication Phase

PSU-CNS Components Delivered

In-Pile Guide Assembly – August 2023

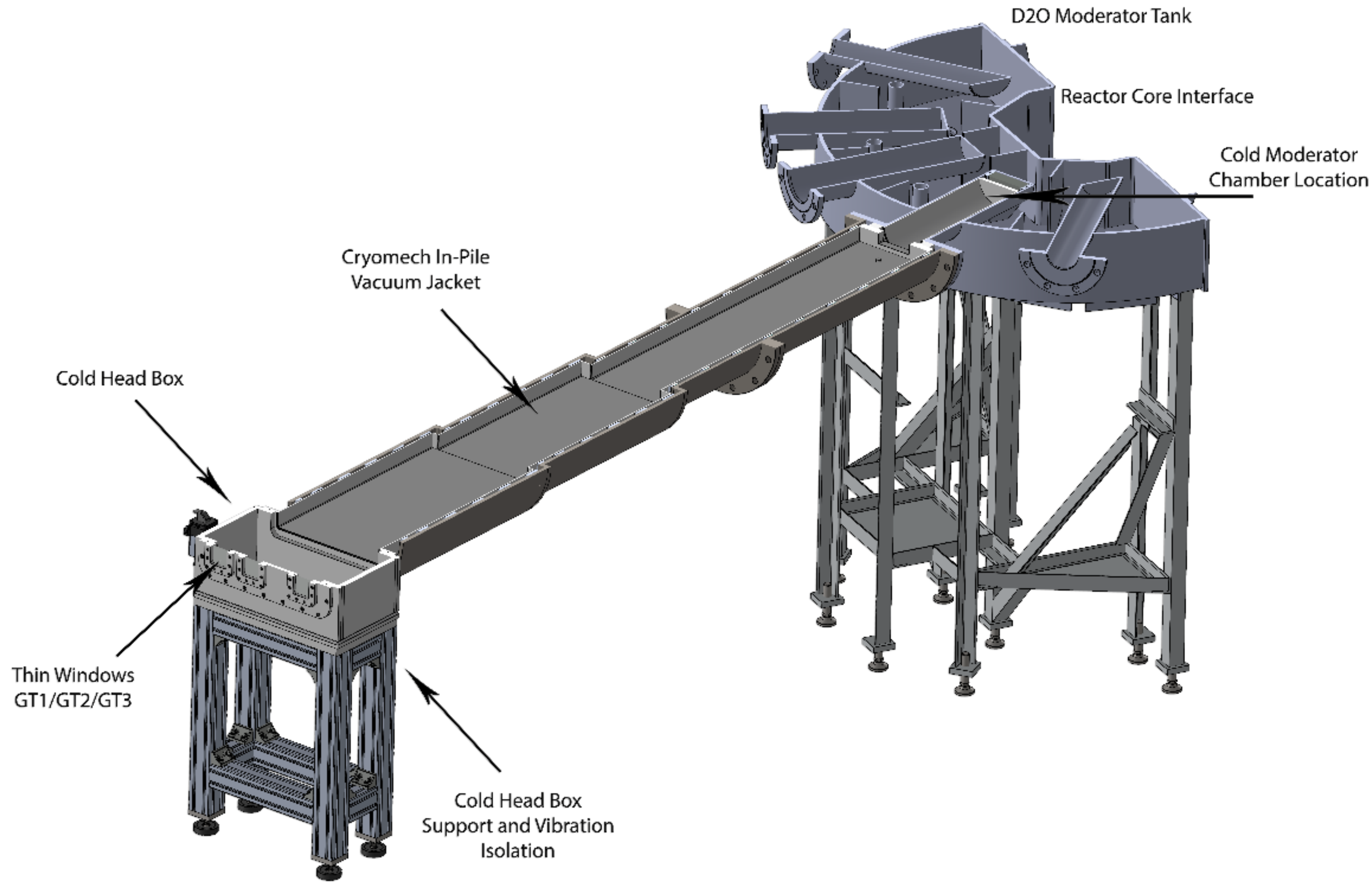


PSU-CNS Components Delivered

Cryomech Insert Components – September 2023

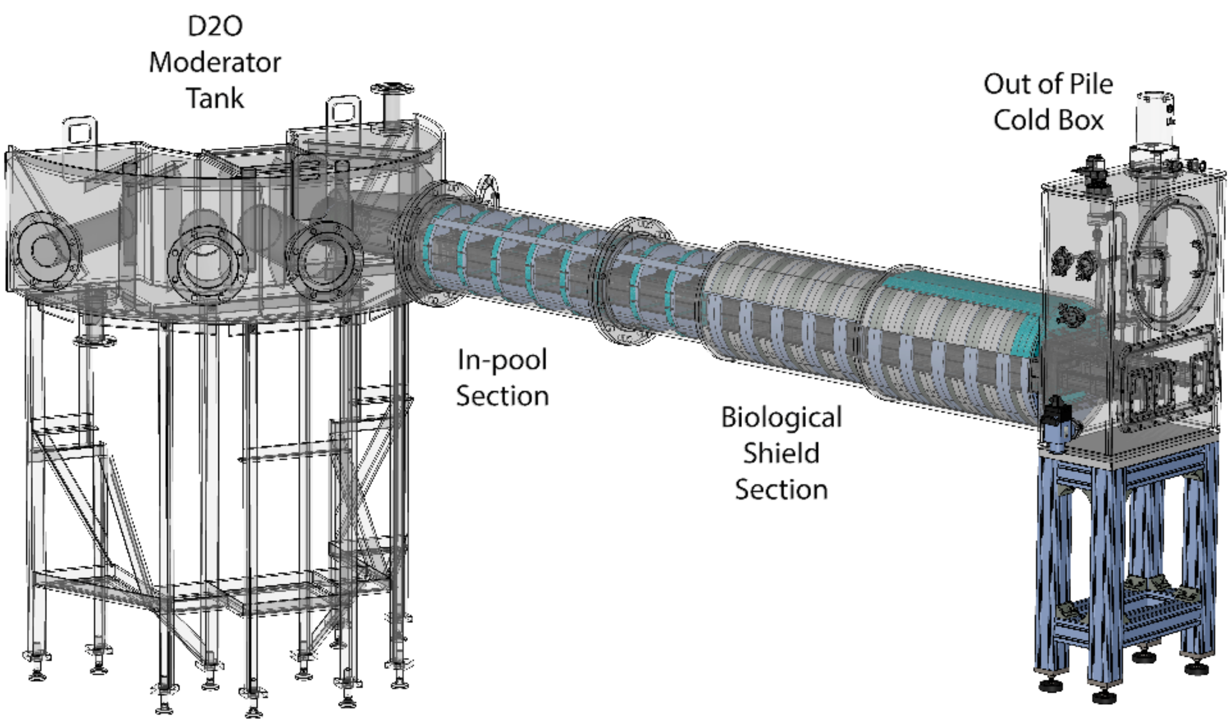
PSU-CNS Assembly

Vacuum Jacket Installed



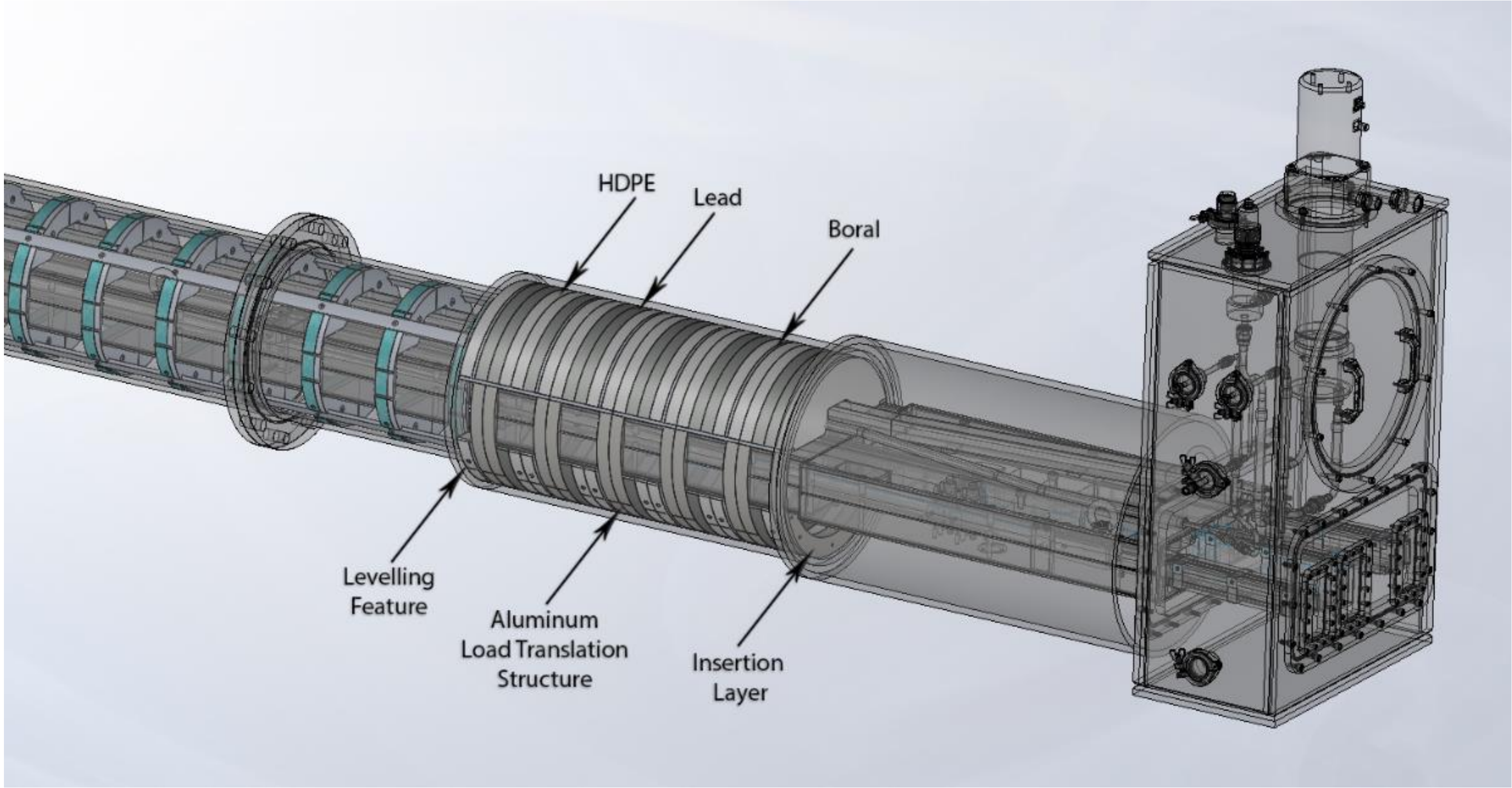
PSU-CNS Assembly Installed

Shielding and Alignment Mechanism



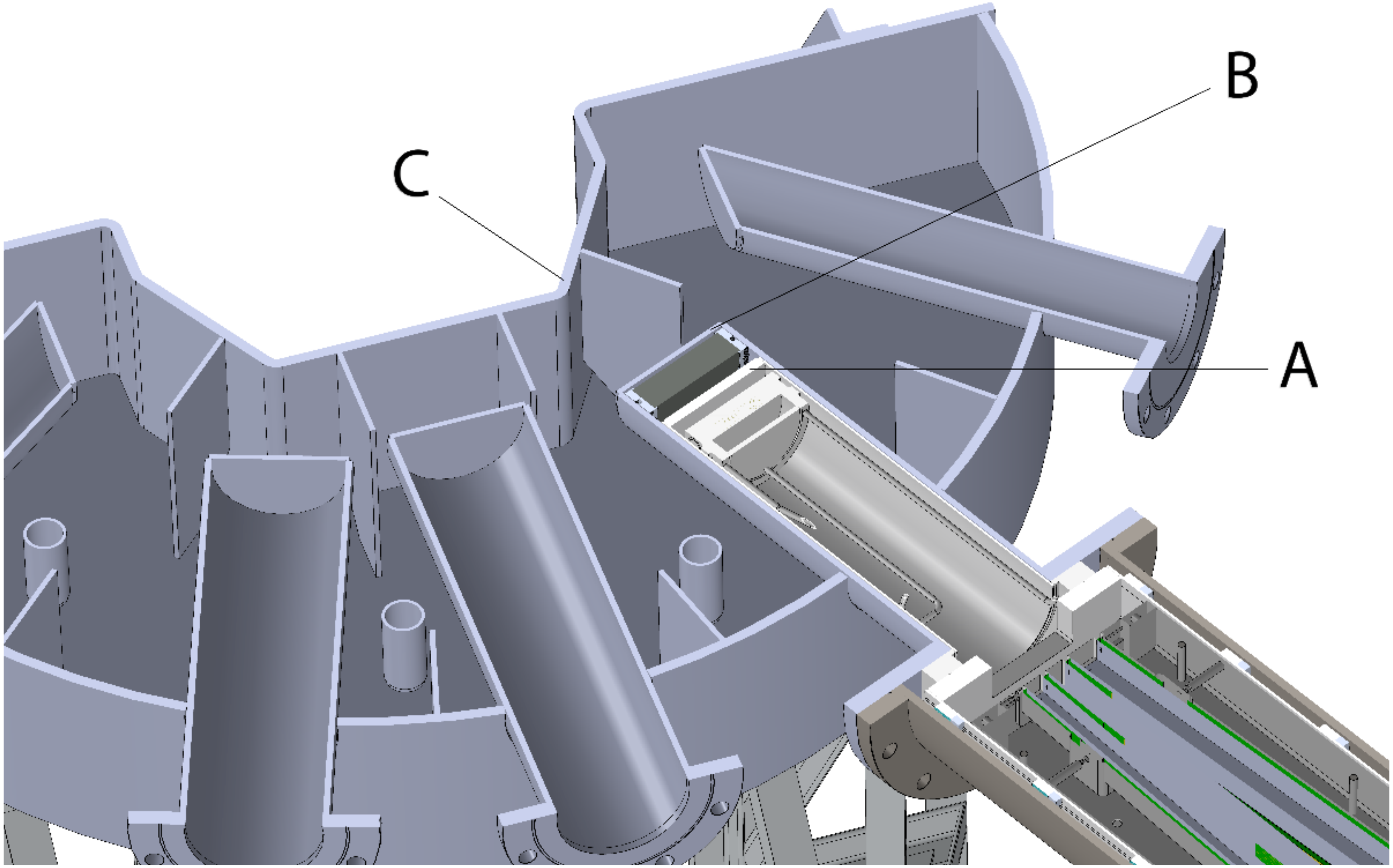
PSU-CNS Assembly Installed

Shielding and Alignment Mechanism

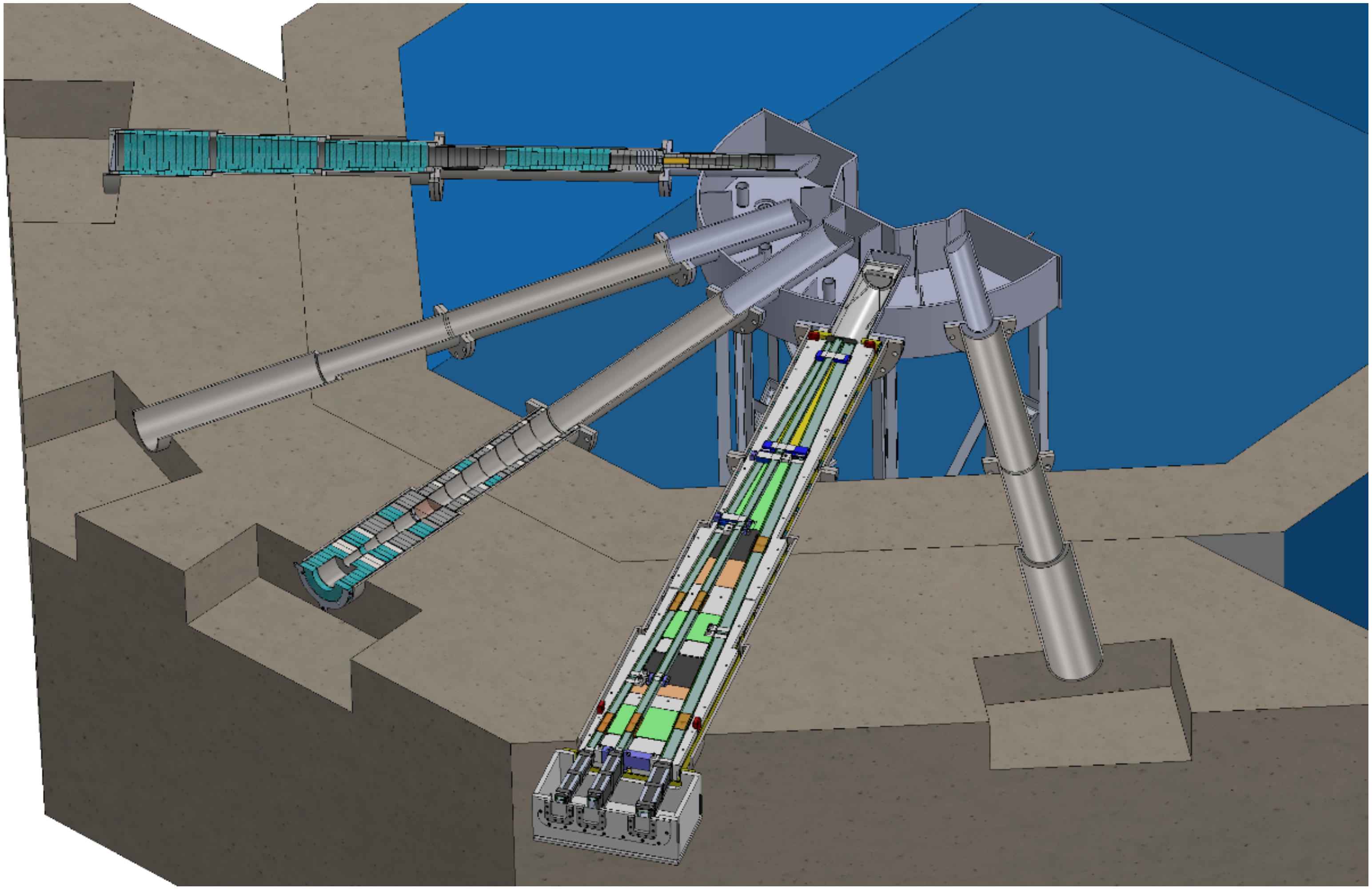


PSU-CNS Assembly Installed

Section View at D2O Tank with Optional Gamma Shield

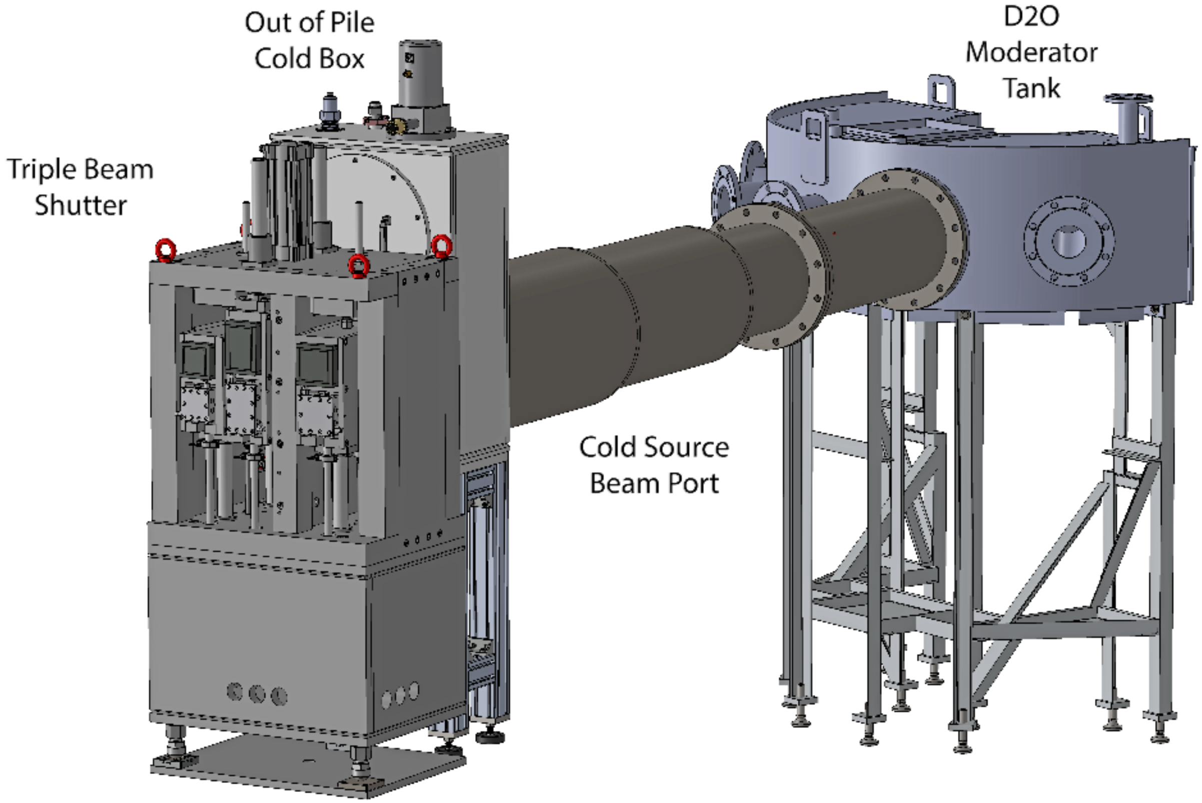


Beam Ports Section View



PSU-CNS Assembly

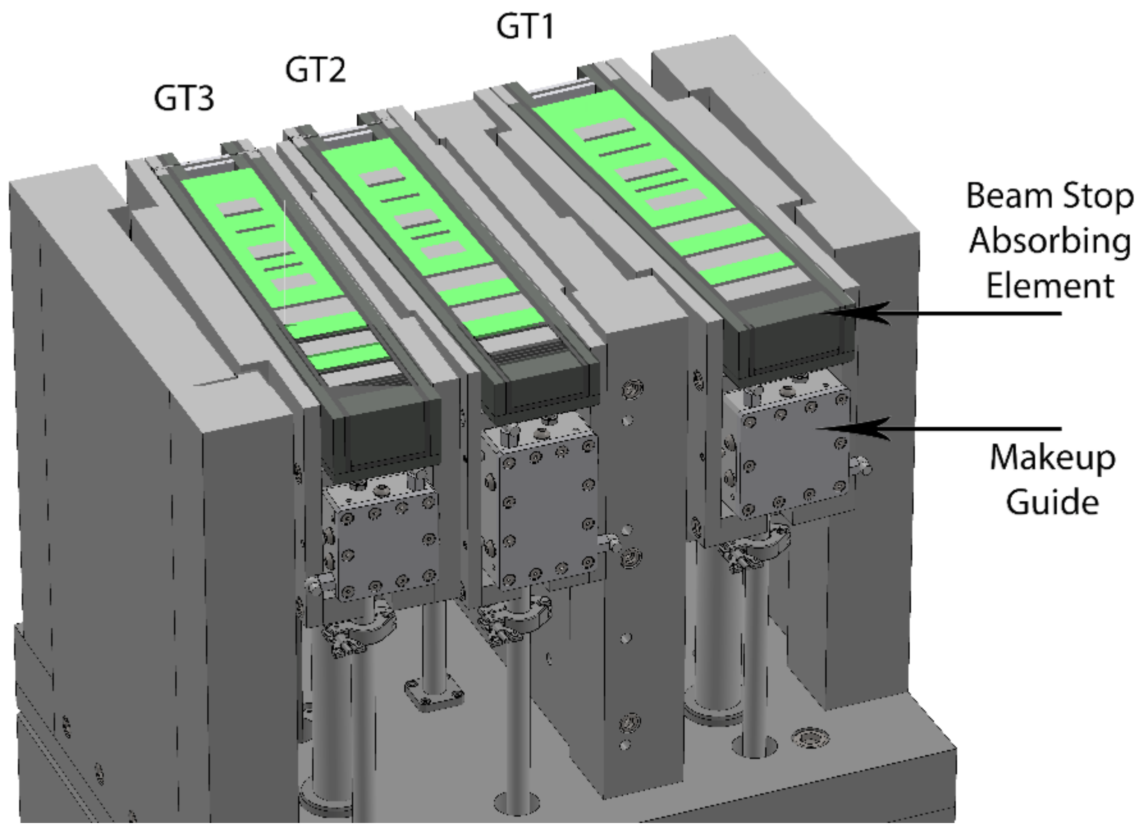
Triple Beam Shutter Installed



PSU-CNS Assembly

Triple Beam Shutter – Section View

Triple Beam Shutter

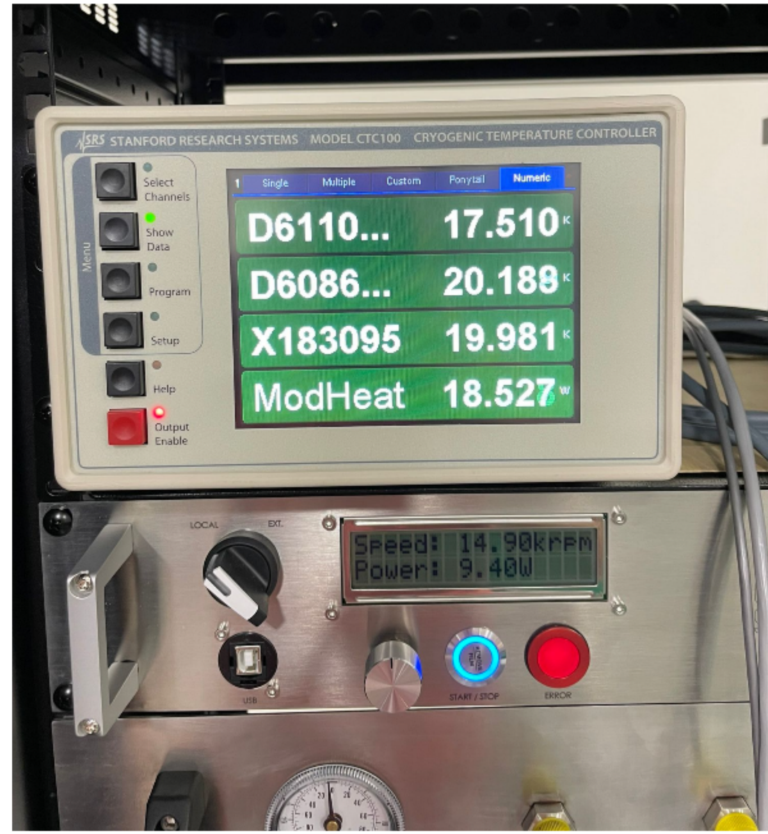


PSU-CNS Installations

Cryomech Insert Out-of-Pile Tests – October 2023

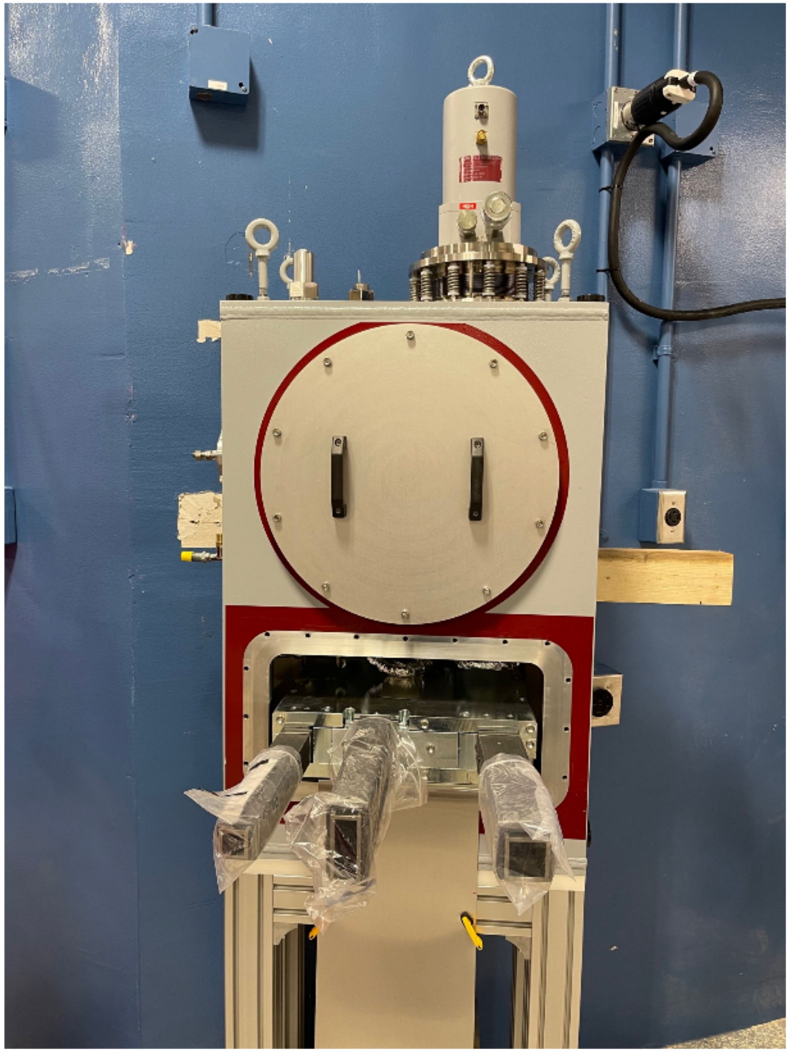
PSU-CNS Installations

Cryomech Insert Out-of-Pile Tests – October 2023



PSU-CNS Installations

Mirrotron triple in-pile super mirror neutron guide installation- October 2023



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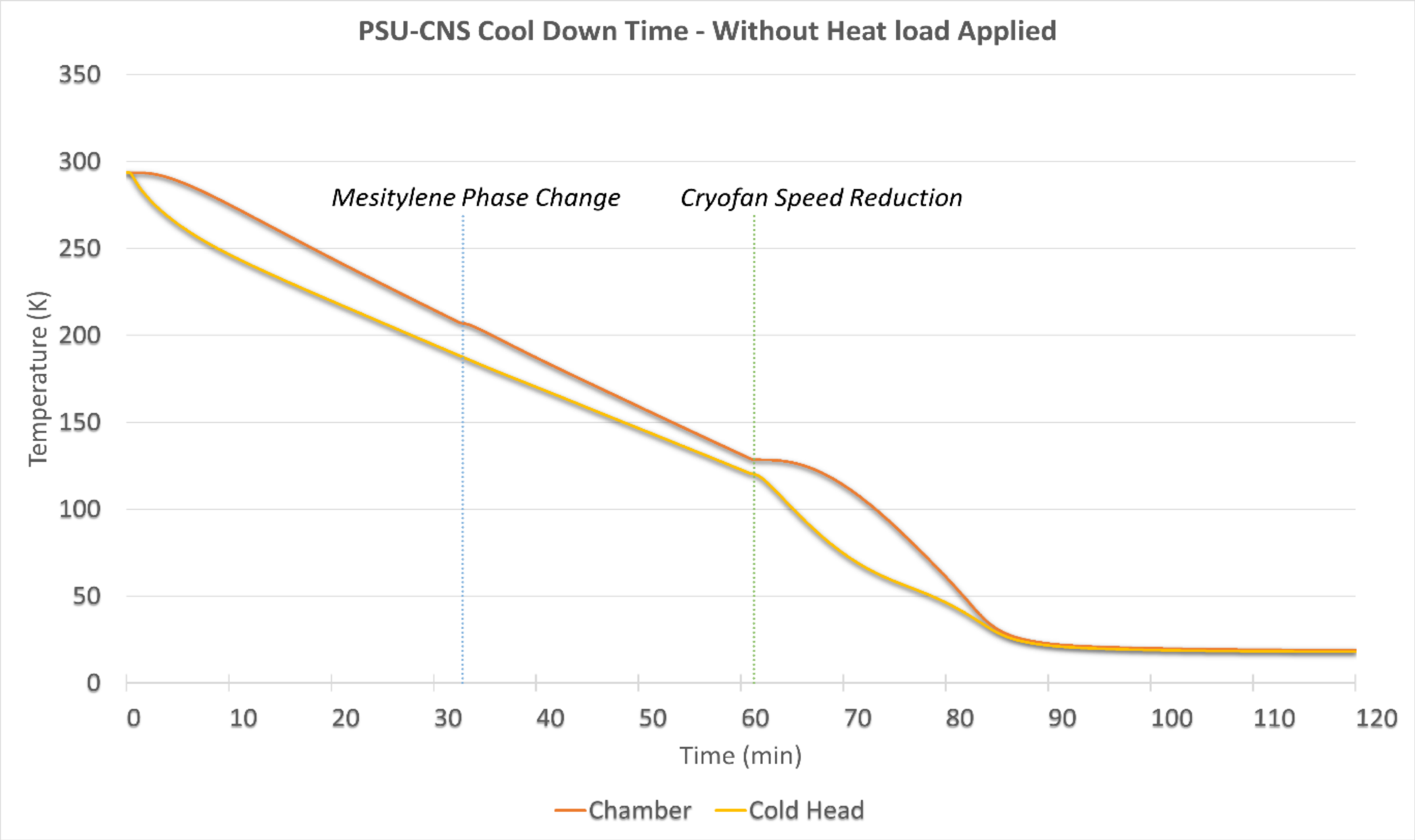
PSU-CNS Installations

Mirrotron triple in-pile super mirror neutron guide installation- October 2023

PSU-CNS Installations

Mirrotron triple in-pile super mirror neutron guide installation & testing- November 2023

PSBR – Cold Neutron Source



Neutron Beam Port Exit Flux Measurements

Measured thermal neutron flux at center of neutron beam port (GT2) at 1 MW reactor power:

1) Empty Beam Port. - **1.03×10^9 n/cm²/sec**

2) Cold neutron source system installed without mesitylene in the chamber - **1.09×10^8 n/cm²/sec**

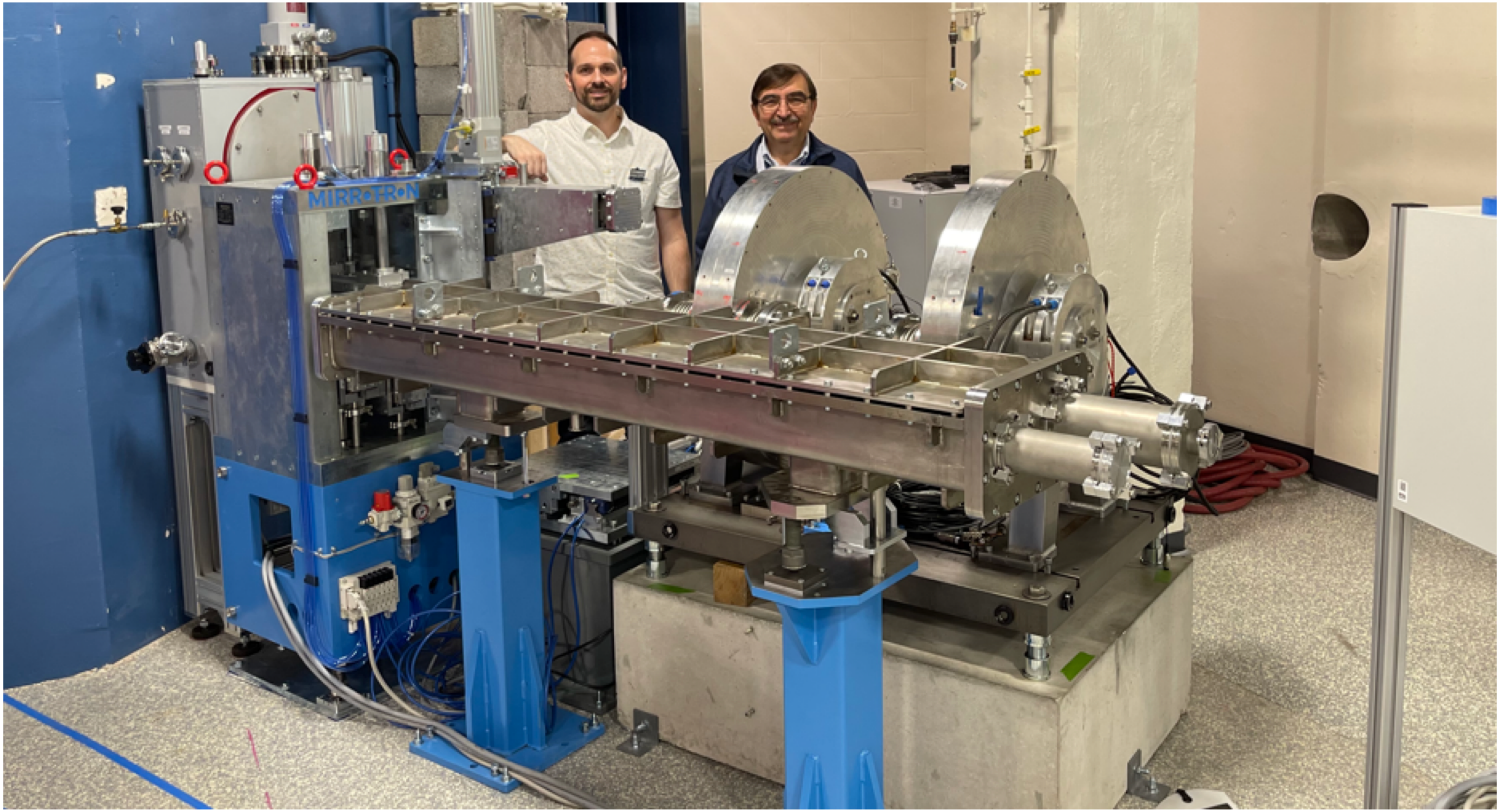
3) Cold moderator at 20K - **2.16×10^8 n/cm²/sec**

Calculated/Measured thermal neutron flux at SANS (GT1) at 1 MW reactor power:

1) Calculated neutron flux by design (Wigner Research Centre for Physics- Hungary) **1.70×10^8 n/cm²/sec**

2) Cold moderator at 20K **1.48×10^8 n/cm²/sec**

HZB BER II VSANS Installation at PSU (2024)



Conclusions

A third-generation cold neutron source was designed, built, and installed at the Penn State Breazeale Reactor. Cold neutron beams from neutron guides have low gamma and fast-neutron backgrounds increasing sensitivity in scattering experiments. In addition, detectors for neutron-capture experiments can be placed closer to the sample increasing sensitivity and making coincidence techniques feasible.

The initial use of the PSU cold neutron beam will be for the SANS facility and experiments which require a low background such as neutron-capture gamma ray analysis and basic nuclear physics research.

Acknowledgement

PSU-CNS development was funded in part by the U.S. Department of Energy (DOE), Nuclear Engineering University Program (NEUP) under Contract No. DE-NE0000640. Triple in-pile neutron guide systems and installation are fully funded by Penn State Radiation Science and Engineering Center.

Questions?