FRM II
Forschungs-Neutronenquelle
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Cryogenic System for the Ultra Cold Neutron Source (UCN Source) at the FRM II

Part 1:
Design, Performances and Unique Properties

Johann Schilcher

Ultra Cold Neutrons

- Definition
  Reflected from walls at any angle of incident, thus can be stored in traps

- Typical values

- Energy	< 300 neV
- Velocity	< 8 m/s
- Wavelength	> 100 Å

- Scientific Use
  - Investigation of the properties of the neutron and its decay
  - Lifetime of the free neutron
  - Electric dipole moment of neutron
  - Quantum states in the gravitation field of the earth
  - ……

Production of Ultra Cold Neutrons

- Cold moderators and extraction of low energy neutrons
- Curved tube, all but UCN be absorbed by the walls
- Vertical guide to separate UCNs by gravity (deceleration)
- Bladed turbine by which neutrons directed tangentially are reflected and decelerated
- Superthermal conversion with superfluid ^{4}He at 0.7K [2]
- Moderation with solid H_2 and subsequent superthermal conversion with solid D_2 at 5 K [1]
  → Method applied at FRM II.

[1] Frei, A: *Produktion von ultrakalten Neutronen mit einem festen Deteriumkonverter,* 2008.
[2] Piegsa, F. M., et al.: *New source for ultracold neutrons at the Institut Laue-Langevin*, 2014

Design and Installation of the UCN source at the FRM II

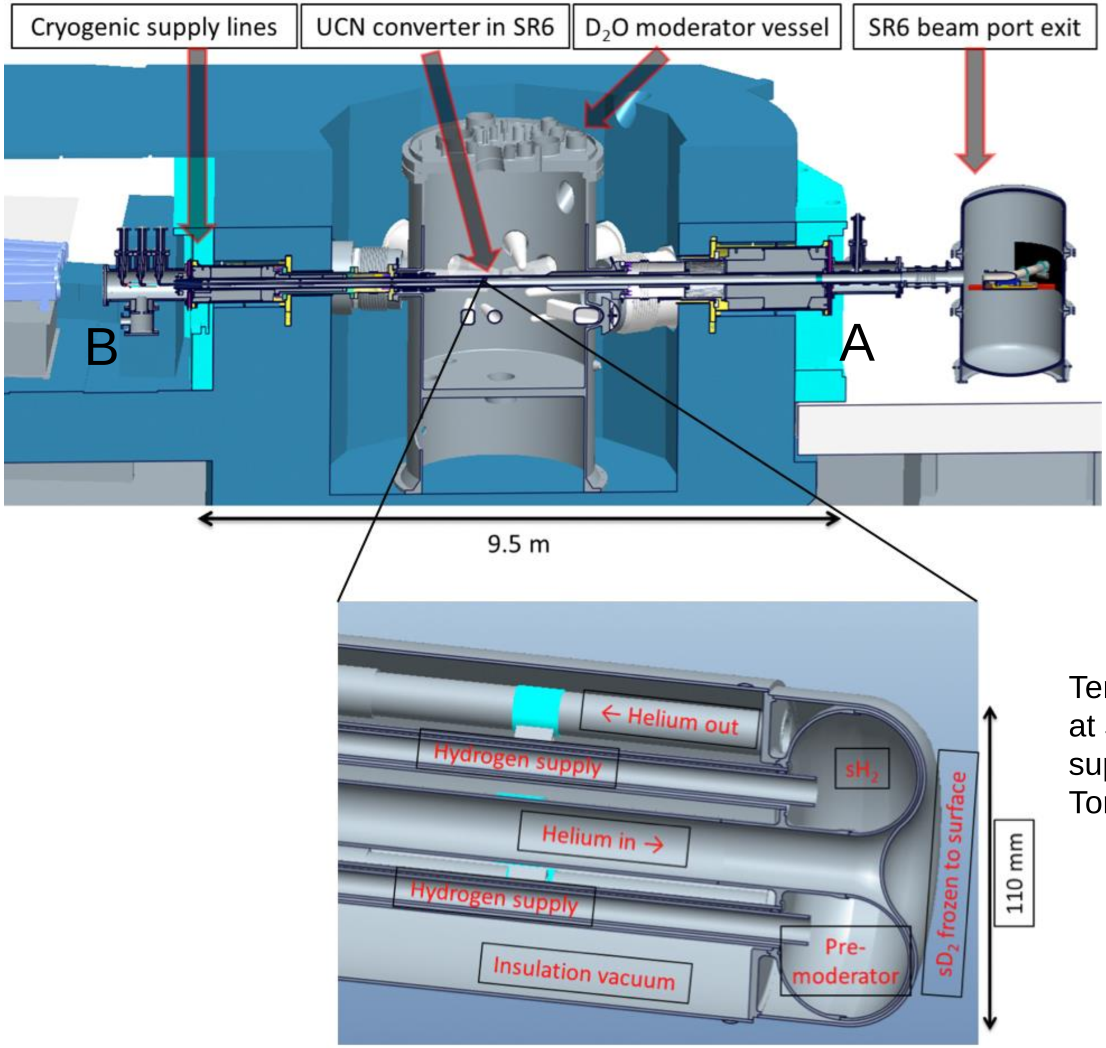

Fig. 1: Cross section of reactor and torus for UCN production

Temperature of sH_2 and sD_2 to be kept at 5 K by cooling system with supercritical Helium.
Torus is made of aluminium

Interfaces

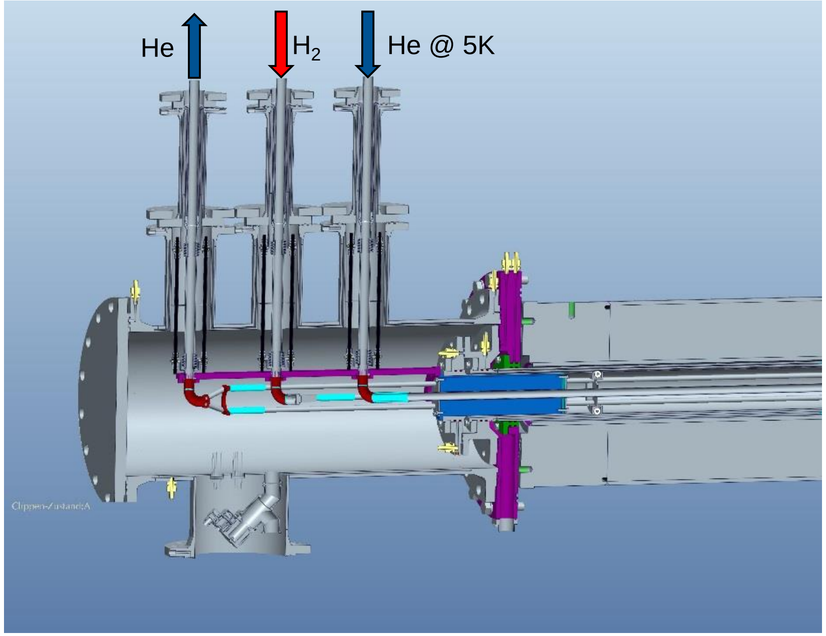

Fig. 2 - Cross Section Interface B side of the reactor

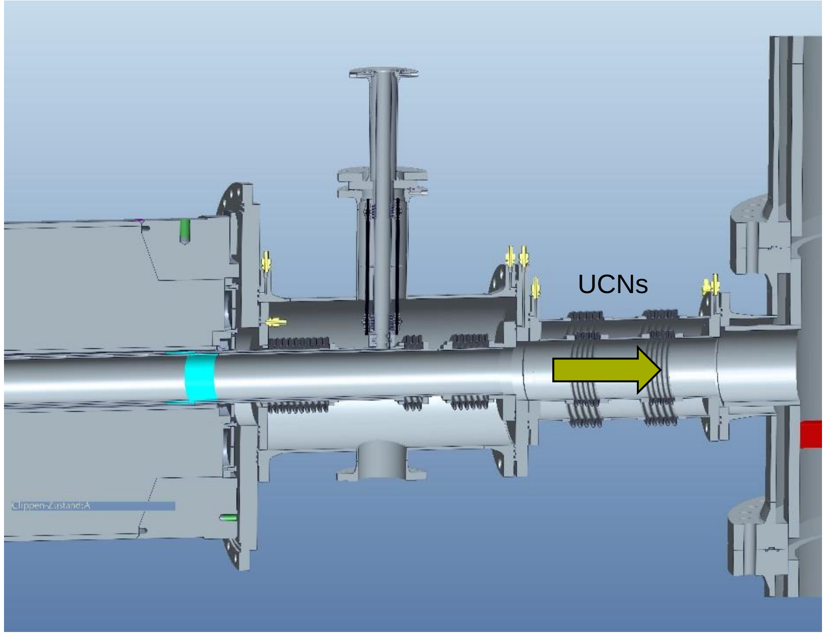

Fig 3. - Cross Section Interface A side of the reactor

Nuclear Heat Deposition on the Converter [3]

Thermal load on the materials of the convertor by

- Neutron scattering: Thermalisation, (n,α)-reactions
- Prompt γ - Contributions
- Creation of the isotope ^{28}Al, β^- decay

→ Total heat load on the converter

~500 W @ 5 K

[3] Röhrmoser, A: *Ultrakalte n-Quelle (UCN) im Strahlrohr SR-6 des FRM II. Verschiedene Studien zu Flussverhältnissen im Reaktor und nuklearer Wärmedisposition*. 2010-12-21

Converter Cooling with Liquid Helium

• Heat load	500	W
• Flowrate lHe, mass	120	g/s
• Flowrate lHe, volume	58	l/min
• Temperature feed line	5	K
• Temperature rise	1,5	K
• Pressure	0,34	MPa (3,4 bar)

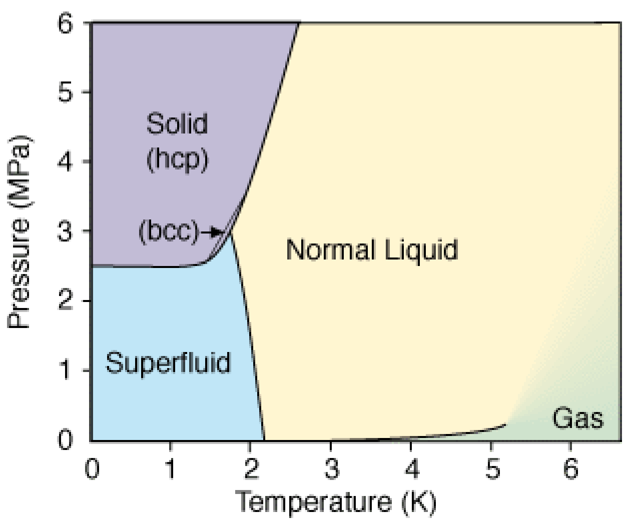

Fig. 4 - Phase diagram of Helium [Wikipedia, *Helium]*

He:
Critical pressure: 2,29 bar
Critical temperature: 5,21 K

The Refrigeration/Cooling System

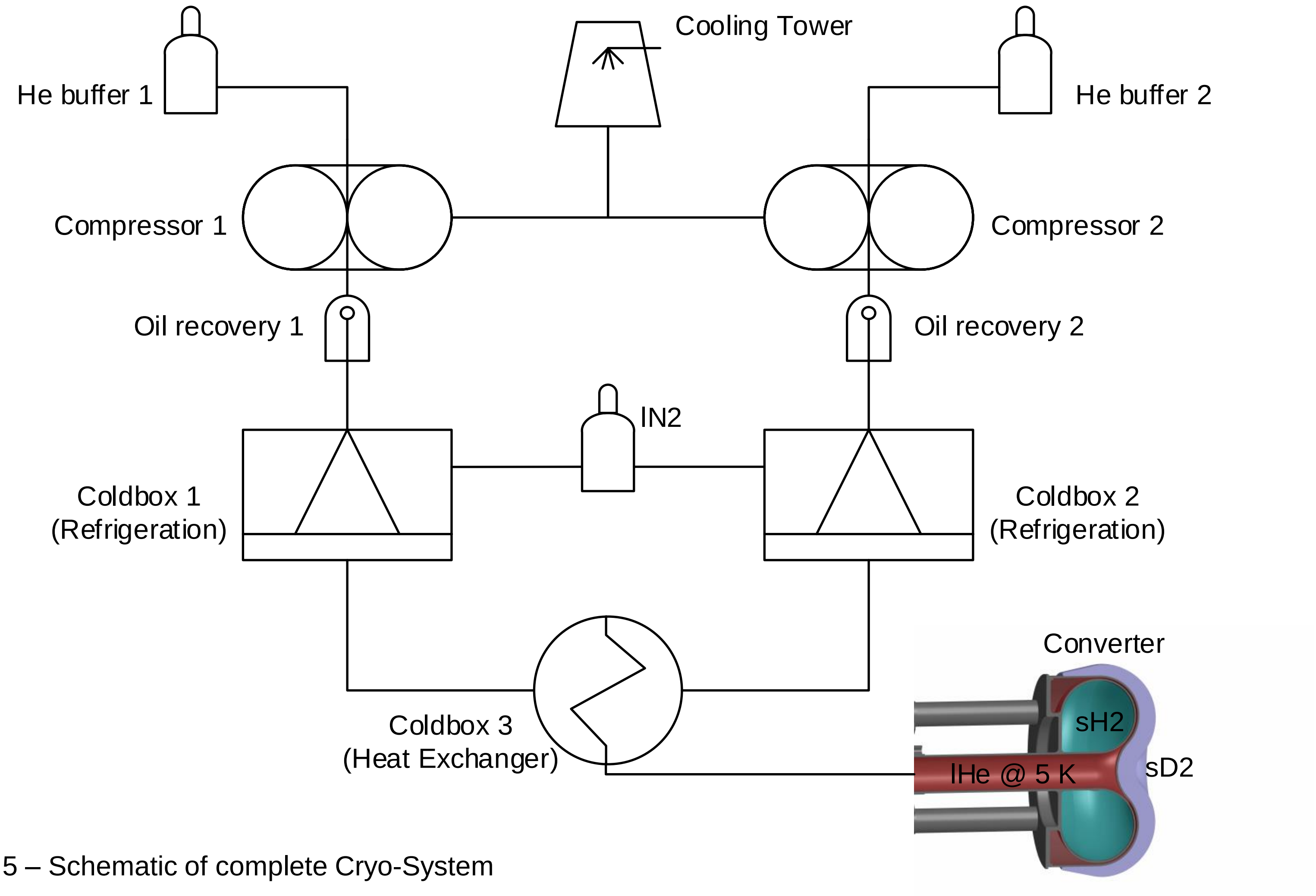

Fig. 5 – Schematic of complete Cryo-System

Specific „Nuclear“ Features

- Separation of cycles
  - Cold Box 3: heat exchanger with buffer system
  - Refrigeration cycles hermetically separated from converter cooling cycle
  - Cold Box 3 serves as barrier / containment
  - All valves physically tight (bellows)

- Isotopically pure ^4He as cooling agent in converter cycle
  - Irradiation by neutrons: ^3He-part of „normal“ helium converts/accumulates to Tritium → β decay, half-life 12.3 years
  - ^4He unaffected by neutron irradiation

- Two compressors/cold boxes each having 100% capacity
  - Redundancy / back-up
  - Provision of liquid helium to other instruments

Technical Data of Cooling System

- Compressors

- Screw compressors with variable frequency drives, single stage, oil lubricated		
- Power, each	250	kW
- Pressure	14,5	bar
- Flowrate max, each	85	g/s / 28,5 $N_{orm}m^3$/min
- Buffer size, each	15	m^3
- Buffer pressure, max	16	bar
- Cooling tower capacity	500	kW

- Cold boxes 1 and 2

- Triple stage refrigeration by lN_2, Brayton cycle (2 turbines) and 2 Joule-Thomson valves		
- Cooling power cont., each	500	W @ 5 K
- He liquification min., each	70	l/h
- LN_2 storage tank	12	m^3

Helium for Refrigeration

- Helium is liquid at very low temperatures
  Solid phase at high pressure only (>25 bar)

- Joule-Thomson with Helium
  - Joule-Thomson process simplest method for refrigeration
  - Prerequisite: Joule Thomson coefficient $\mu_{JT} > 0$.
  - Helium inversion temperature ≈ 40K, above other methods to be applied (Brayton cycle, liquid nitrogen)

$$\mu_{JT} = \left(\frac{\partial T}{\partial P}\right);\ H = \ const\ .$$

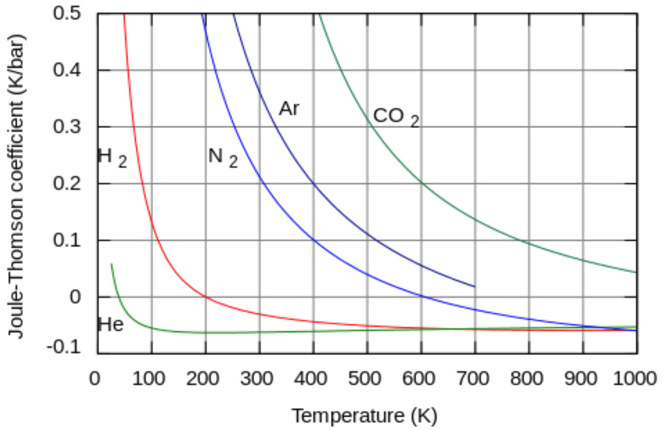

Fig. 6 – JT-coefficients at atmospheric presserure
[Wikipedia, Joule-Thomson effect]

Process Flow

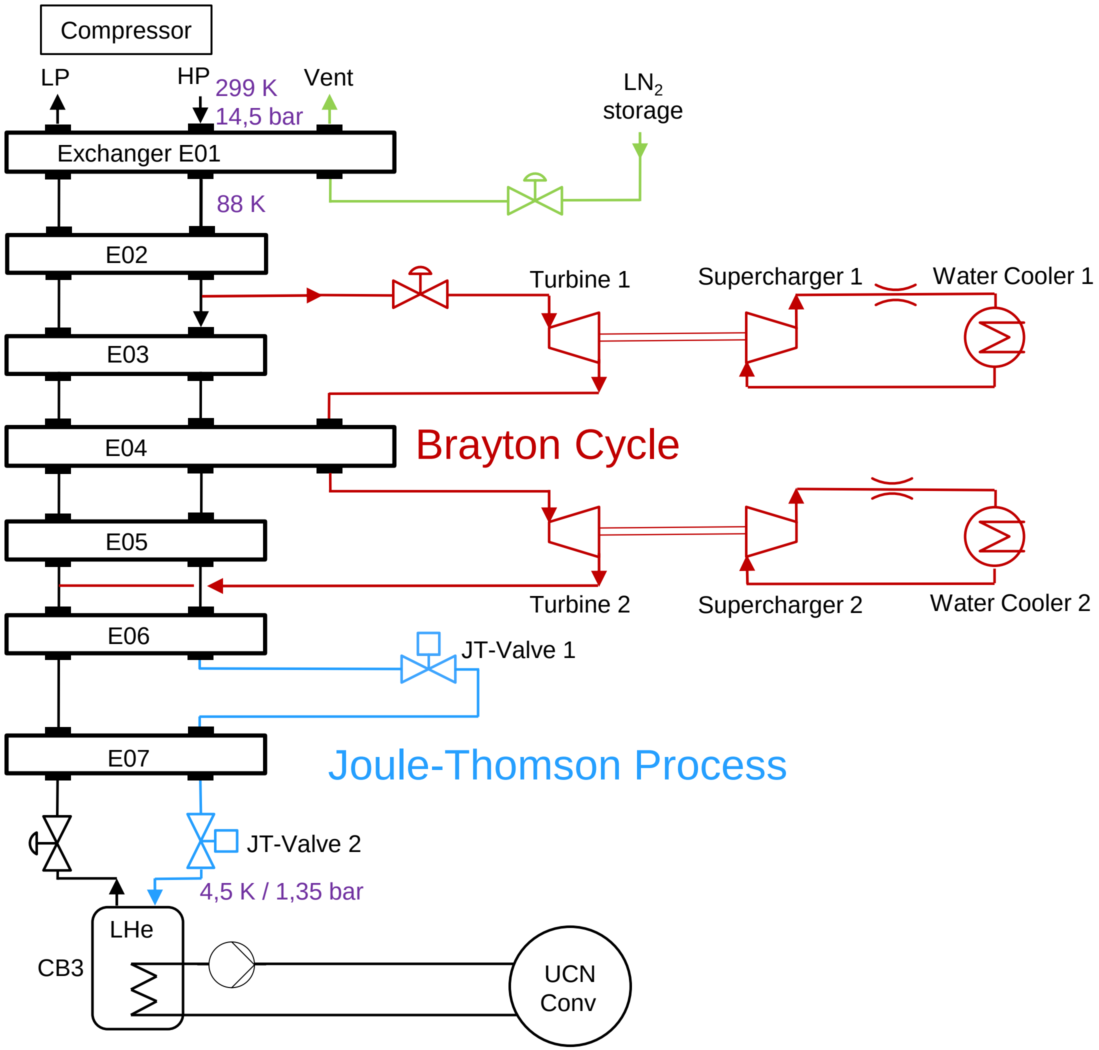

Fig. 7 – Schematic of refrigeration process flow

Cold Boxes (CAD)

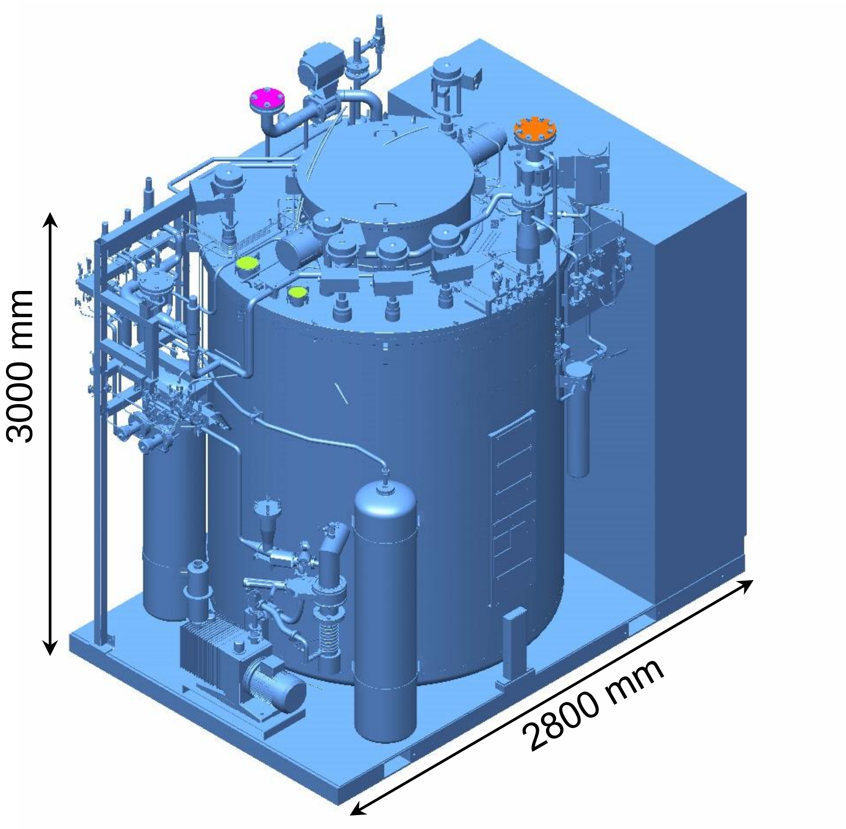

Fig. 8 - Cold Box 1&2

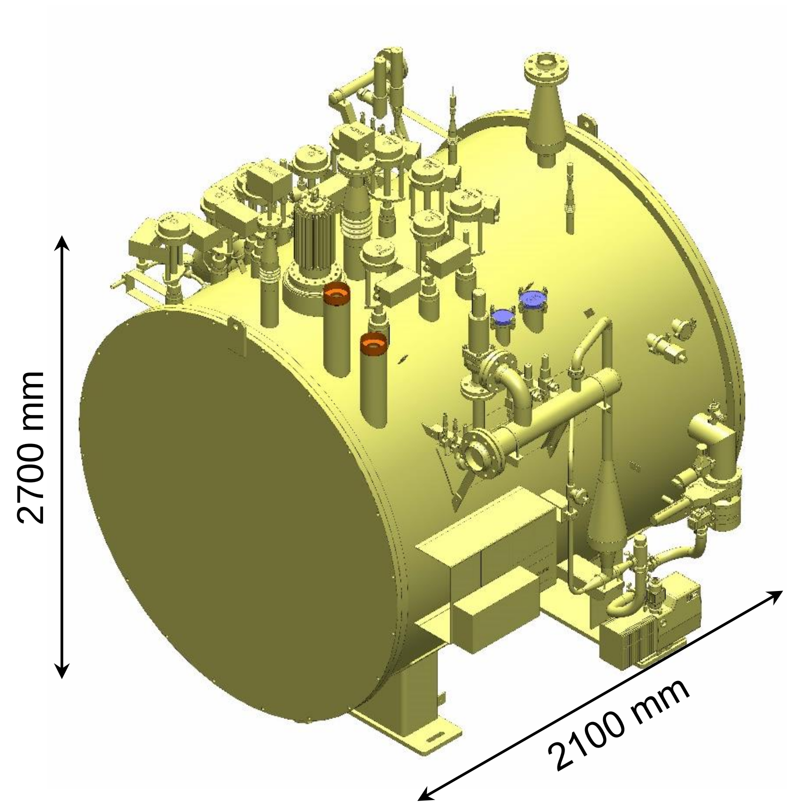

Fig. 9 - Cold Box 3

Non-Nuclear Testing

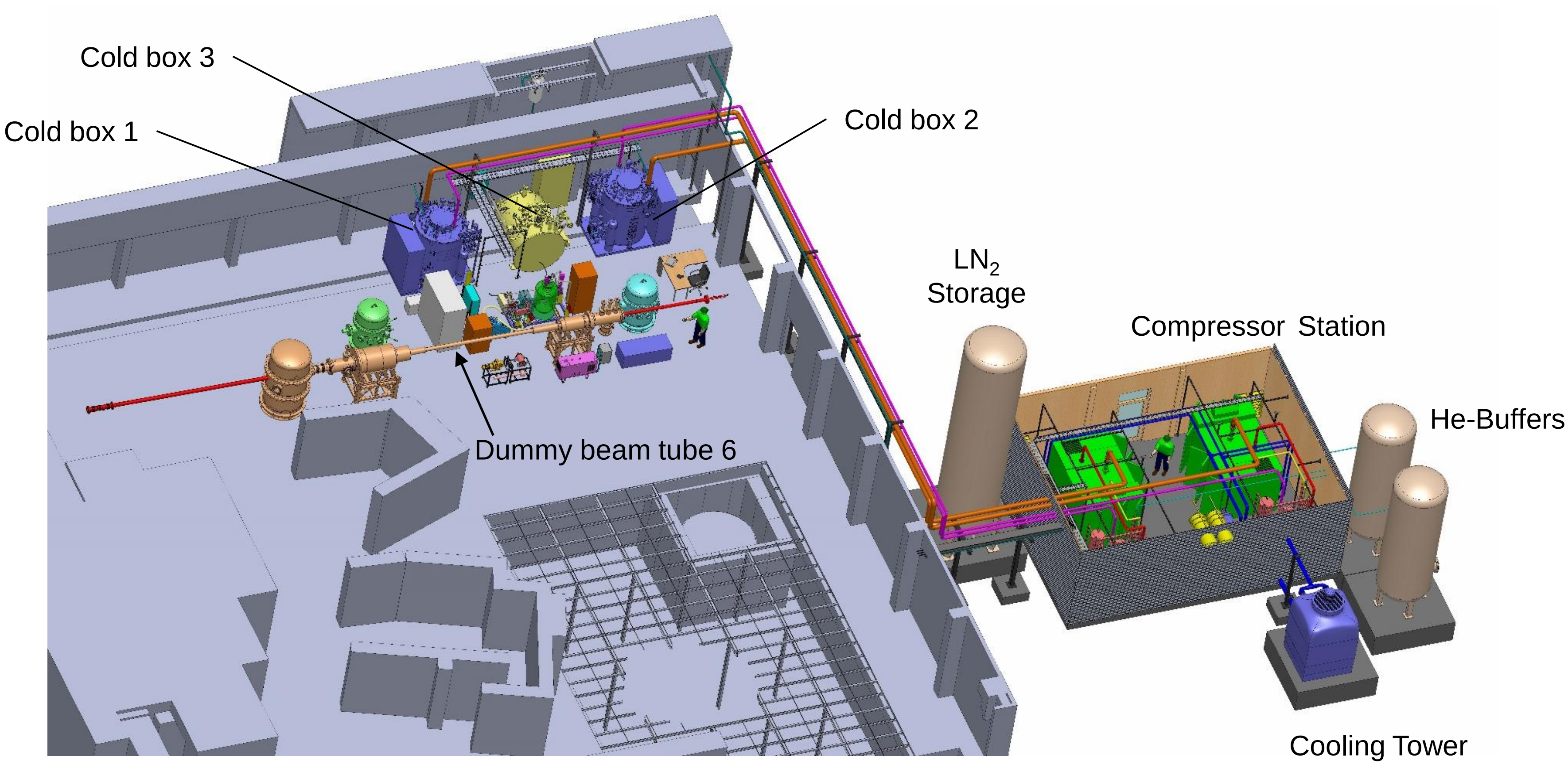

Fig. 10 - Set-up of complete system outside reactor for non-nuclear testing

Testing Set-up

Compressor Station with He-Buffers and LN_2 Storage

Testing Set-up

Cold Boxes with Dummy Beam Tube

Thank You for Your Attention!