TOM III

DESCRIPTION SUBJECT OF ORDER

PROCESS DESIGN OF THE SYSTEM FOR COOLING THE HELIUM IN POLFEL ACCELERATOR WITH ELEMENTS OF TECHNICAL DESIGN

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Contents

TERMINOLOGY

Term	Description
Cooler building	The building, inside which the main elements of the Helium Cooling System will be located – helium chiller with necessary auxiliary equipment. It will be accompanied by a storage facility for process gases (nitrogen and helium) and a local installation for cooling technical water.
Coldbox	The main component of the helium refrigerator, in which helium is cooled/liquefied and where the transfer line starts.
Control system	An autonomous control system for the Helium Cooling System in all of its operational modes.
Daresbury cooler	The helium chiller is a part of the Helium Cooling System. It is a chiller acquired by the Purchaser as part of scientific collaboration with the STFC laboratory in Daresbury.
Cryogenic Distribution System	A set of devices for transporting helium from the Helium Cooling System to the PolFEL cryomodules
Cryomodule	A device cooled by the helium supplied from the Helium Cooling System. It is the main receiver of the HCS refrigerating capacity.
Helium Cooling System	A complete, autonomous set of co-operating devices, supplying the PolFEL Helium Cooling System
Helium purification and oil separation system	A system for removing the impurities, being the result of the installation works and of the operation of the entire cryogenic system, from the process space. Such impurities may be in the form of solids, liquids or gases.
Interconnection	The location of the interconnection between two independent devices.
Interface	Part of the interconnection. A structural element of the device which serves as a connection port.
NCBJ	Narodowe Centrum Badań Jądrowych (Polish National Center for Nuclear Research)
PolFEL	PolFEL – Polish Free Electron Laser
Supplementary refrigerator	A helium cooler that is part of the Helium Cooling System. It is a chiller supporting or replacing the Daresbury chiller to obtain the required parameters of the liquid helium stream
The “purge” system	A system for filling the process space of the Helium Cooling System with helium and removing any gaseous impurities left after the installation stage.
Transfer line	Part of the Cryogenic Distribution System. A four-channel cryogenic line connecting the Helium Cooling System with the cryomodules. Its function is to transfer fluxes of helium which cools the cavities and thermal shields of the cryomodules.

1. INTRODUCTION

PolFEL (Polish Free Electron Laser) will be the first research apparatus of this type in both Poland and Eastern Europe. The technical concept of the PolFEL facility has been selected so as to meet research requirements in various spectral ranges of radiation delivered for experiments. The wavelength of the generated radiation will vary from a fraction of a millimeter, corresponding to a terahertz band, to tens of nanometers, reaching the vacuum ultraviolet range. PolFEL will be powered by a superconducting linear accelerator based on the TESLA SRF technology.

In its current construction phase, which the Contracting Party together with a consortium of 7 other research centers received funding for from the European Regional Development Fund under Action 4.2 of the Smart Growth Operational Program 2014-2020, the PolFEL accelerator will comprise a source of superconducting radio frequency (SRF) electrons, 4 accelerating cryomodules, elements of the electron beam optical system, diagnostic elements and undulators. The electron beam will be generated in the SRF source by irradiating a thin-layer metallic photocathode with short pulses of an optical laser within the range of 3-20 ps, with a wavelength of 257 nm and with the pulse energy of up to 4 μJ. The pulse repetition frequency of the optical system will be 50 kHz.

As part of an independent project of extending its functionality, financed by the European Regional Development Fund under Action 4.2 of the Smart Growth Operational Program 2014-2020, PolFEL will be further equipped with a number of laboratories and test stands, including a test stand of accelerating cryomodules. One of the main tasks to be carried out as part of this project is to provide PolFEL with an efficient Helium Cooling System which would allow the available online time of the apparatus to be extended.

Each accelerating cryomodule will include two TESLA cavities equipped with a power coupler, two higher order mode couplers, a liquid helium storage, a slow and a fast tuner and a field probe. In order to limit the heat leak, the cryomodule will be provided with thermal shields and with vacuum insulation. The cryomodules will be filled with a two-phase, superfluid helium having a temperature of 2 K and a pressure of 30 mbara. The TESLA cavities will be immersed in superfluid helium and will operate at a temperature of 2 K.

In order to ensure that PolFEL operation is stable and efficient in all of its operating modes, a dedicated Cryogenic Distribution System has been designed and thermodynamically optimized. The cryogenic system will be based on a local conversion of supercritical helium into superfluid phase and on the compression of cold vapor, allowing a recovery of the exergy of the cold gas and a reduction of the energy consumed by the System.

2. Purpose of the procedure

The aim of this procedure is to select a party, hereinafter referred to as the Contractor, who will carry out the production, delivery, assembly, and commissioning of the complete **Helium Cooling System**, abbreviated as HCS. The HCS comprises the helium chiller acquired by the Purchaser as part of a scientific collaboration with the STFC laboratory in Daresbury, United Kingdom, hereinafter also referred to as the **Daresbury chiller**, as well as all additional equipment and tanks necessary for the System's operation. The Daresbury chiller is an existing device, currently out of operation, disassembled, and stored on the Purchaser's premises. The Helium Cooling System must ensure the supply of cold helium to the PolFEL laser facility at the necessary level during all operational modes (described in this document) and during the installation and testing of the equipment.

The HCS will become part of the research infrastructure of PolFEL and will be able to meet the cryogenic needs of the PolFEL accelerator, while also being open to future expansion.

The detailed scope of delivery is described in Chapter 16, and it includes the following task:

- Task: Refreshment of the Daresbury chiller (provided by the Purchaser) and its adaptation for operation within the Polish Free Electron Laser Helium Cooling System, PolFEL, by adjusting connections, providing necessary intermediate devices, and updating the control system. The task includes the installation of the refreshed chiller in a manner that enables its use to supply the Central Distribution System (CDS) for all operational modes and the installation, testing, and commissioning of PolFEL accelerator components.

3. The PolFEL Cryogenic System

The PolFEL Cryogenic System will be filled with helium cooled to a temperature of approx. 5 K by the Helium Cooling System. The supercritical helium will be then transferred to valveboxes, in which it will pass into superfluid state due to cooling in the heat exchanger and to the Joule-Thomson throttling. Then the superfluid helium will be transferred, via a jumper connection, to an appropriate cryomodule, in which it will be vaporized due to heat inleaks, and then it will be transferred, as cold low-pressure He vapor, to the HSC.

The PolFEL Cryogenic System comprises three main elements

- The Helium Cooling System (HCS), which provides the cooling power of a required mass flow of supercritical helium and cold He gas to the valveboxes. The main components of this System are: helium refrigerator, a liquefied nitrogen tank, a liquefied helium tank and a helium gas storage.
- The Cryogenic Distribution System (CDS), which delivers supercritical helium to the valveboxes, where helium becomes superfluid and is transferred further to the cryomodules. The CDS also allows the low-pressure He vapor to be returned to the Helium Cooling System. Also, owing to the auxiliary lines, it ensures that helium can be removed from the installation in the case of a pressure rise and that the installation can be purged.
- Elements of the laser comprising the gun cryomodule – an SRF injector, cryomodules 1-4.

The PolFEL Cryogenic System provides helium on three temperature levels:

- 40 K – 80 K to meet the demand of the cryomodule thermal shields and the Cryogenic Distribution System
- 5 K to meet the demand of the power couplers for the accelerating cryomodules and for the gun cryomodule
- 2 K to meet the demand of cryostating the resonance cavities of the cryomodules.

The PolFEL cryomodules are independent cryogenic units and will be cooled in parallel with the use of the Cryogenic Distribution System. They will be supplied with cryogen from dedicated valveboxes.

The Helium Cooling System will provide helium in two thermodynamic states: supercritical (5 K, 4 bara) and in cold gaseous state (40 K, 13 bara). Helium gas will be used to cool the thermal shields of the cryomodules and the Distribution System itself. Superfluid helium having the temperature of 2 K, which is required to cryostate the SRF cavities, will be generated inside the valveboxes dedicated for each cryomodule. The cryomodules will be cooled in the following manner: supercritical helium will flow inside the transfer line into the valveboxes located in the vicinity of the cryomodules. Inside the valveboxes, the helium flux will be redirected from the main transfer line. Supercritical helium will be in the first place delivered to the cryomodules in order to thermalize the power couplers at the temperature of 5 K. After the thermalization, supercritical helium will flow back to the valveboxes in which it will be pre-cooled to 2.2 K in a heat exchanger and subsequently throttled in the JT valve into a the superfluid state required to cryostate the SRF cavities. The superfluid helium thus obtained will flow to the cryomodules, in which it will vaporize, receiving the heat generated in the cryomodules. After being vaporized, helium at a pressure of 30 mbara and a temperature of 2 K will flow back to the valveboxes. It will subsequently pass through the low-pressure part of the heat exchanger and finally, through the transfer line, will reach the Helium Cooling System. Helium vapors are returned to the Helium Cooling System under a pressure of 27 mbara and at a pressure of approx. 4 K. Subsequently, they are compressed to a pressure of approx. 300 mbara with the use of vacuum pumps located in the coldbox. Such a solution will allow the cooling capacity of cold helium vapors to be recovered prior to their compression to the atmospheric pressure in the set of warm vacuum pumps.

The Helium Cooling System will provide supercritical helium to 4 superconducting cryomodules provided with the RF cavities. Helium will be delivered to the valveboxes, and subsequently to the cryomodules, through a multichannel transfer line. The Cryogenic Distribution System will also comprise warm auxiliary lines. The auxiliary lines will serve 4 funcitons: to remove gases from the CDS, to supply helium for washing the installation, to remove helium from the installation after a bleeding event (opening of the safety valves) and to ensure a helium atmosphere for valves with helium shields.

A schematic diagram of the PolFEL Cryogenic System is shown in Fig. 1. A simplified piping and instrumentation diagram (P&ID) is shown in Fig. 2

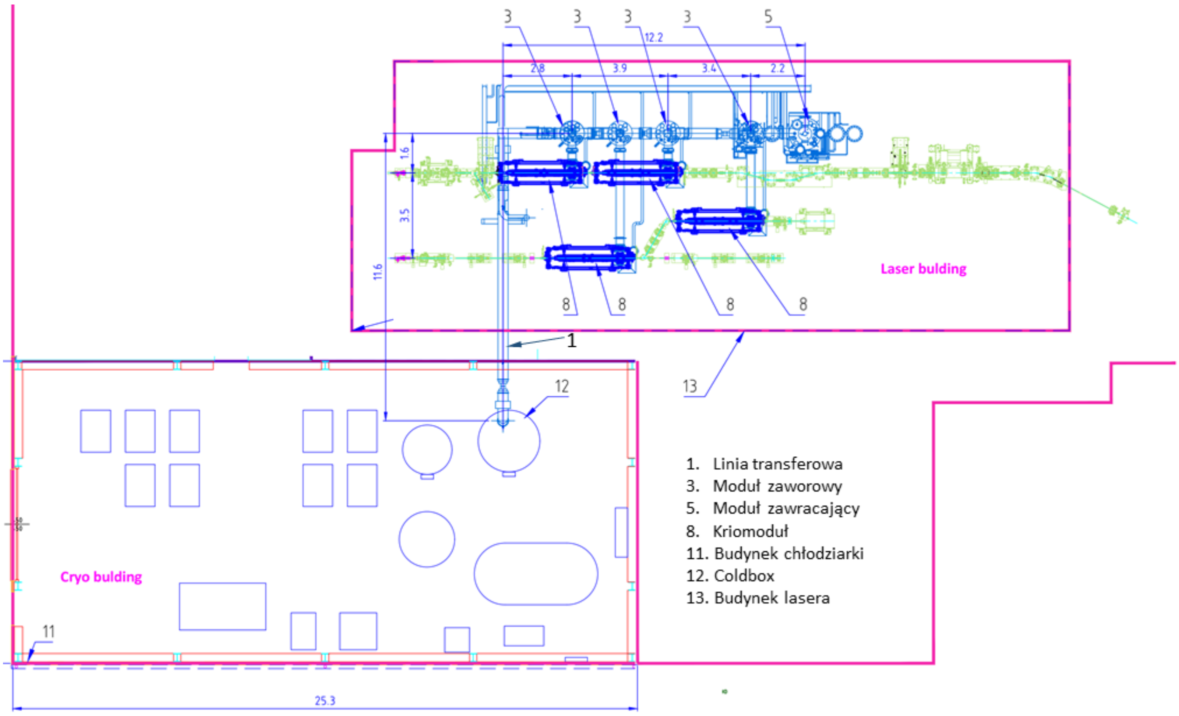

Fig. 1 Diagram of the PolFEL Cryogenic System: 1- transfer line, 2 –valvebox, 3 – return box, 8 – kriomodule, 11 - Cooler building, 12- Coldbox, 13 – Laser building (all values in meters)

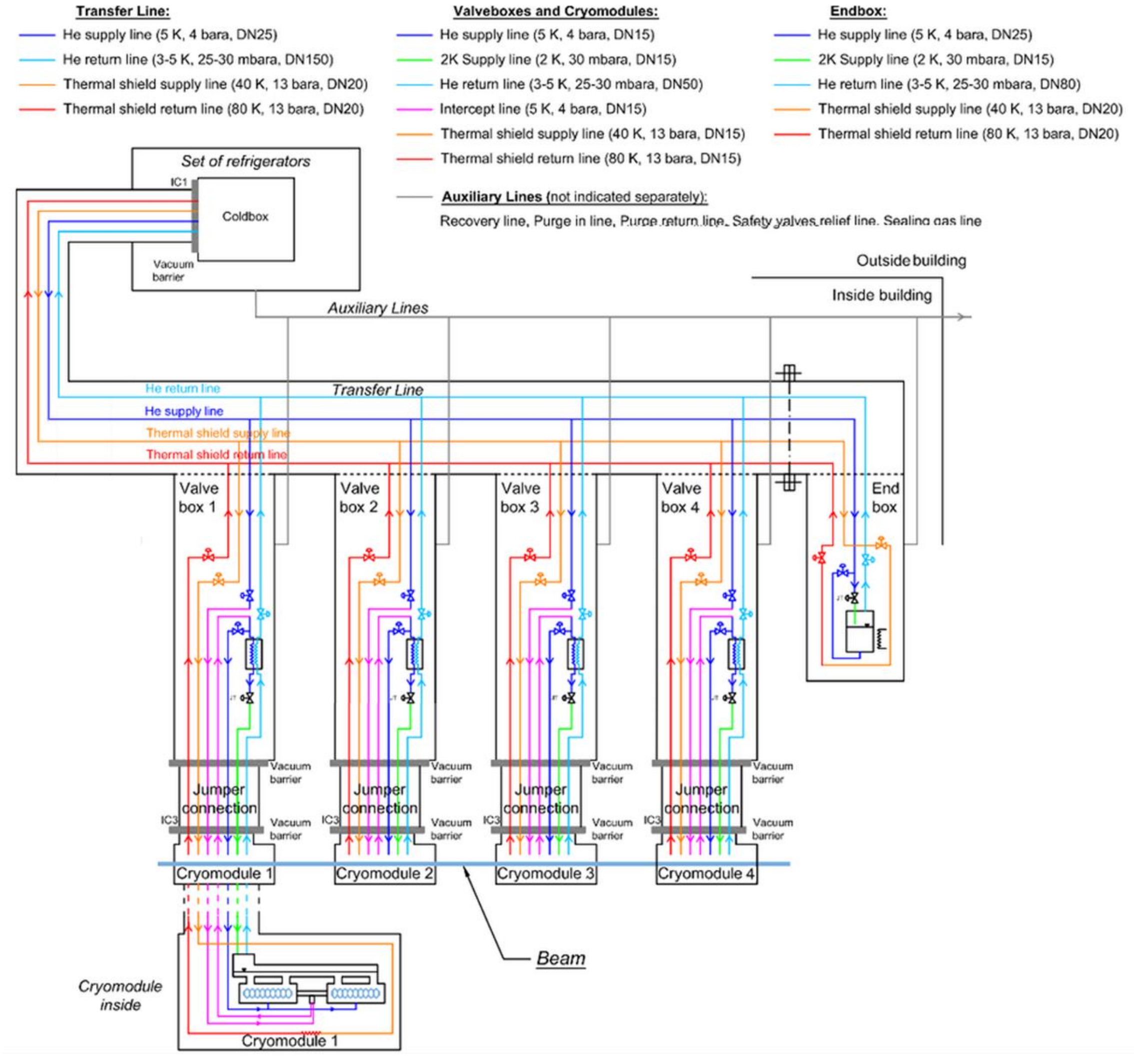

Fig. 2 P&ID diagaram

4. Cryogenic Distribution System (CDS)

4.1. General information

The Cryogenic Distribution System will be responsible for supplying and returning helium between the Helium Cooling System and the cryomodules, as well as for the conversion of supercritical helium to superfluid state. The main components of the Cryogenic Distribution System will be as follows (Fig. 1, Fig. 2):

- Transfer line
- Valveboxes
- Endbox
- Auxiliary lines

The CDS will provide helium to the cryomodules in three thermodynamic states:

- superfluid helium at a pressure of 30 mbara and a temperature of approx. 2 K
- supercritical helium at a pressure of 4 bara and a temperature of approx. 5 K
- gaseous helium at a pressure of 13 bara and a temperature of approx. 40 K

The supercritical helium at the temperature of 5 K will be used to thermalize the power couplers of the cryomodules; the superfluid helium will be used to cryostate the resonance cavities of the accelerator, and the 40 K helium will be used to cool both the thermal shields of the cryomodules and the transfer line. As helium must be delivered to the cryomodules in three different thermodynamic states, its fluxes will be transferred from the Helium Cooling System through a 4-channel transfer line comprising two supply lines and two return lines (for the supercritical and gaseous helium fluxes). Helium will change its state from supercritical to superfluid in the valveboxes, directly before it is supplied to the cryomodules.

4.2. TRANSFER LINE

The transfer line will transport helium in different thermodynamic states from the Helium Cooling System to the valveboxes. The design includes two sections of the transfer line with a shared vacuum insulation:

- The **bridge section of the transfer line**, which will start with interconnection IC1 of the HCS. It will then extend along a trestle bridge at a height of approx. 7.5 m, from where it will be introduced onto the roof of the laser building. This section will end in the vicinity of the entry opening to the building, provided in the roof.
- The **building section of the transfer line**, which will start at the entry opening in the roof of the laser building, and will lead downwards into the interior of the hall, where it will be connected to the gun module and extend further to the endbox. This section will comprise all of the valveboxes.

Both sections of the transfer line will consist of four process lines protected from heat inleaks by a shared thermal shield provided inside the vacuum tank. The four process lines are:

- a **supercritical He supply line** – this line transfers the flux of supercritical helium at the temperature of 5 K and the pressure of 4 bara from the Helium Cooling System to the valveboxes;
- a **He return line** – this line transfers He vapors at a pressure lowered to approx. 30 mbara and a temperature of approx. 4 K from the valveboxes to the Helium Cooling System;
- a **thermal shield supply line** – this line transfers gaseous He at a temperature of approx. 40 K and a pressure of approx. 13 bara from the Helium Cooling System to all the elements of the Cryogenic Distribution System in order to cool the thermal shields;
- a **thermal shield return line** – this line transfers gaseous He at a temperature of approx. 80 K and a pressure of approx. 12.5 mbara from the CDS thermal shields to the Helium Cooling System. This line shall be in thermal connection with all the thermal shields of the Cryogenic Distribution System.

An illustrative cross-section of the transfer line is shown in Fig. 3. The design parameters of the transfer line and of the process lines are shown in Tab. 1

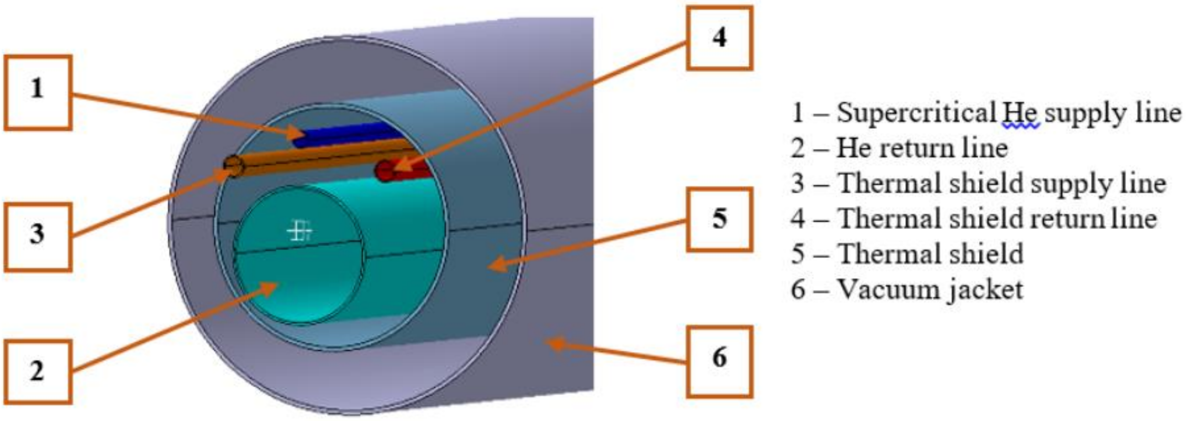

Fig. 3 Illustrative cross-section of the transfer line

No.	Term	Size	Outer diameter [mm]	Design pressure [bara]	Nominal pressure [bara]	Nominal Temperature [K]
1	Supercritical He supply line	DN25	33.7	18	4	5
2	He return line	DN150	168.3	5	0.025 – 0.03	3 – 5
3	Thermal shield supply line	DN20	26.9	18	13	40
4	Thermal shield return line	DN20	26.9	18	13	80
5	Thermal shield	DN300	300	-	-	40 – 80
6	Vacuum jacket	DN400 – 450	406.4 – 457	1.5	1x10E-6	300

Tab. 1 Design parameters of the transfer line

4.3. Interconnection IC1 between the HCS and the transfer line

The transfer line is connected to the coldbox of the refrigerator in the location designated as IC1 in Figs. 4.3.1 and 4.3.2. At this stage, the location of interconnection IC1 remains an assumption of the Contracting Entity, intended only to demonstrate the concept of connecting the transfer line with the HCS. As the location of the IC1 point depends primarily on the design of the refrigerator, the Contractor supplying the Helium Cooling System is obliged to define the location of the interconnection, based on the available space in the refrigerator building and on the technical possibilities of constructing the transfer line. The Contractor supplying the Helium Cooling System shall use the data provided in this specification and own design solutions to define the location of the IC1 point and provide this information to the Contracting Entity during the Preliminary Design Review.

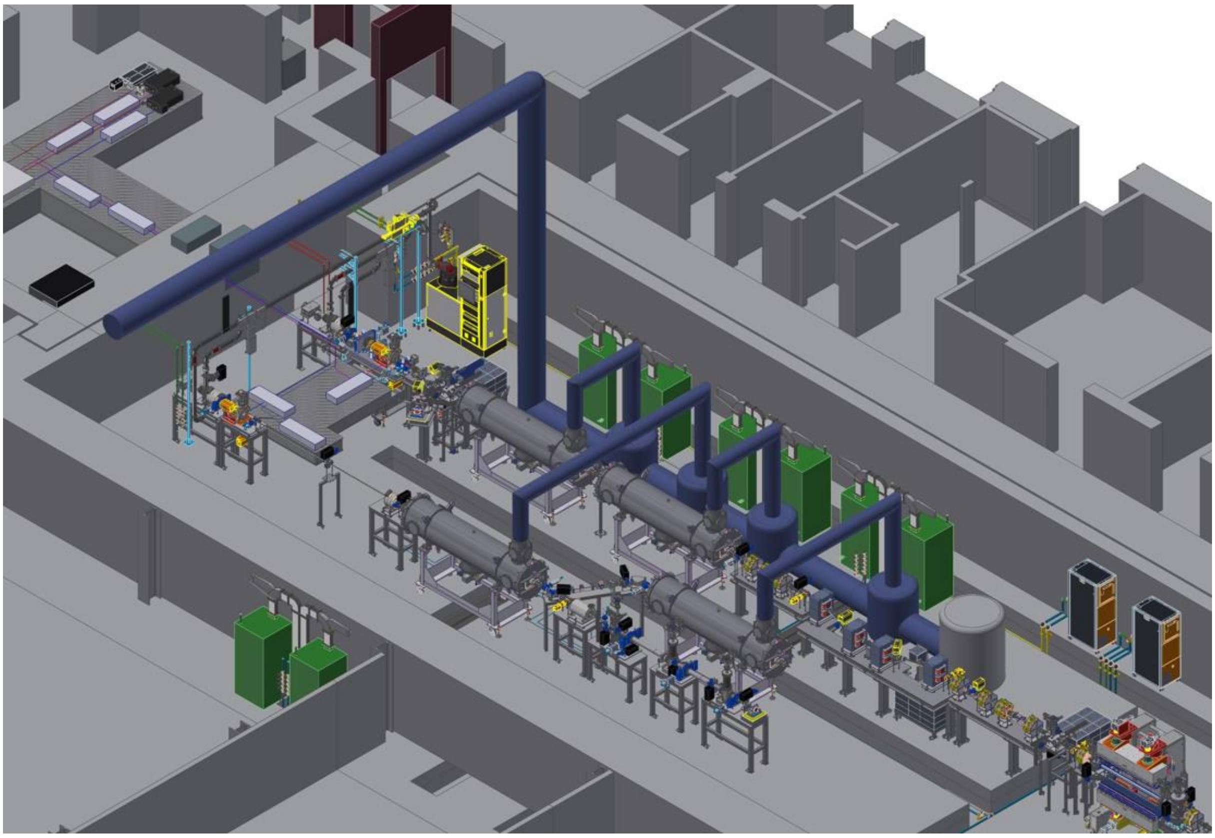

Fig. 4 View of POLFEL "cold" componnets

A potential location of interconnection IC1 in the refrigerator building is shown in Fig. 5.

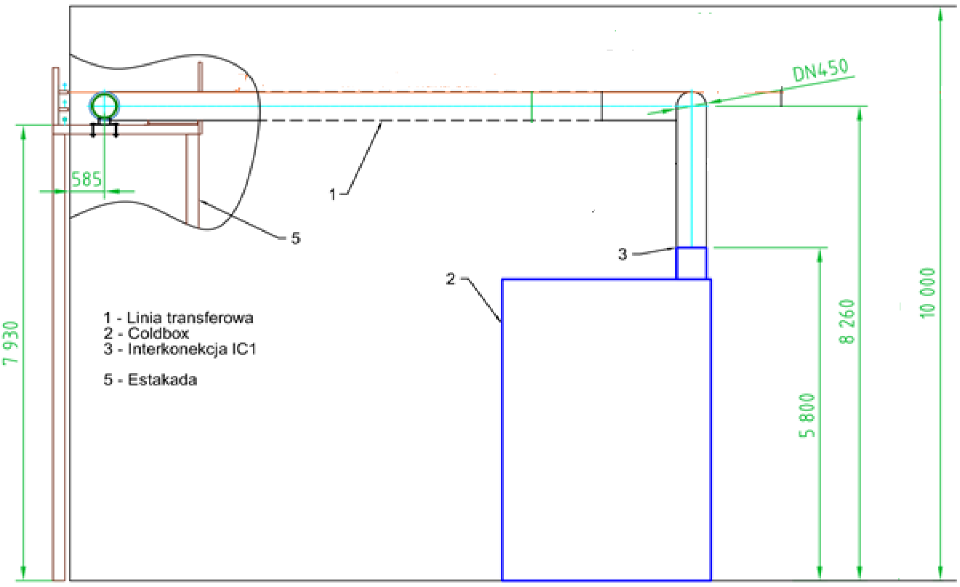

Fig. 5 Refrigerator building – potential location of interconnection IC1

An illustrative design solution of the interconnection is shown in Fig. 6.

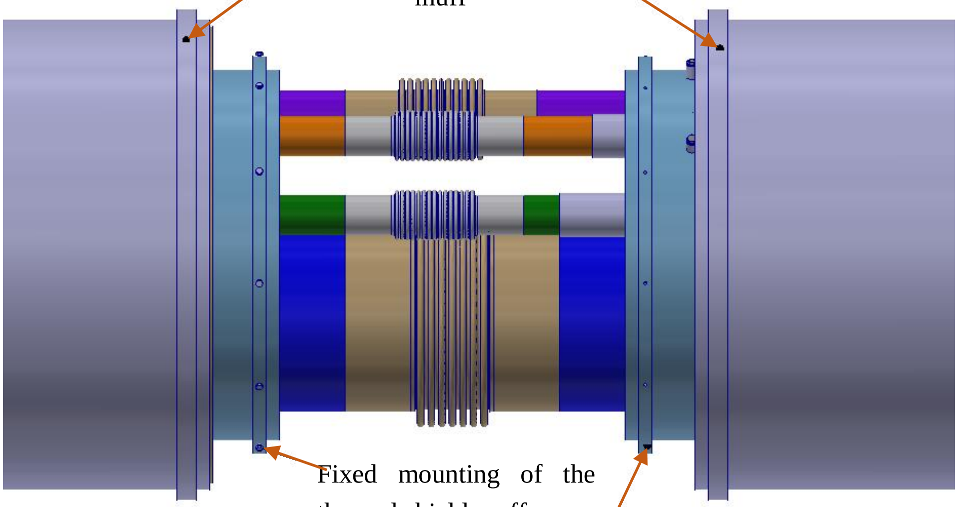

Fig. 6 Example of the interconnection design (the figure does not show either the thermal shield muff or the vacuum jacket muff)

The vacuum jacket of the transfer line and the thermal shield pipe will have rings with the shield pipe and the jacket muff welded thereto.

4.4. AUXILIARY LINES

The purpose of auxiliary lines is to remove gases from the CDS, to supply helium for washing the installation, to remove helium from the installation after a bleeding event (opening of the safety valves) and to ensure a helium atmosphere for valves with helium shields. Except for the safety valves relief line and the sealing gas line, these lines must be supplied from the Helium Cooling System, and their helium demand must be accounted for in the process of designing the Helium Cooling System. Auxiliary lines (with the exception of the safety valves relief line) penetrate outside the refrigerator building and follow the transfer line along its entire length. The auxiliary line comprises the main lines and their submains (connectors to cryomodules).

Four auxiliary lines are distinguished:

- **Recovery line** – a line for removing cold vapors from the thermal shield circuit and from the cooling circuit of the cryomodule cavities.
- **Purge in line** – a line for supplying helium at high-pressure, not greater than 4 bara, in order to purge the installation and remove all impurities and gases other than helium.
- **Purge return line** – a line for removing helium after the purge process.
- **Safety valves relief line** – a line for collecting gases from the safety valves and removing them into the atmosphere.
- **Sealing gas line** – a line for supplying helium protecting the safety valves relief line and the negative pressure valves from impurities.

The design parameters of the auxiliary lines are shown in Tab. 2.

Type of auxiliary line	Line name	Size	Outer diameter [mm]	Design pressure [bara]	Nominal pressure [bara]	Nominal Temperature [K]
Main line	Recovery line	DN80	88.9 [1)]	18	0 – 1.1 0 – 13	4 – 300
	Relief line	DN200	219.1	2	1.1	4 – 300
	Purge in line	DN25	33.7	18	4 – 13	300
	Purge return line	DN50	60.3	5	0 – 1.1	300
	Sealing gas line	DN25	33.7	5	1.1	300
Submain line	Recovery line	DN50	60.3 [2)]	18	0 – 1.1 0 – 13	4 – 300
	Relief line	DN50	60.3	2	1.1	4 – 300
	Purge in line	DN15	21.3	18	4 – 13	300
	Purge return line	DN25	33.7	5	0 – 1.1	300
	Sealing gas line	DN10	13.5	5	1.1	300
	1) The outer diameter of the vacuum jacket DN125 (133 mm) 2) The outer diameter of the vacuum jacket DN100 (101.6 mm)					

Tab. 2 Design parameters of the auxiliary lines

4.5. HEAT INLEAKS

The heat inleaks to the CDS, which must be taken into consideration by the Contractor supplying the Helium Cooling System during the design phase, have been pre-estimated and shown inTab. 3. As the CDS is at the design stage, the values will be specified more precisely at a later stage, when it will be possible to determine their final values for the CDS project, which is the object of a separate tender.

	2 K[1)]			**5 K**	**40 K shield**
	Static inleaks	Dynamic inleaks	Total	Static inleaks	Static inleaks
Cryomodule	10 W	61 W	71 W (4.64 g/s) [1) 2)]	3.3 W	34 W
Valvebox	2.4 W	-	2.1 W (0.5 g/s) [1) 2)]	6 W	15 W
Connecting module	1 W	-	1 W (0.20 g/s) [1)]	0,5 W	15 W
Endbox	2.5 W	-	2.5 W (0.5 g/s) [1) 2)]	8.6 W	13.5 W
Transfer line per 1 meter of length	0.04 W	-	-	0.2 W	2.25 W

1) Flux of supercritical helium at a temperature of 5 K and pressure 4 bara required to be throttled in the valvebox and transferred to the cryomodule in a two-phase state. Helium evaporation heat assumed at 20 J/g; liquid content in the two-phase flux assumed at 80% in the case of the accelerating cryomodules and at 70% in the case of the gun cryomodule.
2) The sum total of the supercritical helium flux (5 K and 4 bara) accounts for the heat inleaks from the thermalization of the power couplers (static inleaks to the intercept line of (5 K)).

Tab. 3 Maximum heat inleaks into the cryomodules and the CDS

With an account for the different CDS operating modes and for the safety margin, the maximum total heat inleaks are estimated at the following levels:

- 140 W at the temperature level of 2 K (the supply line and the cavities of the cryomodules),
- 63 W at the temperature level of 5 K (the supply line and the power couplers of the cryomodules),
- 390 W at the temperature level of 40 – 80 K (the thermal shields).

5. LASER

The main objective of the PolFEL project is to develop an advanced research infrastructure comprising a free electron laser, experimental lines and stations using the radiation generated by the laser, and special-purpose laboratory buildings which allow the installation and usage of the apparatus. PolFEL will be a research facility providing access to its resources to a number of users following clear and non-discriminating rules, after conducting a transparent selection process based on the scientific value of the applicant research projects.

The planned parameters of the apparatus make it a first-class tool for both fundamental and applied research in the fields of chemistry, biology, pharmacy, medicine, physics and material technology, high energy density physics etc., with particular focus on applications in research on process dynamics. The concept and the technical design of the PolFEL infrastructure are developed in their entirety by a research consortium whose leader is the National Center for Nuclear Research (Narodowe Centrum Badań Jądrowych, further: NCBJ). The construction of the facility already has a research potential, and PolFEL will be in many respects a pioneer apparatus.

The main components of the PolFEL laser will be installed in a dedicated protective bunker building. The necessary power supply, control, and electronic control systems will also be located outside the bunker. Due to the significant sensitivity of the PolFEL laser systems to vibrations (especially the superconducting electron accelerator), they will be installed on massive foundation beams, isolated from the ground and sources of vibrations.

The operation of the PolFEL laser requires access to all utilities and the functioning of several supporting systems and installations. Among these, the helium cryogenic system, used for cooling and maintaining the electron accelerator's components at sub-cooled helium temperature, takes precedence. The delivery and commissioning of one of the two main components of this system – the Helium Cooling System, is the subject of this procedure."

6. HELIUM COOLING SYSTEM

6.1. GENERAL INFORMATION

The Helium Cooling System shall be designed and developed in such a manner to ensure the possibility of operating in each of the below described CDS operating modes, and thus of the laser operating modes, and to meet the technical requirements described in the following part of this document.

The main elements of the Helium Cooling System are:

- Daresbury refrigerator
- Compressors
- Helium purification and oil separation system
- The “purge” system
- Helium recovery and storage system
- Control system
- Vacuum pump system

6.2. OPERATING CONDITIONS

Due to the unpredictable PolFEL operating mode and to the necessity to maintain the accelerating cryomodules in cold condition, as well as to the length of experiments performed with the use of the laser, the Helium Cooling System shall operate without breaks for 24 hours a day and for 7 days a week. The only HCS downtime is planned to be due to periodic technical breaks for the maintenance and service works on the HCS itself.

No interruptions in the operation of the Helium Cooling System are planned except for the above downtimes, which will be initiated 1-2 times per year and which will last no longer than 14 days at a time.

6.3. OPERATING MODE

The Cryogenic Distribution System was designed in such a manner that the cryogenic system can operate in the following modes:

- **Purge mode** This mode will be used to remove air and other impurities from all of the CDS lines and to fill them with helium. The process procedure will consist in pumping the gas out from the CDS line and filling the line with helium and will be repeated several times until a desired purity level is achieved. It will be possible to use this mode both for the entire CDS simultaneously and for an individual cryomodule together with the corresponding valvebox.

- **Cooling mode** This mode will be used to cool the CDS and the cryomodules from ambient temperature to operating temperature. During the cooling process, depending on the requirements, one of two scenarios will be performed:
  - The cooling of the entire CDS simultaneously;
  - The cooling of an individual cryomodule together with its corresponding valvebox in the case when the remaining elements of the CDS are already cooled to the nominal operating temperature.
- **Stand-by mode** This mode will be active when the cryomodules and the CDS will be cooled to the operating temperature (2 K), but the linear accelerator system will not be loaded by dynamic heat inleaks. The CDS will be supplying helium fluxes from the HCS to the cryomodules at a level sufficient to remove only static heat inleaks from the system.
- **Nominal operating mode** In this mode, the CDS will supply helium fluxes from the HCS to the cryomodules in order to remove both static and dynamic heat inleaks from the cryomodules, the transfer line and the valveboxes.
- **Warming mode** This mode will be used to warm the CDS to ambient temperature. During the warming mode, heaters arranged inside the cryomodules and the endbox will vaporize liquid helium and warm all of the CDS lines. The HCS will remove the vaporized helium and store it in pressurized gas tanks. During the warming process, depending on the requirements, one of two scenarios will be performed:
  - The warming of the entire CDS simultaneously;
  - The warming of an individual cryomodule together with its corresponding valvebox in the case when the remaining elements of the CDS remain cooled to the nominal operating temperature.

The operating modes of the PolFEL Cryogenic System are discussed below on the basis of an illustrative combination of a valvebox with the cryomodule Fig. 7

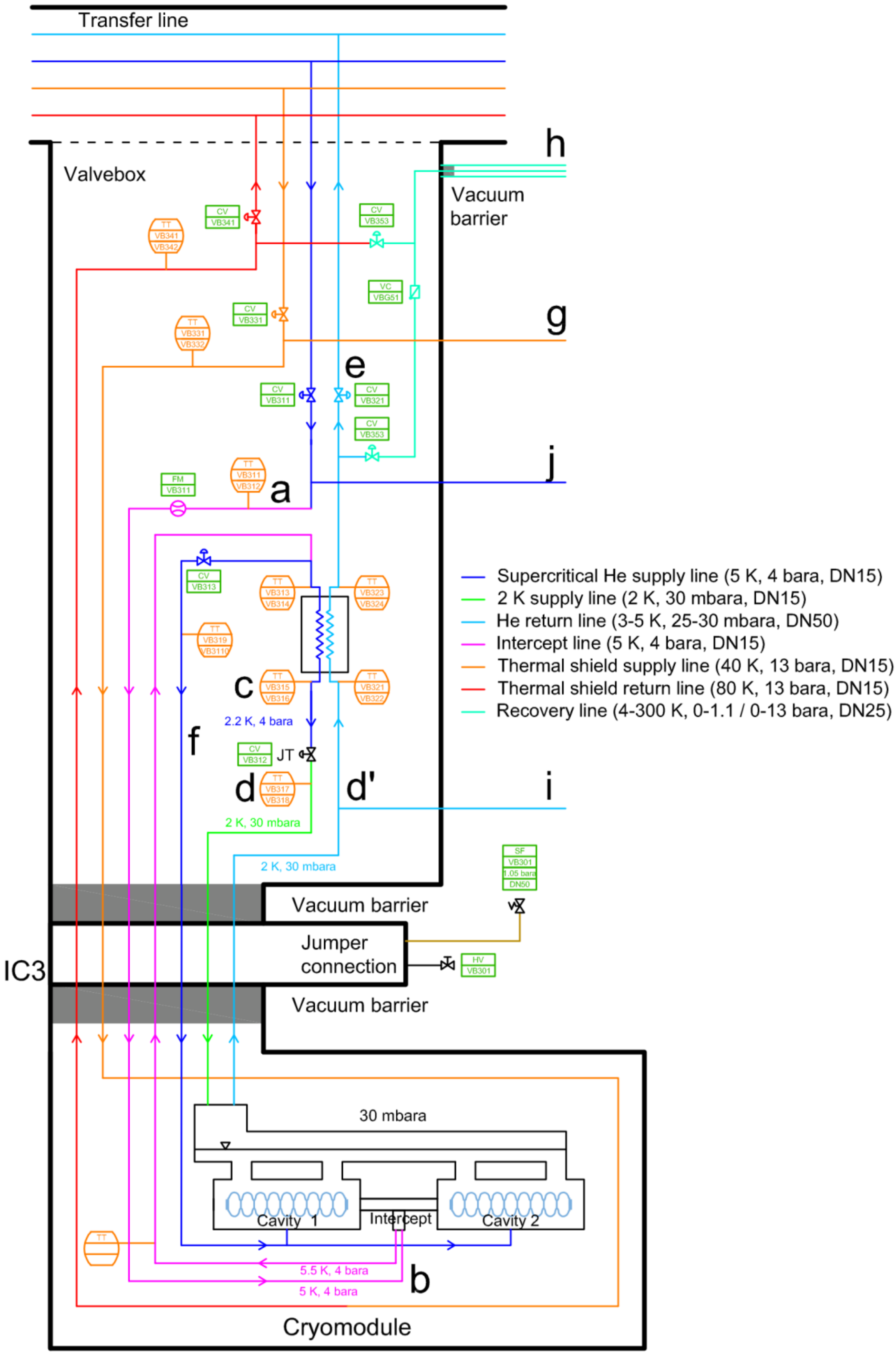

Fig. 7 Schematic view of a single valvebox with the cryomodule

6.3.1. THE COOLING MODE OF THE ENTIRE CDS

The maximum allowed pressure of the cryomodules during cooldown is 1300 mbara with the tolerance for fluctuation in range of ±50 mbar. The cooling process of the CDS will be carried out in five phases.

Phase one consists in cooling the CDS from 300 K to the temperature of the thermal shields (40 K – 70 K). In this phase, the HCS will deliver helium of a controlled thermal gradient between the supply and return lines. This gradient shall not exceed 30 K, and the maximum cooling rate shall not be greater than 30 K/h. Phase one will be performed on all the process lines simultaneously (including the transfer line, the valveboxes, the cryomodules and the endbox). Phase one of the cooling process will end after all of the CDS circuits are cooled to 70 K.

Phase two will be performed in order to cool the cryomodules from the temperature of the thermal shields (40 K – 70 K) to 15 K. In this phase, the HCS will deliver helium of a controlled thermal gradient between the supercritical helium supply line and the helium return line in a manner not to exceed a 30 K thermal gradient and the maximum cooling rate of 30 K/h. Starting at this phase, helium having nominal parameters will be transferred in all of the supply and return lines of the CDS thermal shields. This phase will be conducted on all supply lines and in all valveboxes simultaneously, and it will end when all of the cryomodules are cooled to 15 K.

Phase three will consist in cooling the supercritical helium supply line and the helium return line inside the transfer line to approx. 5 K. The HCS will deliver helium of controlled parameters to the supercritical helium supply line so that the maximum cooling rate of 30 K/h is not exceeded. During this phase, the valveboxes will deliver helium to the cryomodules only through the thermal shield supply lines. Helium from the thermal shield return lines will be transferred to the transfer line. During this phase, pressure may increase inside the cryomodules due to heat inleaks. In order to maintain the pressure inside the cryomodules at a constant level, helium surplus will be transferred through the recovery line (point "h" in Fig. 6.3) to the recovery system in the HCS. The cryomodules will be kept at a constant temperature of 15 K. In the case when the temperature inside the cryomodules rises, its value will be lowered by using a small flux of helium from the supply line. Phase three will end when the supercritical helium supply line reaches nominal parameters (5 K and 4 bara).

Phase four consists in a quick cooling of the cryomodules from 15 K to 5 K. In this phase, the HCS will deliver supercritical helium to the transfer line at 5 K and 4 bara. Helium will pass through the supercritical helium supply line inside the transfer line to the valvebox (point "a" in Fig. 6.3). In the valvebox, helium will pass through the intercept line in order to cool the power couplers of the cryomodule, and subsequently it will return to the valvebox. The helium flux will flow into the filling line, bypassing the heat exchanger, and subsequently it will flow through valve VBx13, where it will be throttled to a pressure of 1.1 bara and temperature of 4.3 K. The two-phase helium flux will flow directly into the cryomodule (point "f" in Fig. 6.3), cooling it in the vaporization process. The vaporized helium will be then returned to the valvebox (point "d'" in Fig. 6.3) and finally, through the recovery line (point "h" in Fig. 6.3), it will return to the helium recovery system being part of the HCS. The mass flow of liquid helium to the cryomodule shall not be smaller 8 g/s in order to ensure a rapid cooling with a speed of approx. 2 – 3 K per minute. This rapid cooling phase will be performed in a sequence for one cryomodule at a time. Prior to the rapid cooling phase, each cryomodule shall be ketp at a constant temperature of 15 K. Each cryomodule cooled to 4.3 K shall be filled with liquid helium and kept at that temperature until phase four is completed.

After all of the cryomodules are cooled and filled with liquid helium at 4.3 K, the rapid cooling phase ends and phase five starts.

The objective of **phase five** is to lower the temperature of liquid helium inside the cryomodules from 4.3 K to 2 K. During this phase, helium will become superfluid. In the valveboxes, helium transfers in the supply lines will be reduced to the nominal 4 g/s. Vacuum pumps will be started in the HCS, in order to lower the pressure inside the cryomodules to 30 mbara. This phase will be performed with the use of all of the valveboxes and will finish when all of the cryomodules will be cooled to 2 K and filled with superfluid helium.

6.3.2. THE COOLING MODE OF AN INDIVIDUAL CRYOMODULE

The CDS shall allow the cooling of an individual cryomodule together with its corresponding valvebox in the case when the remaining elements of the CDS are kept at the nominal operating temperature. In this case, all cooled elements of the CDS shall be in stand-by mode described in section 6.3.3. The maximum allowed pressure of the cryomodules during cooldown is 1300 mbara with the tolerance for fluctuation in range of ±50 mbar. The cooling process of an individual cryomodule will be carried out in four phases.

Phase one is the cooling of the cryomodule thermal shield. The valvebox will receive, through the thermal shield supply line, a 13 bara and 40 K helium flux from the transfer line and will mix it with the helium flux supplied by the purge in line (line “g” in Fig. 6.3) in such a manner that the thermal gradient between the thermal shield supply line and the thermal shield return line does not exceed 30 K. After the thermal shield is cooled, the helium flux will be received by the recovery line (line “h” in Fig. 6.3). After the thermal shield is cooled to nominal temperatures, the helium flux from the shield circuit will be redirected to the transfer line.

Phase two will be performed in order to cool the remaining cold lines of the cryomodule and the valvebox from 300 K to 15 K. The HCS will deliver supercritical helium at 4 bara and 5 K. Helium will flow through the supercritical helium supply line inside the transfer line to the valvebox (point “a” in Fig. 6.3), where it will be mixed with the helium flux supplied by the purge in line (line “j” in Fig. 6.3) so that the thermal gradient between the transfer line (point “a” in Fig. 6.3) and the return line (point “d’” in Fig. 6.3) does not exceed 30 K. In the valvebox, helium will flow through the intercept line in order to cool the power couplers of the cryomodule and then it will return to the valvebox. The helium flux will be directed to the filling line “f” (Fig. 6.3), bypassing the heat exchanger and flowing through valve VBx13, where it will be throttled to 1.1 bara. The helium flux will flow directly into the cryomodule (point “f” in Fig. 6.3), cooling it. Subsequently, the helium flux will be returned to helium recovery line (points “d’” and “h” in Fig. 6.3). This phase will be conducted until the cryomodule is cooled to 15 K.

Phase three consists in a rapid cooling of the cryomodule from 15 K to 5 K. The helium flow scheme in the valvebox is identical as in phase two. The only difference is in the high helium flow to the cooled cryomodule. In this phase, a two-phase flow will be observed in line “f” (Fig. 6.3). The mass flow of liquid helium to the cryomodule shall not be smaller 8 g/s in order to ensure a rapid cooling with a speed of approx. 2 – 3 K per minute. After the cryomodule is rapidly cooled and filled with liquid helium at 4.3 K, the rapid cooling phase ends and phase four starts.

The objective of **phase four** is to lower the temperature of liquid helium inside the cooled cryomodule from 4.3 K to 2 K. During this phase, helium will become superfluid. In the valvebox, helium transfers in the supply lines will be reduced to the nominal 4 g/s. Subsequently, recovery line “h” (Fig. 6.3) will be closed and the valve returning helium vapor to the transfer line through line “e” (Fig. 6.3) will be slowly opened until pressure in the cryomodule is lowered to its nominal value (30 mbara).

6.3.3. STAND-BY MODE

In the stand-by mode. line “f” (Fig. 6.3) will be closed, and helium will pass through the heat exchanger (point “c” in Fig. 6.3 and in Fig. 6.3.3), where it will be pre-cooled and then throttled in the JT valve. The throttled helium will change its state to superfluid and will reach the temperature of 2 K and the pressure of 30 mbara (point “d” in Fig. 6.3 and in Fig. 6.3.3). The superfluid helium will flow into the cryomodule, filling the two-phase helium tank. The vaporized helium will return from the cryomodule through line “d’” (Fig. 6.3) and will flow through the low-pressure section of the heat exchanger (point “e” in Fig. 7 and in Fig. 8). In this mode, the HCS maintains the pressure inside the cryomodules at a constant level of 30 mbara.

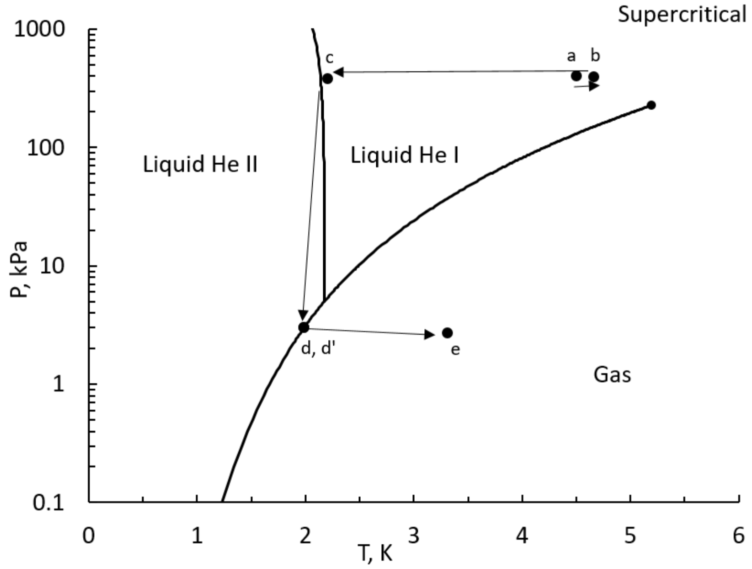

Fig. 8 Temperature-entropy (t-s) diagram of helium during the stand-by mode and in nominal operation. Points a, b, c, d, d’ and e correspond to the points in Fig. 7

In the stand-by mode, only static heat inleaks to the CDS are observed.

6.3.4. NOMINAL OPERATING MODE

From the point of view of thermodynamics, the nominal operating mode is similar to the stand-by mode. The only difference is that in the nominal operating mode, the HCS increases the flow of helium from the supply line, in order to allow for not only the static but also the dynamic heat inleaks to the cryomodules. Helium will be delivered to the gun cryomodule, to the 4 accelerating cryomodules and to the test cryomodule. In the case when the helium fluxs supplied by the HCS cannot be regulated, helium surplus in each phase shall pass through the endbox.

The maximum allowed thermal load for the CDS and for the cryomodules is shown in Table 4.4. The values of heat inleaks have been estimated allowing for the thermal shields, the thermal and radiation insulation, the valves, the fixed and sliding supports, the vacuum barriers and the measurement apparatus.

6.3.5. THE WARMING MODE OF AN INDIVIDUAL CRYOMODULE

The maximum allowed pressure of the cryomodules during warmup is 1300 mbara with the tolerance for fluctuation in range of ±50 mbar. The warming of an individual cryomodule together with the valvebox will be performed in three phases.

Phase one will consist in vaporizing liquid helium from the cryomodule. The supercritical helium supply line will be closed. Next, the heaters inside the cryomodule will be used to vaporize the superfluid helium from the cryomodule. He vapors will be removed to the HCS through the He return line inside the transfer line.

Phase two will consist in lowering the pressure inside the thermal shields to 1.1 bar and in increasing the pressure inside the cryomodule to 1.1 bara. The pressure in the shield lines will be lowered by removing the excess helium to the recovery line (line “h” in Fig. 6.3). The pressure in the cryomodule will be increased by slowly increasing the temperature of the cryomodule with the valves closed on both the supply and return lines.

Phase three will consist in warming all of the valvebox and cryomodule lines while redirecting the helium flux to the recovery line (line “a” in Fig. 6.3). During the warming stage, the temperature change rate shall not exceed 30 K/h.

6.3.6. THE WARMING MODE OF THE ENTIRE CDS

The maximum allowed pressure of the cryomodules during warmup is 1300 mbara with the tolerance for fluctuation in range of ±50 mbar. The warming process of the CDS will be carried out in two phases.

Phase one will consist in increasing the pressure inside the helium return line and the cryomodules to 1.1 bara. This procedure will be carried out by switching off compressors of the HCS.

Phase two will be performed in order to warm the cryomodules to 300 K. In this phase, the HCS will deliver helium at a controlled thermal gradient between the supply and the return lines. The gradient shall not exceed 30 K, and the warming rate shall not be greater than 30 K/h. Helium from the return lines will be transferred through the transfer line to the HCS. This phase will be carried out simultaneously for all cold process pipes of the CDS.

6.4. HCS POWER CONTROL

Due to variable loads on the laser and its operating modes, it is required that the Helium Cooling System allows a smooth adjustment of helium fluxs in the range between 60% and 100% of the nominal values.

6.5. HELIUM MASS FLOW RATES

The number of cryomodules and of valveboxes will vary at various stages of operating the laser. After its final expansion, the system will comprise the following elements:

- 4 accelerating cryomodules
- 4 valveboxes
- Endbox
- a transfer line (approx. 30 m)

In order to meet the demand from the CDS in such a configuration, the **nominal operating mode** will require the following helium fluxes:

- 8 g/s of helium at 5 K and at 4 bara – for cooling the cryomodule structures
- 9 g/s of helium at 40 K and 13 bara – for cooling the thermal shields

The nominal operational mode helium fluxes shown above, are the maximal fluxes for given temperature and pressure. It is not expected to exceed these requirements in any operational mode.

- For the cooled cryomodule, the helium cooling flow will range from 7 g/s at a helium temperature of 270 K (this can be achieved by mixing two helium flows in the valve module - approximately 1 g/s @ 5 K and 6 g/s at 300 K) to a helium flow of 1 g/s at a helium temperature of 5 K.
- For the thermal shield, the helium flow will vary from 11 g/s at a helium temperature of 270 K (this can be achieved by mixing two helium flows in the valve module - approximately 2 g/s @ 40 K and 9 g/s at 300 K) to a helium flow of 2 g/s at a helium temperature of 40 K.

The change in the required helium temperature is due to the maximum cooling rate of 30 K/h (see Chapter 6.3.1).

The required helium flow rates for the rest of the CDS during the cooling of one cryomodule are as follows:

- 4 g/s of supercritical helium (4 bar(a), 5K) - thermal load: 45 W @ 2K, 47 W @ 5K
- 7 g/s of helium for cooling the thermal shield (13 bar(a), 40 K) - thermal load: 290 W @ 40 K

Additionally, each cryomodule requires a flow rate of 8 g/s of liquid helium for rapid cooling from 15 K to 5 K (see Chapter 6.3.1) at a rate of 2-3 K/min. To achieve this cooling rate, the HCS during the rapid cooling phase should provide a flow of supercritical helium (5 K, 4 bar(a)) of no less than 12 g/s of helium to the cooled cryomodule while ensuring an adequate helium flow to maintain the other CDS components at a constant temperature.

The Helium Cooling System (HCS) must allow for the delivery of these flow rates through appropriate supply lines within the transfer line. Helium return to the HCS will occur through return lines within the transfer line.

During the cooling and warming stages, the Helium Cooling System must provide helium flows to ensure a reasonable rate of cooling/warming of the CDS, so that the rate of temperature change does not exceed 30 K/h.

During the cooling/warming mode of the entire CDS simultaneously, the Helium Cooling System will provide helium through supply lines within the transfer line. Helium return to the HCS will occur through return lines within the transfer line (see Chapter 6.3).

In the case of the cooling/warming mode of a single cryomodule, the Helium Cooling System will provide helium at nominal parameters through the transfer line to the cooled CDS. Additionally, it will provide, through a supply line, helium at ambient temperature. Both flows (cold helium from the supply line within the transfer line and helium at ambient temperature) will be mixed inside the valve module to achieve the appropriate temperature gradient during cooling/warming. After cooling the cryomodule, the helium will return to the helium recovery system (HCS) through a recovery line.

Assuming a constant maximum cooling rate, the maximum mass flow rate of helium will change. Below are tables showing the maximum helium flow rates at the beginning of the cooling stages (temperature 270 K). Since the CDS will be designed concurrently with the HSC, the values in the tables below should be considered as approximate.

[Note: The text appears to reference specific tables and chapters, and the values in those tables are not provided in the text. If you need a translation of specific values or further information related to these tables, please provide the relevant data.]

Table 6.4.1 Estimated mass of the transfer line with the endbox and maximum helium mass flow rate during the cooling stage

Transfer line + Endbox	Mass [kg]	He flow rate [g/s] (T=270 K)
Supercritical He supply line + He return line	800	21
Supply line + Thermal shield return line	800	38

Table 6.4.2 Estimated mass of an individual cryomodule with the valvebox and maximum helium mass flow rate during the cooling stage

Valvebox + Cryomodule	Mass [kg]	He flow rate [g/s] (T=270 K)
Supercritical He supply line + He return line	250	7
Supply line + Thermal shield return line	220	11

Table 6.4.3 Estimated mass of the entire CDS and maximum helium mass flow rate during the cooling stage

CDS	Mass [kg]	He flow rate [g/s] (T=270 K)
Supercritical He supply line + He return line	1800	48
Supply line + Thermal shield return line	1700	81

6.6. LIQUEFIED NITROGEN CONSUMPTION

The maximum consumption of liquefied nitrogen by the Helium Cooling System in order to improve efficiency shall not exceed 63 kg/h. The Contractor shall take the necessary measures to minimize the consumption of liquefied nitrogen.

After estimating the necessary quantity of liquefied nitrogen, the Contractor shall estimate the size and type of the storage tank, assuming that the tank will be filled once a week.

The location of the tank is shown in Fig. 8b.

6.7. OTHER SUBSYSTEMS

6.7.1. GENERAL INFORMATION

For the system to operate properly, the Helium Cooling System shall be provided among others with the following auxiliary subsystems which aid the operation of both the Helium Cooling System and the entire CDS.

The calculations, design and selection of appropriate devices rest on the Contractor.

6.7.2. HELIUM PURIFICATION AND OIL SEPARATION SYSTEM

The helium purification system serves to remove impurities, which are present in the process space due to the installation works and the operation of the entire cryogenic system. These impurities may be solid (filings, dust, etc.) liquid (oil, water) or gaseous (gases other than helium). Oil from the operating compressors is a particularly problematic impurity.

The purification system shall allow the impurities to be removed at a degree which ensures the proper operation of the entire PolFEL Cryogenic System.

The helium purification and oil separation system shall also allow measurements of the wear degree of consumable materials such as filters or sorbents.

6.7.3. THE “PURGE” SYSTEM

The so-called “purge” system serves to remove any impurities in the form of gasses other than helium from the process space of the CDS installation. It operates by pumping out vacuum from the process space and filling it with helium, the procedure being repeated three times. The “purge” process must be performed prior to the first launching of the installation and each time when air penetrates into the installation, e.g. during repair works in any of the modules, during the replacement of the test module, regeneration of the gun module or other works.

Parameters of the “purge” system:

- Vacuum level: 1x10E-2 mbara
- Helium pressure: 1.1 bara

6.8. INTERCONNECTIONS

The Helium Cooling System shall be interconnected with the CDS lines in the points shown below. The responsibility for the connection process rests on the supplier of the CDS. The design and delivery processes will continue in parallel for both the Helium Cooling System and the CDS, and therefore the Contractor of the Helium Cooling System, the supplier of the CDS and the Contracting Entity must cooperate closely in order to avoid technical misinterpretations. The nominal pipe size will be confirmed to the Contractor by the supplier of the CDS. The following interconnections are distinguished:

- IC1 – connection of the refrigerator with the CDS transfer line (point 4.2)
- ICR – connection of the HCS with the helium recovery line
- ICPI – connection of the HCS with the purge in line
- ICPO – connection of the HCS with the purge return line
- ICHG – connection of the HCS with the sealing gas line

In addition, the Helium Cooling System must have connections to:

- the liquefied nitrogen tank,
- the helium gas tanks,
- the electrical system,
- the process air system,
- the cooling water system,
- other systems, indicated by the supplier.

The above interconnections and connections must be described by the supplier in terms of technical details and resource demand, and communicated to the Contracting Entity at the Preliminary Design Review (PDR) stage (Table 19.1 and 19.2).

6.9. SUMMARY OF KEY PROCESS REQUIREMENTS

The Helium Cooling System shall supply helium to the transfer line in two independent fluxs:

- Supercritical helium at the temperature of 5 K and at the pressure of 4 bara will be used to thermalize the power couplers and to cool the resonance cavities of the cryomodules. In nominal operating conditions, the required mass flow rate of supercritical helium is 8 g/s. After cooling the cryomodules, this helium will return to the HCS in the form of He vapor. Compressors shall keep the pressure in the He return line at a level not higher than 27 mbara, while ensuring the pressure stability at ± 100 μbar.
- The thermal shield helium at 40 K and 13 bara will be used to cool the thermal shields of the entire Cryogenic Distribution System. In nominal operating conditions, the required mass flow rate of the thermal shield helium is 9 g/s.

The flow rates are provided for nominal conditions, and in the case of other conditions this demand may be different.

With an account for the different CDS operating modes and for the safety margin, the maximum total heat inleaks are estimated at the following levels:

- 140 W at the temperature level of 2 K (the supply line and the cavities of the cryomodules),
- 63 W at the temperature level of 5 K (the supply line and the power couplers of the cryomodules),
- 390 W at the temperature level of 40 – 80 K (the thermal shields).

7. Quantity of helium in the PolFEL Cryogenic System

The total quantity of helium circulating in the PolFEL Cryogenic System can be classified in three sections, in accordance with Fig. 3.1:

- The quantity of helium in the Helium Cooling System together with the storage tanks
- The quantity of helium in the CDS (the transfer line, the valveboxes, the endbox)
- The quantity of helium in the cryomodules

The quantity of helium in the CDS together with the cryomodules is shown tables below, while the quantity of helium in the Helium Cooling System must be defined by the Contractor supplying the HCS (allowing for the size of the storage tanks) and communicated to the Contracting Entity at the PDR stage. Based on the calculations of the quantity of helium required to operate the Helium Cooling System, the HCS Contractor is obliged to estimate the size of the liquefied helium tanks, helium gas tanks and other tanks. These values will help the Contracting Entity to prepare foundations for the tanks and to secure the required floor area for their safe operation (Fig. 8).

Table 7.1. Max. quantity of helium in the CDS – cooling mode

Element		Line	Diameter [mm]	Length [m]	Volume [m3]	Temp [K]	Pressure [bara]	Density [kg/m3]	He mass [kg]
Transfer line		Supercritical He supply line	33.7	30	0.027	5	4	124.25	3.32
		He return line	168.3	30	0.667	4.5	1.3	22.03	14.70
		Thermal shield supply line	26.9	30	0.017	40	13	15.12	0.26
		Thermal shield return line	26.9	30	0.017	50	13	12.13	0.21
Auxiliary lines		Purge in line	33.7	30	0.027	300	1	0.16	0.00
		Purge return line	60.3	30	0.086	300	1	0.16	0.01
		Recovery line	88.9	30	0.186	300	1	0.16	0.03
		Sealing gas line	33.7	30	0.027	300	1	0.16	0.00
Valveboxes	Process lines	Supercritical He supply line	21.3	4	0.001	5	4	124.25	0.89
		He return line	60.3	6	0.017	4.5	1.3	22.03	1.89
		Intercept line	21.3	12	0.004	5	4	124.25	2.66
		2 K He supply line	21.3	3	0.001	4.3	1.3	124.83	0.67
		Filling line	21.3	6	0.002	4.3	1.3	124.83	1.33
		Thermal shield supply line	21.3	4	0.001	40	13	15.12	0.11
		Thermal shield return line	21.3	8	0.003	50	13	12.13	0.17
	Auxiliary lines	Purge in line	21.3	6	0.002	300	1	0.16	0.00
		Purge return line	33.7	8	0.007	300	1	0.16	0.01
		Recovery line	60.3	6	0.017	300	1	0.16	0.01
		Sealing gas line	13.5	6	0.001	300	1	0.16	<0.01

Endbox	Process lines	Supercritical He supply line	33.7	4	0.004	5	4	124.25	0.44
		He return line	88.9	6	0.037	4.5	1.3	22.03	0.82
		2 K He supply line	21.3	3	0.001	4.3	1.3	124.83	0.13
		Filling line	21.3	6	0.002	4.3	1.3	124.83	0.27
		Thermal shield supply line	26.9	4	0.002	40	13	15.12	0.03
		Thermal shield return line	26.9	8	0.005	50	13	12.13	0.06
		Phase separator	TBD	TBD	0.025	4.3	1.3	124.83	3.12
	Auxiliary lines	Purge in line	21.3	6	0.002	300	1	0.16	<0.01
		Purge return line	33.7	8	0.007	300	1	0.16	<0.01
		Recovery line	60.3	6	0.017	300	1	0.16	<0.01
		Sealing gas line	13.5	6	0.001	300	1	0.16	<0.01
Cryomodules (4 pcs)	Process lines	He return line	72	3	0.012	4.5	1.3	22.03	1.35
		Intercept line	10	10	0.001	5	4	124.25	0.49
		2 K He supply line	10	3	0.000	4.3	1.3	124.83	0.15
		Filling line	10	6	0.000	4.3	1.3	124.83	0.29
		Thermal shield supply line	10	4	0.000	40	13	15.12	0.02
		Thermal shield return line	10	8	0.001	50	13	12.13	0.04
		Phase separator	TBD	TBD	0.060	4.3	1.3	124.83	37.45
								Total	**71**

Table 7.2. Quantity of He in the CDS at nominal operating mode

Element		Line	Diameter [mm]	Length [m]	Volume [m3]	Temp [K]	Pressure [bara]	Density [kg/m3]	He mass [kg]
Transfer line		Supercritical He supply line	33.7	30	0.027	5	4	124.25	3.32
		He return line	168.3	30	0.667	2	0.03	0.76	0.51
		Thermal shield supply line	26.9	30	0.017	40	13	15.12	0.26
		Thermal shield return line	26.9	30	0.017	50	13	12.13	0.21
Auxiliary lines		Purge in line	33.7	30	0.027	300	1	0.16	<0.01
		Purge return line	60.3	30	0.086	300	1	0.16	0.01
		Recovery line	88.9	30	0.186	300	1	0.16	0.03
		Sealing gas line	33.7	30	0.027	300	1	0.16	<0.01
Valveboxes (4 pcs)	Process lines	Supercritical He supply line	21.3	4	0.001	5	4	124.25	0.71
		He return line	60.3	6	0.017	2	0.03	0.76	0.05
		Intercept line	21.3	12	0.004	5	4	124.25	2.13
		2 K He supply line	21.3	3	0.001	1.9	0.03	145.53	0.62
		Filling line	21.3	6	0.002	2	0.03	0.76	0.01
		Thermal shield supply line	21.3	4	0.001	40	13	15.12	0.09
		Thermal shield return line	21.3	8	0.003	50	13	12.13	0.14
	Auxiliary lines	Purge in line	21.3	6	0.002	300	1	0.16	<0.01
		Purge return line	33.7	8	0.007	300	1	0.16	<0.01
		Recovery line	60.3	6	0.017	300	1	0.16	0.01
		Sealing gas line	13.5	6	0.001	300	1	0.16	<0.01
Endbo	Process lines	Supercritical He supply line	33.7	4	0.004	5	4	124.25	0.44
		He return line	88.9	6	0.037	2	0.03	0.76	0.03

		2 K He supply line	21.3	3	0.001	1.9	0.03	145.53	0.16
		Filling line	21.3	6	0.002	2	0.03	0.76	<0.01
		Thermal shield supply line	26.9	4	0.002	40	13	15.12	0.03
		Thermal shield return line	26.9	8	0.005	50	13	12.13	0.06
		Phase separator	TBD	TBD	0.025	1.9	0.03	145.53	3.64
	Auxiliary lines	Purge in line	21.3	6	0.002	300	1	0.16	<0.01
		Purge return line	33.7	8	0.007	300	1	0.16	<0.01
		Recovery line	60.3	6	0.017	300	1	0.16	<0.01
		Sealing gas line	13.5	6	0.001	300	1	0.16	<0.01
Cryomodules (4 pcs)	Process lines	He return line	72	3	0.012	2	0.03	0.76	0.04
		Intercept line	10	10	0.001	5	4	124.25	0.39
		2 K He supply line	10	3	0.000	1.9	0.03	145.53	0.14
		Filling line	10	6	0.000	2	0.03	0.76	<0.01
		Thermal shield supply line	10	4	0.000	40	13	15.12	0.02
		Thermal shield return line	10	8	0.001	50	13	12.13	0.03
		Phase separator	TBD	TBD	0.060	1.9	0.03	145.53	34.93
								Total	**48**

8. SPATIAL LIMITATIONS OF THE HELIUM COOLING SYSTEM

8.1. GENERAL INFORMATION

The HCS apparatus will be installed in a dedicated space located south of the main shielded building of the PolFEL accelerator. The space will include:

- The new refrigerator building.
- The area adjacent to the building in the west and south directions, having a surface of 600 m^2 – planned for the liquefied nitrogen tanks and the helium gas tanks.

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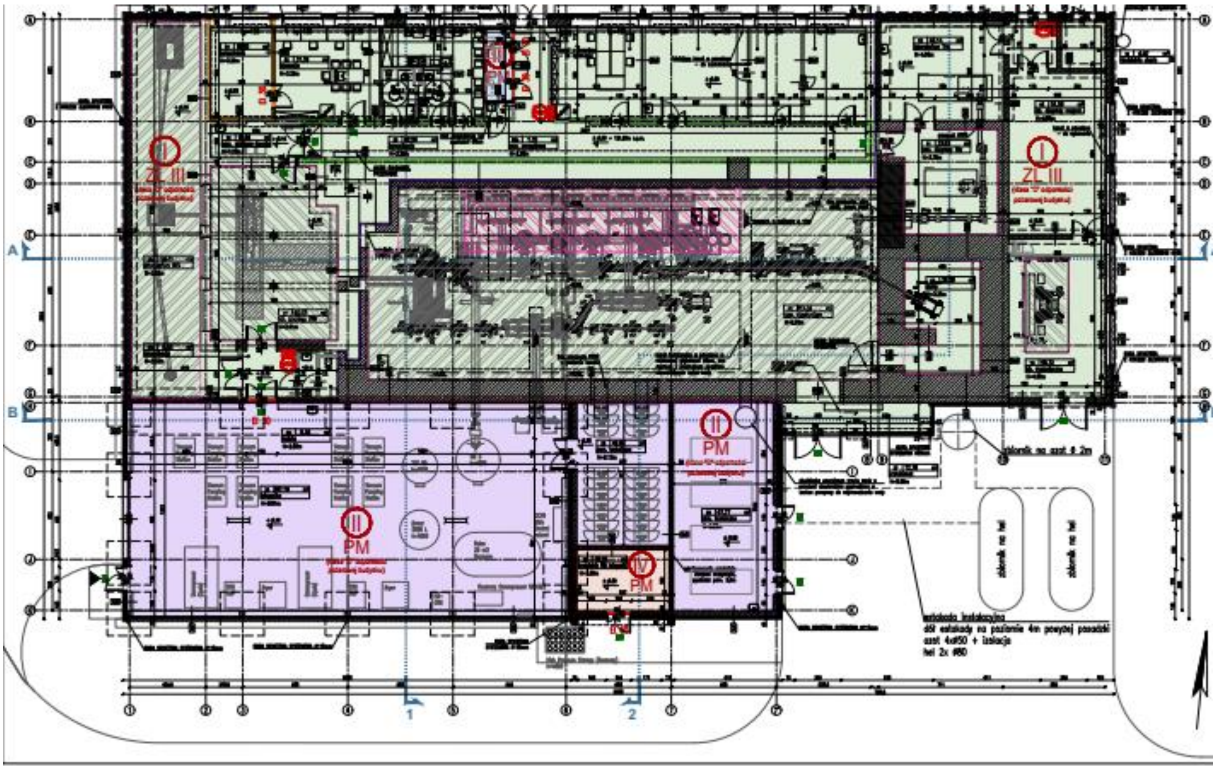

Fig. 8.1 Building for the helium cooling system along with its surroundings.

8.2. Helium refrigerator building

The refrigerator building (currently under design) will be a single-bay hall located approx. 8.4 m south of the shielded building of the PolFEL accelerator. Its only function will be to accommodate the helium refrigerator systems and will be supplemented by a technological gases (nitrogen and helium) storage facility and by a local process water cooling station used in the helium refrigerating process.

The refrigerator building will be connected with the shielded building of the PolFEL accelerator by a dedicated trestle bridge, which will support among others the transfer line of the Cryogenic Distribution System (CDS). The building will have a 4.5 x 4.5 m entry gate located in its western wall.

The basic parameters of the refrigerator building are as follows:

- Length: 25.2 m
- Width: 12.16 m
- Height: 9.2 m
- Surface area: 307.19 m^2
- Volume: 2 826.15 m^3
- Refrigerator building back-up facility: 275.79 m^2

Detailed information on the refrigerator building:

- Design
  Single-bay four-span steel hall. The load-carrying structure is a steel truss on pillars. Individual load-carrying structures are braced with the use of solid rod members. The purlins are designed as single-span beams resting on trusses and on external primary spandrel beams.

- Walls
  The hall envelope has a steel substructure covered with sandwich slabs filled with PIR insulation 20 cm in thickness and with a mineral wool core. On the eastern side, there is a 4.5 x 4.5 m entry gate located in the gable wall.
- Roof
  The shed roofing is made of sandwich slabs filled with PIR insulation 20 cm in thickness. The purlins are designed as single-span beams resting on trusses and on external primary spandrel beams.
- Traveling crane
  The hall is expected to be provided with a traveling crane up to 6 metric tons in capacity and approx. 11 m in the travel range, moving along the main axis of the hall. The height of the crane hook is expected to be at 8.5 m above the floor.
- Foundations
  The refrigerator building is going to be seated on reinforced concrete isolated footing foundations 200 x 200 x 40 cm in cross section and on plinth beams. The foundations are designed to be made of the C30/37 concrete and reinforced with class B steel characterized by yield point fyk = 500 MPa. A sublayer under the footing foundations shall be made of lean concrete having 10 cm in thickness and a minimum C8/10 class.
- Antivibration protection
  The design of the refrigerator building provides for foundations and passive antivibration protection for the designed machinery and technological devices of the Helium Cooling System. Their parameters will be defined on the basis of the technical design of the Cooling System and will be adjusted thereto.
- Media
  Electricity to the refrigerator building is planned to be supplied from a 15/0.4 transformer station and from a low-voltage 1.6 kVA distribution panel located in the adjacent rooms of building 67. Cooling water is planned to be supplied in order to cool the HCS. The installations for supplying cooling water to the facility will be constructed on the trestle bridge connecting the building with the shielded building of the PolFEL accelerator. The cooling process will be carried out by a system of fan coolers having a total power of 300 kW, located outside the building (east of the building and north of building 67). In addition, a water-chilling unit is planned to be installed in the building, for cooling the ventilation and air conditioning systems. Precise parameters of the chilling system will be adjusted to the technical design of the HCS.

A local compressed-air system is also planned, for technological needs.

The building is planned to be provided with IT wiring and an ICT network connections. Their precise locations will be defined after the optimal arrangement of media is jointly agreed on at the technical design stage.

Liquefied nitrogen for the purposes of the LHC will be delivered from an external tank having a capacity of 30 m^3, located east of the building. Precise parameters of the tank will be adjusted to the technical design of the HCS,

The set of helium gas tanks will be located outside, east of the building. Its parameters will be defined on the basis of the offer submitted by the Contractor and of the technical design of the HCS.

The design of the refrigerator building together with the designed location of the interface with the CDS transfer line is shown in Fig. 8.3. The Contractor shall adjust the technical design of the HCS to the indicated interface location.

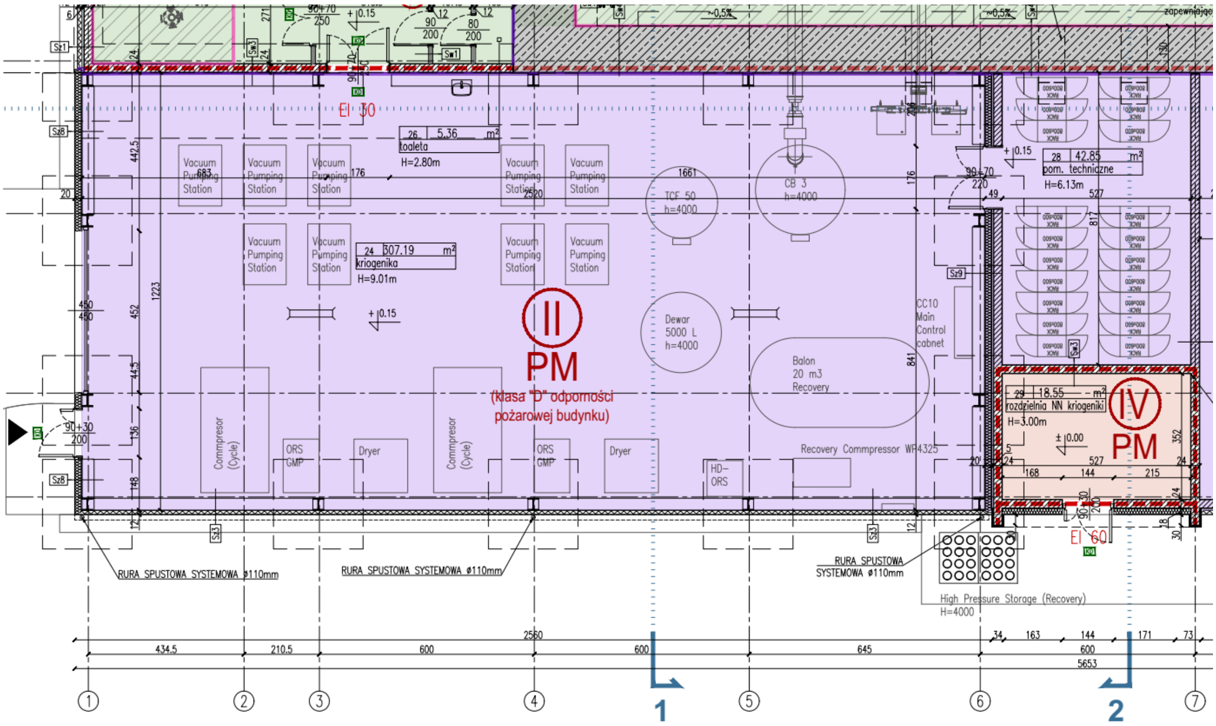

Fig. 8.3 The refrigerator building and its vicinity

8.3. THE AREA ADJACENT TO THE REFRIGERATOR BUILDING

The area adjacent to the building is planned to accommodate devices which, due to their size, cannot be arranged inside the refrigerator building. The surface of the area is approx. 600 m^2. Within the area, there are planned foundations for gas storage tanks (liquefied nitrogen and helium gas, as well as helium gas for the purposes of the recovery system), process pipelines, reduction stations and vaporizers, as well as fan coolers of the cooling system. The technical parameters, the technological penetration openings through walls and the support structures for installations and pipelines etc. will be adjusted to the technical design of the HCS prepared by the Contractor.

9. INSTRUMENTS

9.1. GENERAL INFORMATION

The instruments used in the Helium Cooling System shall meet the following requirements. Only such devices can be used that proved effective in comparable operating conditions. The selection of devices is the responsibility of the Contractor, which is obliged to produce a list of employed devices together with their data sheets and the list of parts which need to be replaced periodically. Approval, by the Contracting Entity, of the proposed devices, does not absolve the Contractor from the responsibility for their proper selection.

9.2. CUT-OFF VALVES

The valves, which will be controlled with the use of compressed air, shall have actuators capable of working with the maximum pressure up to 6 barg.

The valves shall be installed in such a manner to allow repair works to be performed without unnecessary interference in the structure of the apparatus. Also, access to the valves shall not entail a risk of damaging any elements of the Helium Cooling System.

Cold valves shall meet the requirements for applications in vacuum-insulated cryogenic installations designed for helium temperatures in the range from 350 K to 2.2 K.

Both the body seal and the bellows seal shall be located at the upper end of the valve in order to ensure easy access during maintenance or replacement. Both the valve stem and the valve bellows shall be removable from the top and allow the replacement of the valve seat without the need to compromise the vacuum in the system.

The valves which operate at pressures lower than the atmospheric pressure must be provided with helium shields protecting against air penetrating into the valve.

The valves must be installed in a vertical position. During the installation process, appropriate welding procedures shall be implemented in order to avoid stresses, which may cause the valve body to become plastically deformed.

The valves shall move smoothly in all possible working conditions and in the entire range of their mechanical operation, without any visible or audible symptoms and jolts. The potential operating conditions involve not only the warm operating conditions but also cold operating conditions and include all potential transitions between room temperature and the set operating temperature, as well as the changing operating conditions, any combinations of temperatures, pressures and mass flows in the process lines.

9.3. SAFETY VALVES AND PLATES

The design of and the materials used in the safety valves shall be adequate to all possible operating temperatures.

All valves must be full lift safety valves with bellows seals protected against gas leaks. Additionally, the valves installed on the vacuum lines must be provided with helium shields.

The valves must be provided with tools preventing them from being opened during pressure tests.

The safety valves must meet the requirements of the ISO 4126 standard or another equivalent standard and must have appropriate certificates and approvals issued by a certified body.

9.4. PRESSURE MEASUREMENT

9.4.1. PRESSURE TRANSDUCERS

The pressure transducers must be no other than absolute pressure transducers.

The transducers shall be provided with the 4..20 mA communication standard. The transducers must be protected against polarity reversal.

The total measurement error, allowing for the non-linearity and the hysteresis, shall be smaller than or equal to ±0.5% of the set range.

The transducer shall be protected against misconnections of power supply cables (reversing of the „+” and „-” cables).

The transducers must withstand the entire range of pressures, from vacuum to the maximum test pressure, without losing calibration or being subjected to any damage.

The transducers must be provided with process valves (cut-off valves)

9.4.2. PRESSURE INDICATORS

Pressure indicators (manometers) must have housings made of stainless steel. In the case of mechanical vibration, the manometers shall be filled with silicone oil for dampening the vibration. The required accuracy class is at a minimum of 1%. The displayed pressure must be provided in absolute pressure values. The minimum allowed diameter of the manometer dial shall be not smaller than 100 mm.

The manometers must be connected to the system via a cut-off valve, allowing them to be disassembled in the case of repair or replacement.

9.5. TEMPERATURE MEASUREMENTS

The thermometers shall be fastened with strong and durable fixing means, which are insensitive to frequent temperature changes and which ensure a good thermal contact between the pipe surface and the sensor. All of the sensors shall be protected from mechanical damage and from direct contact with multi-layer insulation (MLI), e.g. by using an isolation layer in the form of Kapton foil.

The sensor fastening means shall be designed in a manner to facilitate the replacement of thermometers if needed.

Each helium temperature meter must be provided with documentation prepared in both paper and electronic form for further use in the control system. Each piece of documentation and the sensor shall be allow easy identification, in order to easily assign a particular piece of documentation to the particular sensor and thus avoid a mistake. The thermometers must be calibrated within the entire range of the operating temperatures.

The temperature sensors for shield and 2K string must satisfy the following requirements:

- Short-term repeatability < 0.05% @ 4.2 K
- Accuracy < 0.05%
- Thermal response < 1 mS @ 4.2 K
- Sensitivity up to 1800 Ω/K @ 4.2 K

Other thermometers must satisfy the following requirements:

- Short-term repeatability < 0.12% @ 4.2 K
- Accuracy < 0.12%
- Thermal response < 10 mS @ 4.2 K
- Sensitivity up to 22 Ω/K @ 4.2 K

The documents provided with the helium-dedicated sensor shall include:

- A calibration certificate
- Records of experiments including all the data and experiment conditions
- All data of the interpolating polynomial, such as for example the type of the polynomial, polynomial coefficients etc. The function shall be provided in the form of T=f (R), and not in reverse order.
- The diagram of the function R=f (T) together with the indicated calibration points
- A table containing the temperature and the sensitivity (dR/dT) for at least 150 resistance values at equal and rounded resistance steps for temperature converter installed at thermal shields and 2K string circuit.

Thermometers operating at temperatures above 40 K can serve as PT100 sensors.

Thermometers operating at temperatures above 8 K can serve as CLTS sensors.

The wiring of the thermometers shall be protected from damage, accidental breaks etc. Such wires shall not be arranged gravitationally and be submerged in a helium bath. The wires shall be connected to the electrical connectors which shall be then secured in penetration openings, e.g. the KF type sealed with O'ring seals.

The pins of the electric connections shall be arranged unambiguously, so that they can be identified with respect to the allocation diagram provided by the Contractor.

9.6. FLOW MEASUREMENTS

The flowmeters shall be secured to the process lines by welding. It is not acceptable to secure them with the use of threaded joints. Metal elements shall be made of stainless steel having an appropriate grade, in accordance with the requirements presented in section 11.2.

The electronic part shall be led outside the vacuum jacket and if needed – outside the radiation zone.

The accumulated measurement error of the flowmeters shall not be greater than 1%, and shall be confirmed by in tests performed by accredited laboratories in accordance with EN ISO/IEC 17025 or an equivalent standard.

The pins of the electric connections shall be arranged unambiguously, so that they can be identified with respect to the allocation diagram provided by the Contractor.

10. CONTROL SYSTEM

The refrigerator control system shall operate autonomously, by implementing the necessary algorithms and service procedures, and ensuring a safe operation of the installation. The System shall have its own operator control desk allowing all possible operating parameters to be set and all possible operating values to be read. The purpose of the operator control desk is to prepare the HCS to operate and to perform maintenance works by a personnel qualified to operate the HCS. The parameters set and the values read by the operators during the normal operation of the PolFEL accelerator shall be shared with and remotely set from the central system via Ethernet or RS485, with the MODBUS protocol. The HCS operator control desk shall be located in the area of the HCS, but its usage must not be a condition necessary for the normal operation of the PolFEL accelerator.

Apart from using the MODBUS protocol to remotely set and read the parameters by the central control system, the local HCS control system must deliver low-level electric signals in the standard of 4-20 mA current loops, which allow quick reactions in case of emergency. In particular, the HCS control system must use the above-mentioned signals to inform about:

- a failure or any other situation requiring a quick reaction from the other systems of the PolFEL accelerator,
- current operating mode, e.g. start-up, cooling/warming, normal operation etc. (the operating modes and their number will depend on the design of the HCS and on the implemented algorithms/procedures),
- selected key parameters or the state of selected HCS components, knowledge of which is crucial in a particular operating mode, in case the MODBUS interface was not available, e.g.: whether the pressure at a certain point does not exceed allowed values or whether a critical valve remains in open position, etc.).

Except for the information provided by the HCS control system, it must also accept rapid electric signals, which:

- necessitate an immediate shutdown or pause of the HCS operation and a switching to the safe mode,

- inform about a failure or another situation which takes place in another system of the PolFEL accelerator but are undesirable from the perspective of the HCS (what situations will be important from the perspective of the HCS will depend on the its design and operating algorithms/procedures).

11. Technical requirements

11.1. General information

The design and the calculations of the pipelines and process lines systems of the Helium Cooling System together with the supports shall be prepared in accordance with EN 13480-3. The pipelines system, including the supports, shall be manufactured and assembled in accordance with EN 13480-4. Inspections and tests of the pipelines, including the inspections and tests of the manufacturing process, shall be performed in accordance with EN 13480-5.

The values provided in this document, such as distances, pipeline diameters, valve sizes, operating pressures of individual components, etc. must be verified by the Contractor at the design stage.

In addition, the Pressure Equipment Directive 2014/68/UE shall be applied during the design and manufacturing stages and during the evaluation of the conformity of the HCS components.

11.2. Selection of materials

The materials must be selected in accordance with directive 2014/68/UE and with the most recent edition of the EN 13480 standard.

All elements which come in contact with the process medium, i.e. helium, as well as the vacuum tanks, must be made of stainless steel, whose quality must be confirmed by certificates of tests in accordance with EN 10204-3.1. The Awarding Entity approves the use of the materials other than stainless steel for vacuum jackets of the coldboxes provided that other requirements for these components as specified in this document are maintained, independently of the material used.

The thermal shields shall be made of copper or aluminum alloys.

The fixed supports of the process pipes and of the vacuum jacket shall be made of the same type of material as the pipes and the vacuum jacket and shall be designed in a manner to minimize heat inleaks. The sliding supports of the process pipes shall be made of composite materials having low thermal conductivity, high mechanical strength, and being suitable for cryogenic applications, such as G10.

Additional materials used in welding and brazing/soldering shall be selected in accordance with European standards, regulations of the notified body and appropriate technical requirements. Additional materials used in low temperatures require their conformity to be attested by appropriate certificates.

11.3. Process pipes and vacuum jackets

The process pipes classified as pressure equipment shall be designed, manufactured and tested in order to meet the requirements of the Pressure Equipment Directive 2014/68/UE and in accordance with EN 13480. Only seamless elements can be used, and this applies to elbow and tee pipes, reducers, etc.

The vacuum jackets of the Helium Cooling System components are not treated as pressure equipment. However, they shall be designed as tanks and pipeline elements operating under external pressure in accordance with EN 13480, EN 13445 and EN 13458.

The jacket shall be protected by relief devices, such as safety flap valves or other equivalent valves capable of removing the maximum helium flow to the atmosphere and simultaneously of limiting the internal excess pressure. The Contractor is responsible for providing the relief devices. The devices shall be arranged and designed in a manner to prevent the personnel from being injured by the flux of cold helium and to avoid a situation in which an oxygen-deficient life-threatening atmosphere is formed in the refrigerator building. The Contractor shall agree the precise arrangement of the safety devices with the Contracting Entity during the Technical Design Review (TDR).

The Contractor must perform all the required calculations in order to verify whether the general stresses and the stresses on the vacuum jacket are within the allowed limits. Particular attention shall be paid to a case when the process pipe depressurizes and the vacuum is lost. In such case the temperature of the vacuum jacket decreases significantly below ambient temperature. The verification calculations shall be performed for a case in which the vacuum jacket is cooled to 195 K due to a failure.

The vacuum barriers which separate the successive vacuum spaces shall have a mechanical strength adequate to withstand, without damage or permanent deformations, a pressure difference of 1.5 bar and to withstand any mechanical loads expected during the transportation and assembly. Particular focus shall be placed on the connection between the Helium Cooling System and the CDS transfer line. If the vacuum barriers are to be treated as a fixed point, their structure shall allow for the total stresses in the process pipes and in the jacket due to the CDS.

Each of the vacuum jackets with its individual vacuum must be provided with one or more ports for pumping vacuum in accordance with ISO 2861 and ISO 1609 or equivalent standards. The location of the vacuum-pumping ports must be agreed with the Contracting Entity, as it is needed to arrange an adequate infrastructure for potential works related to vacuum regeneration.

The Awarding Entity releases Contractor from the obligation to perform thermal calculations of the external jacket of Daresbury refrigerator, due to the fact, that this element is the property of the Awarding Entity and has been already manufactured.

11.4. COMPENSATION FOR NEGATIVE THERMAL EXPANSION

If low temperature can cause negative thermal expansion (thermal shrinkage) leading to unacceptable stresses, loads or deformations, it shall be eliminated with the use of appropriate compensating elements, support systems etc.

Compensation means can be used on both process lines and vacuum jackets. All compensation means must conform to EN 14917. The compensation means for the process pipes shall meet the requirements of the Pressure Equipment Directive 2014/68/UE and shall conform to EN 13480.

Where possible, the use of compensation means shall be avoided on the process lines, and their application as compensation means shall be justified only if other thermal compensation solutions would lead to lowering the parameters of the mechanical structure.

The bellows shall have a minimum life of at least 1000 full compression and extension cycles.

In the case when multi-layer bellows are used for internal pressure compensation means, only the inner layer shall be hermetic, and the remaining layers shall be provided with a vent opening. In the case of external pressure compensation means, it’s the outer layer that shall be hermetic.

The external bellows shall have a minimum life of at least 200 full compression and extension cycles. These bellows shall be provided with metal shields made of the same material as the process pipe of the jacket.

Metal hoses shall be made in accordance with EN 13480, EN 12434 and EN 14585. They shall be designed in such a manner to resist any load provided for in the design without the risk of mechanical damage or permanent deformation. The hoses shall have a protective braid made of an appropriate stainless steel grade.

11.5. Supports and fastening means

Any support installations and structures for the refrigerator elements and for the auxiliary elements must be fastened to the supports, which shall be designed by the Contractor and which shall rest on the foundation plates of the building. Any changes made for the above purpose to the load-carrying structure and to the envelope of the building are prohibited, and this prohibition applies in particular to drilling, welding, or compromising the continuity of anti-corrosion coatings. The supports and the structures for supporting the elements of the refrigerator shall be designed with allowance for all requirements regarding the supports for pipeline elements and tank jackets under external pressure, in accordance with EN 13480, EN 13445 and EN 13458, as well as PN-EN 13480-1:2017-10 Metallic industrial piping, PN-EN 13480-3:2012/A1:2017-08 Design and calculation, PN-EN ISO 12944 Corrosion protection of steel structures by protective paint systems or with an equivalent standard.

In the case when balloon helium tanks are installed, it is allowed to hang the balloons and small elements of the system to the load-bearing structure of the hall, while observing the above regulation which prevents the coatings of the structure from being compromised. Details regarding the design of the fastening means for hanging the balloons and of any potentially required penetration openings in the walls must be approved by the Contracting Entity and their delivery, adjustments to the load-carrying structure in order to allow their installation, as well as the construction of the penetration openings are within the scope of the contract.

The supports shall be designed in such a manner to resist load cases defined in the design without mechanical damage or permanent deformation. Their design shall allow the elements to be positioned longitudinally and vertically, and shall also allow the positions to be regulated.

Fixed internal supports shall limit the displacement and rotation of the refrigerator elements and shall transfer their weight and pressure, as well their mechanical and thermal load to the structure of the building, i.e. to the floors, walls and roofs. The sliding supports shall only limit lateral displacements and carry loads.

During the FDR, The Contractor must inform the Contracting Entity about the locations of the supports and about the maximum expected loads in the locations where the supports are installed.

All of the support elements which have direct contact with external surfaces of the refrigerator components shall be made of an appropriate stainless steel grade, as defined in section 11.2.

11.6. Positioning

The components of the Helium Cooling System shall be positioned in accordance with the documentation describing the arrangement of the components and with the accuracies indicated in the documentation. The documentation shall be agreed with the Contracting Entity. The most important element, which shall be positioned with an accuracy down to +/- 0.5 mm, is the IC1 interface – the connection between the Helium Cooling System and the CDS transfer line.

11.7. Vacuum insulation

The vacuum insulation of the Helium Cooling System components shall be static and shall be constantly monitored by the HCS. In nominal operating conditions, without active vacuum pumping, the pressure inside the vacuum jacket shall remain below 1x10E-6 mbar.

12. Specification for work accomplishment

12.1. Mechanical properties

The HCS shall be designed, manufactured and installed in such a manner to ensure a reliable and uninterrupted operation of the laser (except for the planned downtime and maintenance procedures) for a minimum period of 20 years. The structure shall ensure a proper mechanical and thermodynamic operation of all elements without any damage or deterioration in quality for the entire service life of the apparatus.

All elements exposed to low temperatures and high temperature fluctuations must be designed in such a manner to resist the maximum possible temperature changes which may occur during the operation of the apparatus as well as all maximum possible temperature differences along the entire length of the element. The design of the pressure-carrying elements, including the supports, shall ensure that the stresses do not exceed their maximum allowed values. The design shall allow for the nominal operating conditions, the cooling and warming cycles, as well as for pressure tests and emergency situations. The design shall also allow for independent cooling and warming cycles in different circuits of the process loops.

All vacuum tanks must be designed for pressures from 0 bara to the maximum of 1.5 bara (absolute pressure). The design of the pressure tanks shall allow for the fact that a break in any of the process line elements may cause the temperature of the vacuum jacket to locally decrease to a level significantly lower than its nominal operating conditions.

All of the elements shall be designed to pass pressure tests in accordance with 2014/68/UE and EN 13480. The pressure tests shall be performed at a minimum pressure being 1.43 times higher than the design pressure.

12.2. Helium-tightness level

The helium-tightness level shall not exceed the following values:

- An individual inleak from the outside to the inside of the tested element through a weld: 1x10E-8 mbar·l/sec.
- An individual inleak from the inside of the component (weld, bellow, elastic hose, valve etc.) to the vacuum: 1x10E-8 mbar·l/sec.
- In operating conditions (temperature and pressure), the measured total inleak of the system to the vacuum: 1x10E-6 mbar·l/sec.
- Sum total inleak of an individual component, installed on the vacuum tank, e.g., a pressure transducer, a cut-off valve etc., measured from the outside of the component to the tank vacuum: 1x10E-7 mbar·l/sec.
- Sum total inleak of an individual safety flap installed on the vacuum tank, measured from the outside of the component to the tank vacuum: 1x10E-6 mbar·l/sec.
- Sum total inleak of an individual pressure-carrying component installed outside of the vacuum tank, e.g. a safety valve, a pressure transducer, a manometer, etc., as measured from the inside of the component to the atmosphere. 1x10E-6 mbar·l/sec.

For each helium-tightness test, the sensitivity of the helium detector must be at least 1x10E-11 mbar l/s.

12.3. Valve tightness

The helium inleak level of the cut-off valve, as measured from the vacuum side at operating parameters (pressure and temperature, including room temperature) must not exceed 1x10E-4 mbar l/sec. The inleak level of the cut-off valves shall be measured in both directions, when the pressure and the vacuum are provided successively first from the inlet and then from the outlet side of the valve seat.

The helium inleak level of the safety valve, from the vacuum side to the atmosphere and at operating parameters (pressure and temperature, including room temperature) must not exceed 1x10E- 4 mbar l/sec.

13. Technological requirements

13.1. Welding

All permanent joints in pressure-carrying process pipes shall be made with the use of welding methods. This rule applies to piping, elastic hoses, compensation means, tee pipes etc. In the case of process pipes, only complete penetration butt welds are allowed. During the manufacturing process at the premises of the Contractor, the elements of the external jacket of vacuum tanks shall be joined with each other by means of longitudinal or circumferential complete penetration butt welds. During the installation process at the premises of the Contracting Entity, the vacuum jacket between the two systems can be joined by means of fillet welds.

In the case of process pipes and vacuum jackets, the welding process shall be performed by means of TIG welding. The external supports can be welded by means of TIG and MIG methods.

Any activities related to the welding process shall be performed with respect to the requirements of the ISO 3834-2 standard or an equivalent standard. This fact shall be confirmed by a valid certificate issued to the Contractor by an appropriate notified body.

The welding technologies shall conform to the ISO 15609 standard or an equivalent standard.

Tests of the welding technologies shall conform to the ISO 15614-1 standard or an equivalent standard.

The welding works may be performed only by appropriately qualified welding professionals. Their qualifications shall be confirmed by a certificate issued in accordance with ISO 9606-1 or an equivalent standard.

Specialists supervising the welding process shall have their qualifications confirmed in accordance with ISO 14731 or an equivalent standard.

The welding tolerances shall be in accordance with ISO 13920 or an equivalent standard, in the C and G weld class.

During the welding process, both the backing gas and the shielding gas must conform to ISO 14175 or an equivalent standard. The color of the weld shall be as close as possible to the natural color of the joined metals, but it is acceptable for the weld to have a straw color.

The requirements regarding non-destructive testing (NDT) of welds, which will be performed at the manufacturing and assembly stages, shall be in accordance with ISO 13480-5 or an equivalent standard and with the requirements provided in Table 15.1.

Table 15.1. Range of weld non-destructive testing

Weld	Phase	VT	RTG	Helium test	LN2 thermal shock testing
Process pipe	Manufacturing	100%	50 %	100%	100%
	Installation	100%	100%	100%	not applicable
Vacuum jacket	Manufacturing	100%	10 %	100%	not applicable
	Installation	100%	not applicable	100%	not applicable

Visual tests (VT) of the welds shall be performed in accordance with ISO 17637 or an equivalent standard. The weld quality level and the weld defect acceptance criteria as per ISO 5817 or an equivalent standard shall be B for the process pipes, C for the vacuum jackets and D for the supports and other structural elements. In the case when ISO 10042 or an equivalent standard is used, the quality and defect acceptance is allowed at level C.

The radiographic examinations shall be performed in accordance with ISO 17636 or an equivalent standard. The quality level shall be B in accordance with ISO 5817 or an equivalent standard. The weld defect acceptance criteria shall be in accordance with ISO 10675-1 or an equivalent standard. In the case when a defect is detected, the range of RTG tests shall be extended by a minimum of further 20%, depending on the number of welds tested in a particular series. A precise range within which the tests shall be extended shall be dictated by the Contracting Entity after having analyzed the defect.

The helium-tightness tests and the thermal shock tests with liquefied nitrogen are described in section 14.

Prior to the manufacturing stage, the Contractor must submit to the Contracting Entity the following documents confirming the qualifications and readiness to perform the welding processes:

- Qualification certificate issued to the Contractor in accordance with ISO 3834-2 or an equivalent standard
- Qualification certificate issued to the welders in accordance with ISO 9606-1 or an equivalent standard
- Welding plans
- Weld test plans
- Welding procedures (Welding Procedure Qualification Record, Welding Procedure Specification)

During both the manufacturing stage and the installation at the premises of the Contracting Entity, all records and protocols related to the welding process must be kept available and must be disclosed to the Contracting Entity, at the request of the Contracting Entity. After the completion of the installation procedure, the Contractor is obliged to pass all the welding documentation in accordance with section 16.

13.2. Brazing/Soldering

All brazing/soldering works must be performed while observing the quality requirements for brazing in accordance with the following standards. This fact shall be confirmed by an appropriate certificate.

The copper-stainless steel, copper-copper, etc. joints may be brazed only by means of the 912 brazing method as per ISO 13585 or an equivalent standard. The only exception applies to electric wires etc. which can be soldered.

The brazing technology shall be accepted in accordance with EN 13134 or an equivalent standard.

Tests of brazed joints shall be performed in accordance with ISO 12797 and ISO 12799 or equivalent standards.

The brazing/soldering procedures can be performed only by workers with appropriate qualifications confirmed by relevant certificates. The brazing specialists shall be qualified in accordance with ISO 13585 or an equivalent standard.

Specialists supervising the brazing/soldering process shall have their qualifications confirmed in accordance with ISO 14731 or an equivalent standard.

The filler metals shall be selected in accordance with ISO 17672 or an equivalent standard.

The flux agents used in brazing shall be selected in accordance with ISO 1045 or an equivalent standard.

Defects in brazed/soldered joints shall be evaluated in accordance with ISO 18279 or an equivalent standard.

The brazing/soldering tolerances shall conform to the documentation.

After the brazing/soldering process is finished, all surfaces shall be cleaned from impurities, dust, oxidation coloring etc. due to brazing/soldering.

13.3. Surface cleaning and preparation

All stainless steel surfaces must be cleaned in such a manner that they are metallically clean, light-color and dry, free from oils, greases, oxide layers, oxidation coloring, ferritic impurities, dusts, etc.

All surfaces which are in direct contact with helium or which are subjected to vacuum must be free from dirt, welding slag, or other impurities.

A particular cleanness level is required on the internal surfaces of all pipelines in the helium system. The lines must be metallically clean and free from particles greater than 5 µm in size. Soluble residues shall be removed with acetone or alcohol.

Measures shall be taken to ensure that all flux residues were removed from the brazed/soldered parts.

After welding, all welds exposed to atmospheric conditions shall be subjected to etching and passivation in order to avoid corrosion and rust.

All regions of the vacuum jacket which were in contact with carbon steel, e.g. by being accidentally scratched during the manufacturing or transportation process, must be carefully polished and passivized in order to avoid corrosion.

14. Tests

14.1. General information

All tests shall be performed in accordance with the test procedure agreed with the Contracting Entity.

The Contractor is held responsible for performing all tests, and for this reason the Contractor shall ensure a qualified personnel, a sufficient quantity of equipment, and adequate conditions for performing these tests at the premises of both the Contractor and the NCBJ. The responsibility for all the necessary documents, such as the list of materials, drawings, records, calibration certificates for test devices, specifications and procedures regarding non-destructive testing etc. shall rest on the Contractor and shall be provided by the Contractor.

The pressure-carrying parts which may require authorized examinations in accordance with the Pressure Equipment Directive shall be supervized and monitored in accordance with appropriate modules of the 2014/68/UE Pressure Equipment Directive (PED). The responsibility for defining the category in which the components of the Helium Cooling System are classified rests on the Contractor, while the selection of a module of the conformity procedure for the components from among the category defined by the Contractor shall be the responsibility of the Contracting Entity. If needed, these components shall be inspected by a third party (a notified body). The cost of such an inspection shall be covered by the Contractor.

All pressure tests shall be performed under a preliminary pressure defined in the Pressure Equipment Directive and in EN 13480, as well as in accordance with any other applicable standard. Only pneumatic pressure tests are allowed, as the presence of residues left by water or any other liquid is not allowable.

All materials, semi-finished and finished products obtained or used by the Contractor or its subcontractors require to have acceptance certificates in accordance with EN 10204 or an equivalent standard. For metal elements, the material certificates shall be type 3.1, and for the remaining materials they can be a lower type. The certificates shall be made available during the tests and shown to the Contracting Entity, if it participates in the tests.

Inspectors tasked with non-destructive and destructive tests of materials and with controlling the leak-tightness, shall have extensive technical knowledge allowing them to perform the tests in full agreement with the requirements.

The Contractor shall propose a test plan and test procedures and shall present them to the Contracting Entity for approval during the final design review (at least 4 weeks before the tests). After the tests, the Contractor must provide the Contracting Entity with all records and protocols of the tests which were performed at the premises of both the Contractor and the Contracting Entity. This must be done not later than 2 weeks after the tests are finished. If the tests demonstrate any defects, the tests must be repeated in part or completely, after the defect is removed. In the case when the defect is beyond repair, a defect report must be prepared and passed to the Contracting Entity in order to take further decisions.

The test sequence shall ensure a logical order is preserved and allow for the structural complexity of individual components of the Helium Cooling System. The tests must allow the verification of all of the parameters necessary for the proper operation of the apparatus and for ensuring its safe and failure-free use, by minimizing the risk of malfunctions.

Due to the different character of the Helium Cooling System components, the type of tests, their sequence, etc. may be different for individual components. Before it is delivered to the premises of the Contracting Entity, each element shall be subjected to preliminary tests in a manner most closely reflecting actual operating conditions. For this purpose, the tests shall be performed in cold conditions, with the use of LN2 (where possible), with the instruments (valves, sensors, transducers etc.) installed and in pressure conditions corresponding to the operating pressure. Some components which are individual sections subjected to a limited risk of failure (e.g. simple sections of the transfer line without compensating means or elastic hoses) may be tested without the need to perform cold tests. This must be however earlier agreed with the Contracting Entity.

The completion of all the required tests, confirmed by consistent test protocols, shall be a necessary condition for accepting the contracted works.

14.2. TESTS AT THE PREMISES OF THE CONTRACTOR

14.2.1. GENERAL INFORMATION

Each pressure-bearing component shall be subjected to tests before it is sent to the premises of the Contracting Entity. The tests are to ensure that the safe operation of the elements during the operation of the laser. The tests apply in particular to the process pipes, compensating means, elastic hoses, valves and instruments. The Contractor shall decide if any of the components need to be tested as individual subassemblies or as a whole, being installed in a larger element. This decision may be dictated by the component design, test simplicity, its economic and technical reasons or other external factors such as risk analysis.

14.2.2. TESTS OF INDIVIDUAL COMPONENTS

Each individual component originally produced by the Contractor or carrying pressure or vacuum (such as prefabricated pipe sections, compensating means, elastic hoses, etc.) which are not designed to be installed in any device at the premises of the Contractor (e.g. in the transfer line, coldbox, etc.), but will be in the future installed at the premises of NCBJ, shall be tested in accordance with the above instructions.

14.2.2.1. TESTS OF WELDS

All welds shall be verified and tested in accordance with EN 13480-5. The inspection and the tests shall include a review of the welding documents, as well as a control of the elements prepared for welding, of the welding process itself and the welding results. The tests shall be performed in accordance with the requirements regarding weld inspections defined in section 13.1, which describes inter alia the requirements regarding visual and RTG tests.

14.2.2.2. LEAK-TIGHTNESS TESTS OF INDIVIDUAL WELDS

The pressure in the tested element shall be reduced to 5x10E-3 mbar, and then the test element shall be subjected to a helium test by introducing helium to the external surface of the weld. The observed leak must meet the criteria described in section 12.2.

14.2.2.3. PRESSURE TEST

The pressure test shall be performed in accordance with PED and EN 13480-5. The pressure during the test shall not be smaller than 1.43-fold the maximum allowed pressure.

Leak-tightness test of the entire component

After the pressure test, another helium-tightness test shall be performed. The observed leak must meet the criteria described in section 12.2.

In the case of compensating means or elastic hoses produced by the Contractor, it is necessary to perform an additional cold test combined with a helium-tightness test.

14.2.2.4. SHOCKING

The tested component shall be cooled to 80 K with the use of liquefied nitrogen. If the component is arranged in a temporary vacuum tank, it shall be filled in such a manner that the liquid nitrogen is introduced through a port located on the one side, and removed through a port located opposite. During the tests, particular attention shall be paid to any noise from the inside of the tank, as this may be the effect of damage, fractures, etc.

14.2.2.5. COLD TIGHTNESS TEST

After the component is cooled, the system shall be purged with dry nitrogen in order to remove liquids and then it shall be filled with helium or with a He/N mixture (min. 20% of helium) until design pressure is reached. The tested component shall be then subjected to tightness tests in accordance with the description provided in section 14.2.2.4.

14.2.2.6. WARMING AND WARM TIGHTNESS TEST

The tested component shall be warmed with dry nitrogen to a temperature above 275 K, and then it shall be emptied and filled with helium or with a He/N mixture (min. 20% of helium) until design pressure is reached. The tested component shall be then subjected to an additional tightness test in accordance with the description provided in section 14.2.2.4.

14.2.3. TESTS OF COMPONENT ASSEMBLIES

14.2.3.1. GENERAL INFORMATION

This section describes tests which apply to multi-element structures such as the coldbox, the transfer line modules, connection modules, etc. The number of tests performed during the examinations depends on the complexity of a particular system.

14.2.3.2. Tests of welds

Each weld made during the construction of the apparatus shall be subjected to identical tests as in the case of individual components, described in section 14.2.2.1. Importantly, during the installation, some welds may be more difficult to test and inspect.

14.2.3.3. Tightness test of process pipes

The tightness of welded joints in process pipes shall be inspected with the use of a helium leak detector. For this purpose, the pressure in the inner space shall be reduced to 5x10E-3 mbar. Subsequently, helium shall be blown from outside on each weld. In the case of pipes with a diameter greater than DN65 and of all welds on vertical pipes, the welds shall be shielded with plastic film and adhesive tape. Direct application of adhesive tape on welds is not allowed, as the glue may block the leak. The space under the film shall be filled with helium and left for 5 minutes. After this time, tightness measurement shall be performed.

The observed leak must meet the criteria described in section 12.2.

14.2.3.4. Pressure tests

The pressure tests shall be performed at least before the application of multi-layer insulation (MLI), in order to be certain that all of the welded parts have adequate strength. Importantly, the manufacturing stage during which a pressure test is performed shall provide the possibility for making quick repairs in the case the test is failed.

The number of pressure tests depends on the complexity of the design. The Contractor must estimate whether more than one pressure test is required. There might be a threat that as the structure is expanded some elements may have an impact on other elements and influence them negatively during the tests by generating additional forces or stresses (e.g. the supports, compensating means, etc.). In such case, the pressure tests shall be performed at several manufacturing stages.

The pressure test shall be performed in accordance with PED and EN 13480-5. The pressure during the test shall not be smaller than 1.43-fold the maximum allowed pressure.

The test time at full test pressure must be at least 20 minutes, unless authorized inspectors decide otherwise.

14.2.3.5. Visual tests of MLI

Each time after MLI is applied, a detailed inspection is required in order to verify whether the assembly was performed in a manner ensuring the best possible protection against thermal radiation and the reduction of heat exchange between the process pipes and the environment.

Adjacent layers of MLI must not be arranged in such a manner that thermal short-circuiting occurs between them, e.g. by the last MLI layer of one element coming into contact with the first MLI layer of the second element.

14.2.3.6. Tightness tests of vacuum jacket

Vacuum inside the jacket must be lowered to 5x10E-3 mbar, and then the test element shall be subjected to a helium tightness test. All welds must be hermetically covered with plastic film from the outside and protected with adhesive tape. The space under the film shall be filled with helium and left for 5 minutes. After this time, tightness measurement shall be performed. The test must be performed without the process pipes inside the jacket, or all the pipes must be kept open, so that at the same time vacuum is removed from their interior as well, or the process pipes must be removed from the vacuum jacket so that they are not involved in the test.

The observed leaks must meet the criteria described in section 12.2.

14.2.3.7. Tightness tests of valves

Valve tightness tests must be performed at several stages of the Helium Cooling System manufacturing process. First, the valves must be examined after they have been delivered by the valve manufacturer, but before they are installed in the apparatus.

The tightness of the valve seats must be verified on both sides, with consideration to the fact that pressure may be observed on both sides (inlet/outlet) of the valve.

When tests are performed on valves already installed in the system, all valves shall be in closed position, and the pressure in the entire system shall be reduced to 5x10E-3 mbar. Subsequently, each of the lines shall be successively filled with helium at the design pressure. A helium leak detector shall be connected on the other end of the installation, behind the valve, in order to check the tightness of the valve seats.

The observed leaks must meet the criteria described in section 12.3.

14.2.3.8. Functional tests of valves

The valves must be examined several times for full opening and closure range. The valves must move smoothly in the entire range of their mechanical operation, without any visible or audible symptoms and jolts.

14.2.3.9. Tests of temperature sensors

The functioning of the temperature sensors must be controlled before and after each manufacturing and assembly stage, such as installation in the measurement point, connection to the electric wire passage, thermal shocking, application of MLI, etc. The tests shall include measurements of resistances between each pair of wires.

After they have been installed on the pipe, but before the MLI is applied, the sensors must be verified for correct operation by pouring liquefied nitrogen on them. The resistance values shall be verified with the use of appropriate calibration characteristics. The test shall be repeated at least 5 times.

14.2.4. Functional tests of the produced devices

14.2.4.1. General information

In order to minimize the risk of failure, when the manufacturing of individual devices or their sections, such as valveboxes, connection modules, transfer line modules, etc., is finished, functional tests must be performed in conditions as close as possible to the operating conditions of the apparatus. For this purpose, both warm and cold tests shall be performed. All valves, temperature sensors, level indicators, heaters, pressure transducers and manometers shall be installed in their final positions and shall be involved in the tests.

If failures are observed during any of the tests, the procedure shall be interrupted, the failure shall be repaired and the tests shall be resumed from the beginning.

14.2.4.2. Tightness test of vacuum jacket

The pressures in the space inside the vacuum jacket shall be reduced to 5x10E-3 mbar. Any potential leaks in the vacuum jacket, such as welds, collar joints, valves, electric wire passages etc., shall be hermetically covered with plastic film and secured with adhesive tape. The space under the film shall be filled with helium and left for 5 minutes. After this time, tightness measurement shall be performed.

The leak detector shall be connected to a port arranged on a temporary plug for closing the vacuum jacket. The vacuum port welded directly to the jacket shall be plugged and included in the tightness test.

The observed leaks must meet the criteria described in section 12.2.

14.2.4.3. PRESSURE TEST OF PROCESS PIPES

After the successful tightness test of the vacuum jacket, the entire system of process pipes shall be filled with helium (or with He/N mixture, minimum 20% of helium) up to a pressure not smaller than 1.43 fold the maximum allowed pressure.

The test time at full test pressure must be at least 20 minutes, unless authorized inspectors decide otherwise.

14.2.4.4. TIGHTNESS TEST OF PROCESS PIPES

After the pressure test of the process pipes proves successful, the pressure inside the pipes shall be lowered to the design pressure. The leak detector connected to the vacuum jacket shall start to operate and measure the leaks from the process pipes to the vacuum space.

The observed leaks must meet the criteria described in section 14.3.

14.2.4.5. COOLING OF THE PROCESS PIPES

After successful leak tightness tests, pressure shall be removed from the process pipes and the pipes shall be cooled to 80 K with the use of liquefied nitrogen. The pipes shall be filled in such a manner that liquid nitrogen is introduced through one port, flows through all the process pipes and valves, and exits through the opposite port. During the tests, particular attention shall be paid to any noise from the inside of the apparatus, as this may be the effect of damage, fractures, etc.

14.2.4.6. COLD TIGHTNESS TEST OF PROCESS PIPES

After the system is cooled, liquids shall be blown from the process pipes and a cold helium tightness test shall be performed, following the same procedures which were described in section 14.2.2.6.

14.2.4.7. WARMING OF THE PROCESS PIPES

After successful leak tightness tests in cold conditions, all the process pipes shall be warmed with warm nitrogen. The temperature of nitrogen must not exceed 360 K, so that the MLI is not destroyed. The process shall be finished when the temperature sensors at the end of the outlet opening show 275 K.

14.2.4.8. WARM TIGHTNESS TEST OF PROCESS PIPES

After the process pipes have been warmed, warm helium tightness test shall be performed. For this purpose, the system shall be filled with helium or with He/N mixture (minimum 20% of helium) until the design pressure is reached. The leak detector connected to the vacuum space shall start to operate and measure the leaks from the process pipes.

The observed leaks must meet the criteria described in section 12.2.

14.2.4.9. TIGHTNESS TESTS OF VALVES

The valves must be tested in the final devices. Tightness tests shall be performed in various conditions, i.e. before, during and after the cooling and warming processes.

The tightness of the valve seats must be verified on both sides, with consideration to the fact that pressure may be observed on both sides (inlet/outlet) of the valve.

The observed leaks must meet the criteria described in section 12.2.

14.2.4.10. FUNCTIONAL TESTS OF VALVES

Functional tests of the valves shall be performed in various conditions, i.e. before, during and after the cooling and warming processes.

The valves must be examined several times for full opening and closure range. The valves must move smoothly in the entire range of their mechanical operation, without any visible or audible symptoms and jolts.

14.2.4.11. TESTS OF PRESSURE TRANSDUCERS

Pressure transducers shall be installed in their final positions and shall be included in all of the above-listed tests.

The tests shall involve general functions of the transducers, such as signal readout, reception, menu selection, settings etc. The tests shall also verify whether the transducer receives the signal properly and whether it is capable of sending it further to the controller.

The test shall also demonstrate whether the transducer indicates correct pressure values. For this purpose, another pressure transducer or a manometer with an adequate range of indication shall be used.

The valve block of the pressure transducer (or a cut-off valve) shall be controlled for proper operation and whether it is capable of separating the transducer from the gas inlet, as well as whether it helium-tight in accordance with the requirements described in sections 14.3 and 14.4. 12.2. It must be also verified whether the valves move smoothly in the entire range of their mechanical operation, without any visible or audible symptoms and jolts.

14.2.4.12. TESTS OF TEMPERATURE SENSORS

The correct operation of the temperature sensors must be controlled on all stages of the tests described in section 14.2.4.

The resistance values recorded by the sensors shall be monitored with particular attention in low temperatures, and verified with the use of appropriate calibration characteristics.

14.2.4.13. TESTS OF HEATERS

During the tests, the heaters shall be installed in their final positions and shall be included in all of the above-listed tests.

The heaters shall be tested for the maximum attainable temperatures, which shall not exceed the maximum temperature allowed for the MLI and for the heater itself. The test shall be also performed at the moment when the apparatus is cold. After the apparatus has been powered off, the temperature of the heaters shall decrease to the temperature level of the cold system. The test shall be repeated at least 3 times.

14.2.4.14. TESTS OF HELIUM LEVEL INDICATORS

The level indicators shall be tested according to technical possibilities, which are limited, as tests are impossible to be performed in liquefied helium.

14.2.4.15. TESTS OF FLOWMETERS

The flowmeters shall be tested according to technical possibilities, which are limited, as tests are impossible to be performed in liquefied helium.

The tests shall involve general functions of the flowmeters, such as signal readout, reception, menu selection, settings etc. The tests shall also verify whether the transducer receives the signal properly and whether it is capable of sending it further to the controller.

14.2.4.16. Measurement verification

After the assembly works, the relevant dimensions of the HCS components shall be verified. Relevant dimensions are key dimensions, which have a direct influence on the proper and quick assembly of the apparatus in the final location. Their potential deviations may prolong or complicate the assembly process. Such dimensions may include the heights of the connections, the distances between the collars, as well as the perpendicularity, parallelism, and concentricity of the co-operating elements etc.

All dimensions shall correspond to the values provided in the final production and assembly drawings.

14.3. Tests at the premises of the Contracting Entity

14.3.1. Examination of the elements delivered to NCBJ

All elements of the Helium Cooling System delivered to the premises of NCBJ shall undergo examinations, which shall include:

- The integrity of the package, and checking for potential internal damage during transportation.
- The integrity of the delivered devices, and checking for potential internal damage during transportation.
- The cleanliness regime during the transportation, and checking for potential internal contamination during transportation.
- Accelerations during the transportation, and checking whether the acceleration levels remained below the allowed values.

14.3.2. Controlling of the positions of elements

Installation of the elements of the Helium Cooling System shall be started by arranging the supports in appropriate locations, as indicated in the documents. Any fasteners of the supports (also preliminary fasteners), as well as their positioning shall be controlled and approved by the Contracting Entity. Any drilling in the walls, floors, roofs etc. is not allowed until the Contracting Entity grants a written permission thereto. Prior to any final fastening, the Contractor must ensure that the components are arranged in an appropriate position. Non-reversible processes, such as welding, shall be preceded by ensuring that the elements are in appropriate positions. Any position adjustments shall be made prior to welding to the adjacent part, which means that a set of two or more elements must not be moved after they have been welded together.

The arrangement of critical components, such as refrigerators and connection elements having defined interface points, shall be verified and approved by the Contracting Entity.

14.3.3. Tests and control of welds

Each weld made during the installation of the apparatus shall be subjected to identical tests as in the case of producing individual components, described in section 14.2.2.1. Importantly, during the installation, some welds may be more difficult to test and inspect, as access to them is limited.

14.3.4. Tightness tests of process pipes

Each weld made during the installation process shall be subjected to identical helium tightness tests as in the case of the manufacturing process, described in section 14.2.3.3.

14.3.5. PRESSURE TESTS

Pressure tests shall be performed when all process pipes have been connected in loops, in accordance with their final configuration. The tests must be performed prior to applying the MLI, in order to maintain access to the connections made during the installation process. Importantly, the manufacturing stage shall provide the possibility for making potential repairs if the test is failed.

The pressure test shall be performed in a manner identical to that described in section 14.2.3.4.

During the pressure tests, relevant safety valves and sliding supports shall be locked.

14.3.6. TIGHTNESS TEST OF VACUUM JACKET

After all of the muffs connecting the adjacent elements have been installed, and all the vacuum barriers have been closed, the pressure in each volume inside the vacuum jacket shall be lowered to 5x10E-3 mbar and then subjected to a helium tightness test by blowing helium onto all the new welds, connections, collars etc. made at NCBJ. The new elements shall be hermetically covered with plastic film and adhesive tape. The space under the film shall be filled with helium and left for 5 minutes. After this time, tightness measurement shall be performed.

The observed leaks must meet the criteria described in section 12.2.

14.3.7. TIGHTNESS TESTS OF PROCESS PIPES AFTER CLOSING THE VACUUM JACKET

After the tightness tests of the vacuum jacket have been finished, the internal system of process pipes shall be controlled for helium tightness. The process pipes shall be filled with helium or with He/N mixture (minimum 20% of helium) until the design pressure is reached. A leak detector shall be connected to one of the vacuum-pumping ports.

The observed leaks must meet the criteria described in section 12.2.

During the pressure test, relevant safety valves shall be locked.

14.3.8. TIGHTNESS TESTS OF UNINSULATED PIPELINES

All uninsulated pipelines, auxiliary lines and warm connections with cold process pipes (impulse tubes of pressure transducers, connections to pressure-lowering devices etc.) shall be subjected to helium tightness tests. For this purpose, the pressure of the volume inside the process pipe shall be lowered to 5x10E-3 mbar, and then tests shall be conducted in a manner identical to that described in section 14.2.3.3.

The observed leaks must meet the criteria described in section 12.2.

14.3.9. PRESSURE TESTS OF UNINSULATED PIPELINES

All uninsulated pipelines, auxiliary lines and warm connections with cold process pipes (impulse tubes of pressure transducers, connections to pressure-lowering devices etc.) shall be subjected to pressure tests. The pressure test shall be performed in accordance with PED and EN 13480-5. The pressure during the test shall not be smaller than 1.43-fold the maximum allowed pressure.

The test time at full test pressure must be at least 20 minutes, unless authorized inspectors decide otherwise.

Depending on the test procedure and purpose, the following gases can be used in the pressure test: nitrogen, helium, He/N mixture (minimum 20% helium).

14.4. ACCEPTANCE TESTS

14.4.1. GENERAL INFORMATION

The acceptance tests shall be carried out in three stages:

- Stage 1: test with the use of an apparatus imitating loads from the CDS
- Stage 2: test after connecting the CDS (optionally)
- Stage 3: test after starting the laser (optionally)

The acceptance tests (both preliminary and final) shall be performed both for the delivery of the supplementary refrigerator and for the complete Helium Cooling System (unless the entire Helium Cooling System is delivered at the same time).

The acceptance tests include preliminary acceptance tests (PAT) and final acceptance tests (FAT).

The preliminary acceptance tests include the verification of all preliminary tests performed during the production and installation processes (such as weld tests, pressure tests, tightness tests etc.) together with 2 full cooling/warming cycles of the Helium Cooling System. Additional requirements are described in section 14.4.2.

The final acceptance tests include 1 full operating cycle and the operation of the System for 3 weeks. Additional requirements are described in section 14.4.4.

14.4.2. PRELIMINARY ACCEPTANCE TESTS

Preliminary acceptance tests (PAT) shall be performed by the Contracting Entity in the presence of the Contractor. The Helium Cooling System/supplementary refrigerator shall be connected to a test device which generates thermal loads for the CDS and the laser. The design and delivery of the test device remains the responsibility of the Contractor.

PAT include 2 full cycles of complete cooling and warming all of the HCS/supplementary refrigerator process pipes together with the thermal shields from room temperature to the operating temperature.

14.4.3. FUNCTIONAL TESTS

During the cooling phase, during the operation in steady state, and during the warming phase, the monitoring parameters shall include vacuum level in the vacuum jackets and helium leak values from the process pipes to the vacuum space of the jacket. The recorded leaks must meet the criteria described in section 12.2.

Functions of all of the process valves shall be tested remotely. The tests shall include such instruments as pressure transducers, manometers, temperature sensors, helium level sensors, heaters, etc. Their functions must meet the criteria described in the sections pertaining to the previous tests.

The tests shall also involve the control system and verify whether the signals are properly received by the sensors and transmitted further to the central laser control system.

The tests shall also involve the proper operation of other Helium Cooling System components, such as compressors, oil separators, vacuum pumps, the purification system and other systems being part of the contracted delivery.

14.4.4. MEASUREMENTS OF THERMODYNAMIC AND HYDRAULIC PARAMETERS

Thermodynamic measurements shall include measurements of the generated refrigerating capacity and of helium thermodynamic parameters at the studs of the CDS auxiliary lines for all process pipes and for the thermal shield. The Helium Cooling System shall have a refrigerating capacity allowing the compensation of heat inleaks to the CDS described in section 4.5.

The measurements shall include in particular the thermodynamic parameters inside the transfer line:

- for the supercritical He supply line – temperature, pressure and mass flows of helium leaving the Helium Cooling System
- for the thermal shields – temperature, pressure and mass flows of helium leaving the Helium Cooling System
- for the He return line – temperature and pressure of helium returning to the Helium Cooling System
- for the thermal shield return line – temperature and pressure of helium vapors returning to the Helium Cooling System

The delivery of the Helium Cooling System shall receive preliminary acceptance when the directly and indirectly measured thermal and hydraulic parameters meet the requirements described in sections 6.3 and 6.4.

14.4.5. FINAL ACCEPTANCE TESTS

FAT include 1 full operating cycle and the operation of the System for 3 weeks. If no defects or failures are observed during the tests, the Helium Cooling System shall receive final acceptance. One operating cycle means complete cooling and warming all of the CDS process pipes together with the thermal shields from room temperature to the operating temperature.

Final acceptance tests shall be performed immediately after the successful completion of PAT. If for some reasons beyond the control of the Contractor the connection of the HCS/supplementary refrigerator to the CDS is impossible, e.g. due to a delay in the delivery of the said apparatus, and if therefore it is impossible to perform FAT according to the schedule presented in section 19, then the Contractor has the right to demand performing the tests in a different reasonable manner, e.g. with the use of a device which imitates loads generated by the CDS.

15. DELIVERY

After the production tests are completed at the premises of the Contractor, the Contractor must inform the Contracting Entity that the product is ready for shipment and agree a delivery date with the Contracting Entity. The shipment shall be made only by a prior consent from the Contracting Entity. The delivery of the Helium Cooling System components shall be deemed accepted only after all tests have been performed at the premises of the Contractor and after the Contracting Entity has received the required documents which, if no defects are found, shall be accepted by the Contracting Entity in written form.

The Contractor is fully responsible for the delivery and unloading of all the Helium Cooling System components at the premises of the Contracting Entity. The Contracting Entity shall indicate a temporary storage location for the products delivered by the Contractor. The storage, packing, maintenance and transport of the HCS components must be performed in such a manner that protects the components from factors which may decrease their quality. The Contractor shall cover any costs related to the damage caused by inadequate packing, protection and transport.

The vacuum jackets, process pipes and internal parts of any of the components must be closed with plugs in order to prevent dust and moisture from penetrating inside. In addition, the internal space must be filled with dry nitrogen. All sealing surfaces shall be protected against rust and damage. Any protruding, freely hanging, or moving parts must be specially protected.

Particular attention shall be given to internal elements, which may be damaged or exposed to excessive loads due to accelerations during the transportation process. If required, transport blocking systems or additional internal supports shall be used.

After each delivery to the premises of the Contracting Entity, the components must be examined by both the Contractor and the Contracting Entity in order to identify any damage which may be attributed to the transportation process.

The components must be labeled in a durable and clear manner, by applying a label including the name and number of the part. The label shall be visibly placed.

The temporary storage location for the HCS components prior to installation shall be indicated by the Contracting Entity.

Delivery destination:

Narodowe Centrum Badań Jądrowych (Polish National Center for Nuclear Research)
ul. Andrzeja Sołtana 7, 05-400 Otwock, Poland

16. SCOPE OF DELIVERY

16.1. COMPONENTS

The scope of delivery includes the Helium Cooling System, which must consist of the following components:

- Refreshed Daresbury refrigerator, previously provided by the Ordering Party (see Chapter 16.5.2); refreshing the refrigerator entails cleaning it of oil, replacing connections as needed according to the technical design of the Helium Cooling System, and replacing the control system.
- Independent helium refrigerator, improving the performance of the System, if its presence is required by the technical design.
- Liquid helium Dewar tank, replacing the tank included in the original Daresbury refrigerator system (see Chapter 16.5.2).
- Helium screw compressor, part of the original Daresbury refrigerator system (see Chapter 16.5.2), provided earlier by the Ordering Party for adaptation and inclusion in the Helium Cooling System.
- Vacuum pump, replacing the pump included in the original Daresbury refrigerator system (see Chapter 16.5.2).
- Control cabinet with control system.
- Oil separators.
- Helium compressors.
- Gas management system.
- Vacuum pump systems.
- Helium purification system.
- Installation purification system ("purge").
- Helium recovery system.
  - Buffer tanks for gaseous helium.
  - High-pressure tanks (up to 200 bar) for collecting gas from the helium recovery system.
  - Additional gaseous helium tanks collecting gas from the helium recovery system, if their delivery is required by the technical design.
- Vacuum-insulated liquid nitrogen line (as required by the refrigerator).
- Transfer lines between individual components.

- Accessories for the supplied components, such as cryogenic valves, warm valves, manual valves, safety valves, rupture discs, pressure transducers, pressure indicators, temperature sensors, level sensors, heaters, etc., in accordance with the technical design.
- External supports (with screws and mounting elements, etc.) for the aforementioned components.
- Other components not mentioned but necessary for the operation of the helium refrigerator and HCS (Helium Cooling System), as specified in the technical design.

In addition, the Contractor will provide, in a timely manner, the following for the installation:

Tools necessary for installation.

- Equipment required for conducting pressure tests, helium leak tests, performance tests, etc.
- Positioning devices.
- Technical gases for welding, testing, and flushing the installation.
- All specialized tools and lifting equipment required during installation and work at heights, including scaffolding, hoists, cranes, platforms, etc.
- Other tools that may be needed for repairs or maintenance.

16.2. THE SCOPE OF WORKS:

The delivery shall include the following works:

- Preparing of the process engineering design for the Helium Cooling System, based on Daresbury refrigerator in accordance with the requirements of the Pressure Equipment Directive 2014/68/UE and standards mentioned in this document. The responsibility for defining the category in which the refrigerator system is classified rests on the Contractor, while the selection of a module of the conformity procedure for the refrigerator components from among the category defined by the Contractor shall be the responsibility of the Contracting Entity.
- Performing necessary thermal, thermodynamic, mechanical and strength calculations.
- Performing calculations and analyses and selecting devices such as valves, sensors, transducers etc.
- Reconditioning the Daresbury refrigerator, which involves:
  - removing oil from the Daresbury refrigerator and from the cooperating elements;
  - replacing connectors and adjusting them to the standards used in other elements of the System;
  - changing and updating the Daresbury refrigerator control system so that it is compatible with the control systems of the remaining HCS components, in particular – of the primary refrigerator;
  - replacing the Dewar tank with a new one;
- Verifying whether the remaining components provided by the Contracting Entity and cooperating with the Daresbury refrigerator operate correctly and are adjusted to operation as part of the cooling system.
- Producing or purchasing all components, elements or additional systems required for incorporating the Daresbury refrigerator into the HCS (including as an option, additional refrigerator)in accordance with the design.
- Transporting the components provided by the Contracting Entity to the premises of the Contractor.
- Transporting the HCS components to the premises of the Contracting Entity and their unloading, as well as providing any tools required for this purpose;
- Positioning, with particular attention paid to the elements allowing connection to other subsystems, e.g. to the CDS or the compressor cooling system;
- Installing all of the components, including all of the necessary support elements. The Contractor shall be also responsible for all necessary scaffolds, cranes and working platforms required for this purpose;
- Starting-up and testing the Daresbury refrigerator in accordance with the description in section 14.

16.3. DOCUMENTS

The below listed documents belong to the scope of delivery:

- The entire reqiored documentation made on the basis of the requirements from the following sources:
  - Pressure Equipment Directive 2014/68/UE
  - Office of Technical Inspection
  - notified bodies
  - CE marking
  - declarations of conformity
- Detailed specification as well as operating and maintenance manuals for all components
- Current P&ID
- Necessary calculations of diameters, wall thicknesses, flow rates, pressure drops, etc.
- Calculations and selection of valves, including safety valves
- 3D models of the delivered apparatus, including a 3D design of the systems in an stp file and in native files, including detailed models of the components produced directly by the Contractor – list of excluded components must be placed at Kick-off meeting.
- A complete set of assembly and working drawings, as well as updated as-built drawings of all components such as pipelines, interfaces etc., together with specifications of parts, lists of used materials etc.
- Quality management plan together with the schedule
- Lists of used materials together with test reports and the EN 10204-3.1 material certificates
- Documents pertaining to welding procedures, including certificates of welding technology tests and welding samples, as well as welder certificates
- All reports from tests and inspections, including protocols from RTG tests of welds, VT protocols, protocols from helium tightness tests, from pressure tests, etc.
- Reports and any other documents prepared during periodic meetings/visits etc.
- Documents related to the performing of each stage of the project, as described in section 18.

All documents shall be delivered electronically, on a CD, and on two USB drives, and also in 3 printed copies.

The above documents shall be delivered in English or Polish.

All units of measurements, weights etc. shall belong to the SI system. Independently of the documentation for the Contracting Entity, the Contractor must keep a list of all prepared documents together with their revision status. All changes to important documents shall be clearly marked in order to indicate the revision status (change index). In the case of repeated changes, the marks from the previous revision shall be removed. Documents which do not conform to the above requirements shall be rejected and deemed as not submitted. All documents shall have identification numbers.

16.4. TRAINING

The Contractor shall provide training on the operation of the Helium Cooling System to the personnel of the Contracting Entity. The scope of both the training and the documents must include such topics as: the construction of the HCS, start-up, operating modes, System shutdown, System testing, procedures for emergency situations, replacement of parts in the case when the assistance of the Contractor is not necessary.

16.5. COOLER

The HSC chiller(s) must provide sufficient cooling power for all operational modes described in this document

16.5.1. SCOPE OF WORKS

Currently, the Daresbury refrigerator is disassembled and together with the auxiliary components (inter alia the Dewar tank, the compressor) it is stored at the premises of the Contracting Entity. The scope of works required to adjust the Daresbury refrigerator to work with the primary refrigerator has been defined in sections 16.2 and 16.3, and its implementation remains the responsibility of the Contractor, who shall cover any costs related thereto. The Contracting Entity allows this scope to be extended on condition that such an extension will be first agreed with the Contracting Entity and that its cost will be covered by the Contractor.

Section 16.4.2 below contains the technical description of the Daresbury refrigerator. At the tender submission stage, the Contracting Entity shall render it possible for each participant of the tender procedure to access the Daresbury refrigerator at will in order to become familiar with its technical condition, the contents of the documents set, etc.

16.5.2. TECHNICAL DESCRIPTION

The Daresbury refrigerator, originally installed and operated in the STFC laboratory in Daresbury as an element of the infrastructure of the CLARA accelerator, was developed on the basis of the Linde TFC 50 coldbox (year of production: 2006), with a nominal capacity of 190 l/h for helium at 4.45 K and 1.25 bara. Directly before it was disassembled, the condenser had been fully operational.

Apart from the condenser coldbox, the system also comprised:

- A screw compressor
- A distribution panel
- A 2 K vacuum pump system
- A liquid helium Dewar 2000 l in capacity.

Of the above components, only the condenser coldbox and the compressor can be used in the PolFEL Helium Cooling System. The condenser control system (including the distribution panel) shall be replaced with a new one, compatible with the control system of the primary refrigerator. The 2 K pump was not provided to the Contracting Entity and must be replaced with a new device. The technical condition of the Dewar is questionable and for safety reasons it shall be replaced with a new tank provided by the Contractor.

16.5.2.1. THE DARESBURY REFRIGERATOR IN THE ORIGINAL SYSTEM

The Daresbury refrigerator is an automatized apparatus provided with a control system. It comprises a screw compressor, gas decompression turbines which enable continuous helium liquefaction. Helium was liquefied in accordance with the Claude cycle (in adiabatic conditions, work performed by gas leads to lowering its temperature). A block diagram of the refrigerator operating in its original system is shown in Fig. 16.1.

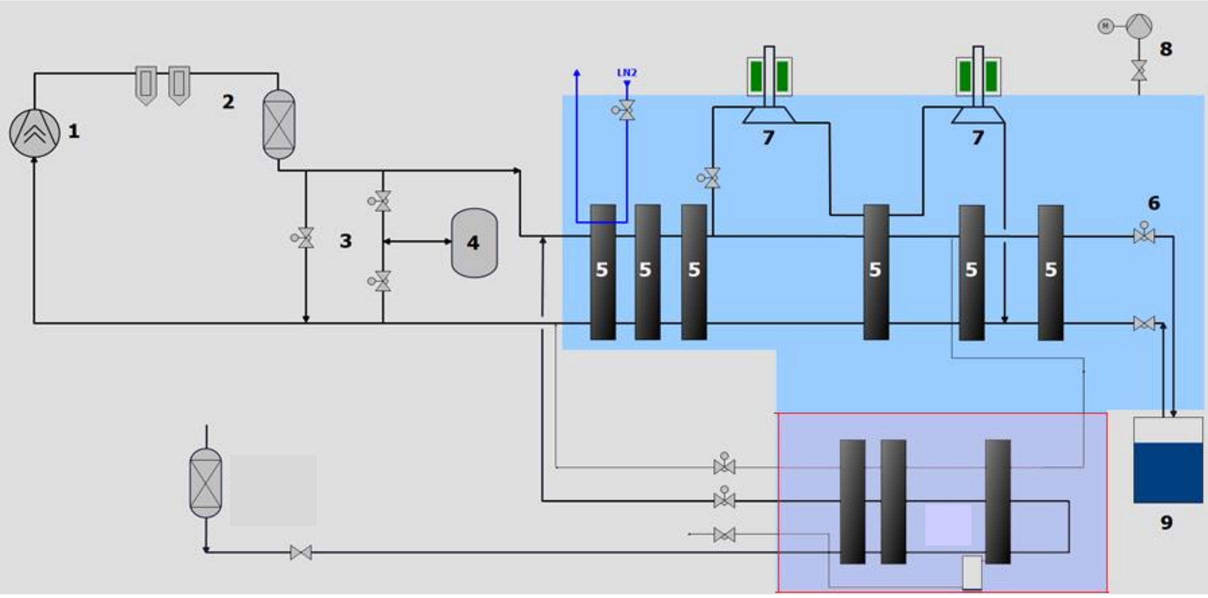

Fig. 16.1 Block diagram of the Daresbury refrigerator:
1. Screw compressor; 2. Oil removal system; 3. Gas management panel; 4. Pure helium buffer tank; 5. Heat exchanger; 6. Joule-Thomson valve; 7. Turboexpander; 8. Vacuum system; 9. Liquid helium Dewar; Blue color indicates the condenser coldbox.

The screw condenser with oil injection manufactured by Kaeser, with a single frequency converter (indicated with number 1 in Fig. 16.1) ensured the compression of purified helium from 1.05 bar to approx. 13 bar while constantly dispersing the heat generated due to compression. In the next step, the oil was removed from the circulating cold helium gas through a coalescer filter and a dedicated absorber (designated as number 2 in Fig. 16.1).

The proper cooling process took place on two successively arranged expansion turbines (turboexpanders, indicated with number 7 in Fig. 16.1), on which part of the circulating helium performed external work. In stationary conditions, the final temperature at the outlet from the second turbine was approx. 10 K.

At a temperature below 8 K, part of the circulating gas was throttled to a pressure of approx. 1.3 bar by the Joule-Thomson valve (indicated with number 6 in the block diagram). In this case, a 4.5 K vapor-liquid mixture was obtained, which was subsequently removed to the liquid helium tank through the transfer line. The cold helium gas produced during the throttling process was used in a closed circuit together with the low-pressure helium flowing from the turbines in the process of countercurrent exchange for the cooling of warm gas. For this purpose, aluminum plate heat exchangers were used (indicated with number 5 in Fig. 16.1).

16.5.2.2. TECHNICAL PARAMETERS OF THE DARESBURY REFRIGERATOR COMPONENTS

The parameters of the Daresbury refrigerator systems are provided in the following tables. The tables do not include data on the components which are missing or planned to be replaced.

Table 16.1. Operating conditions and main efficiency-related parameters of the condenser

Storage temperature	-15 – +33 ºC
Ambient temperature	3 – 38 ºC
Humidity	25 – 75 %

Helium gas flow rate in the compressor		79.4 g/s
Pressure and temperature in the compressor		1.05 bara, 297 K
Liquid nitrogen cooling	pressure	< 3.5 bara
	flow rate	40 g/s
Helium inlet to the condenser	pressure	13 bara
	temperature	< 303 K
	helium gas	79.4 g/s
Helium pressure at the outlet		1.05 bara
Helium parameters in the tank	pressure	1.25 bara
	temperature	4.45 K
	condenser capacity	190 l/h

Table 16.2. Electrical parameters of the refrigerator systems

Compressor	
Voltage	400 V
Frequency	50 Hz
Number of phases	3
Input power	250 kW
Start-up current	1080 A
Current protection – slow	500 A
Power supply cables	2 cables 4 x 150 mm^2

Condenser coldbox	
Voltage	400 V
Frequency	50 Hz
Number of phases	3
Input power	16 kW
Current protection – slow	32 A
Power supply cables	1 cable 5 x 10 mm^2

Table 16.3. Water-cooling parameters

General parameters of the cooling water	
Feed pressure	4 – 8 barg
Temperature	20 – 30 ^{o}C
pH	7 – 10
inclusions	None
Hardness (French scale)	< 18

Biological contamination	None
glycol content	< 20 wt%
Return pressure	approx. 2.5 barg
Compressor	
Consumption	9500 m^3/h
Temperature increase	approx. 11 ºC
Pressure difference (inlet – outlet)	0.4 mbar

17. INSTALLATION WORKS AT THE PREMISES OF THE CONTRACTING ENTITY

Before starting works at the premises of the Contracting Entity, the Contractor must deliver a complete list of the names of all employees delegated to the installation works on the Helium Cooling System. These employees shall be then trained by the Contracting Entity, which fact shall be confirmed in written form.

The Contractor is obliged to conform to the legal and health and safety regulations, as well as to the in-company regulations of the Contracting Entity, which may go beyond the general legal regulations. In the case when the employee hired by the Contractor breaks the safety regulations, the Contracting Entity reserves the right to immediately remove the employee from the construction site. In such case, the Contractor must immediately provide a substitution employee.

The components of the Helium Cooling System shall be delivered to the Contracting Entity in a form which maximally limits the assembly works on location.

As the buildings and rooms at the premises of NCBJ have a laboratory character, all works shall be performed in an appropriately clean manner. All works which entail emissions of dust or other impurities, such as cutting, drilling, grinding, polishing, milling etc. shall be avoided or at least limited and whenever possible performed outdoors or in specially provided locations. If some of the above processes is necessary, it shall be performed with the use of curtains, fume-removal devices, vacuum cleaners etc., in order to avoid any contamination.

All devices necessary in the assembly works, such as cranes, jacks, scaffolds, hand tools, welding gases etc. shall be provided by the Contractor.

Toilets and showers for the employees of the Contractor shall be available at the premises of NCBJ.

The Contracting Entity provides power supply, but it should be understood that the power connection points may be located at a significant distance from the workplace and additional power extension cables may be required. All extension cables shall be provided by the Contractor.

Drilling in the walls, floors and roofs is strictly limited and shall be performed only after receiving a written approval from the Contracting Entity. All drilling locations shall be predicted at the design stage and clearly indicated during the Technical Design Review. The drilling description shall include any necessary information important for the structure of the building, such as the drillhole diameter and length, the type of the drilling device and the type of the bolt. The maximum allowed thread is 24 mm. Chemical and expansion anchors can be used. The need to make a drillhole shall be reported to the Contracting Entity five days before the start of the operation.

18. Performance of the contract

18.1. General information

This section describes the works and operations which lead to the performing of the delivery scope defined in section 16. The works were divided allowing for the milestones described in section 19 of this document. The contract shall be performed in accordance with the stages defined below.

18.2. Phase 1: Conceptual design

The conceptual design was prepared by Wroclaw University of Science and Technology which participates in the PolFEL Consortium. Phase 1 was finished by a successful completion of the conceptual design review for the Helium Cooling System in August 2021.

The conceptual design is the basis for the preparation of the technical requirements for the Helium Cooling System as well as for further design works which allow the Contractor to produce the technical design during phase 2.

18.3. Phase 2: Preliminary Technical Design

Phase 2 starts with a kick-off meeting (KOM) in which the Contracting Entity and the Contractor shall discuss the details of the design and in which they will clarify potential questions and outline the rules of cooperation.

The preliminary design phase shall end with the technical design review (TDR) in the form of a report.

The criterion for the positive completion of the PTDR is for the Contracting Entity to approve the documents presented by the Contractor, and the documents shall include at least the following:

- the project management plan (PMP) together with the delivery schedule plan (this document shall be presented at the earlies stage of this phase)
- Updated P&ID
- Preliminary selection of devices

18.4. Phase 3: Technical design

Phase 3 begins with a meeting (or online meeting) where the Contracting Entity and the Contractor will discuss the details of the preliminary technical design. The preliminary project phase concludes with a review of the technical design (TDR) in the form of a report.

The preliminary design phase shall end with the technical design review (TDR) in the form of a report.

The criterion for the positive completion of the TDR is for the Contracting Entity to approve the documents presented by the Contractor, and the documents shall include at least the following:

- Preliminary set of 3D components
- the project management plan (PMP) together with the delivery schedule plan (this document shall be presented at the earlies stage of this phase)
- Updated P&ID
- Preliminary selection of devices
- Preliminary set of 3D components
- Technical studies, calculations and analyses
- Structural, thermal and flow calculations
- Lists of the media required for the HCS (electricity, cooling capacity, water and process air consumption, LN2 consumption, other)

- Interface-related documents
- Preliminary locations for the devices and pipelines as well as their supports

18.5. Phase 4: Final technical design

This phase consists in preparing the final technical design and the manufacturing documents required for the Contractor to produce the components of the Helium Cooling System. The documents shall include all the requirements related to the HCS and the definitions of the interfaces.

The final technical design phase shall end with the final design review (FDR) in the form of a report.

The criterion for the positive completion of the FDR is for the Contracting Entity to approve the documents presented by the Contractor, and the documents shall include at least the following:

- Updated P&ID
- Final versions of the mathematical, thermal and hydraulic calculations, as well as technical analyses and engineering notes.
- Design for incorporating the Daresbury refrigerator
- Selection of the HCS devices
- Design of the arrangement and foundations of the HCS devices
- Complete set of 2D drawings and 3D models required to start the production
- Structural calculations and analysis of accelerations in transport in order to ensure proper transport conditions
- Interface-related documents
- Methodology for verifying if the specified requirements are met and an acceptance test plan
- Specifications for the servicing of the HCS components after delivery to the Contracting Entity
- Complete data and specifications required to purchase spare elements listed in section 16.2.
- List of producers supplying instrumentation and selected components
- Updated lists of the media required for the HCS (electricity, cooling capacity, water and process air consumption, LN2 consumption, other)

All of the specified requirements for the HCS must be verified by the Contractor and documented in the form of analyses, tests, inspections and/or demonstrations in the final design phase, in order to meet the requirements of the technical specification. Even in the case when the Contracting Entity approves the presented documents (drawing, calculations, analyses, selections etc.), the Contractor shall still be responsible for their content and potential mistakes made during their preparation.

18.6. Phase 5: Manufacturing

At the manufacturing stage, after the Contractor reaches the manufacturing readiness, the components are produced and tested. The declaration of the manufacturing readiness shall be preceded by the manufacturing readiness review (MRR).

The manufacturing phase finishes with the manufacturing assessment review (MAR) in the form of report.

The scope of the MRR includes:

- Quality assessment plan
- Verification documents of the Contractor
- Welding procedures and the qualifications of the Contractor in the area of making welded connections

The manufacturing phase may be started after the preparation and presentation to the Contracting Entity of the final technical drawings of the components, the assembly methods, the material certificates, the welding procedures, the manufacturing process plans and the quality assurance plan.

Phase 4 also includes manufacturing acceptance tests (MAT) which are performed following the manufacturing of the HCS components. The tests shall be planned and performed by the Contractor prior to shipping the devices to the premises of the Contracting Entity. The tests shall be performed in the presence of the representative of the Contracting Entity.

The manufacturing phase finishes when the manufacturing of all the HCS components is completed, when the manufacturing acceptance tests are successfully completed, and when the relevant documents (MAR) are delivered to the Contracting Entity and approved.

The criterion for the positive completion of the manufacturing acceptance tests is for the authorized representative of the Contracting Entity to approve the documents presented by the Contractor and the documents shall include at least the following:

- Test protocols
- Manufacturing assessment documents
- Material certificates
- Measurement protocols

18.7. PHASE 6: DELIVERY

The delivery phase is described in section 15, which addresses among other the methods for the protection of the apparatus, and in section 14.3.1, which describes the inspection of the components delivered to the construction site at NCBJ. This phase finishes by verifying each batch of components delivered to the premises of the Contracting Entity.

The criterion for the successful completion of the delivery phase is the delivery acceptance certificate (DAC) issued by the authorized representative of the Contracting Entity and confirming that all the requirements described in sections 15 and 14.3.1. are met.

18.8. PHASE 7: INSTALLATION

The installation phase consists of the following stages:

- Positioning of the supports
- Installation of the HCS components on the supports
- Positioning of the interface points
- Connecting of the HCS elements
- Tests of the connections
- Closing of the vacuum jacket (applies to relevant elements)
- Pressure tests, tightness tests, control system tests etc.
- Preparation for the acceptance test (section 14.4) and for phase 7 – preparation of the (step-by-step) test procedure for the entire HCS together with the connection of a device for generating the required thermal load.

This phase shall finish with the installation acceptance, which shall involve the accepting of all the reports and protocols produced in this phase, and also include a statement confirming readiness for acceptance tests.

The criterion for the successful completion of phase 6 is for the Contractor to fulfil the requirements pertaining to each of the stages described in this section and to successfully pass all the tests described in section 14.3, which fact shall be confirmed by an appropriate review document for this phase, issued in the form of an installation acceptance review (IAR).

18.1. Phase 8: Start-up and acceptance

The start-up and acceptance phase is based on the instructions presented in section 14.4, which describes the tests required after the installation process is finished This phase will involve both preliminary acceptance tests (PAT) and final acceptance tests (FAT). During the review of the results of these tests, the Contractor will be obliged to prove that the installation meets the design criteria and any requirements specified in this document, as well as the assumptions made during the design stage. The preliminary acceptance review (PAR) must include reports and PAT protocols described in section 14.4.2 together with the confirmation of their positive results.

The successful completion of the final acceptance tests (1 full operating cycle and failure-free operation of the System for 3 weeks) shall be followed by the final acceptance test (FAR). At this stage, all documents, components and actions listed in section 14 shall be already finished and delivered by the Contractor to the premises of the Contracting Entity, without any negative feedback information from the Contracting Entity. These actions shall be inspected and verified during the System acceptance review (SAR). During the SAR, a representative of the Contracting Entity shall inspect and verify both the test data and all documents for their content and completeness. The prerequisite for completing the SAR is to present the reports and FAT protocols described in section 14.4.4 together with the confirmation of their positive results.

The criterion for the successful completion of the SAR is also to present a document issued by the Contracting Entity and confirming that all the requirements described in sections 16 and 14.4 are met.

19. Milestones

The milestones presented in Tables 19.1 and 19.2 are the basic mechanism for the monitoring of the progress of works performed by the Contractor. The milestones refer to each element of system which are delivered as part of the contract, and which are regulated in the relevant documents of the specification.

Reaching of a milestone is typically related to holding a meeting between the Contracting Entity and the Contractor. If needed, the structure of the milestones may be modified by agreement of both parties, without consequence to the final deadline of the project.

Table 19.1. Task 1 milestones

Step	ID	Milestones and delivery scheme	Acceptance document	Payment [% of the contract]	Duration time
	Phase 1: Conceptual design				
1	CDR	Conceptual design review			
2	STC	Signing of the contract	Down payment invoice	20%	
	Phase 2: Preliminary technical design				
3	KOM	Kick-off meeting			start
4	PRDS	Review of Preliminary Design Schedule		30	8 weeks
5	PTDR	Preliminary technical design review	PTDR		
	Phase 3: Final technical design				
6	RDS	Review of Design Schedule		10	22 weeks
7	RQP	Review of project management and quality assurance plans			
8	TDR	Technical design review	TDR		
	Phase 3: Detailed Design				
9	DPC	P&ID and calculations	MRR	5	15 weeks
10	DOR	Design of the Daresbury refrigerator and the cooperating elements	MAR DR		
11	SOD	Selection of devices for Helium Cooling System	MAR TL		
12	FDR	Final design review	MAR OE		
	Phase 4: Manufacturing				
13	MRR	Manufacturing readiness review	MRR	10	25 weeks
14	MVB	Daresbury refrigerator	MAR DR		
15	MEB	Transfer lines	MAR TL		
16	MOE	Remaining components	MAR OE		
	Phase 5: Delivery				
17	DTL	Daresbury refrigerator – after adjustments	DAC DR	10	2 weeks
18	DWC	Compressors – after adjustments	DAC WC		
19	DVP	Vacuum pumps – after adjustments	DAC VP		
20	DCS	Control system	DAC CS		
21	DOE	Remaining components	DAC OE		
	Phase 6: Installation				
22	ITL	Daresbury refrigerator	DAC DR	10	9 weeks
23	IWC	Compressors	DAC WC		
24	IVP	Vacuum pumps	DAC VP		
25	ICS	Control system	DAC CS		
26	IOE	Remaining components	DAC OE		
	Phase 7: Start-up and acceptance				
27	PAT	Preliminary acceptance tests	PAR	3	5 weeks
28	FAT	Final acceptance tests	FAR, SAR	2	4 weeks

20. PROJECT MANAGEMENT

20.1. GENERAL INFORMATION

The duties of the Contractor include the management of the project and its supervision (quality assurance, section 22). The project manager must coordinate and control all activities related to the project as well as the resources related thereto. The project manager must also ensure that the standards specified in this document are met and that the contract is successfully completed.

The project management must involve:

- Designating a project manager known by name and defining their duties and competences, as well as integrating the team with the organizational structure of the company. The project manager shall be the contact person in all matters related to the contract. If another person is responsible for any issues related to the contract, this person shall also be designated and known by name.
- Designating by name and defining the functions of other members of the project management personnel.

20.2. PROJECT MONITORING

20.2.1. PROJECT ORGANIZATION

The monitoring of the project shall involve:

- Designating by name and defining the functions of the personnel responsible for the project.
- Defining tasks and assigning personnel to particular tasks, describing special qualifications of the personnel, assigning assistant (deputy) members of the personnel.
- Defining the basic elements of project supervision, such as periodical meetings of the project management, regular meetings with the Contracting Entity and with subcontractors, etc.

20.2.2. PROJECT PLAN

The Contractor is obliged to present a detailed project schedule plan to the Contracting Entity. The plan shall be presented during the review of the design schedule (RDS). The schedule plan shall include the milestones presented in Table 19.1. The plan must include the works performed by both the Contractor and subcontractors. It must include such processes as: design, purchase of raw materials, purchase of instrumentation, manufacturing, assembly, tests, shipment, installation, control, free time etc.

The time intervals in the schedule plan shall not exceed one week. The schedule plan must be prepared in a dedicated software application, which shall be selected by the Contractor in agreement with the Contracting Entity, and delivered to the premises of the Contracting Entity in both printed and digital form.

The Contractor is obliged to update the schedule plan every month, during the entire period of the contract. In special cases, the Contracting Entity may demand updates at shorter time intervals.

The schedule plan shall indicate what percent of the task has been completed.

In the case of events which may have an influence on the schedule plan, the Contractor shall undertake steps necessary to stay on the schedule. The above shall include assigning additional personnel (working overtime and shifts) and additional equipment. The costs related thereto shall be covered by the Contractor. Manufacturing stages must not be shortened or omitted in order to compensate for the delay.

All delays (both the already experienced and the potential delays) shall be immediately reported to the Contracting Entity.

20.2.3. PROGRESS MONITORING

The Contractor shall prepare regular reports to the Contracting Entity. The reports must be prepared every month and delivered to the premises of the Contracting Entity not later than on the third working day of a month. In special individual cases, especially in the case of technical problems and delays in the schedule plan, the Contracting Entity may request the reports be delivered at shorter intervals. The reports must contain clear information on all of the planned tasks.

Irrespectively of the regular reports, all events which may have an influence on the schedule plan shall be reported to the Contracting Entity. In the case of serious problems, which endanger the completion of the agreed milestones, the Contracting Entity shall be immediately informed in writing.

Irrespectively of the regular reports, each milestone shall be completed with a separate report delivered to the Contracting Entity. The report shall include all important information obtained in the manufacturing, delivery or assembly processes, and shall take the form of partial reports, drawings, models, calculations, descriptions, explanations, test protocols, statuses of the schedule plan, etc. supplemented with photographic documentation.

The Contracting Entity shall have an unlimited and free-of-charge access to all processes related to the carrying out of the contract at the premises of both the Contractor and its subcontractors. The Contracting Entity shall be allowed to take photographs for the purpose of project monitoring.

20.2.4. PROJECT MEETINGS

Over the duration time of the project, the Contracting Entity shall organize project meetings in order to discuss current issues.

The so-called kick-off meeting (KOM) shall be held after the contract is signed.

Working meetings shall be held not more than once a week. A meeting may be in the form of a teleconference or may be held “in person”. Depending on the agenda, the number of participants, etc. the location of each meeting shall be decided individually.

The Contracting Entity and the Contractor have the right to demand special meetings as required.

The Contracting Entity also has the right to invite other participants to the meetings at its own discretion. In such case, the Contracting Entity shall inform the Contractor about any external participants.

At a request of the Contracting Entity, the Contractor shall organize meetings with the subcontractors, also in their place of business.

Unless agreed otherwise, the Contractor must prepare protocols from the meetings within five working days. The protocol must be signed by the representatives of both parties. The signatures confirm only that the content of the protocol correctly represents the agenda and the agreed actions.

21. QUALITY MANAGEMENT

21.1. GENERAL INFORMATION

With respect to quality assurance, the Contractor shall prepare a quality monitoring plan, which shall be presented to the Contracting Entity at the stage referred to as the review of quality management plans (RQP). For this purpose, the entire documentation related to the quality monitoring plan shall be delivered to the Contracting Entity within 15 days before the review.

During the contract, the Contractor shall review the effectiveness of the quality monitoring plan and improve it if needed. The Contractor is obliged to introduce any changes and corrective means required by the Contracting Entity or deemed necessary.

The manufacturing processes must conform to the requirements of this technical specification. The Contractor shall meet the following requirements on all manufacturing stages:

- The Contractor must define the critical processes and monitor them with special diligence
- The Contractor must undertake special steps, such as research and tests, in order to ensure compliance with the quality requirements
- The Contractor must prepare a plan and a sequence of tests, defining their details
- In the case of defects, the Contractor must take any necessary corrective steps and verify the usefulness and effectiveness of these steps
- The Contractor must prevent the recurrence of known defects

21.2. Introducing changes and modifications

In the case of a conflict identified in this specification, in the related documents or in important instructions, the Contractor shall immediately inform the Contracting Entity in order to clarify the differences.

If the Contractor deems it necessary to conform to additional instructions and regulations, the Contracting Entity must be immediately informed about this fact. The Contractor shall cover all expenses resulting from not complying to this specification or to appropriate instructions.

Both the Contracting Entity and the Contractor have the right to inform the other party about any demanded changes. Each requested modification must be clearly marked (with a unique number).

In the case of each change, the following information shall be provided:

- Reason for change
- Evaluation of technical feasibility (where needed)
- Evaluation of the influence on other elements of the contract
- Influence on the scope of works, documentation and drawings
- Influence on the schedule plan of the project
- Influence on the total cost
- Influence on other factors such as reliability, safety, maintenance etc.
- Additional supporting documents

Changes shall not be valid until confirmed in written form by the Contracting Entity.

The cost of modifications introduced by the Contractor without observing the above provision shall be in their entirity covered by the Contractor.

21.3. Defects

The Contractor shall make note of and document any defects noticed during the realization of the contract, at each stage of works, design, manufacturing, installation and tests. The Contractor must immediately inform the Contracting Entity about the defects.

In the case when defects are identified, the Contractor shall introduce corrective means and present them for approval in writing to the Contracting Entity.

22. LIST OF ATTACHMENTS

I. The P&ID of the CDS