User Manual

LD System

January 12, 2022

Version 2.0

support@bluefors.com
+358 9 5617 4800

BF1000-1234517327-9

IMPORTANT

Read the User Manual for the LD System carefully before use. Keep the documentation for future reference:

- Pre-Installation Guide
- LD System User Manual
- LD System Description

For reading digital copies of this document, use a PDF reader, such as Adobe Acrobat Reader DC: https://get.adobe.com/reader/.

IMPORTANT

The information contained within this document is effective as of the publication date. Bluefors Oy reserves the right to make changes to the product and information contained within this document relative to the specifications, features and design of the product.

IMPORTANT

The information contained within this publication covers a wide range of applications and may not specifically apply to your equipment layout or custom set-up. Contact us directly (support@bluefors.com) if you have any question about the specifications or any other content contained within this publication.

BF1000-1234517327-9

Table of Contents

BLUEFORS

Table of Figures

List of Tables

1 Organization of this manual

The instructions of the Bluefors dilution refrigerator (DR) measurement system consist of three separate manuals: the Pre-installation Guide, the User Manual, and the System Description Manual. A more detailed description of the system and its operation principles is provided in the System Description Manual.

This manual addresses the basic operation of the system. Warranty and safety issues are addressed in chapters 3 and 4 of this manual

Chapter 5 gives a brief description on the installation of the equipment and more detailed instructions are given in the Pre-installation Guide. However, we strongly recommend the system is installed and initially tested by a qualified Bluefors engineer.

Chapter 6 has detailed step by step instructions of the basic operation of the system. The computer control functions for the system are described in chapter 7. For more details on the computer controls, refer to the separate manual for the Control Software. Finally, routine maintenance instructions are given in chapter 8. The appendices contain additional information.

This User Manual applies to models LD250 and LD400. Applicable Pulse Tube & Compressor pairs are listed in LD System Description Manuals. Please refer to the nameplate on the equipment for electric power requirements.

IMPORTANT

Read the Pre-installation Guide carefully before installation. It contains necessary information on the layout planning, laboratory preparations and connections and unpacking the crates. It is the responsibility of the customer to find out if the local laws and regulations prohibit installation and service by non-skilled persons. It is strongly recommended that the installation and initial testing is done by a qualified Bluefors engineer.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

IMPORTANT

Please study the operating manuals delivered with the standard options carefully prior to using them.

IMPORTANT

This manual is essential for the use of the Bluefors equipment, so please keep it for future reference.

2 Overview

2.1 General description

The cryogen-free dilution refrigerator (DR), with closed helium cycle, is a measurement system for ultra-low temperatures in the range of 7 mK to 4.2 K. This provides a measurement environment with minimal thermal noise. These types of systems are essential in the research fields of nano- and quantum technologies, radio astronomy and particle-physics with novel radiation detectors.

Table 1: Main technical characteristics

	LD250	**LD400**
Base temperature:	≤ 10 mK	≤ 10 mK
Cooling power at 20 mK:	≥ 10 μW	≥ 12 μW
Cooling power at 100 mK:	≥ 250 μW	≥ 400 μW
Cooling power at 120 mK:	≥ 360 μW	≥ 575 μW

The Bluefors cryogen-free dilution refrigerator measurement systems consist of 4 basic components. Please refer to the separate System Description document for details of the system and specific construction.

The system contains optimized He-3/He-4 mixture (approximately 18 NTP liters of helium-3 and 90 liters of helium-4).

For the operation of the Cryomech Pulse Tube cooler and compressor, please see the Cryomech User Manual.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

The Control Unit (CU) is equipped with a USB-connection for communication with a PC by the Control Software.

The system is designed to be compliant with the Low Voltage Directive (LVD) 2014/35/EU and the standard IEC/EN 61010-1:2010.

Figure 1: LD System in testing at Bluefors factory

2.2 Environmental conditions

The system is designed for laboratory use only. The environmental conditions must meet the requirements as seen in Table 2.

Table 2: Environmental conditions

Ambient temperature	+10°C . . . +35°C (50°F . . . 95°F)
Relative humidity max.	80%RH @ 30°C (86°F), 65%RH @ 35°C (95°F)
Altitude	max. 2 000 meters (6 500 feet) above sea level
Pollution degree	PD2 (laboratory conditions)

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

3 Warranty and support

- Bluefors warrants Bluefors manufactured products ("Bluefors Product") to operate in accordance with the technical and other specifications for the Bluefors Product described in the Bluefors Product quotation for a period of thirty-six (36) months from the date of customer's acceptance or deemed acceptance of the Bluefors Product. Third-party products (such as magnets, pumps, compressors etc.) included in the Bluefors Product are covered by the manufacturer's warranty.

- Bluefors will at its own expense, and as its sole liability and obligation and the customer's sole right and remedy, promptly rectify any covered non-conformity with the above warranty, that arises and is reported to Bluefors during the warranty period, by repairing or replacing products or components at Bluefors' option.

- If the repairs are covered under this warranty, then standard shipping for return to the customer is paid for by Bluefors (shipping terms DAP Incoterms 2020). Before shipping any item to Bluefors for repair, the customer must first obtain an RMA number from an authorized Bluefors representative. Do not attempt to repair or replace any items without first contacting an authorized Bluefors representative. Doing so may expose the customer to hazards and will void this warranty. Customers requiring a more comprehensive warranty program may purchase additional coverage, the price of which may vary by product type. Any additional warranty or service program that Bluefors may choose to make available to the customer is subject to a separate written agreement.

- The above stated warranty for Bluefors Products is subject to the condition that the Bluefors Product is used according to the manuals and guidelines for operation that are provided to the customer. The warranty shall not apply to damages to Bluefors Products that arise from the misuse or negligent use of the Bluefors Product, or which are caused by circumstances which arise after the risk has passed to the Customer e.g. faulty maintenance, incorrect installation or faulty repair by the customer or alterations carried out without Bluefors' consent.

- EXCEPT AS EXPRESSLY STATED IN THE ABOVE WARRANTY, BLUEFORS MAKES NO REPRESENTATIONS, WARRANTIES OR COVENANTS, EXPRESS, IMPLIED OR STATUTORY WITH RESPECT TO ANY BLUEFORS PRODUCTS OR SERVICES OR ANY OTHER ITEM OR MATERIAL FURNISHED BY BLUEFORS. IN PARTICULAR, BLUEFORS EXPRESSLY DISCLAIMS ANY AND ALL REPRESENTATIONS, WARRANTIES AND COVENANTS OF MERCHANTABILITY, QUALITY, TITLE, FITNESS FOR A PARTICULAR PURPOSE AND NON-INFRINGEMENT, TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW. IN NO EVENT SHALL BLUEFORS BE LIABLE FOR ANY INDIRECT, CONSEQUENTIAL, INCIDENTAL, EXEMPLARY, PUNITIVE, STATUTORY OR SPECIAL DAMAGES, INCLUDING BUT NOT LIMITED TO ANY DAMAGES FOR LOST REVENUE, INTERRUPTION OF BUSINESS, LOSS OF TECHNOLOGY OR DATA, LOSS OF USE OF THE PRODUCTS, COST OF CAPITAL, COST OF SUBSTITUTE OR REPLACEMENT EQUIPMENT, FACILITIES OR SERVICES, DOWN TIME, OR THE CLAIMS OF

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

THIRD PARTIES, UNDER ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, TORT (INCLUDING, WITHOUT LIMITATION, NEGLIGENCE), INDEMNITY, BREACH OF WARRANTY OR OTHER THEORY AND REGARDLESS OF WHETHER BLUEFORS WAS ADVISED OF OR WAS AWARE OF THE POSSIBILITY OF SUCH DAMAGES.

Support:

- Bluefors support includes reasonable telephone and email customer service during normal business hours (Finland). Support is provided by experienced technical personnel.

- Bluefors has arrangements in place with its third-party suppliers for critical system sub-components (including pumps, cryocoolers and compressors) to ensure that these components will receive prompt warranty service in the case of malfunction. Most of our suppliers have a worldwide service and distribution network. Bluefors will only buy critical subcomponents from well-established suppliers who have sufficient service and repair capability.

Please see also chapter 8.5 Customer service for contact details.

4 Safety

4.1 Warnings and cautions

Upon delivery, all of the system components have to be unpacked and assembled to make up a working system. This is discussed in chapters 4.2, 4.3 and 5. Please refer to the Pre-Installation Guide for more details.

WARNING

The intended use of Bluefors dilution refrigerator measurement system is to cool a sample to an ultra-low temperature. Operating the system otherwise and against this manual is forbidden and may impair the protection provided by the equipment and could void the warranty.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

WARNING

The cryostat itself should remain stored in the shipping crate until final installation into the frame. The cryostat has a very high center of mass and it is not safe standing freely on the floor.

CAUTION

If there is any indication of damage or mishandling during shipment, the delivery should not be accepted and Bluefors should be contacted immediately.

CAUTION

It is recommended, that system installation and initial testing are performed by a qualified Bluefors engineer.

When the installation takes place in a seismically active area, seismic anchorage is recommended.

The frame construction and the fastening of the Vacuum Can shall be checked during and after the installation to prevent accidents due to mechanical failure or fall of the system.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

CAUTION

The Gas Handling System contains precious helium gas. Special care is required during use and maintenance.

The main circulation circuit is closed and containing precious He-3/He-4 mixture. Always pay extra attention when connecting the service manifold with the main circulation circuit in order not to lose any mixture.

WARNING

The Cryomech compressor and lines can have high pressure (2 MPa). High pressure in any of the components can blow off the coupling with sufficient force to cause injury.

WARNING

When the refrigerator is in use, parts inside the isolating vacuum act as an effective cryopump. A considerable amount of air can accumulate. Pay attention during warmup of the system.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

WARNING

The heatpipe (if applicable) has high pressure (10 MPa). Handle with care. Puncture can cause dangerous release of pressure.

DANGER

Electric shock hazard. This equipment is to be serviced by trained personnel only.

DANGER

Hazardous voltage. Disconnect power before servicing.

DANGER

Electric shock hazard. Do not touch magnet current leads while the power is on. (Applies for systems with magnet current leads)..

CAUTION

Before connecting system to power outlet check that the voltages on the nameplates match with the local power outlet. This system must be connected to a grounded outlet only.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

WARNING

For systems with an integrated superconducting solenoid magnet, the stray field outside the experimental space is potentially harmful to devices such as pacemakers, watches and credit cards. Please refer to the stray field map of the specific magnet, and any local regulations.

WARNING

For system with an integrated superconducting solenoid magnet, the stray field outside the experimental area may strongly attract metal objects. Be careful to follow the instructions on minimum distances between the cryostat and other metal objects. Please refer to the stray field map of the specific magnet, and any local regulations.

CAUTION

The gate valve should never be operated when it has a pressure difference (> 30 mbar) across it, because it will not open/close properly, which can result in damage. Always first open *V2* to equalize the pressure.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

CAUTION

Make sure the water cooling of the pulse tube is running, otherwise the temperature protection circuit of the pulse tube will trip (see manual of the Cryomech Pulse Tube). If the water cooling is at halt, the Pulse Tube will stop, even though the LED on the front panel and the indicator in the Control Software show it is running.

CAUTION

If the LN2 cold trap is used, user must to refill its dewar regularly with liquid nitrogen (approximately once a week) to make sure the trap will not warm up during a run.

CAUTION

The gate valve *V1* should never be closed during operation of the system (condensed mixture inside) because it provides the only return path for the mixture to the tanks in case the pulse tube switches off (for example during a power failure).

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

CAUTION

Only operate the software with the correct layout file for your system. Otherwise unexpected behavior might occur because of wrong addressing for valves, pumps etc.

The Control Software (incl. scripts) has full control of the Gas Handling System. Malfunction or careless use can result in loss of the precious He-3 gas.

CAUTION

When servicing pumps in the main circulation circuit (*Scroll1* and *Compressor*) it is important to make sure no mixture is lost, and no air contamination of the mixture will take place.

The servicing procedures for *Scroll1* and *Compressor* should always be performed independently (one after the other, not at the same time).

After the servicing procedure(s) for *Scroll1* and/or *Compressor* the pumps itself and all O-ring seals in the Gas Handling System should be carefully leak tested with a helium leak detector.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

CAUTION

Only remove the cold LN2 trap from the dewar when it is being pumped (to air). If this is not carried out correctly there can be unwanted pressure build up in the trap, due to a large amount of impure gas (air) collected.

WARNING

The detachable power cord of the Control Unit must be replaced with a cord with suitable ratings.

WARNING

In case of power failure in the Control Unit, the temperature of the system may rise to 3 K. In a total power failure, the system starts warming up to room temperature. With simultaneous severe misuse by the user, loss of helium is possible.

WARNING

Frostbite hazard. Contains liquid nitrogen.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

WARNING

Frostbite hazard. Extremely cold parts inside.

WARNING

Risk of personal injury. During sample preparation, when the sample holder is not inside the cryostat, fingers may be crushed if the Fast Sample Exchange's Lift Motor is turned on accidentally. (Applies for systems with Fast Sample Exchange mechanism).

4.2 Inspection

The crates should be carefully inspected on arrival for any damage. All the Tip-N-Tell and shock sensors should be checked. If there is any indication of damage or mishandling during shipment, the delivery should not be accepted and Bluefors should be contacted immediately.

CAUTION

If there is any indication of damage or mishandling during shipment, the delivery should not be accepted and Bluefors should be contacted immediately.

4.3 Unpacking

- All crates can be moved around with a standard pallet jack.
- All crates must be unpacked by removing the top-panel first (in order to see how items are packed inside).
- At least one of the side-panels is closed with screws only (no nails) for easy opening.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

WARNING

The cryostat itself should remain stored in the shipping crate until final installation into the frame. The cryostat has a very high center of mass and it is not safe standing freely on the floor.

Typical packing crate dimensions are presented in Appendix I and typical component weights and dimensions in Appendix II.

5 Installation

5.1 Main components installation procedure

CAUTION

It is recommended that the system installation and the initial testing are performed by a qualified Bluefors engineer.
When the installation takes place in a seismically active area, seismic anchorage is recommended.

The frame construction and the fastening of the Vacuum Can shall be checked during and after the installation to prevent accidents due to mechanical failure or fall of the system.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

WARNING

Frame consists of heavy parts. Mishandling can result in physical injury or damage to health.

NOTE: The safety of any system incorporating the Bluefors dilution refrigerator is the responsibility of the assembler of the system.

IMPORTANT

A lifting table is recommended to accommodate installation and removal of the optional superconducting solenoid magnets. In this case we also recommend user to put a warning label for strong magnetic field to be attached on the cryostat.

The general steps for a system installation are following:

1. Assemble the frame components and mount the cryostat in the frame.
2. Connect the pumping lines between cryostat and GHS. Make sure lines and surfaces are clean.
3. Connect the LN cold-trap, making sure the flow direction is correct (lower line of the LN-trap connects to V7 and upper line to V9).
4. Connect the pulse tube compressor pressure lines and additional lines (motor line, ballast tanks). Refer to the pulse tube manual for correct procedures.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

WARNING

When the refrigerator is in use, parts inside the isolating vacuum act as an effective cryopump. Considerable amount of air can accumulate. Pay attention during warmup of the system.

5. Connect electrical and water-cooling lines in accordance with local regulations and safety codes. Make sure the cooling water flow is adequate, cooling water requirements are specified in the Pre-installation Guide.

DANGER

Electric shock hazard. This equipment is to be serviced by trained personnel only.

DANGER

Hazardous voltage. Disconnect power before servicing.

6. Connect the Control Unit to a pressurized air supply, a minimum of 5 bars is required. Check that pressure is regulated to ~5 bars inside the CU.
7. Connect the cables between the CU and the GHS (pressured air lines, vacuum gauge cables, flow-meter cable and electrical relay cables).
8. Connect the control PC and the CU with a USB-cable. Connection on the CU is behind the control panel.
9. Remove packing material from inside the cryostat. Soft foam is used between the shields and Vacuum Can to protect the insert during shipping.
10. Evacuate and leak test the dilution refrigerator, Still/Condensing Lines, and the LN Trap carefully.
11. Before the first run, make sure the radiation shields and the Vacuum Cans are fitted appropriately. It is strongly recommended that a check for any leaks is carried out before each run.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

Installation of the Temperature Controller:

1. Make sure the voltage setting on the temperature controller is correct for your region.
2. Connect the cables between the cryostat, pre-amp and temperature controller.
3. Connect the control PC and temperature controller with a USB cable or with a LAN cable depending on the type of the temperature controller. Refer to the temperature controller documentation.

For the operation of the temperature controller, refer to the separate manual for the specific device.

5.2 Software installation

Use your Bluefors support web login for obtaining the latest software and help on software installation. See chapter 7.

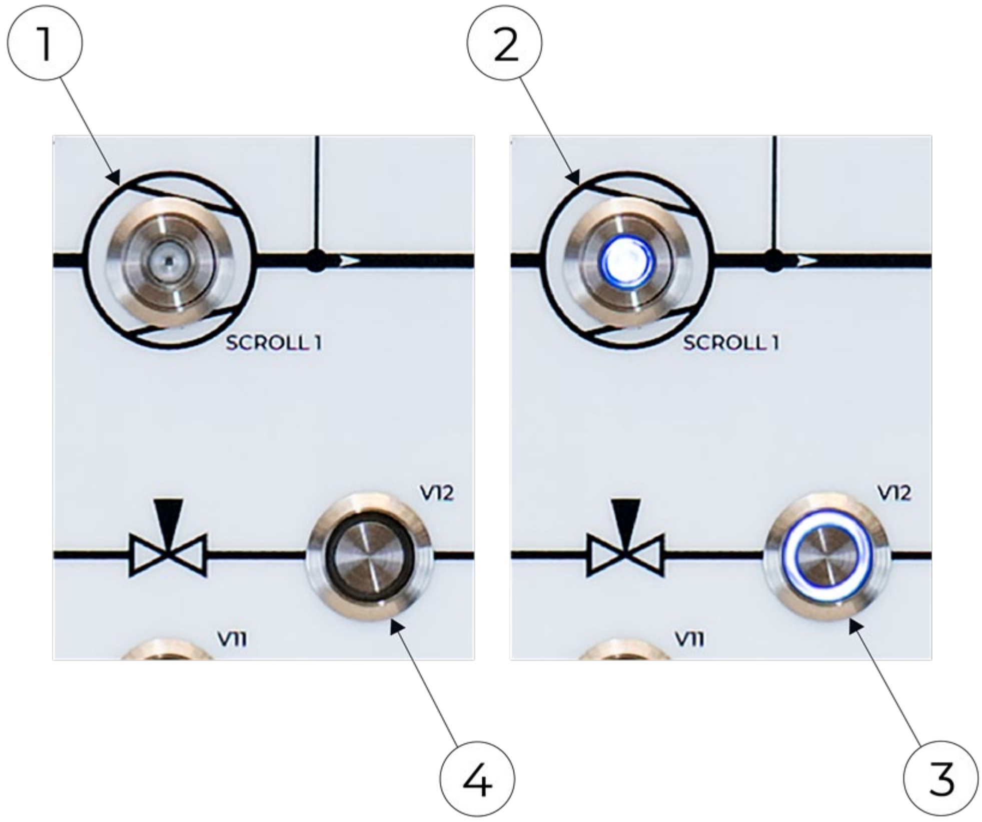
6 Operation

CAUTION

The Gas Handling System has precious helium gas. Special care is required during use and maintenance.

The system can be operated manually with the push buttons on the Control Panel on the top of the Control Unit. The status of the pumps and valves can be observed with the LEDs on the push buttons, see Figure 2. Operating the system with the Control Software is recommended, as this enables running scripts for automatic operation, and the system parameters to be logged.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**



Item	Description
1	Pump off
2	Pump on
3	Valve open
4	Valve closed

Figure 2: Pump and valve control buttons

6.1 Preparing for a cool-down

Before closing the system for cool-down, check all required heaters and sensors for functionality. This is especially important with the heaters found on Heat-Switches and the Still. The correct values can be found in the system test report provided with the system. When all is in order, the radiation shields can be mounted. The stainless steel Torx screws on the Still radiation shield should be screwed to firm hand-tight. The Allen-head bolts on the 4K and 50K shields should also be tightened to firm hand-tight. The outermost set of radiation shields also act as hermetic shield for the system, referred to later as Vacuum Cans. Before mounting these shields, check the condition of the O-rings and O-ring surfaces to ensure a good hermetic shield. When mounting the radiation shields and the Vacuum Can, make sure there are no thermal shorts between the different temperature stages via the radiation shields.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

The upper part of the Vacuum Can is sealed with M8 Allen-head bolts and the lower part(s) with wingnuts. All of these fixings should be tightened to firm hand-tight. When the Vacuum Can is being pumped, the ambient pressure will exert a large and evenly distributed force on the O-rings. At this point, the wingnuts will get somewhat loose. Do not re-tighten them at this stage or they will become difficult to open once the ambient pressure is admitted back into the Vacuum Can. The twist-locking bolts of the lower parts of the radiation shields and the Vacuum Cans allow easy operation also by a single user.

WARNING

When the refrigerator is in use, parts inside the isolating vacuum act as an effective cryopump. A considerable amount of air can accumulate. Pay attention during warmup of the system.

Before starting the cool-down procedure, make sure the dilution refrigerator is evacuated. This is done by checking that the value at the Condensing Line (p3) is less than 10 mbar. Also, make sure that the turbo volume (p2) is evacuated (less than 1 mbar). The Still Line side can then also be checked from p2 by opening V2. If the pressures are at the recommended levels, close V2 and proceed to the cool-down procedure. If the pressure is too high, the dilution refrigerator can be evacuated through the service manifold. **The safest option is to have the Manual Valve on the mixture tank closed** (see Figure 3)**. It is recommended to always keep the manual mixture tank valve closed when the system is not running.**

First, start *Scroll 2*, wait approximately 10 seconds for the internal relay of the pump to switch on. Then, open *V21* to evacuate the service manifold. Before opening the service manifold to the dilution refrigerator circulation circuit, make sure that all valves in the dilution refrigerator circulation are closed and that there is no pumping path to the mixture tank. Also make sure there is no He-3/He-4-mixture left in the dilution refrigerator and cold trap from a previous run.

Now *V2* should be opened to equalize the pressure over the gate valve.

CAUTION

The gate valve should never be operated when it has a pressure difference (> 30 mbar) across it, because it will not open/close properly, which can result in damage. Always first open *V2* to equalize the pressure.

After the pressure has equalized, the gate valve *V1* can be opened. Open also V3 and V4 to connect the condensing and pumping side of the dilution refrigerator at the Gas Handling System. At the same time, the cold trap can also be evacuated by opening V7 *(assuming the trap is at room temperature)*. To start evacuation of the dilution refrigerator, open *V18*, connecting the service manifold with the dilution refrigerator circulation circuit. When the pressure p6 in the service manifold is below 1 mbar, *Turbo 1* of the main evacuation can be started. After approximately 15 minutes of pumping with *Turbo 1*, the system will be clean enough to start a cool-down.

After the evacuation, all valves should be closed, and pumps switched off. If the liquid nitrogen cold trap is to be used, it should now be inserted into a filled LN2-Dewar (see also Section 8.3).

Figure 3: Mixture Tank Manual Valve

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

6.2 Cool-down

A cool-down can be carried out fully automatically, manually, or as a combination of the two. The fully automated cool-down sequence consists of four basic phases.

Evacuating the Vacuum Can (VC). To create a good enough vacuum at low temperatures for optimal operation of the system, the pressure *p1* of the VC should be pumped at room temperature down to <1x10^{-3} mbar before the pulse tube can be started.

Initial pre-cooling of the system with the Pulse Tube cooler (PT). In a period of approximately 10–12 hours (empty LD system), the pulse tube will cool the 50K and quasi 4K stages and radiation shields. Simultaneously also the dilution refrigerator will be cooled to around 10 K through the internal Heat Switches.

Pulse pre-cooling (PPC). The Bluefors developed pulse pre-cooling sequence can be used to reduce the cool-down time. As no exchange gas is used in the cool-down, some parts of the system stay 'hot' after the initial pre-cooling with the Pulse Tube. These hot spots prevent condensing the mixture in the dilution refrigerator. By repeatedly admitting the mixture from the tanks through the flow impedance Still side of the dilution refrigerator and then pumping it out again, these hot-spots can be effectively erased.

Condensing the mixture and starting of the circulation. The He-3/He-4 mixture is condensed from the tanks into the dilution refrigerator using a small compressor. Afterwards, this compressor is bypassed and the normal circulation is started.

These phases are explained in more detail in separate subsections.

For each of these four phases, there is a pre-programmed command script, which can be executed for a semi-automated cool-down (Pump VC, Start PT pre-cool, Pulse pre-cool and Condensing). In a semi-automated cool-down, each of these scripts is ran individually and the time of execution is defined by the user (to understand running scripts for automation, see Section 7.2). For a fully automated cool-down, there is a larger combined script. This script executes each of the four basic scripts, one after the other, on certain triggers, which can be modified depending on the system options. The general cool-down sequence will be explained, based on these scripts and default trigger parameters.

6.2.1 Evacuating the Vacuum Can

Start by switching on *Scroll 2*, and wait approximately 10 seconds until the internal relay of the pump switches on. Open V21 and confirm the operation of the pump by monitoring p6. Then, open *V16* and *V14* to rough pump the VC. Depending, whether the system is equipped with the Turbo 2 option, choose between the two methods below:

Without Turbo 2: Open *V18* to the backside of *Turbo 1*. When the pressure p1 of the VC has reached < 1 mbar, close V16, and open V18 and V15. In this state, the rough pumping is continued through the turbo pump. Now the Turbo 1 can be turned on to pump the VC to a sufficient pressure to start the Pulse Tube Cooler.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

With Turbo 2: Open *V23* to the back of *Turbo 2*. When the pressure *p1* of the VC has reached <1 mbar, close *V21,* and open *V23* and *V22*. In this state, the rough pumping is continued through the turbo pump. Now *Turbo 2* should be started to pump the VC to sufficient pressure to start the Pulse Tube Cooler.

While evacuating the VC manually, it is recommended to connect a leak checker to the TEST port at the GHS. The VC can then be leak checked parallel to the pumping line. Please make sure to have all lines evacuated before opening the Manual Valve to the leak checker. If evacuation of the VC is done by a script, the script will monitor that a sufficient pressure is reached in a reasonable time before moving to the next step. This prevents the system from being cooled in case of a major air leak to the VC.

6.2.2 Starting the Pulse Tube cooler

When then the pressure *p1* in the VC has reached <$2x10^{-3}$ mbar, the pulse tube can be started. The threshold value of p1 for the pulse tube to be started is higher on systems with integrated superconducting magnets (5E-2 mbar).

CAUTION

Make sure the water cooling of the pulse tube is running, otherwise the temperature protection circuit of the pulse tube will trip (see manual of the Cryomech Pulse Tube). In this case the pulse tube will stop, even though the LED on the front panel stays on.

For pre-cooling the dilution refrigerator it is important that the gas cap heat-switches, *HS-STILL* and *HS-MC*, are turned ON. To do so, the active-carbon pumps, which will evacuate the internal exchange gas at low temperatures, have to be heated. In a standard LD configuration, there are four 120 Ohm resistor heaters in parallel at channel 1, and two 120 Ohm resistor heaters at channel 2. The default current to the heater channels 1 (*HS-STILL)* and 2 *(HS-MC)* are 60 mA and 30 mA, respectively. Please refer to the system test report for the correct values.

In standard configuration, 4 resistor channels and 4 heater channels are connected to the diagnostics wiring harness, thus leaving 4 resistor channels available inside the system. The factory-connected channels are presented in tables Table 3 and Table 4. Please refer to the system test report for systems specific configuration.

Table 3: Standard configuration of factory connected resistors

Res. Ch1	**Res. Ch2**	**Res. Ch5**	**Res. Ch6**
50K Flange thermometer	4K Flange thermometer	Still thermometer	MC thermometer

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

Table 4: Standard configuration of factory connected heater

Heater Ch1	Heater Ch2	Heater Ch3	Heater Ch4
HS-STILL	HS-MC	Still heater	MC heater

It may be beneficial to cool-down the system with some exchange gas inside the dilution refrigerator. While benefit of thermalizing the dilution refrigerator this way is negligible, this step has been removed from the latest versions of automatic scripts. If using exchange gas in the dilution refrigerator is preferred, then, a few hours after the pulse tube is switched on, open *V8* and *V13* to let mixture from the tank into the line that connect to the Still. To admit the mixture in this volume, close *V13* to the mixture tank and open *V3* to the Still-side of the dilution refrigerator. Because part of this mixture was the last of mixture to come out after the previous cool-down, it is possible that it might have some contamination. Therefore it is suggested to first run the pulse tube for a few hours, so any possible contamination will freeze out on the walls of the Still-side of the dilution refrigerator and not be able to reach the main condensing impedance. When the pressure has equalized (after approximately 10 seconds), close *V3* and *V8*. Make sure all the system operators are aware that some of the mix is in the dilution refrigerator.

When the pressure *p1* in the VC has become $<1\times10^{-4}$ mbar, the pumping of the VC can be stopped. In order to do so, close *V14* and then all other valves (depending on the turbo-option *V16*, *V22* and *V23* or *V15*, *V18* and *V21*). Also, switch off *Turbo (1 or 2)* and *Scroll 2*. It is recommended to keep on pumping the VC until all the temperatures inside the system are below 77 K.

Before moving to the next step, the temperature of the dilution refrigerator should be low enough. Typically, the Pulsed Pre-Cooling (PPC) sequence can be started, when the temperature at the Still Flange has reached 15 K. In the script for fully automated cool-down, the pulse pre-cooling sequence can be triggered by a pre-set waiting time. The temperature of the Still Flange can be used as a trigger parameter on some system/software combinations.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

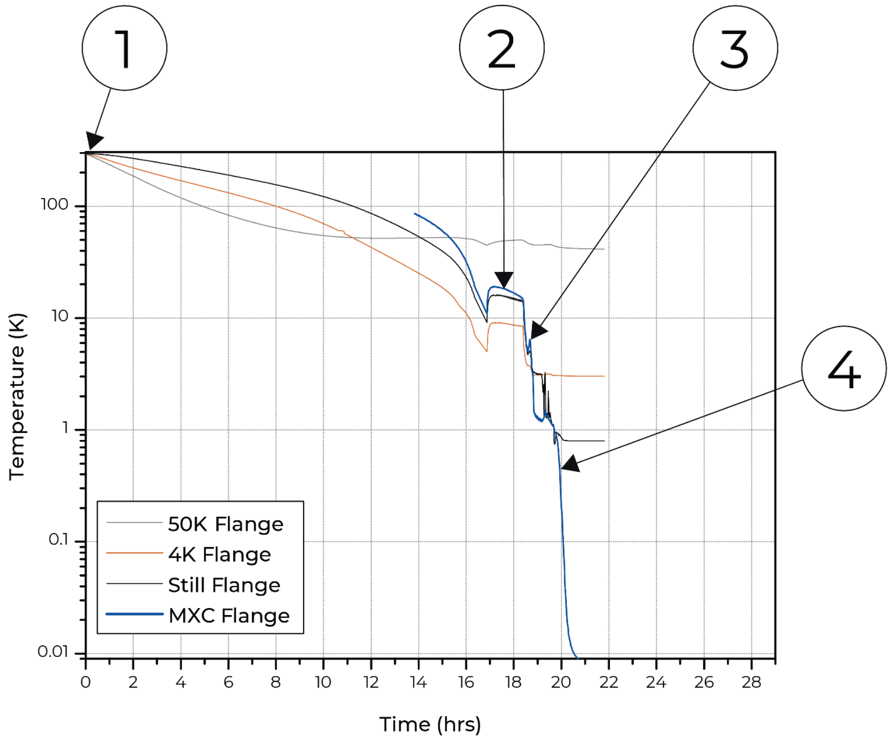
BLUEFORS

IMPORTANT

If a lot of experimental mass and/or measurement lines are added to the system, the trigger time might need to be adjusted for optimal performance. Make sure any adjustments reflect the actual cool-down time of the system. For reference, Figure 4 shows a typical cool-down curve of the Mixing Chamber Flange for a system with no experiments attached. In ~18 hrs the Still reaches 15 K, the cooling curve slows down and PPC sequence is started.

NOTE: If you want to do a fully manual cool-down or omit the PPC sequence, you have to continue the initial cool down a few hours longer before condensation of the mixture can be started. Omitting PPC is justified if the pre-cooling is slow, for example if a large superconducting magnet is integrated.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**



Item	Description
1	Start cool-down
2	Start pulse pre-cooling
3	Stop pulse pre-cooling
4	Start condensing mixture

Figure 4: Example of cool-down curve

6.2.3 Pulse Pre-Cooling

To begin the PPC sequence, first *Scroll 1* of the main circulation must be started (wait approximately 10 seconds to confirm the pump operates normally). Then, if applied, the exchange gas has to be pumped out of the dilution refrigerator to the tanks. This is necessary as in the automatic cool-down mode the condensing pressure *p3*, which rises during the PPC sequence, serves as a control parameter in the sequence. To pump out the mixture, first open *V13* to the mixture tank. **Before starting pulse pre-cooling, make sure the Manual Valve to the tank is open.** Open *V2* to monitor the Still pressure *p2*. Open *V3, V4* and *V10* to the pump. When the Still and condensing pressures, *p2* and *p3*, are both < 10 mbar, close *V4* to the Condensing Line and close *V10* to the pump.

The PPC sequence is started as follows; open V2, V3 and V10 (if they are not already opened). Admit mixture from the tank into the Still by opening *V8*. When the pressure in the Still and mixture tank have equalized, close *V3* and open *V10* to pump the mixture back into the tank (in the script, this is triggered by a pre-set time of 15 seconds). When the Still is pumped empty, again admit mixture to the

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Still by closing *V10* and opening *V3* (in the script this is triggered by a pre-set time of 8 seconds). These last two steps are repeated, until all hot spots from inside the RD are erased. After a few cycles, there should be a notable, gradual increase in the value of p3, indicating that the dilution refrigerator is not blocked.

> NOTE: the pulse pre-cool sequence runs for over an hour, over 100 repetitions, therefore it cannot be run manually.

In the automated cool-down script, there is a pre-set time trigger that will stop the PPC sequence. The pulse pre-cooling sequence is stopped at the end of a pumping cycle, after the trigger condition is met. Thus, *V13* to the tank is closed and V4 is opened, enabling the small amount of mixture left in the main circulation circuit circulate through the dilution refrigerator. As a preparation for normal circulation, the gate valve *V1* is opened and its bypass *V2* closed.

6.2.4 Condensing the mixture

At this point, it is assumed that the complete dilution refrigerator is pre-cooled to a low enough temperature (< 10K) to allow for condensation of the mixture. It is recommended to use the liquid nitrogen cold trap, so it should now be confirmed to be ready for operation (dewar filled with liquid nitrogen). Here, it is assumed that the system is at the state of circulating the small amount of mix after the PPC. If not, start by turning on *Scroll 1*. Assuming the cold trap is ready for operation (see 6.1), open *V9* and *V7* and close the bypass *V8*. To condense the mixture, the condensing pressure has to be increased to about 2 bars. Therefore, open *V6* and start the *Compressor*. The back-pressure valve *BPV1* (see Figure 5), bypassing the compressor, has been factory set to a cracking value of about 2 bar. First close *V4* and then open *V5* to add the compressor into the main circulation. If V1 is not open already, open *V2* to equalize the pressure on both sides of *V1*. Open *V1* and *V10*, and close *V2*.

CAUTION

The gate valve *V1* should never be closed during operation of the system (when there is condensed mixture inside) because it provides the only return path for the mixture to the tanks in case the pulse tube switches off (for example during a power failure).

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

IMPORTANT

V4 and V5 are high pressure valves. The ingoing Condensing Line after these valves is made to withstand pressures up to 10 bar.

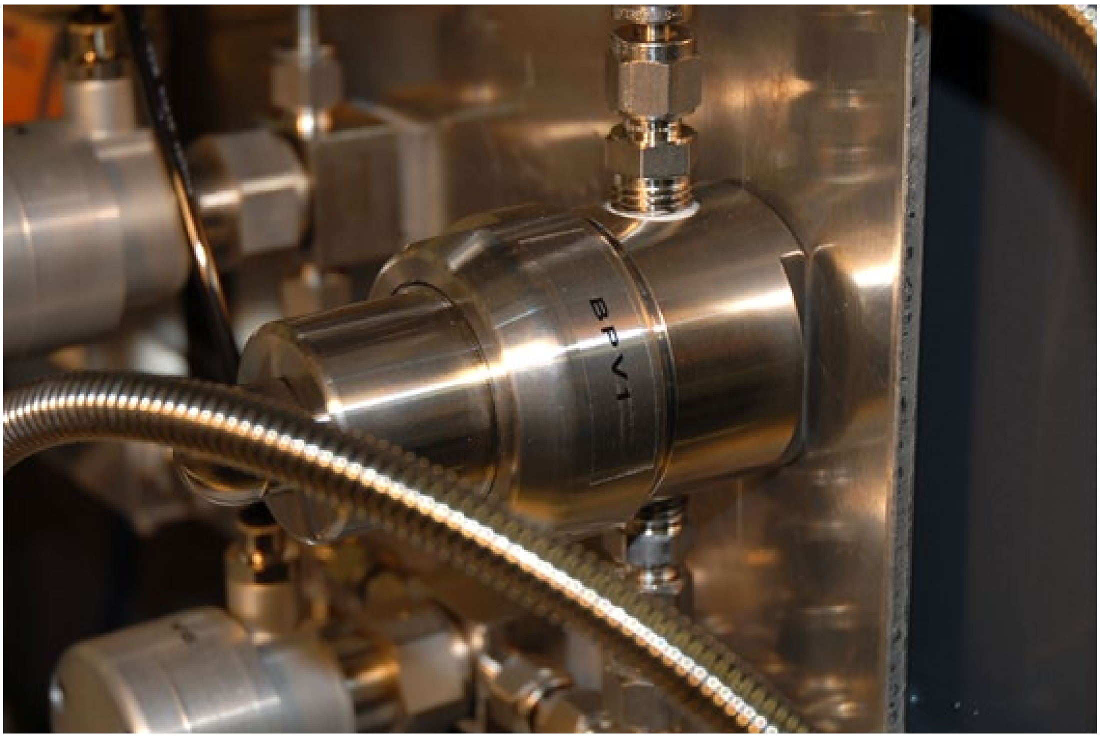


Figure 5: Back-pressure valve BPV1 at the high pressure panel of the GHS

To start condensing, mixture from the tank has to be added into the circulation. In the script, this is done by closing *V10* to the Still Line and opening *V12*. Now the mixture is pumped from the tank into the circulation through the Needle Valve (see Figure 6). The Needle Valve is pre-set to a value where the mixture can be added to the circulation at a controllable flow-rate. When the condensing pressure *p4* at the back of the *Scroll 1* gets > 900 mbar, the mixture intake from the tank is stopped. *V12* is closed and *V10* is opened again to restore the circulation. In case the pressure *p4* overshoots, the back pressure valve *BPV3* (see Figure 6) is set to a cracking pressure of approximately 1.2 bar and provides a path back to the mixture tank. Now the added mixture will condense into the dilution refrigerator and consequently pressure at *p4* will drop. When *p4* < 600 mbar, *V10* is closed and *V12* opened again. These steps are repeated and as a result, the pressure p5 in the mixture tank will start to decrease. **This is the indication that the dilution refrigerator is completely pre-cooled and the heaters on the Heat Switches *HS-STILL* and *HS-MC* should be switched off.** This will break the thermal contact between the dilution refrigerator and the pulse tube. The condensing script will

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

turn the Heat Switches off when the tank pressure p5 has decreased by 80 mbar from its initial value at the beginning of the condensing phase.

The steps as described above are repeated until the pressure in the mixture tank *p5* becomes < 250 mbar. At this pressure, the condensing will become slower through the Needle Valve. Therefore, for following mix injections, the Needle Valve is bypassed and the mixture will now be added directly from the tank by closing *V10* and opening *V11* (instead of *V12*). Eventually, when the pressure in the mixture tank *p5* becomes < 50 mbar, adding mixture repetitively via *V11* will also become too slow. To condense the final portion of mixture, *V11* is opened continuously. The tank pressure is now so low that *V10* will not be closed (which earlier prevented back-flow to the Still side of the dilution refrigerator). In this state, the pressure in the tank can be pumped empty to a pressure equal to the returning mixture from the dilution refrigerator, typically less than 10 mbar. After that *V11* is closed.

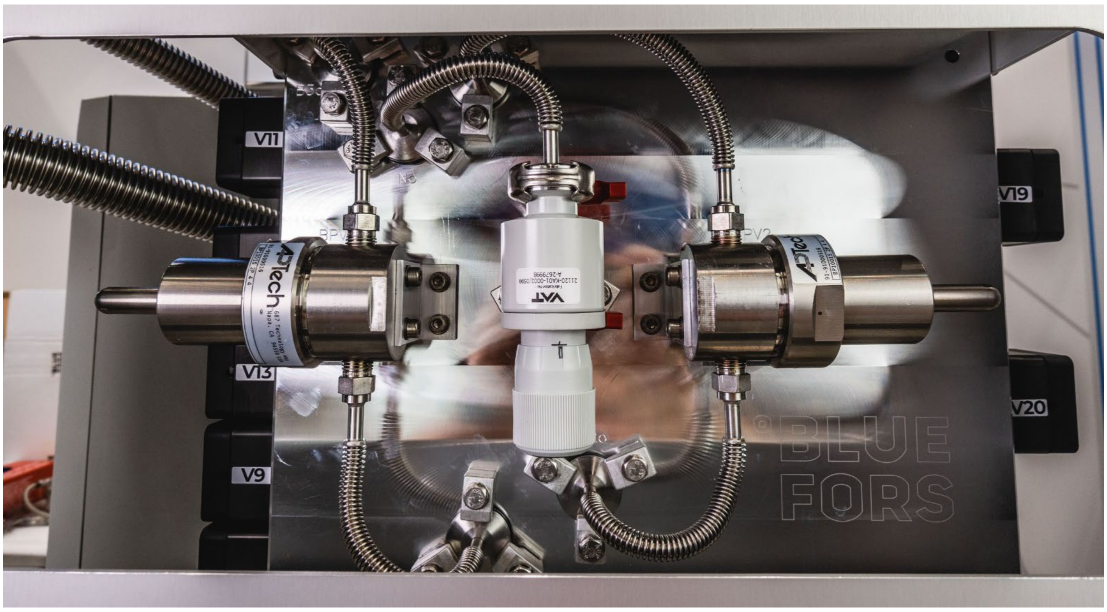


Figure 6: Needle Valve and BPV valves 3 and 2 (left and right side respectively)

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

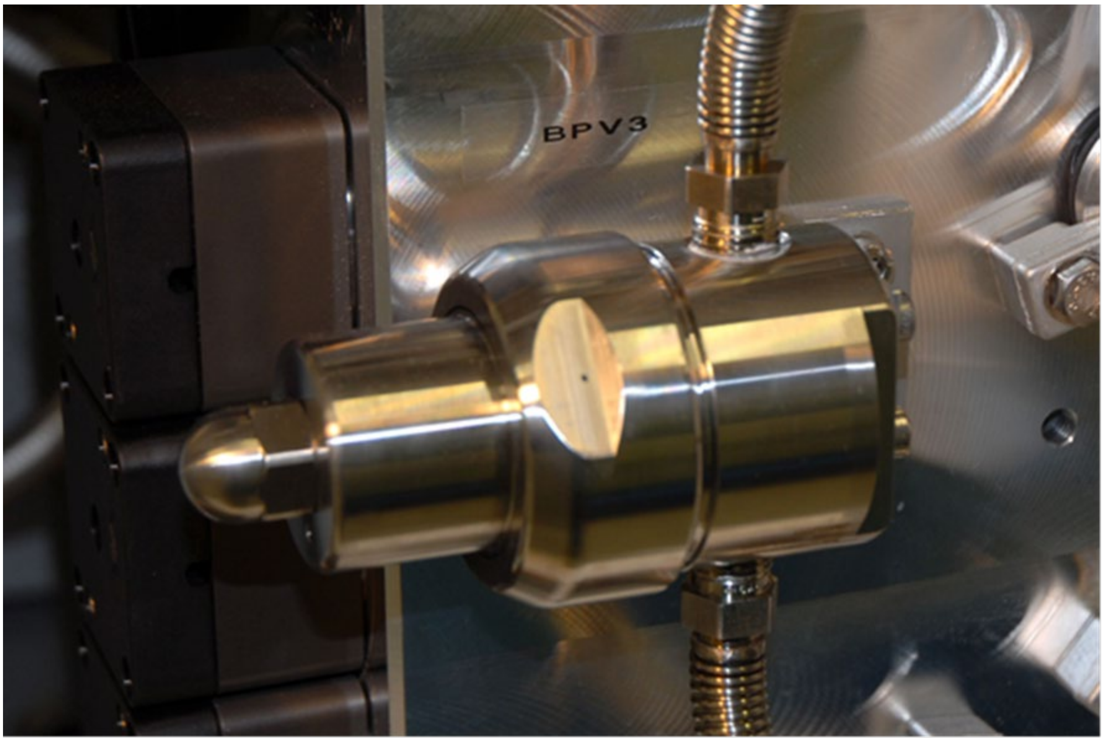


Figure 7: Backing pressure valve BPV3

After the mixture has condensed (~10 mbar or less left in the tank, *p5*), the *Compressor* is switched off. When *p3* is < 1000 mbar, V5 and V6 are closed (leaving some mixture in the small compressor volume). Because at this point V4 is Still closed, the pressure *p4* after the *Scroll 1* circulation pump will increase while the condensing pressure *p3* will continue to decrease. When pressures p3 and p4 are equalized, *V4* is opened. Once the condensing pressure *p3* drops to < 700 mbar (in several minutes) the *Turbo 1* of the main circulation is started.

> NOTE: *Turbo1* cannot be started immediately, because initially the Still is very warm while the Still pressure *p2* can be high. If the *Turbo 1* is started when condensing pressure *p3* (which is close to *p4*) is too high, the increased pumping speed will also increase *p4* and *BPV3* will leak some mixture back into the tank. After starting the *Turbo 1*, **the system is now in normal operation mode** and will start to cool-down to base temperature.

To decrease the cool-down time at temperatures below 1 K, after approximately 20 minutes, some heat should be applied to the Still heater (~7 mA). Without heat applied to the Still, the temperature will get too low for the Helium-3 to evaporate efficiently from the Still. This results in a very low Still pressure (*p2*), hence low flow rate and low cooling power. When the Still heater is connected to channel 3 of the Bluefors Temperature Controller, a fixed amount of Still heat can be applied by the *EXT* button on the front panel or the Control Software.

If you want to condense the mixture manually, we recommend opening *V12* and regulating the Needle Valve to a setting where the *p4* approximately 1.0 bar. As the pressure *p5* in the mixture tank will go down, so will also the flow through the Needle Valve. Consequently, *p4* will start to decrease. At this point, the Needle

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Valve can be adjusted again to increase the flow and to increase *p4* to the original value. Eventually, the Needle Valve will be completely open. At this moment, there is still some mixture left in the tank, but *p4* will continue dropping. When there is about 50 mbar left in the tank (*p5*), close *V12* and open *V11* to condense the last bit of mixture. When all mixture is condensed, close *V11*. To get the system from here, in normal operation mode, follow the same steps as in automated scripting mode, described in the previous paragraphs.

6.3 Continuous operation

In normal operation mode, He-3 gas is circulated through the dilution refrigerator and Gas Handling System. The system is designed so that it is protected against incidents and abnormal behavior. Any excessive pressure build-up or loss of mixture in the system is unwanted and there must always be a return path for the mixture from the Still Pumping Line via the gate valve *V1*, back pressure valves *BPV2* and *BPV3* (see Figure 6), and the manual tank valve to the mixture tank. **Therefore, the gate valve *V1 or the manual tank valve* should never be closed during normal operation**. For example, in the case of the most common incident, a power failure, the pulse tube will switch off. As a consequence, the dilution refrigerator will start to warm up and after a while (approximately 10 minutes) the mixture inside will start to boil off. During a power failure, also all pumps will switch off and all valves (except the gate valve *V1*) will close. If the pressure in the Still Line reaches > 1.1 bar, *BPV2* will crack and shortly after that, the *BPV3*. The four valves (V1, BPV2, BPV3, and manual tank valve) offer an escape route for the mixture back to the tank.

NOTE: As the backpressure valve *BPV2* is set to only a slight overpressure-value it may let some air bleed through if the line is vented too quickly.

CAUTION

The gate valve *V1* should never be closed during operation of the system (condensed mixture inside) because it provides the only return path for the mixture to the tanks in case the pulse tube switches off (for example during a power failure).

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

WARNING

In case of power failure of the Control Unit the temperature of the system may rise to 3 K. In total power failure the system starts warming up to room temperature. With simultaneous severe misuse by the user, loss of helium is possible.

NOTE: All pneumatic valves in the system, except the gate valve *V1*, are of the 'normally closed' type. This means that without pressurized air, a spring will force these valves in the closed position. The gate valve *V1* does not work against a spring (dual action), this means that both in the case of power failure or loss of pressurized air, this valve will remain in the state it has been set.

In the unlikely case of a system blockage, either in the Condensing Line of the dilution refrigerator or the liquid nitrogen cold trap, the back pressure valve *BPV3* will provide a path for the mixture to the tank (for cleaning the cold trap see Section 8.3).

CAUTION

If the LN2 cold trap is used, user must refill its dewar regularly with liquid nitrogen (approximately once a week) to make sure it will not warm up during a run.

For reference and troubleshooting, Table 5 shows some typical values of the most important system parameters of an LD400 system during normal operation. For LD250, the value at p2 is typically higher. For the actual values, please refer to the test report accompanied with your system.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Table 5: Typical values of most important system parameters of a LD400 System during normal operation

I_{still} [mA]	p_{still} (*p2*) [mbar]	*n* [mmol/s]	p_{cond} (*p3*) [mbar]	p_{VC} (*p1*) [mbar]
12	0.03	0.5	500	1-5E-6*

*NOTE: Due to a pressure gradient, the value at the pressure gauge depends on the length of the pumping line. The example value is for a two-meter pumping line.

6.4 Warm-up

The automatic warmup script assumes the system is operating at normal circulation mode. Before starting the warmup, it is also advised to make sure the p6 has remained at low level throughout the cool-down (less than 10 mbar). It is also highly recommended to turn the gauge p1 that monitors the pressure at the VC off before the warmup procedure to avoid contaminating the cold cathode filament.

To warm up the system from normal circulation mode to room temperature, first the *Turbo1* pump should be stopped. Then *V9* should be closed to stop the circulation (if the external trap was not used, close *V8* instead to close the circulation). Then, *V13* to the mixture tank should be opened to provide a route for the mix to be pumped back to the tank. At this point, the pulse tube can be stopped. After approximately 15 minutes, when *Turbo 1* has slowed down and the condensing pressure at p3 dropped, *V3* can also be opened to pump the mixture from the condensing side of the dilution refrigerator to the tank. To increase the warm-up rate, user should let some heat-exchange gas (air) into the VC. This is done by opening V19 to vent the service manifold (the p6 volume). When the volume is at atmospheric pressure, close *V19* and open *V16* and *V14* to the VC, so that only this small amount of air is admitted to the VC. The warmup script does this air injection twice.

NOTE: Injecting an excessive amount of air / other gas to the VC of a cold system can cause damage on the system (condensing water on the surfaces) and increases the possibility of over pressurizing the VC (as the cold gas warms up).

If the system is equipped with a warm-up heater, it can be turned on once a small amount of air has been admitted to the VC. If a warm-up heater is used when the system remains in vacuum, there is a risk of the 4K Flange to overheat.

Once heat-exchange gas has been admitted to the VC, the mixture will pump out quickly (less than 1 hour) to the storage tanks. To define if all the mix has been collected, the values at p2 and p4 are monitored. The value at p4 will indicate the pressure at the tank, and the value at p2 will indicate, if mix is still evaporating from the dilution refrigerator. After the pressure at p4 has increased to above 650 mbar, the pressure at the p2 should go down to 5E-2. The warmup script will keep on pumping the mix out for another 30 minutes after these conditions have been met.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Once all mixture has been pumped back to the tanks, all open valves can be closed. It is recommended to close the valves in the direction of the circulation (V7, V4, V3, V1, V10, V13). The scroll can be turned off once the valves are closed. If the system will be warm for more than a few days, it is also recommended that the Mixture Tank Manual Valve (see Figure 3Figure 3) is closed for safety.

The system can be fully vented, once the full system is at a temperature above the dew point. Before venting the system, make sure the air flow to the system is restricted at the vent port (see Figure 8). Venting the system through an open KF16 port can result in increased pressure differential over the radiation shields, which may damage the shields. To vent the system, open *V19*, *V16* and *V14*. After the system is fully vented, the shields can be removed from the cryostat. Evacuating the vented volumes inside the GHS is recommended (start scroll2, close V19 and V14, open V16, pump until p2 is ~1E-1 mbar). If a warm-up heater was used, make sure that it has been turned off to prevent overheating the system.

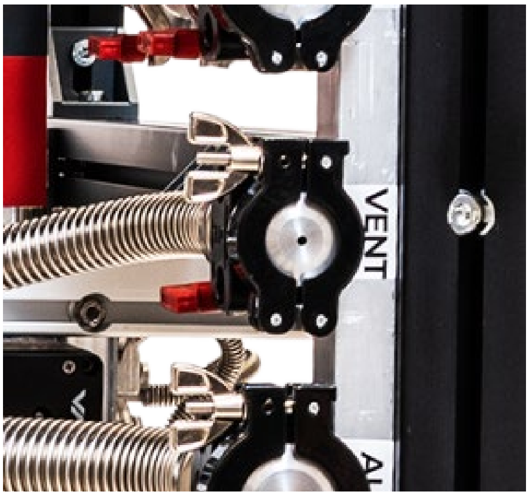


Figure 8: Vent port with flow restriction

7 Remote control

The complete system can be controlled by a computer, which enables full remote control and system status check plus the possibility of running scripts (for automated cool-down). For remote control, the system should be connected to a computer via the USB connector on the backside of the manual push-button panel and Bluefors software called ValveControl shall be installed on the computer. Some functionalities may require additional connections.

> NOTE: The latest version of the ValveControl Software and the installation guide can be downloaded from the support section on the Bluefors website https://bluefors.com/support/. For further information, contact support@bluefors.com.

See separate Bluefors Control Software Manual in the near future for details about the new software which will replace ValveControl software (coming soon to our website). This manual is for using ValveControl only.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

CAUTION

Computer control has full control of the Gas Handling System. Malfunction or careless use can result in loss of precious He-3 gas.

7.1 Software installation and layout files

It is important that a correct layout file is used when installing the Control Software. This file contains information on the used control channels (see LD System Description Manual), what they are controlling (addressing), the position of the control buttons on the software background image, and the file name of the background image (.png). There is a default layout and background integrated in the software that can be used with standard systems. Depending on some options, for example with a secondary turbo pump, or any other extra controls, you have to browse to the location of the layout file you want to use (you can also decide to first do the installation with the default layout and then later change to the correct layout).

CAUTION

Only operate the software with the correct layout file for your system as otherwise unexpected behavior might occur because of wrong addressing for valves, pumps etc.

It is recommended to store custom layout-files and background images (and maybe other important information such as the manual) in the same directory the software is installed. If you want to update the control software to a later version, the older version needs to be removed. These files will remain in the folder, even if the software is removed. The layout file can also be changed after the software is installed from the software setup.

> NOTE: The background image file must be saved in the same directory as the layout file.

The layout file can be modified, if necessary. It is recommended to make a copy of the layout being modified and give a unique name to the configuration before

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

editing. Most importantly, in the last column, there is a flag defining whether confirmation after pressing a control in the software is active ('1') or not ('0'). This can be used to enable or disable the operation of some valves. If '0', the control will not be visible on the background image but can be controlled through its variable name in a script. If you want to completely take the control out of use, the whole line has to be commented out (or deleted). For more information, please refer to the manual for the control software, and the LD Description Manual for the connection diagram of the different channels at the Control Unit.

The default files can be downloaded from the user support section of the Bluefors web site.

7.2 Running scripts

CAUTION

Scripts have full control of the Gas Handling System. Malfunction or careless use can result in loss of precious He-3 gas.

For system automation, the ValveControl software has the possibility of executing simple scripts. These scripts are run from the 'Programming' tab. A script can be directly written into the code-window or loaded from a file ('Load' button). The scripts are simple text files (.txt) and can either be created with a text editor or directly from the ValveControl software ('Save' button).

When a script is running, the computer is in constant communication with the system, hence the remote light will be on the entire time and the manual push button panel will be disabled. If for some reason manual action is desired, the 'Local' button on the front panel can be pressed. This will disable computer communication and stop any script that is running and instantly enable manual control through the push button front panel.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

IMPORTANT

When a script has been stopped (either by pressing the local button on the front panel or by pressing the stop button in the software), it has to be considered whether it is OK to restart it again, as the script will not continue at the point it was stopped, but instead will start all over from the beginning.

NOTE: When a script is running, the reading interval is automatically set as fast as possible (~500 ms). During this time, all graphs will be updated at this same fast rate. The log saving frequency will not change.

The basic commands of the scripting code are displayed on the right-hand side of the code area. The variables in use, as defined in the layout-file (see Section 7.1), are shown in the 'Variables' table. There are 4 extra variables, not defined in the layout-file: time (time elapsed in seconds since script was started) and var1, var2, and var3. These last three variables are the only variables that can be user set to a certain value within the script (for example the command var1=time will assign the value equal to the amount of seconds elapsed since starting the script at the moment of assignment to var1).

Table 6 shows a list of operators which are supported in the scripting code. So for example IF ((p1-p2) 100)||(p3>=100) is a valid command line.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Table 6: Supported operators in scripting code

Operator	Description
+	Addition
-	Subtraction
/	Division
*	Multiplication
%	Modulo
==	Equal to
!=	Not equal to
<	Less than
>	Greater than
<=	Less or equal
>=	Greater or equal
&&	And
||	Or
!	Negation

7.3 Basic scripts

For cooling down the cryostat there are 4 basic scripts that perform the 4 phases of a typical cooldown; pumping the Vacuum Can, starting the pulse tube, running the PPC sequence and condensing of the mixture. For a fully automated cooldown these 4 basic scripts are all combined in one script named 'Auto_CoolDown'. The operations these scripts perform are explained in detail in Chapter 7.2. These scripts can be downloaded from the user support section on the Bluefors website. Note that the first two scripts (Pump VC and Start PT pre-cool) are different depending on whether the system has the optional 2nd service turbo pump installed.

8 Routine maintenance

8.1 Connection warnings

DANGER

Electric shock hazard. This equipment is to be serviced by trained personnel only.

DANGER

Hazardous voltage. Disconnect power before servicing.

Please refer to the separate Maintenance Service instruction document for more detailed instructions (for example service intervals, tip seal changing etc).

There are some connections in the Gas Handling System that we strongly recommend not to be disconnected by the end-user. These connections contain epoxy-seals and can easily be damaged if mishandled. These connections include the outlet of the condensing compressor (see Figure 9) and the feedthrough / electrical insulator of the Condensing Line on top of the GHS (see Figure 10 and Figure 11). If the GHS needs to be moved, the Condensing Line should be disconnected at the 6 mm Swagelok connection on the Room Temperature Flange.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

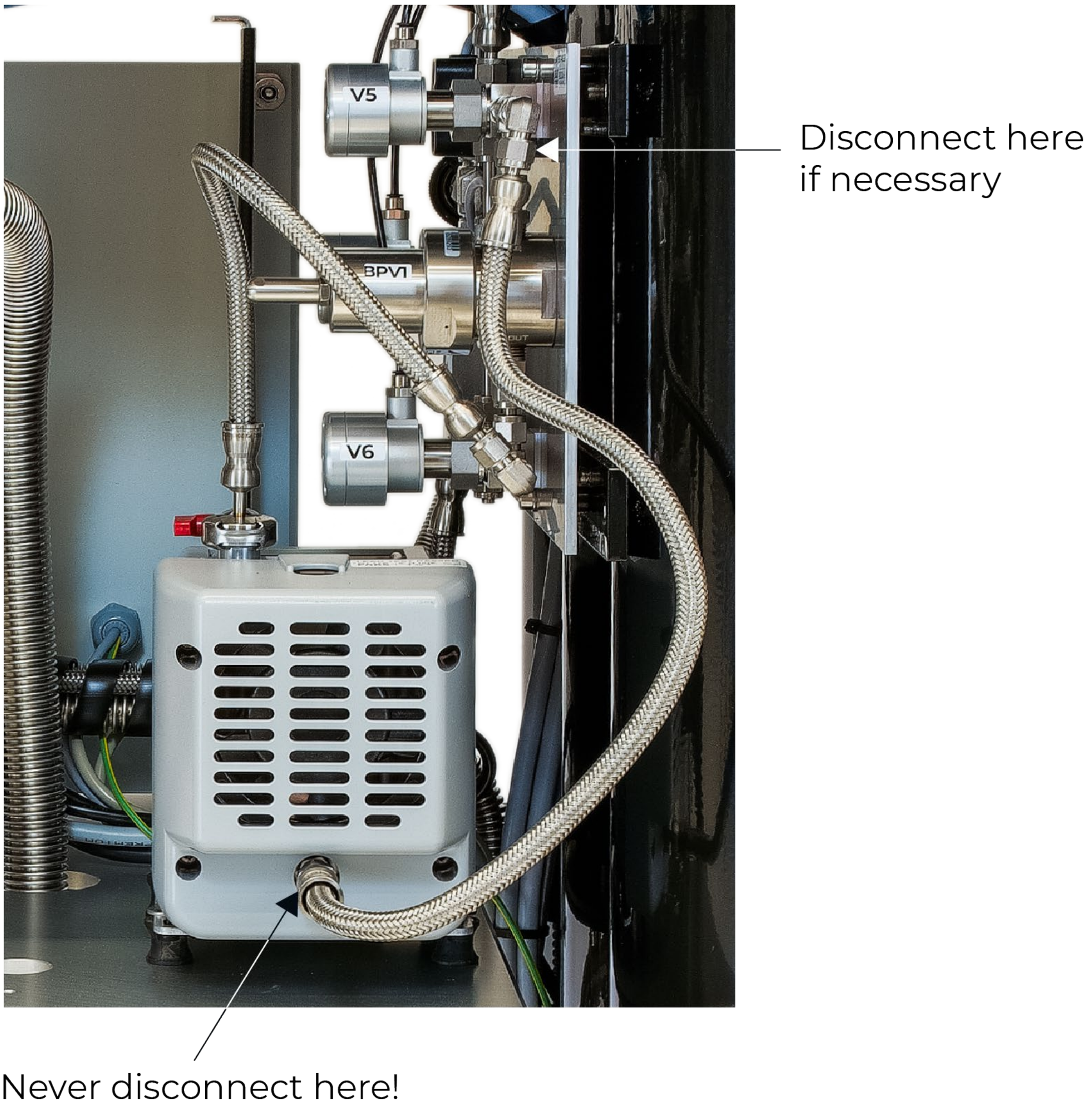


Figure 9: Compressor service warning

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

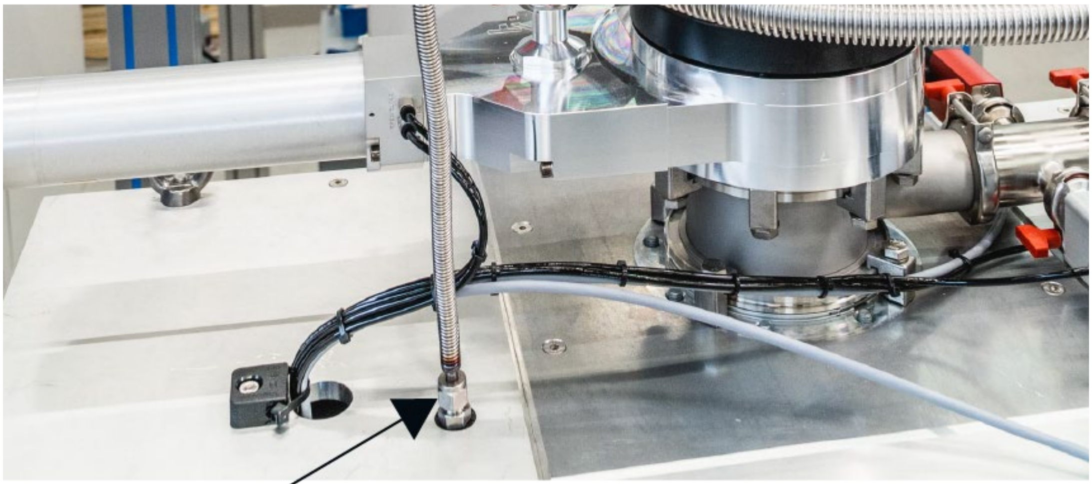


Figure 10: Condensing Line top connection warning, part 1

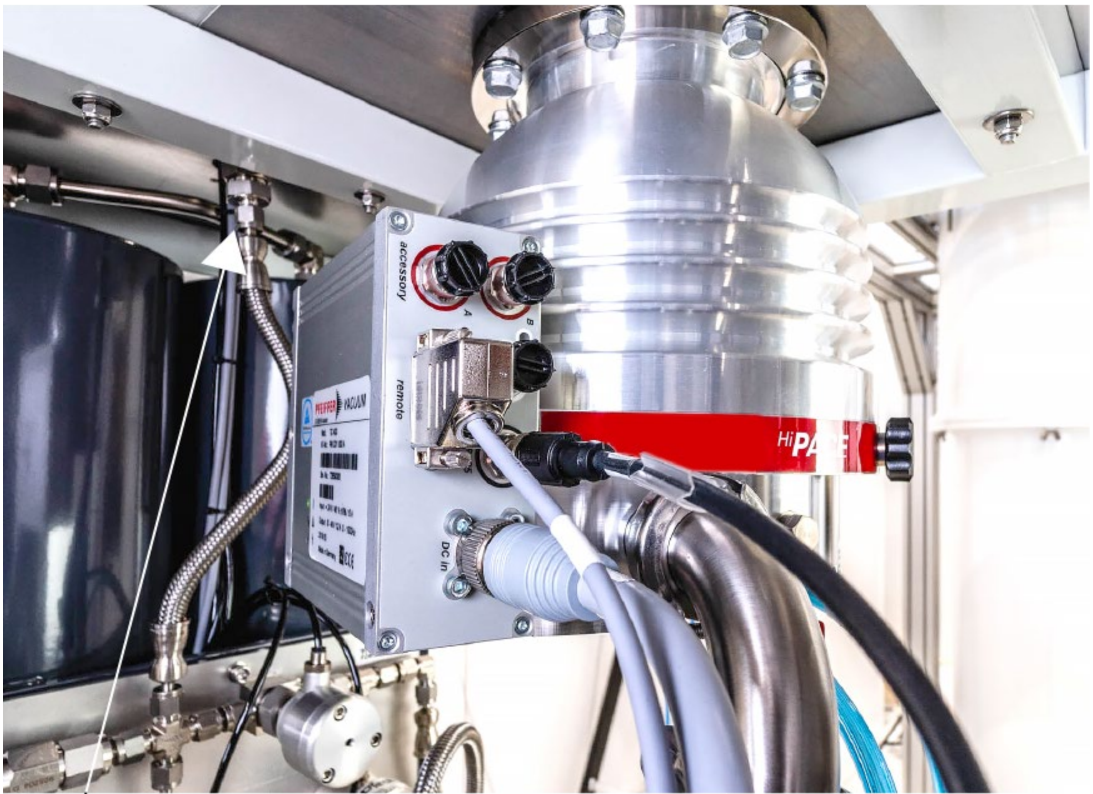


Figure 11: Condensing Line top connection warning, part 2

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

8.2 The Pulse Tube and the Pulse Tube compressor

The Pulse Tube Cryocooler cold head contains no user-serviceable parts. For connecting and disconnecting the Aeroquip flex-lines, refer to the Pulse Tube Cryocooler User Manual. The Pulse Tube compressor maintenance schedule is given in Table 7.

Table 7: The PT compressor maintenance schedule

Maintenance	Maintenance interval
Replace absorber	Every 20 000 hours (see separate Maintenance Service instruction for details)
Vent helium gas	As required
Charge helium gas	As required

8.3 Cleaning the external cold trap

When the external LN2 cold trap is in use, the active carbon inside should be regenerated regularly. Typically, this should be done at the end of a run when the dilution refrigerator measurement system is warmed up to room temperature, and the mix has been collected safely to the tanks. If there is still some mix in the trap, all mixture should be evacuated from it, when it is still cold. This can be done by pumping the mix into the mixture tank with Scroll1 via V7, V3, V2, V10 and V13 (keeping V9 closed).

> NOTE: Because the evacuation of the mixture from the trap is done via the Still Pumping Line, it should only be done when the dilution refrigerator is already evacuated. After the mixture is evacuated from the trap, all valves should be closed.

The contamination can be pumped from the trap with Scroll2 via the service manifold (open V21, V17 and V7). The trap can now be removed from the LN2 dewar.

While the cold trap is still being pumped, its body should be heated with a heat-gun for approximately 5-10 minutes to approximately 100 degrees Celsius to regenerate the charcoal inside. Afterwards all valves should be closed and the trap should be stored with vacuum inside.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

CAUTION

Only remove the cold LN2 trap from the dewar when it is being pumped (to air), as otherwise there can be unwanted pressure build up in the trap in case it has collected large amounts of impure gas (air).

8.4 Disposal information

The device must be taken to an appropriate recycling facility at the end of their working life. Within the EU the devices can be delivered to the manufacturer. Elsewhere, dispose of the device in accordance with your local applicable laws and regulations.

8.5 Customer service

For support documents and downloadable software, see Bluefors Support's website: https://bluefors.com/support

Or contact us via email: support@bluefors.com.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Appendix I: Packing crate dimensions

Typical packing crate dimensions. Please note that the exact crate sizes depend on the system configuration.

Table 8: Typical packing crate dimensions for standard systems

No	**Contents**	**Dimensions** (length x width x height in cm)	**Weight**
Box 1	Cryostat and PT compressor	130 x 90 x 210 cm^3	400 kg
Box 2	Gas Handling System	115 x 90 x 230 cm^3 (LD400) 115 x 90 x 210 cm^3 (LD250)	475 kg 450 kg
Box 3	Control Unit	115 x 90 x 200 cm^3	225 kg
Box 4	Frame and misc.	245 x 130 x 70 cm^3	450 kg

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Appendix II: Component dimensions

Table 9: Typical component weights and dimensions

Contents	**Dimensions** (length x width x height in cm)	**Weight**
Gas Handling System	90 x 75 x 215 cm^3 (LD400) 90 x 75 x 200 cm^3 (LD250)	350 kg 300 kg
Control cabinet	70 x 100 x 180 cm^3 (Big table) 70 x 80 x 180 cm^3 (Small table)	115 kg 115 kg
Frame (not assembled)	210 x 100 x 30 cm^3	130 kg
Cryostat	200 x 65 x 65 cm^3	150 kg
Compressor	65 x 65 x 95 cm^3 (PT415) 70 x 50 x 70 cm^3 (PT400)	215 kg 120 kg

Please check more detailed dimension pics from LD System Description document and also additional information is found from pre-installation guide.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

Appendix III: Technical specifications

Electrical properties are listed in Table 10.

Table 10: Electrical properties

Unit:	USA/Canada Models:		European Models:	
	Voltage	**Current**	**Voltage**	**Current**
GHS250	115 VAC ± 10%, 60 Hz	20 A	230 VAC ± 10%, 50/60 Hz	16 A
GHS400	115 VAC ± 10%, 60 Hz	20 A	230 VAC ± 10%, 50/60 Hz	16 A
Control Unit	115 VAC ± 10%, 60 Hz	10 A	230 VAC ± 10%, 50/60 Hz	10 A

Remark: Japanese models use 100 VAC/60Hz

Cryocooler options are listed in Table 11.

Table 11: Cryocooler options

Cold head	Cryomech PT 415 RM	Cryomech PT 410 RM	Cryomech PT 420 RM
Compressor	Cryomech CP1110	Cryomech CP289C	Cryomech CPA1114

IMPORTANT

For each cold head/compressor pair there are several power requirement options. Please carefully check the power requirements expressed on the nameplate of the compressor before connecting that they match with the power delivered through the local outlet.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

BLUEFORS

Table 12: Power requirement options for cold heads and compressors

PT410, CP289C	220/230 VAC; 3 Phase; 60 Hz	460 VAC; 3 Phase; 60 Hz	200/220 VAC; 3 Phase; 50 Hz	380/420 VAC; 3 Phase; 50 Hz
PT415, CP1110	200/230 VAC; 3 Phase; 60 Hz	440/480 VAC; 3 Phase; 60 Hz	200V AC; 3 Phase; 50 Hz	380/415 VAC; 3 Phase; 50 Hz
PT420, CPA1114	440/480 VAC; 3 Phase; 60 Hz	380/415 VAC; 3 Phase; 50 Hz		

Integrated pumps

Please see the pump listing from LD System Description document.

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

Appendix IV: Layout file (example)

ValveControlLayout;ValveControl;1;0;

Comment;Ch_data:_"Ch;Name;Var_name;X;Y;Use;Address;Confirmation_required"

Ch;V1;v1;428;193;1;2;0

Ch;V2;v2;482;232;1;1;0

Ch;V3;v3;537;271;1;9;0

Ch;V4;v4;662;193;1;17;0

Ch;V5;v5;716;154;1;25;0

Ch;V6;v6;716;232;1;33;0

Ch;V7;v7;716;349;1;41;0

Ch;V8;v8;662;388;1;49;0

Ch;V9;v9;716;427;1;57;0

Ch;V10;v10;482;505;1;10;0

Ch;V11;v11;552;622;1;0;0

Ch;V12;v12;607;583;1;8;0

Ch;V13;v13;662;544;1;18;0

Ch;V14;v14;209;193;1;16;0

Ch;V15;v15;318;232;1;24;1

Ch;V16;v16;209;427;1;32;0

Ch;V17;v17;318;427;1;40;1

Ch;V18;v18;373;466;1;48;1

Ch;V19;v19;318;505;1;51;0

Ch;V20;v20;264;505;1;56;0

Ch;V21;v21;100;505;1;27;0

Comment;Ch;V22;v22;209;505;1;35;0

Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**

```
Comment;Ch;V23;v23;154;583;1;43;0

Ch;R1;hs-still;69;200;1;26;0

Ch;R2;hs-mc;69;291;1;58;0

Ch;R3;ext;69;381;1;59;0

Ch;Turbo1;turbo1;428;271;1;3;0

Ch;Scroll1;scroll1;553;506;1;34;0

Comment;Ch;Turbo2;turbo2;209;583;1;11;0

Ch;Scroll2;scroll2;100;583;1;42;0

Ch;Comp;compressor;771;193;1;19;0

Ch;Pulsetube;pulsetube;69;110;1;50;0

Meter;P1;1;159;164

Meter;P2;1;324;164

Meter;P3;1;611;164

Meter;P4;1;613;437

Meter;P5;1;744;593

Meter;P6;1;50;476

Meter;Flow;1;650;275

Config;Width;855

Config;Height;654

Config;Xoffset;12

Config;Yoffset;15

Config;name;STANDARD

Config;Background;BF_standard.png
```


Bluefors Oy, Arinatie 10, 00370 Helsinki, Finland | VAT: FI 2183 2199
support@bluefors.com | +358 9 5617 4800 | **BLUEFORS.COM**