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| System definition – SOLUTION  Target Helium Cooling Systems |
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(ESS-0012527)

|  | Name | Title |
| --- | --- | --- |
| **Owner** | Jens Harborn | Work unit leader - Target Cooling |
| **Reviewer** | Ulf Oden  Leif Emås | Lead Engineer - Target Systems  Gas & Process Engineer |
| **Approver** | Eric Pitcher | Deputy Head of Target division |

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# Introduction

## Objective of this document

The main goal of this document is to describe solutions, layout and detailed functions needed to fulfil requirements and basic functions described in the system requirement description document [1] for **Target Helium Cooling systems** consisting of the 3 sub-systems;

* Target Primary Cooling, system 1010
* Pressure Control and helium storage, system 1011
* Helium Injection, system 1013

## Scope of the document

To achieve the objective of this document the following topics are covered:

* Technical solutions(chapter 2); components and layout
* Modes of operation (chapter 3); behavior of the system in different operating modes and fault modes and transitions between modes
* Process Control system (chapter 4); detailed functional specification
* Electric power and grounding (chapter 5)
* Documentation (chapter 6); List of planned documentation and planned simulation models relevant for the detailed system engineering
* Models (chapter 7); Reference to used calculation and simulation tools/files
* Other (chapter 8-10); Safety assessment reference, Glossary, Document references, Document rev. history
* APPENDECIES; Process overview PFD and P&ID’s

# Technical solution

This chapter describes the chosen technical solutions and present justifications that each of the requirements listed in the system requirements description [1] is fulfilled.

## Basic design

### General

The proton beam target consists of a number of *tungsten rods* mounted in a number of separate sectors of the target wheel. The basic target cooling principle is to circulate helium gas around the tungsten slabs.

**Properties of helium**

The table below shows the approximate physical data for helium at the inlet (40°C) to and outlet from the target. Helium mass flow is 3 kg/s, and the specific heat for helium is 5.2 J/gK.

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Table 1 Physical data and flow speed at chosen operation points

**Flow velocity and pressure drop**

The flow velocity in the main circuit should not exceed a specific value to avoid increased flow resistance, wear etc. Choice of filter material, filter configuration and filtering area are also crucial for both filtering functionality and pressure drop.

### Process flow diagrams and P&ID’s

Refer to APPENDICES:

* Appendix 1: PFD Overview Target cooling
* Appendix 2: P&ID Target primary cooling circuit, 1010
* Appendix 3: P&ID Pressure control and Helium storage, 1011
* Appendix 4: P&ID Helium injection, 1013

### Brief description of the 3 sub-systems

#### Primary cooling circuit, system 1010

1010 is the main target cooling system. One or more circulators of a turbo type is driving the flow and is assumed to be oil free. The helium flow enters and leaves the target wheel via shut-off valves **YSV-001** and **YSV-002** at the top of the shaft. The heat is removed from the system by heat exchangers **W-001, W-002** and **W-003** connected to the intermediate cooling circuit.

Particles released are captured in 2 sets of filters; after the outlet from the target **F-001** and after the blower another coarse filter **F-002** is planned to protect the target from clogging if particles of size > 0.5 mm is released after filter F001, assumed mainly from the blower. However if the blower can be considered as free from releasing any particles bigger than e.g. 2 µm filter F-002 is not needed.

The circuit has a set of support systems described below. Refer to appendix 1 and 2.

#### Pressure control and helium storage, system 1011

This system is connected to the target primary cooling system via valve **YSV-011**. The circuit pressure controller uses the compressor **V-010** to adjust to lower pressure in 1010 and valve **V-015** to higher pressure by using gas from either Pristine helium system 1030 or the Nitrogen supply. The normal flow goes to 1010 from 1030 to replace leaked helium. When lowering the pressure in system 1010 the flow goes to either storage volume B-20a/b in system 1011 via YSV-011, buffer B-010, blower V-010, and YSV-023a/b.

Note that system for pristine helium is not included in Target helium cooling systems.

The buffer tank 1011.B-010 is just a passive buffer to even out pressure differences when opening valves to the path between YSV-011 and the storage volume. Refer to appendix 1 and 3.

The compressor V-010 drives the flow from system 1011 to the storage volume, B-020a/b, when system 1010 is drained. When filling 1010 from the storage volume, the accumulated pressure drives the flow to system 1010 via YSV-22a/b, YSV-13, YSV-15 and YSV-11. If more helium is needed, the filling continues using the pristine helium system. This system can also have provision for storage of potentially contaminated **nitrogen** (gas cylinders, B020b) from the flushing process. Refer to appendix 1 and 3.

#### Helium injection system, 1013

The helium buffer tank, B-030, with a pressure controller drives the flow to the upper target rotational seal. A separate pipe with a mechanical pressure control valve drives the flow to the lower seal. Refer to appendix 1 and 4.

### Major components in Target primary cooling, system 1010

Figure 1 shows the major components in the primary cooling circuit. On the right is the connection to Target Primary Cooling Pressure control, **1011**. During operation the pressure in the circuit is controlled by **system 1011**.

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Figure 1 Flow diagram primary cooling circuit, connected systems in blue.

### Helium circulator

A helium circulator unit drives the flow and a flow controller monitors and controls the helium flow. A mass flow of 3.0 kg/s is needed to remove the total maximum heating power of up to 3.0 MW at planned temperatures of the helium inlet and outlet from target wheel. The preferred machine type is a turbo type with magnetic bearings and the electric motor integrated in the pressurized housing.

Preferred configuration is two circulators in parallel.

### Heat exchangers

The heat from the target circuit to the target intermediate water cooling system is removed in three steps to support the ESS goals for energy recovery. Heat exchangers have a robust design to secure a strong separation between primary and secondary side.

Heat exchanger #1, W001 removes approximately 1.6 MW at maximum power and uses inlet water not lower than 55°C, gives outlet water at 100-110°C and outlet helium at 100-130°C, see figure 2 – 4. As shown in figures 1 - 4 this exchanger is connected for co-current flow, the reason for this is that the water outlet temperature can be kept at a higher level at low heat loads compared to a counter-current flow configuration.

A controller keeps the helium outlet at a stable temperature by manipulating the cooling water flow in system “Target Intermediate Water Cooling System”.

Heat exchanger #2, W002 before the circulator removes approximately 1.4 MW at maximum power, uses inlet water at 35 or 55°C, gives outlet water at 105°C (see figure 2) at maximum heat load. At 50% of the heat load the outlet water can be kept above 95°C (see figure 3). A controller keeps the helium outlet at a stable temperature approximately 40-60°C for inlet to the compressor by manipulating the cooling water flow. At maximum heat load the helium outlet temperature shall be kept at 45-55°C.

Heat exchanger #3, W003 uses inlet water at 35°C, outlet water at 60-70°C. A controller keeps the helium outlet at a stable temperature for inlet to the target wheel approximately 40°C, by manipulating the cooling flow. At e.g. 10% of the heat load this heat exchanger can be turned off, see figure 4.

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Figure 2 Heat exchanger diagrams at maximum 3 MW cooling power

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Figure 3 Heat exchanger diagrams at 1.5 MW cooling power

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Figure 4 Heat exchanger diagrams at 0.3 MW cooling power

Also refer to section “Process Control Loops” and appendix 1.

### Flow sensor

Either an ultra-sonic flow sensor or Corioli’s mass flow sensor is used to measure the flow in the cooling circuit. Since a Corioli’s device often has additional output signals for both temperature and density, an abnormal shift in density due to e.g. leakage of water into the helium flow, can be detected. Furthermore, the same principle can be used to detect leakage of helium into the water side. For more details refer to PDR “Target Intermediate Water Cooling System”.

### Other sensors

A number of industrial standard temperature and pressure sensors are placed at several locations in the systems to enable monitoring and process control functions, refer to P&ID appendix 2.

### Filters

Refer to section “Maintenance and handling solutions”

### Shut off valves

The circuit is connected to the target shaft housing via valves on both inlet and outlet pipe; 1010:YSV-01 and 1010:YSV-02. The valves are remotely operated and are used to isolate the target wheel volume from the circuit volume during maintenance. The valves can also be replaced by pipe connections enabling circuit tests without the target wheel involved. Refer to P&ID appendix 2.

### Relief valves/rupture discs

A rupture disc and a pressure relief valve is installed in series on the circuit pipe after the circulator unit. The valve outlet is connected to the Offgas system, 1140. The reason not only a relief valve can be used is that they don’t fulfill the maximum leakage requirement. The reason the rupture disc alone is not enough is that the relief flow is limited to keep the capacity of the Offgas system at a reasonable level. With this configuration we can allow a high flow if needed at the same time as the flow will decrease as soon as the over pressure is reduced.

### Major components in system 1011

**Gas cylinders for potentially contaminated helium, 1011:B020a, -b**

Standard gas cylinder units connected to the Offgas system 1140 via a rupture disc and relief valve. Also connected to the Offgas system via a shut off valve for controlled draining.

**Buffer tank, 1011:B010**

The tank is a gas tank of X m3 volume.. [motivation by Mathieu!]. The tank has a connection to compressor P11 and a rupture disc and relief valve.

**Compressor, 1011:P011 (motor drive 1011:SC-011)**

The compressor drives the flow from the target primary cooling loop to the gas cylinders for storage, both during normal operation to adjust to lower pressure in system 1010 and when draining.

Also refer to appendix 1 and 3.

### Major components in system 1013

Refer to appendix 1 and 4.

## Layout and piping Target helium cooling systems

The figure below is from the ESS 3D model, showing an overview of the target helium cooling system objects and pipes locations in the target building. Tag numbers, i.e. Object/instance id’s are shown for all major objects; serial numbers starting with 0=1010, 1 or 2=1011 and 3=1013.

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Figure 5 Target helium cooling systems layout in the target building. All objects within this systems are green. UPDATED PICTURE SHOWING TUBE HX AND MORE CORRECT FILTER UNITS IS NEEDED!

Also refer to ESS 3D model part assemblies and appendix 1 an overview that includes all target helium cooling systems, Target Helium Purification, Monolith Helium Purification, Monolith Atmosphere and Monolith Atmosphere Pressure.

Each sub system consists of a number of major objects/instances according to the tables in the following sections. Pipe parts has separate serial numbers that can be used in isometric pipe drawings, e.g. “1010-L001”.

### Major objects in system 1010

The object id numbering starts at the highest pressure point, i.e. the outlet from blowers and follows the flow direction.

|  |  |  |  |
| --- | --- | --- | --- |
| **Object id** | **Part** | **Length (m)** | **Volume (m3)** |
| V001a, V001b | BLOWERS |  | 4,00 |
| L001 | pipe DN200: 90° bends 2 pieces | 7 | 0,3 |
| L002 | pipe DN200: 90° bends 3 pieces | 18 | 0,7 |
| W03 | Heat exchanger #3 |  | 1,57 |
| L003 | pipe DN200: 45° bends 2 pieces | 3 | 0,1 |
| L004 | reducer DN200 - DN450 |  | 0,01 |
| F00a-g | Carbon filter incl. manifold |  | 7,20 |
| F01a-d | Particle filter #1 incl. manifold |  | 1,98 |
| L005 | reducer DN200 - DN450 |  | 0,01 |
| L006 | pipe DN200 | 8 | 0,3 |
| V001 | Inlet valve target valve |  | 0,01 |
| wheel | TARGET WHEEL AND SHAFT |  | 1,50 |
| V002 | Outlet valve target valve |  | 0,01 |
| L007 | pipe DN250: 45° bends 2 pcs, 30° bend 1 pcs | 11 | 0,6 |
| L008 | reducer DN250 - DN450 |  | 0,01 |
| F002a-f | Particle filter #2 incl. manifold |  | 1,98 |
| L009 | reducer DN250 - DN450 |  | 0,01 |
| L010 | pipe DN250: 30° bend 1 piece | 15 | 0,8 |
| W001 | Heat exchanger #1 |  | 0,79 |
| W002 | Heat exchanger #2 |  | 1,57 |
| L012 | pipe DN250: 90° bends 2 pieces | 4 | 0,2 |
| L013 | connection piping blowers inlet | 4 | 0,2 |
| L014 | connection piping 20mm; He purification |  |  |
| L015 | connection piping DN50; 1011 | 32 | 0,1 |
|  |  | ***Total volume*** | ***23,9*** |

Table 2 System 1010 main objects with lengths and volumes

### Major objects in system 1011

|  |  |  |  |
| --- | --- | --- | --- |
| **Object id** | **Part** | **Length (m)** | **Volume (m3)** |
| L111, L112 | Pipe DN100 | 23 | 1,23 |
| L101, L102… | Pipe DN50 | 18 | 0,05 |
| L121, L122… | Pipe DN25 | 28 | 0,02 |
| V-010 | COMPRESSOR |  | 0,10 |
| B-010 | BUFFER TANK |  | 1,01 |
| L201, L202… | Pipe DN50 | 26 | 0,07 |
| B-020a , -b | GAS CYLINDERS |  | 1,00 |
|  |  | ***Total volume*** | ***2,4*** |

Table 3 System 1011 main objects with lengths and volumes

### Major objects in system 1013

|  |  |  |  |
| --- | --- | --- | --- |
| **Object id** | **Part** | **Length (m)** | **Volume (m3)** |
| L401.. | Pipe DN15 |  | 0,02 |
| L421.. | Pipe DN50 |  | 0,03 |
| B-030 | BUFFER TANK |  | 0,05 |
|  |  | ***Total volume*** | ***0,1*** |

Table 6 System 1013 main objects with lengths and volumes

## Radiation protection and shielding

### Particles content in the helium

The particulates concentration in the loop helium is less than 2 ppm by weight, sizes around 300 nm. The particles consists of mainly tungsten, tungsten oxides, steel or iron oxides.

Rationale:

* + - * 1. Particles is **released from the target** at a rate of 1.9 mg/h in average during operation (10g [10] /5400h). The majority >99% (10g eroded and 0.05g emitted) of the total weight of particles are about 10 µm - 100 µm in size, i.e. **eroded** from the tungsten rods (0 - 5 pcs/s). The coarse filters in the loop will keep the concentration of larger particles very close to zero, this is possible since the whole helium volume is filtered 0.1 times per second(3kg/s flow / 30 kg total weight of He) or 6 times each minute through mesh 5 µm.
        2. The tungsten wheel is **emitting spallation atoms** that get carried away by the helium cooling stream. Within the time it takes the atoms to get to the cooler areas in the loop, they will have a chance to collide with surfaces of the loop or collide with other atoms. Since the thermal stability of particles less than ≈300nm in size is low at elevated temperatures >200 °C as is the case here, these particulates tend to agglomerate to larger units or react with surfaces they collide with.
        3. A **HEPA filter** that captures particles of 300 nm with 99.97% efficiency at each passage, has an even greater efficiency against larger AND smaller sizes since small particles often lack sufficient mass to penetrate the media. So our current estimate is that we will capture 99.97% of all particles at each passage. A flow of 2 g/s helium gas will pass the HEPA filters, thus the whole volume will be filtered 1 time in 4 hours (3600\*0.002 kg HEPA flow/30 kg total weight of He = 0.24). Any particulates not captured in the loop filters is expected to be captured by the HEPA filters.
        4. Based on the assumptions b and c above the **concentration of smallest particulates in the loop is calculated** vs. production time. The concentration reaches a steady state after less than one day of production at maximum proton beam power. The whole volume has been HEPA-filtered 5-6 times. Steady state amount is approximately 50mg, thus the concentration is constantly around 0.4 ppm (0.012 g / 30000 g helium in the loop)

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*Figure 2. Expected development of amount of particles from start vs log scaled time*

The figure above shows free particulates in the loop (blue) and amount particles captured in loop filters (red). As expected, eroded larger particles are captured to 100% in the coarse loop filters, thus the 10 g released during 5400h is captured. The concentration of smallest particulates in the loop reaches a steady state after less than a day.

### Radiation

Expected radiation levels inside the circulator has low impact on material. Three sources of radiation is present in the loop;

1) gas and free smallest particulates(Bq/m3)

2) dust layer (Bq/m2); the dust layer can be seen as evenly spread and/or concentrated to a few hot-spots

3) particulates in loop filters (Bq) or (Bq/filter)

Gas: The total radiation level in the loop (except loop filters) is ≈**125 GBq/m3** helium gas at 10bar(g) after one year of operation.

*Rationale: The dose in the loop gas comes from smallest particulates (with a concentration of 1.7ppm, see item d in section 2.3.1 above), single atoms and free molecules, i.e. 3.2E+12Bq [6], value[1010.4-24.2], according to the dose calculation. The system volume is 25 m3.*

Dust layer: A conservative estimation regarding dust layer forming inside pipes and components in the loop is that the layer consists of 10 % accumulation of all smallest particulates during one year. The resulting average radiation is **0.4 GBq/m2** inside surface. Estimated dust layer thickness is XXX.

*Rationale: 50GBq / 150m2; The system total pipe length is ≈90m and inner diameter of ≈0.3m gives ≈85m2 + components area of 65m2 (except the filter media area)*

Expected radiation in the **loop filters is 3100 GBq** after one year of operation including the material from possible released dust layer.

*Rationale: Particles and dust from mainly the tungsten in the target wheel will be radioactive. 100% of all larger particles > 5µm are captured in the loop filters(see item a in section 3.2 above) thus the resulting dose comes from the ≈10g [10] eroded spallation material accumulated during one year and decayed from the moment it was captured according to dose calculations.*

*According to the TDR preliminary estimate, the total amount of particles and dust formed during 5000h of neutron production is assumed to be 3.5kg and forming a dust layer \*. However 10g/5400h [10] is used since it is the latest estimate.*

*(****\*****) TDR chapter 10 page 580 section “Radioactive waste in fluid cooling systems – preliminary estimates”; 0.07% of the total tungsten mass, 5000kg is becoming dust/particles per year, i.e. during 5000h of operation. TDR chapter 10, table 10.9 page 580; The total radiation level from collected dust during one year of operation is 500+400+30+20+7=957 MBq/g dust, 957 MBq/g x 3500g = 3.4 TBq / year. TDR section 10.4.1 page 580. Comparison: Total area of inside 333m2. Estimated dust layer thickness 0.1mm and dust density 3kg/m3 gives a dust layer weight of 100g. 3.4TBq from 3.5kg/year gives 97GBq from 100g.*

### Functions related to protection safety barriers

The target primary cooling circuit is designed to confine all activated particles and gaseous compounds except leakage, i.e. barriers are basically the pipes and the heat exchanger plates.

### Functions related to containment of radioactive inventory

***Intermediate water circuit***

To avoid contamination of CF water/equipment, the intermediate water circuit is separated from the helium circuit by the heat exchanger stainless steel walls. However tritium will diffuse through the metal barriers from the helium side to the water side. Based on expected tritium flux through a thin metal layer [9] the resulting radiation in the intermediate water circuits will be approximately 4E+11 Bq/m3 after one year of full production. This value is seemed as far too high to be accepted, however the requirements of maximum levels in the intermediate water circuits must be decided before we can decide if e.g. double walled pipes are required in the heat exchangers. Thicker metal barrier, e.g. 3 mm does not lower the diffusion enough.

***Target primary cooling circuit***

The radioactivity level of the helium inside the cooling circuit is constantly monitored, probably by instruments belonging to TSS. If the level of radioactivity is outside maximum limit or an abnormal leakage is detected, either an off-normal event or a signal/sensor fault is the reason. The preliminary hazard analysis [5] states what action(s) is needed in this case. Examples of actions:

* Immediate order to shut down the proton beam by TSS
* Continue cooling at maximum helium flow rate and maximum cooling water flow on all heat exchangers for a limited time period

***Leakage of helium from all target cooling systems***

Requirement 1010-102 defines the maximum leakage of helium from all target helium cooling systems. Blowers and compressor axis sealing are assumed to be leak-free using either membrane-piston, liquid axis sealing or magnetic coupling. Valve axis sealing are also assumed to be leak-free using metal bellows.

The leakage requirement is based on the value stated in the TDR page 226, as a comparison a calculation based on two different valve supplier leakage data gives a total leakage for all flange joints of 16 g/24h:

The system has 8 large objects with flange joints >=DN150 and approximately 30 objects with flange joints < DN150. For total leakage calculations, 20 large objects with DN250 joints used since supplier data for DN250 is received.

Input data from valve supplier KSB: 0.001 mbar.l/s of air at 11bar test pressure difference for one flange DN100 with best possible packing material. A bellow seal flange for the axis seal has same leakage, thus the leakage for a big object is assumed to be 0.005 mbar.l/s. This value corresponds to **0.0375 mbar.l/s** for helium (0.005 x 7.5\*).

Input data from valve supplier Fagerberg: 0.00094 mbar.l/s of air at 1 bar test pressure difference for a complete valve DN250 with 2 flange joints and welded bellow sealing and best possible packing material. This value corresponds to **0.072 mbar.l/s** for helium at 9 bar test pressure difference (0.00001 x 7.5 x 10\*\*).

According to both suppliers, 1 mbar.l/s equals 0.00017 g/s, thus one object leaks 0.00001 g/s using the average of the input data sources (0.00017 x (0.0375+0.072)/2) and the total system leakage equals 16g/24h (0.00001 x 20 x 3600 x 24).

(\*) The leak ratio between air and helium is based on the molar weight ratio, i.e. assumed that small helium atoms leaks 7.5 times more than larger N2 and O2 molecules through very narrow gaps. He is 4g/mole and air gas mix is 30g/mole, 30/4=7.5.

(\*\*) If a leakage test is performed at 1 bar pressure difference, we assume 10 times more leakage at 9 bar pressure difference. KSB used 11 bar and we made no pressure compensation for this case.

### Functions related to protection of safety barriers

The target helium cooling systems are all closed fluid systems designed to confine all activated particles and gaseous contaminants, i.e. barriers are basically the tanks and pipes. Highest levels of contamination will be in the target primary cooling circuit, mechanically protected from damage since they are stably mounted in thick concrete walls.

## Over-pressure protection

The helium cooling loop and all buffer tanks are protected from over-pressure by relief valves and rupture discs connected to the offgas system 1140 to keep potentially contaminated gas enclosed in case of exceeded maximum pressure.

## Maintenance and handling solutions

### General

All of the major objects listed in section “Layout Target helium cooling systems” needs maintenance and/or needs to be inspected. Most of the components can be handled as in ordinary industrial applications at its ordinary locations after the potentially contaminated helium is either replaced by dry air, purified helium or pristine helium. Personnel protection has to be adapted depending on the activation level of parts to be replaced/repaired/inspected.

### Gas draining

The purpose of draining is to prepare for repair- and maintenance work, to minimize He consumption, minimize contamination release in the atmosphere and reduce airborne contamination in the utility room during maintenance. At the end of this phase, the system shall be filled with N2 or dry air at normal atmosphere pressure before opening it. The filter units must not be exposed to moisture in any form during a longer period, e.g. the water content in normal air will be absorbed inside the filter media and released during refill/run.

The system will be designed to allow several sequences of discharging to, and re-filling from, **system 1011,** which may be needed to reach an acceptable contamination level before opening the Target helium cooling system for hands-on maintenance. The gas cylinder units in 1011 is for both helium and nitrogen, which to use depends on the actual case.

The primary airborne contaminant that will be released into the utility room when the loop is opened is expected to be tritium. Depending on the efficiency of the flushing procedure, appropriate personnel protective equipment (e.g. self-contained breathing system or local ventilation hoods) may be required in order to enter the utility room when the loop is open to air.

All sub-systems do not need to be drained each time, options:

* Only the primary cooling circuit in **1010** is drained (to gas cylinders via the compressor in **1011**)
* The primary cooling circuit in **1010**, the tanks and pipes in **1011** and the **Target shaft and wheel** is drained (to **1011** via the compressor in 1011)

Systems **1011 and 1013** can also be drained/flushed individually and independently via service valves and a service vacuum pump/compressor/dry air/gas cylinders.



Table 7 Proposed steps for draining from He to an acceptable content of N2, O2 and He

The helium purity is assumed to be 99.999%.

Evacuation, general: The pressure control of the circuit in **1010** is used and the gas is sent to 1011 via V-011 and the compressor in system 1011.

Evacuations step 1, 3 and 5: The whole volume is stored in system **1011**. In step 1, gas cylinders for potentially contaminatedHelium are used. In steps 3 & 5 gas cylinders for potentially contaminated Nitrogen are used.

Fillings: In steps 2, 4 and 6 Pristine Helium system with nitrogen gas cylinder units connected, valve 1011:V12b, or separate gas cylinders with nitrogen and a pressure limiting valve of 1MPa is connected to a service valve in system **1010**.

NOTE. Since a compressor normally cannot give a high flow at very low inlet pressures, an evacuation pressure of 10kPa is proposed to avoid very long time periods to reach e.g. <1kPa. Further investigations regarding optimum evacuation pressure vs. evacuation times will be needed.

### Gas filling

To fill the system/systems, several sequences of discharging to **1011** and re-filling from **Pristine helium** system or separate gas cylinder volume in **1011** is needed to reach to an acceptable purity level. At the final stage the correct amount of helium shall be filled, i.e. a pressure set point based on current temperature.

Systems **1011** and **1013** can also be filled individually via service valves and a service vacuum pump/compressor.



Table 8 Proposed steps for filling helium to an acceptable content of N2, O2 and He

Filling, general: The pressure control for the circuit **1010** is used, i.e. system **1011**. The flow goes from system pristine helium 1011:V-012 or from gas cylinders B20a or -b 1011:V-013 via valve 1011:V-015 and valve 1011:V-011.

Evacuation step 1 and 3: The whole volume is sent to the Offgas system via system **1140**.

Evacuation step 5: The whole volume is stored in system **1011**. Gas cylinders for potentially contaminated Helium is used.

Filling steps 2, 4 and 6: Pristine Helium system is used (or system **1011**, gas cylinder unit for potentially contaminated Helium with acceptable purity level).

### Hands on / repair

During hands on / repair a system is constantly flushed with surrounding air via the evacuation system for gases, e.g. a local exhaust is connected to the pipes at suitable locations\*. The goal is to organize the air flow from the Utility rooms into the opening of the circuit to reduce airborne contamination for the workers. In case of significant tritium contamination in the circuit, the air velocity required to avoid retro diffusion is higher (1.5 m/s) than for other species.

(\*)This air flow from the Utility rooms ultimately exhausted via the monitored stack sets a minimum flow requirement on the HVAC system. This flow rate should be defined in an ICD-R document between Target cooling and HVAC.

### Floor/ceiling hatches

The building has floor/ceiling hatches to enable installation/replacement of the complete blower units, compressor units and filter units, which are the only parts that needs to be handled using the overhead crane accessing the large openings shown in the figure below. “OPENING 1” for filter units (F-001, F-002) and “OPENING 2” is used for the compressor units (V001a, -b). Final dimensions and locations may differ from the ones proposed in this document.

Also refer to the complete building model.

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Figure 6 Roof hatches

### Filters, general

Particles contamination of the helium circuit is foreseen and the basic idea is;

* All filters are placed in a protected area of red zone, left triangular room in the figure above.
* F002: Largest particles is collected just before the inlet to the target using a set of particle filters, based on the assumption that largest particles has the highest probability to get released from the circulator. Proposed screen openings 100 μm.
* F001: Particles of many different sizes are released from the tungsten and probably from other surfaces; the largest and medium particles are collected downstream of the target using a set of particle filters. Proposed screen openings 5 μm, figure 7 shows the resulting efficiency for helium passages up to 5 times/minute through the filter.
* Helium purification: Smallest Particles are collected in a HEPA filter with a bleed flow of 1-2g/s from the main loop. Figure 7 shows the resulting efficiency for one passage through the filter. As seen, the overlap between the 2 types of filters allow only smallest particulates between 200 and 400nm to stay in the loop at a low concentration, refer to section 2.3.1.

Note that this filter is not a part of Target helium cooling systems but belongs to “Helium purification, system 1015”

* All filters are constantly monitored regarding pressure drop. Filters are emptied or filter media replaced during periods when the system is not operating.
* A further analysis of contamination levels, type of dust/particle material, expected amount and size distribution of particles may be needed before final filtering requirements and design can be decided.

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Figure 7 approximate capture efficiency for the HEPA filter, and the particle filter in the Loop

### Filter media handling

The particle filter units must be emptied on regular basis and cannot be emptied during operation, thus the filters are sized to hold at least for several months of normal operation and the basic principle is to empty filters/replace filter media during planned outages. The pressure drop over the filters is monitored and if a high pressure drop is detected the circuit may have to be shut off to examine the cause.

In the figure below the planned location of the particle filter units (F-001), and the filter units for particles at the outlet from target (F-002) is shown together with reserved space for maintenance handling, shown as transparent boxes in the figure below. Carbon filters are filled from top with removed blind flanges.

Remote handling to empty and restore filter units must be planned since e.g. a situation with abnormal radioactivity in a filter may not allow manual handling. Even if the direct radiation level is known and low enough for manual handling a situation with too high radiation level cannot be ignored.

Details regarding filter handling and maintenance and also possible remote handling systems will be defined together with chosen filter supplier.

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Figure 7 One possible layout for the 1010 filters. The oil capture filter (F-000) is most probably not needed since an oil free circulator is planned. W003 will in this case be located in the rectangular room instead. UPDATE FIGURE ACCORDING TO Mathieu’s proposal

# MODES OF OPERATION

## **ESS operation modes**

ESS operational modes are: Start, Production, Studies and Maintenance, [2].

Maintenance: The Accelerator is “off”. All the necessary checks on systems, including control systems are performed prior to switching to “Restart” mode.

Start: During Restart, the Accelerator is “ON” to produce a proton beam suitable for Studies mode or to reach the nominal operating power in preparation for Production mode. The proton beam is sent initially to the beam dump, with proton beam powers up to the operational limit of the beam dump, and then to the target. The Target Station is constantly in a position to receive the proton beam.

Production: The Accelerator is “ON” and the proton beam is on Target. Neutron beams are delivered to instruments.

Studies on Target: The Accelerator is “ON”. The beam is sent to the Target.

Studies on Dump: The Accelerator is “ON”. The beam is sent to the beam dump.

## **Target Station operation modes**

The Target Station modes are derived from ESS operational modes: Start, Production, Studies on Target, Studies on dump and Maintenance, as defined in the Cross Functional Working Group on Operations.

## Target cooling systems operation modes

Target helium cooling system operation modes related to ESS and the Target station operation modes according to the table below;



Table 9 relations between ESS and Target helium cooling systems modes of operation

a: ESS requests Start and Target cooling enters Start and confirms OPERATION before ESS can enter Start, Production or Studies on Target

b: Target cooling must be in Operation mode, or in FAULT mode (e) during limited time periods

c: ESS confirms Maintenance mode before Target cooling can leave Operation mode

d: Target cooling can be in any of these modes if ESS s in mode Maintenance or Studies on Dump

e: Target cooling can stay in FAULT for a limited time period before ESS is affected

f: If Target cooling cannot return to Operation from FAULT, ESS is forced to Maintenance mode

g: If Target cooling is in OFF NORMAL SITUATION, ESS must be in Maintenance.

Note that this behavior is also described as requirements, refer to ESSM-101. Also refer to section “System Mode transitions / coordination unit logic”. Under main section “PROCESS CONTROL SYSTEM”

## Normal operation mode, general

*A normal condition* is when none of the process values are outside normal limits, i.e. not exceeding warning high limit (H) or below warning low limit (L), green in fig 3.

An anticipated operational occurrence is any event that affects the system performance but is mitigated or corrected before any process value goes outside critical limits, i.e. not exceeding HH or below LL process value limits. It is an operational process deviating from normal operation which is expected to occur during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety or lead to accident conditions.

*Exception handling* is normally included in control system functions to handle signal faults, object fault, power supply fault etc. This means that if a fault in a single object occurs, it can be handled by e.g. manual interaction to keep the overall system performance within acceptable conditions, i.e. if a critical process value is between H and HH or between L and LL (yellow in the figure below) for a limited time period.

Note that an exception handling also can be initiated directly by a manual decision, e.g. if an object is malfunctioning without any impact on process values, it may be necessary to restart the object or disconnect during corrective action.



Figure 8 process value limits

More information about all normal operation modes for target helium cooling systems is found under figure 9 below.

## Abnormal system operation

*An off normal event* is any event that affects the system performance and cannot be corrected before at least one critical process value goes outside normal limits, i.e. exceeding HH or below LL (red in the figure above). In other words an off-normal situation is when conditions are outside the normal conditions design limits for the system, thus outside normal expected technical performance limits. Off-normal events include incidents (restart is possible with repairs or specific check on the system) and accidents (restart is not possible or possible with replacement of systems).

Note that off normal events can also be faults that prevent the system from performing its function, such as a breaker trip taking a pump off line without any values yet reached outside limits. Off-normal events may invoke the MPS to take action in order to protect equipment, or TSS to take action in order to protect workers or the public.

Furthermore an off normal event can also be initiated directly by a manual decision, e.g. if any deviation or malfunction is expected to lead to a severe event.

Future Design Basis Accident (DBA) analyses may influence the design, and may require the implementation of one or more safety classified systems in order to keep the release of radioactive material within authorized limits (GSO).

## Abnormal Target Station operation

In case other systems within the target station is in an abnormal operation, target helium cooling systems may be affected depending on TSS and MPS system detail design. E.g. if an increased level of radiation is detected, maximum cooling power may be ordered.

# Process control system

## Processing units; PLC’s

A local industrial controller includes all automation programs for all Target helium cooling systems. The local controller hosts all control unit control blocks and process controller logic.

## Coordination unit, general

The systems have a superior central logic “Coordination unit” that controls the modes of operation with the different operation parameter settings. This mode control logic sets and controls all **subsystems** within target helium cooling systems regarding modes of operation and start condition checks. This unit also handles the operational mode related communication with superior systems and the Target wheel, drive and shaft system, i.e. order and status signals. Below is described the basic logic in this module.

### System mode transitions / coordination unit logic

Since this system have mainly automated objects, the complete system modes of operation need to be managed as a part of the local control system. The figure below shows the system situations and included modes of operation, often called steps. Actions within the steps and the cause to leave a step is described in the step and transition logic below. The figure also states possible paths between modes and situations/modes.

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Figure 9 Mode logic of Target helium cooling systems

***STEPS (synchronization signals to e.g. Target wheel not included at this stage)***

S0. Off: The system is completely turned off, i.e. without power supply. This mode is also used at DECOMISSIONING and can also be used during MAINTENANCE.

S1. Stand by: The system and all included devices are off, i.e. motors are not running, valves are in safe position. None of the devices indicates fault. The head control logic for the system is inactive and no control signals goes from the system. Signals in to the system are ignored *except activation signals*, see transitions below.

S2. Start: The head control logic for the system performs a set of start activities, i.e. devices and controllers are forced to AUTO or REMOTE mode and started using *start parameters*. Alarms or information about objects that don’t perform expected action is generated and users can make corrective actions. The system leaves the START mode when all *start conditions* are fulfilled.

S3. Operation: The system is running normally, i.e. all process values are within normal value limits. Control loops active and system devices/objects are running in AUTO, REMOTE or MANUAL mode, i.e. parts of the system can be taken over by a user. During tests, maintenance and minor process value deviation corrections, single objects often has to be put in MANUAL mode for a limited time period.

S4. Stop: The head control logic for the system performs a set of stop activities, i.e. devices and controllers are forced to AUTO or REMOTE mode using *stop parameters*.

S5. Fill: The cooling circuit is filled with helium, air or nitrogen via system 1011 *using fill process values* (temperatures and pressures) in 1011 to fill the correct amount of correct gas. The controllers in system 1010 are inactive.

The cooling circuit is filled with helium; source either system “Pristine helium” or “Storage for potentially contaminated He”, or nitrogen from system “Pristine helium”. The circuit can also be filled with air via service valves.

S6. Drain: The cooling circuit is drained to a certain pressure set point, i.e. the value is sent to SWITCH-11 and used by pressure controller 1011:PIC-11. Gas is discharged using the gas cylinders in system 1011. The compressor in 1011 is capable of reaching a pressure down to 1-10kPa in the cooling circuit. When draining helium the storage tank/gas cylinders are used. When draining from clean air or clean nitrogen a connection directly to the offgas system 1140 is used.

S7. Maintenance: Before it is allowed to enter this mode all subsystems conditions for “maintenance” are fulfilled, e.g. a valve feedback signal for safe mode=true, compressor unit off. Control system modules and single objects can be put in any mode but the superior logic will not allow entering operation mode unless special conditions are fulfilled, e.g. blowers/compressors security switches off and simulated compressor flow or test mode parameters used.

Note that system TWDS can order this system to Maintenance mode.

S8. FAULT: If any type of fault has occurred this mode is entered. Depending on the type and severity of the fault, different actions are taken. E.g. process value deviations can be corrected by manual action and the system mode is manually put back to same mode as before the fault, also refer to “*Normal events*” and “Exception handling” in next section.

S9. OFF NORMAL SITUATIONS: If the fault is severe and was not possible to correct in FAULT mode the system is entering this mode. A fault signal may be sent for use by TSS and MPS.

Also refer to appendix 1 and 2

***Transitions:***

Transitions are labelled TNn with N=step number to leave, n=serial number.

A transition is a logic describing the cause to pass the transition. Following is transition condition logics for the mode Coordination unit described in words:

T01: Target helium cooling system activate signal goes true AND no control object fault

T10, T20, T30, T40, T50, T60, T80: Summary FAULT signal=true

T11: Circuit-breakers=true AND Target helium cooling system off signal goes true\*

T12: START signal goes true\*

T13: MAINTENANCE signal goes true\*

T21: Start conditions fulfilled, e.g. controller deviations within limits

T31: Target helium cooling system Stop signal = true AND system TWDS Stop signal = true

T41: Stop conditions fulfilled AND no control object fault

T51: system 1011 FILL\_READY signal goes true AND MAINTENANCE signal=true\*

T52: system 1011 FILL\_READY signal goes true AND no control object fault

T61: system 1011 DRAIN\_READY signal goes true

T71: Target cooling MAINTENANCE\_READY signal=true AND no control object fault

T72: Target cooling FILL signal = true AND (TWDS FILL signal = true OR 1010:V01 closed AND 1010:V02 closed)

T73: Target cooling DRAIN signal=true AND (TWDS DRAIN signal = true OR 1010:V01 closed AND 1010:V02 closed)

T81: Summary FAULT signal=true AND no fatal error detected

T82: Summary FAULT signal=false

T91: Summary FAULT signal=false AND current system reset signal=true AND no control object fault

(\*) signal origin is often this Coordination unit; either logic generated or manual input, but can also be another Superior system. Note that “signal goes true” means flank and “signal=true” means it needs to be true for a time period.

## Process values

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Description** | **ID** | **Eng. unit** | **Planned value** | **Comment** |
| Flow of Helium in circuit | A | kg/s | 0.3 – 3.0 |  |
| Pressure of Helium shaft target inlet | B | kPa(a) | 700 - 1000 |  |
| Pressure of Helium shaft target outlet | C | kPa(a) | 620 - 910 |  |
| Temperature helium into TARGET | D | °C | 40 – 60 |  |
| Temperature of Helium shaft outlet, in normal case almost same into heat exchanger 1 | E | °C | 220 - 240 |  |
| Temperature helium out from heat exchanger 1 | K | °C | 110-130 |  |
| Temperature helium out from heat exchanger 2 AND into compressors |  | °C | 45-65 |  |

Table 10 Process values in 1010 during OPERATION mode

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Description** | **ID** | **Eng.unit** | **Planned value** | **Comment** |
| Helium mass flow from 1010 circuit | a | g/s | 0.3 | To purification system 1015 |
| Volume of buffer tank | f | m3 | 1.0 | system 1011 |
| Maximum membrane compressor mass flow of Helium | K | g/s | 6 | System 1011. At 0.1bar inlet and 50 bar outlet |
| Pressure in buffer tank | g | kPa(a) | F + offset | System 1013 |
| Volume of buffer tank | h | m3 | 0.05 | system 1013 |
| Pressure after compressor =  maximum in the gas cylinders | H | kPa(a) | 100 -20000 | system 1011 |

Table 11 Object constants and process values, general

## Sensors and instrumentation

### Transmitters

Refer to appendix 2-4

Safety related process value sensors, switches, location and types TBD by TSS.

### Calculation blocks

* Integral sum of radiation level in system 1010 surrounding area (the alternative is a separate dosimeter instrument. Note not decided yet)
* Pressure difference over particle filter #1 1010:DIFF PD-01
* Pressure difference over particle filter #2 1010:DIFF PD-02
* Pressure difference over heat exchanger 1 1010:DIFF PD-04
* Pressure difference over heat exchanger 2 1010:DIFF PD-05
* Pressure difference over TARGET 1010:DIFF PD-06

Actuators and monitoring;

* Valve actuator 1010:YSV-01 Open/close valve, outlet from target
* Valve actuator 1010:YSV-02 Open/close valve, inlet to target
* Blowers unit control: 1010:V01-DISTR (distribution logic)
* Blowers unit monitoring system: 1010:V01-MON (monitoring systems)

## Process control loops

### Process control loops system 1010

*FLOW CONTROLLER Helium circuit*

In Remote mode the set point (SP) for flow in kg/s is proportional to the proton beam power in MW since a fixed temperature rise of helium through the system is desired for proper operation of the ESS energy recovery system. Output is the frequency value to the compressor motor rotational speed.

*TEMP. CONTROLLER Helium inlet to TARGET*

The temperature SP is 40°C. Output is the flow rate\* for the cooling water through heat exchanger #3.

*TEMP. CONTROLLER Helium inlet to BLOWER*

The temperature SP is 40 - 60°C. Output is the flow rate\* for the cooling water through heat exchanger #2.

*TEMP. CONTROLLER Water return temperature*

The temperature SP is approximately 115°C. Output is the flow rate\* for the cooling water through heat exchanger #1.

(\*) The cooling water flow control actuators are included in system “Target intermediate cooling system”.

Also refer to appendix 2.

### Process control loops system 1011

Refer to appendix 3.

### Process control loops system 1013

Refer to appendix 4.

## Summary actuators control logic in system 1010

Refer to appendix 3.



Figure 12 Example of split range logic for 2 valves as actuators

## Human-Machine Interface (HMI) design

Refer to requirements 1010-301 and 1010-302 in [3]

*Note that details regarding HMI process pictures are NOT a part of this document, rather a part of the DS phase (detail design) together with ICS since most standard process pictures are actually similar to the P&ID’s!*

# Electric power & grounding

*Refer to top level document ESS-0005109\_TD\_PN140321 where all power supply needs and* ***grounding solutions*** *are listed.*

# Documentation

## Interface with the SAR documentation

To be decided and completed together with the in-kind partner.

## Documents to be prepared for the Final Design Review

Refer to [7], section “Final Design”

## Documents to be prepared before the commissioning starts

Refer to [7]

## Documents to be prepared before ESS accelerator and target station start

Refer to [7]

# Models

## Geometrical models

Refer to Catia 3D master model and potential sub-models

## Analysis models

### Hydro-thermo-mechanical

Fluid and heat transfer simulations: DYMOLA*, Modelica TargetLibrary*;

* package *TargetCoolingSystem*
* model *TargetCoolingCircuit*

Simplified fluid and heat transfer simulation, Mode logic and Objects operation logic simulations: Refer to [4]

### Neutronic

N/A

### CFD

N/A

### Other

N/A

## System engineering models

N/A

# Safety assessment

## Radiation safety assessment

Refer to [5]

## General safety assessment (excluding radiation safety)

To be decided and completed together with the in-kind partner.

# Glossary and abbreviations

| Term | Definition |
| --- | --- |
| SIC | Safety Important Components |
| RT | Radiation transmitter |
| TT | Temperature transmitter |
| PT | Pressure transmitter |
| FT | Flow transmitter |
| TIC | Temperature controller |
| PIC | Pressure controller |
| FIC | Flow controller |
| PV | Process value, e.g. from a transmitter |
| SP | Set point to a controller |
| Q | Control signal; output from a controller |
| SC | Speed controller, i.e. frequency converter |
| PCV | Actuator for a control valve, i.e. opening angle from 0 to 100% |
| YSV | Actuator for an open/closed valve |
| PS | Pressure switch |
| TS | Temperature switch |
| TSZ | Temperature switch; safety qualified, i.e. a SIC |
| GS | Position switch, e.g. for an indication of a valve in closed position |
| GUI | Graphical User Interface |
| HMI | Human Machine interface |
| TWDS | Target Wheel, Drive & Shaft |

Note that most abbreviations above is control system and instrumentation related following standards ISO 14617-6:2002 and ISO 10628:2000. Refer to [8] for general ESS glossary and abbreviations.

# References

[1] J. Harborn, ESS-0012524 System Requirements & description Target Primary Cooling Systems

[2] ESS-0001803 Cross Functional Working Group Report – 2014-04-25

[3] J. Harborn, ESS-0019347 ICD-R Target Cooling-Process control

[4] J. Harborn, Target Helium Cooling Simulation

[5] J-E. Presteng, Hazard analysis Target and Target Helium Cooling

[6] J. Harborn, ESS-0044590 Dose calculations for system 1010

[7] J. Haines, ESS-0037005 Target Project Process for Project Phase Transition

[8] H. Björkman ESS-0000385 European spallation source glossary

[9] Y. Lee ESS-0054291 One dimensional permeation of tritium through a thin stainless steel plate

[10] Y. Lee ESS-0051742 Integrity of spallation material in the target wheel during operation and accidents

Document Revision history

| Version | Reason for revision | Date |
| --- | --- | --- |
| 1.0  2.0 | First release using the new template  Updates after PDR | 2015.11.11  2015.12.14 |
| 3.0 | Updates before CDR start | 2016.05.02 |

# APPENDECIES

Appendix 1: PFD Target helium cooling systems. Latest revision on Chess ESS-0040855.

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Appendix 2: Target primary cooling loop, 1010. Latest revision on Chess ESS-0040854.

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Appendix 3: Target primary cooling loop pressure control, 1011. Latest revision on Chess ESS-0040876.

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Appendix 4: Helium injection, 1013. Latest revision on Chess ESS-0040873.

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