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| ESS-0051820 |
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| **TECHNICAL DESCRIPTION**  Target primary cooling loop circulator |
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**EUROPEAN SPALLATION SOURCE**

**ESS AB**



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# Introduction

A circulator/blower/compressor unit is needed to create a flow in a closed circuit of pure helium. The unit is hereafter named “circulator” and can consist of one or more single machines.

The main function of the helium circuit is continuous heat removal from a warm “target” during a normal uptime period with a flow of at least 1.5 kg/s of 4 months with planned weekly short stops. The basic cooling principle is to circulate helium gas at approximately 10 bar(a) and 40°C inlet through the target and heat exchangers in a closed circuit of pure helium, see fig 1. The heat exchangers transfer the heat energy to water circuits.

The circulator electric motor control is connected to the output of a flow controller, thus the motor drive/drives needs to be speed controlled.

In fig 1 a single CIRCULATOR unit is shown but due to high reliability requirements based on 50% of normal maximum flow, more than one single circulator is needed, preferably two units.

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*Figure 1. Flow diagram for the helium cooling circuit.*

# Process values

## Normal operation

SYSTEM PRESSURE: 0.7 - 1.1 MPa (a) defined at the outlet from the **circulator**.

PRESSURE DROP: Maximum total pressure drop to overcome is 160 kPa defined at the maximum helium flow 3.0 kg/s and system pressure 1.0 MPa(a) at the outlet from the circulator, and 40°C at the inlet to the circulator/circulators.

FLOW RANGE: For process control reasons and to minimize wear of components in the circuit, the motor speed shall be stepless variable between minimum and maximum flow. E.g. for a turbo type machine, the minimum flow is approximately 50% of maximum flow since the efficiency is very low below this limit. Thus the total flow span for two turbo machines in parallel, is 0.25%-100%.

TEMPERATURES: 40-60°C at the inlet to the circulator. If the circulator can operate at exceeding 95°C it is a benefit.

## Process parameters in exception conditions

FLOW: Maximum flow is the same as for normal maximum proton beam power operation.

SYSTEM PRESSURE: Pressure rating PN16 for all components and a pressure relief system will protect all components in the circuit from pressures exceeding 1.2 MPa(a).

CIRCUIT PRESSURE DROP: The pressure drop is monitored and if exceeding a certain value the plant is shut off or will run with limited mass flow.

TEMPERATURE: If all machine protection systems fails, the temperature can reach 250°C. The circulator must withstand short periods of 250°C without getting damaged. During this period it may be ordered to shut down.

# Process conditions

## MEDIA

Helium with a purity of >99.9%

## PARTICLE CONTENT IN THE HELIUM

The particulates concentration is ≈0.40 ppm by weight, sizes ≈200nm -400 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 (10g/5400h). The majority (>99.9%; 1mg emitted/10g eroded) of the total weight of particles are about 10 µm - 100 µm in size, i.e. **eroded** from the tungsten rods. 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 1-4 g/s helium gas will pass the HEPA filters, thus the whole volume will be filtered, e.g. 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.

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*Figure 2. Approximate capture efficiency for the HEPA filter, and the particle filter in the Loop*

* + - * 1. 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 2 days 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 3. Expected development of amount of particles from start vs log scaled time*

The figure above shows free particulates in the loop (red) and amount particles captured in loop filters (blue). 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 48h.

## OIL TRACES

No oil release from the circulator is acceptable. No oil traces are expected in the helium.

## MAINTENANCE

Maintenance can be done twice a year, i.e. after each production period of 2700 h. Short inspections can be done once in two weeks.

## 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(a) after one year of operation.

*Rationale: The dose in the loop gas comes from smallest particulates (with a concentration of 0.4ppm, see item d in section 3.2 above), single atoms and free molecules, i.e. 3.2E+12Bq. 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.

*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 1100 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.*

Expected radiation levels inside the circulator has low impact on material.

# Layout

* Circulator units are planned to be placed in the dashed marked area, fig. 2.
* Free height between floor level and beams is 3.0 m. Beams height is 1.0 m.
* Pipe connections towards the target is shown as a blue line top middle, fig 2.
* The circuit cold side has a pipe dimension of DN200 or DN250 and the warm side DN250 or DN300.

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*Fig 2 Equipment location in the target station building*

# Drive axis sealing

A common drive configuration is an electric motor, mechanical coupling and an axis to drive the rotational parts and a single axis sealing, left fig 3. Since a very low leak rate, or no leakage to the outside [h] is required an axis sealing with a sealing flow is needed, right fig 3.

**Gas sealing:** The seal flow [a] may come from a buffer tank at a pressure slightly higher than the pressure at the inside of the circulator. [a] will divide into [b] entering the helium circuit and [c]. Flow [e] (c+d) enters a helium buffer tank at a pressure slightly lower than the outside. This low pressure creates a small air inlet flow [d].

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*Fig 3 drive axis sealing principles. The axis is represented by the black dashed line.*

**Liquid sealing:** Similar to the gas sealing but the gas flows [d] and [h] will be zero, thus a liquid sealing is more beneficial than a gas sealing.

**Seal less:** However a *sealless solution* is preferable, either a magnetic coupling that are common in liquid pump applications, left fig 4, or with the motor-axis unit enclosed in the machine/circuit, i.e. submerged, right fig. 4 The torque in the magnetic coupling cannot exceed a certain limit, thus a submerged gear box may be needed.

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*Fig 4 axis seal less principles. The axis is represented by the black dashed line.*

# Requirements

|  | **Description** | **value** | **Eng. unit** | **Rationale / note** |
| --- | --- | --- | --- | --- |
| 1000-201 | Cooling media | Helium | N/A |  |
| 1000-202 | Cooling media maximum normal flow | 3.0 | kg/s | At normal operational pressure inlet 840kPa and inlet temperature 40°C |
| 1000-204 | Maximum operational pressure | 11 | Bar(a) | Based on engineering judgment by the target division, basic functions, cost, safety |
| 1000-209 | Concentration of particulates | (up to 1) | ppm | Cooling media maximum concentration of particulates >= 5 µm size is 0.00.  Cooling media maximum concentration of metallic particulates <= 400nm size is maximum 1 ppm by weight |
| 1010-150 | Design pressure | 1300 | kPa | Design pressure of the primary cooling circuit. Normal operational pressure 10-11 bar(a) |
| 1010-001 | Reliability | Normal industrial standard | N/A | The target helium cooling system components shall have a reliability according to normal industry standard |
| 1010-157 | Mechanical Quality class according to code RCC-MRx | class 3 | N/A | The whole loop is covered by this requirement |
| 1010-158 | Minimized possible Hot-spot areas |  |  | Potential radiological hot-spots in pipes shall be minimized to fulfil radiation protection and availability requirements |
| 1010-161 | Helium flow control; Flow range | 50 - 100 | *%* | Continuously controlled flow within at least this span for the total installed circulator function. Thus e.g. 25-100% fulfils this requirement, while 60-100% does not. |
| 1010.V001-1 | Maximum leakage of helium to surrounding rooms | 0.1 | g/h | Related to req. 1010-101 for all target helium cooling systems 1g/h |
| 1010.V001-2 | The blower shall create a pressure difference up to | 160 | kPa | Defined as difference between inlet and outlet of the circulator(s), 40°C at the inlet, i.e max pressure drop over the target wheel and the cooling loop at maximum flow |
| 1010.V001-3 | Machine protection | N/A | N/A | A condition monitoring system is required, preferable integrated in the manufacturer’s proposed stand-alone machine control system. Input- and output signals needs to be defined. |

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| |  | **Description** | **value** | **Eng. unit** | **Rationale / note** | | --- | --- | --- | --- | --- | | 1010.V001-4 | Maximum release of lubrication | 0 | g/h |  | | 1010.V001-5 | Design temperature | 100 | C | Normal operational temperature is 40-60°C. | | 1010.V001-6 | Maximum helium seal flow | TBD | *g/s* | flow [a] according to fig.3 | | 1010.V001-7 | Maximum leakage into circuit | TBD | *g/s* | flow [b] according to fig.3 | | 1010.V001-8 | Maximum leakage towards low pressure | TBD | *g/s* | flow [c] according to fig.3 | | 1010.V001-9 | Maximum AIR leakage in | TBD | *g/s* | flow [d] according to fig.3 |   *Table 2 summary of requirements*  If gas sealed axis the requirements related to this, e.g. 1010.V001-6, -7, -8, -9 is to be defined together with the supplier since a standard product is preferred to keep the over-all project and technical risk low. For a non-standard solution the development time, cost and risks are higher than for a standard solution. |