ESS Cryogenic System Process Design

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View of the Southwest in 2025

- Max IV – a national research facility, under construction, opens up in 2016
- Science City – a new part of town

Malmö (309 000)
Copenhagen (1 200 000)
Lund (113 500)
Cryogenics at ESS

Coldbox building

Compressor building
Outline

1) System Overview
2) Accelerator Load and its Cryoplant
3) Target Moderator Load and its Cryoplant
4) Helium Management and Storage
5) Reliability and Availability
6) Energy
(1) System overview
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(2.1) The Accelerator cryogenic setup
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(2.2) Cryomodule cooling at 2K

Production of 2 K helium in 2 K heat exchanger and a subsequent Joule-Thomson valve in each of the cryomodule–valve box assemblies.
(2.3) The Accelerator cryoplant dutiespec

| Type                              | Temperature range | Max. load Stage 1 | Max. load Stage 2 |
|-----------------------------------|-------------------|-------------------|-------------------|
| Static and dynamic load in CMs    | 2 K               | 1850 W            | 2230 W            |
| Recuperators and CDS load         | 2 – 4 K           | 630 W             | 830 W             |
| Thermal shields                   | 33 – 53 K         | 8 550 W           | 11 380 W          |
| Coupler cooling                   | 4.5 – 300 K       | 6.8 g/s           | 9.0 g/s           |
(2.4) The Accelerator cryogenic load

ACCP 2K heat load vs number of installed CMs

- Beam ON w/ safety factors
- Beam ON w/o safety factors
- Beam OFF w/ safety factors
- Beam OFF w/o safety factors

ACCP 2K heat load, W

Number of Cryomodules

Beam commissioning | Medium beta CM complete | High beta CM 1-11 complete | Optimus+ High beta CM complete (Stage 1) | Optimus+ High beta CM complete (Stage 2)
(2.5) The Accelerator cryoplant process

Compressor skids with
3 identical screws

300 K

VFD for SP → MP and LP → MP

115 K

Thermal shield ~43K

70 K

6 turbo expanders

53 K

3 cold turbo compressors

33 K

24 K

9 K

6 K

4.5 K Connection to 20 m³ tank

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), July 2015.
Invited presentation C1OrE-01 given at CEC-ICMC 2015, Tucson, USA, June 28 – July 2, 2015.
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(3.1) The Target Monolith

- Neutron beam extraction
- Target wheel
- Moderator and reflector plugs
- Proton beam window
- Neutron beam windows
(3.2) The Target Monolith inside

Moderator and reflector plugs

Target wheel

Proton beam window
(3.3) Moderator-Reflector system

Target wheel

Top MR plug

Bottom MR plug

Proton beam
(3.4) The Target cryogenic load

TMCP 15-20K heat load vs. beam power

- Load w/ safety factors
- Load w/o safety factors

Beam power, MW

0 1 2 3 4 5 6

TMCP heat load, kW

0 5 10 15 20 25 30 35
(3.5) The Target Moderator cryoplant process (proposed by ESS)

Helium buffers with “low” and “high” pressure region

2 screw compressor skids

300 K

90...120 K  
Turbine for HXs

60...80 K  
Intermediate “heating” of feed flow upstream turbines

23 K  
20 K  
2 expansion turbines

15K  
Multi purpose ambient heater
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(4.1) Where sits the helium

1) ACCP: Over 2000 kg in Cryomodules and distribution system

2) TMCP: Over 350 kg in Cryotransferline between helium and hydrogen box

3) TICP: About 600 kg in open loop system for neutron instruments
(4.2) Helium storage

1) Pure medium pressure tanks
   - 19 x 67 m³
   - Theoretically up to 3.5 tons
   - Pressure restrictions for TICP and TMCP
   - Effectively ~ 3 tons

2) Liquid helium storage tank
   - 20 m³
   - When filled to 80% another 2 tons
   - Used as “2nd fill” and help in transient modes
     (cool-down, pump-down)

3) Impure high pressure tanks or bundles
   - 12 m³
   - Nearly 300 kg
   - Used as buffer in recovery system
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(5.1) Definitions

Kinetic Experiments

A reliability of at least 90% should be provided for the duration of the measurement. The measurement will be considered failed when the beam power is reduced to less than 50% of the scheduled power for more than 1/10th of the measurement length.

Flux Integrated Experiments

For the duration of the experiment at least 90% of the experiments should have at least 85% of beam availability and on average more than 80% of the scheduled beam power. The beam will be considered unavailable when its power is less than 50% of its scheduled power for more than one minute.

At least 90% of the users should receive a neutron beam that will allow them to execute the full scope of their experiments
(5.2) Anticipated failure rates

| Downtime duration       | Accelerator | Target          | ICS            | SI              |
|-------------------------|-------------|-----------------|----------------|-----------------|
| 3 hours - 8 hours       | 15 per year | 1 every 2 years | 1 every 2 years| 1 every 2 years |
| 8 hours - 1 day         | 5.5 per year| 1 every 2 years | 1 every 5 years| 1 every 3 years |
| 1 day - 3 days          | 2.3 per year| 1 every 2 years | -              | 1 every 10 years|
| 3 days - 10 days        | 1 every 5 years| 1 every 20 years| -              | -               |
| more than 10 days       | 3 every 40 years| 1 every 40 years| -              | -               |
(5.3) Backup compressor system
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(6.1) Energy high level goals

**Renewable:**
All energy from new, dedicated renewable production at a stable and competitive cost

**Responsible:**
Reduce energy use to under 270 GWh per year

**Recyclable:**
Completely replace cooling towers with a cooling system based on heat recycling.
(6.2) Heat recovery

- No elevated oil or helium temperatures out of compressor suppliers specs
- More efficient heat exchangers, especially oil coolers
- Dedicated cooling water circuit for cryoplant
- Cooling function has priority over heat recovery
(6.3) Energy efficiency and sustainability

- Focus on process design and optimization
- Good match between plant and load by staging, dual equipment, VFDs for low pressure machines
- Focus on turn-down scenarios
- Incentive OPEX approach in ACCP and TMCP tender evaluation and contracts as well
- As much as possible helium recovery
Conclusions

- The conceptual design of the cryogenic system at ESS is finished
- One cryoplant is ordered, one out for quote, one to 90% specified → ESS is rolling
- High level goals in terms of energy efficiency and sustainability can be met
- Continued work on meeting reliability and availability requirements