The ESS Cryogenics System


February 2016
Outline

- Introduction to ESS
- Applications of Cryogenics at ESS
  - Accelerator Cryoplant
  - Cryogenic Distribution System
  - Target Moderator Cryoplant
  - Test and Instruments Cryoplant
- He Recovery and Storage
- Energy Recovery
- Summary
The goal of ESS is to provide a spallation based neutron source significantly more powerful than existing sources: 30 - 100 times brighter than ILL and 5 times more powerful than SNS.

This facility will enable neutron based research in a wide range of fields including: materials science, condensed matter and biomedical studies.
ESS Overview

5 Times more powerful than SNS
30 - 100 times brighter than ILL

Linear proton accelerator (600 m)

Target station

Neutron science systems
The 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
- ESS – an international research facility

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

- Cooling for the cryomodules (2 K, 4.5 – 300 K and 40 K)
- Cooling for the Target supercritical H₂ Moderator (16.5 K)
- Liquid Helium and Liquid Nitrogen for the Neutron Instruments
- Cooling for the cryomodule test stand (2 K, 4.5 – 300 K and 40 K)
- This is accomplished via 3 separate cryoplants
Bulk of acceleration is carried out via 3 classes of SRF cavities: Spoke, Medium ($\beta = 0.67$) Beta Elliptical and High ($\beta = 0.86$) Beta Elliptical

No superconducting magnets in the accelerator. There are some in the instruments

Cavities operate at 2 K with a 40 – 50 K thermal shield

Inner power coupler cooling from 4.2 K to 300 K

Accelerator lattice permits an 14 additional cryomodules to compensate for lower than expected cryomodule gradients (Stage 2)
## ESS Linac

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (MeV)</th>
<th>No. of Modules</th>
<th>No. of Cavities</th>
<th>$\beta$ g</th>
<th>Temp (K)</th>
<th>Cryo Length (m)</th>
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<td>0.075</td>
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<tr>
<td>Spoke</td>
<td>220</td>
<td>13</td>
<td>2 (2S) × 13</td>
<td>0.5 $\beta_{\text{opt}}$</td>
<td>~2</td>
<td>4.14</td>
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<td>Medium $\beta$</td>
<td>570</td>
<td>9</td>
<td>4 (6C) × 9</td>
<td>0.67</td>
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<td>High $\beta$</td>
<td>2000</td>
<td>21</td>
<td>4 (5C) × 21</td>
<td>0.86</td>
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<td>8.28</td>
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<td>0</td>
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<td>~300</td>
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**Notes:**
- $\beta_{\text{opt}}$ is the optimal $\beta$ for the Medium $\beta$ section.
- Cryo Length (m) values are approximate and may vary slightly.

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Elliptical Cavities & Cryomodule

- Similar to CEBAF/SNS cryomodule concept with 4 cavities per cryomodule
- Common design for medium (6 cells) and high beta (5 cells) cavities
Spoke cavity string and cryomodule package

Diameter 1350 mm

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2900 mm

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ESS Accelerator Cryoplant (ACCP)

• Provides cryogenic cooling to Cryomodules
  • 13 Spoke and 30 Elliptical (Stage 1)
  • Sized to allow an additional 14 Elliptical Cryomodules for design contingency (Stage 2) – will take roughly 1 year to implement if required

• Allows for number of operating modes
• Connected to the cryomodules via a cryogenic distribution system
• High availability and turn down capability are important features
• Compressor heat is absorbed by Lund District Heating System (unique ESS feature)
# Accelerator Cryoplant (ACCP) Capacities

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<tr>
<th>Operation modes</th>
<th>2 K Load, W</th>
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<th>4.5 K Load</th>
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<td>Isothermal</td>
<td>Non-</td>
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<td>Liquefaction,</td>
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<td>Nominal</td>
<td>1852</td>
<td>627</td>
<td>2478</td>
<td>6.8</td>
<td>8551</td>
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<tr>
<td>Turndown</td>
<td>845</td>
<td>627</td>
<td>1472</td>
<td>6.8</td>
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<td>Standby</td>
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<td>1472</td>
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<td>TS Standby</td>
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<tr>
<td>Maximal Liquefaction</td>
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|                          | Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank
| Stage 2 2023-...         |             |          |          |            |          |          |          |
| Nominal                  | 2226        | 824      | 3050     | 9.0        | 11380    |          |          |
| Turndown                 | 1166        | 824      | 1990     | 9.0        | 11380    |          |          |
| Standby                  |             |          | 1990     | 9.0        | 11380    |          |          |
| TS Standby               |             |          |          |            |          |          | 11380    |
| Maximal Liquefaction     |             |          |          |            |          |          | 11380    |
|                          | Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank
ACCP – Contract Award to Linde Kryotechnik AG in December 2014

Compressor System:
Three identical machines for SP→MP, LP→MP and MP→HP compression, hot standby compressor is under discussion

System uses 3 cold compressors + 1 warm sub-atmospheric compressor for 2 K cooling

One Coldbox comprising 6 expansion turbines, 3 cold compressors, in-built acceptance test equipment

Kick Off Meeting was held on May 8
PDR-1: Sept 2 -3

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Note:
1) No LN$_2$ Precooling
2) Last stage of subatmospheric pumping is warm
Cryogenic Distribution System

- Allows warm up and cool down of one or more cryomodules w/o affecting remaining cryomodules
- Connection between distribution line & cryomodule is done via fixed connections
- Separate isolation vacuums in the distribution lines and cryomodules
- Operating modes defined
- Conceptual design complete
- Provided as an In Kind Contribution by IPN Orsay (France) and WrUT (Poland)
- Cryogenic Distribution System must be complete and installed by December of 2017
Cryogenic System of the Optimus Linac

- Cryogenic Distribution Line (310 m) comprising 43 valve boxes
- Linac Cryoplant
- Cryogenic Transfer Line (75 m)
- Splitting box
- 21 High Beta Cryomodules (174 m)
- 9 Medium Beta Cryomodules (75 m)
- 13 Spoke Cryomodules (54 m)
- Superconducting section of the Optimus Linac (303 m)
- Auxiliary process lines
- Endbox

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Valve box – vacuum jacket

- Jumper connection vacuum jacket with a lateral compensators (vertical: DN350 horizontal: DN450)
- Interconnection sleeve at the interface to the cryomodule
- Cryoline interconnection sleeve with axial compensator (DN600)
- Valve box vacuum jacket
- Bottom plate (demountable)
- Cryoline vacuum jacket (DN550)
- Valve box supports
- Cryoline support

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CDS – In kind Agreements with IPNO and WrUT

PDR was held with WrUT on May 20
Heat Load at 15 K increased from 20 kW to 30.3 kW due to moderator re-design (higher brightness, more neutrons)

Impact on space requirements, utilities, interference with other cryoplants and budget (minimal impact on schedule) – technical solutions are currently worked out

Tight collaboration with FZ Jülich, TU-Dresden and Hans Quack

Proposals received in January 2016

Plant will likely be ordered in Q1 2016
Target Moderator Cryoplant
Test & Instruments Cryoplant (TICP)

- Provides cooling for Cryomodule Test Stand
- During Science Operations, also provides LHe for sample environments and Science Instruments
- TICP provides for CM testing: 76 W at 2 K, 422 W at 40 K and 0.2 g/s of liquid helium
- Sub-atmospheric operation via warm vacuum pumps
- During Science Operations, the TICP shall provide more than 7500 liters of LHe per month
- A recovery system is being built to recover all He gas from instrument halls and return it for purification and liquefaction.
- Vendor selected (Air Liquide). Kick off meeting this week
Helium Recovery and Storage

- The ESS goal is to recovery, purify and reuse as much He as possible
- ACCP and TICP cryoplants will share a common gas system while TMCP has separate storage that can be cross connected
- The system will include a separate cryogenic purifier
- Systems will be provided by IKC or separate contracts
- Expected He Storage Capacities:
  - LHe
    - 20 m³ (Includes storage for second fill of linac)
    - 5 m³ (Backup for Instruments He)
  - GHe (20 Bar)
    - 1000 m³ - sufficient to hold all the linac inventory
  - GHe (200 Bar)
    - 12 m³ - Instrument He storage
Plant arrangement in the Cold Box Building

ACCP

5 m³ LHe Tank

TICP

20 m³ LHe Tank

TMCP
Plant arrangement in the Compressor Building

Compressor Hall for TICP and TMCP

Compressor Hall for ACCP

Compressor Building Foundation Work on Site Started in August 2015

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During nominal operating mode in Stage 2 – a total of 2.48 MW are deposited into District Heating from the ACCP.
WP11 Master Schedule

**MASTER SCHEDULE - WP11 CRYOGENICS**

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**MILESTONES**

- **SYSTEM DESIGN AND PROCUREMENT**
- **INSTALLATION AND COMMISSIONING**

**WARM PIPING**
- CALL FOR TENDERS PUBLISHED
- INSTALLATION STARTS
- WARM PIPING READY

**ACCELERATOR CRYOPLANT**
- CALL FOR TENDERS PUBLISHED
- INSTALLATION STARTS
- ACCELERATOR CRYOPLANT READY

**INSTRUMENTS AND TESTS CRYOPLANT**
- CALL FOR TENDERS PUBLISHED
- INSTALLATION STARTS
- INSTRUMENTS AND TESTS CRYOPLANT READY

**TARGET CRYOPLANT**
- CALL FOR TENDERS PUBLISHED
- INSTALLATION STARTS
- TARGET CRYOPLANT READY

**CRYOGENIC DISTRIBUTION LINE**
- TECHNICAL SPECIFICATION PUBLISHED FOR IN-KIND AGREEMENT
- INSTALLATION STARTS
- CRYOGENIC DISTRIBUTION LINE READY

**FIRST PROTONS ON TARGET 570 MeV**
- 13-AUG-2019

**2 GeV PROTONS AVAILABLE**
- 23-SEP-2022

**Data Extracted by P6 Planning - May 2015**

**Prepared by P. Arnold & L. Lari**

**Checked by J. Weisend**

**Approved by M. Lindroos**

February 2015  J.G. Weisend II
Comments on Operations & Tunnels

Access

• Linac will remain cold for more than 2 years at a time. – Thermal cycling of the complete system will be infrequent. Thermal cycling of single cryomodule will occur more often but should still be somewhat rare.

• Regular access to the tunnel with the linac cold is required

• It is expected that all beam line gate valves will be closed prior to tunnel access

• We estimate that it only takes 2 – 3 hours for the entire linac to go from LHe at 4.2 K to LHe at 2 K

• However, going from 5 K without liquid to 4.2 K LHe has to be done carefully to avoid flashing, pressure spikes and sudden venting. This could take many hours.
Summary

• Cryogenics will play a major role in ESS and affects the accelerator, target and instruments projects

• Work is well underway
  • A very skilled team has been assembled
  • Conceptual designs and technical specifications are complete
  • Required buildings and utilities have been defined and are under construction
  • Accelerator Cryoplant order has been placed (Kick off meeting was held on May 8)
  • Test & Instruments Cryoplant order has been placed (Kick off meeting this week)
  • PDR1 and PDR2 for the ACCP has been held.
  • PDR for the WrUT portion of the CDS was held on May 2015
  • Additional cryoplant orders will be placed in early 2016