Cryogenics at The European Spallation Source

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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

• Opportunities for In-Kind Contributions

• Summary
The goal of ESS is to provide a spallation based neutron source significantly more powerful than existing sources: 30 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.
Why Neutrons?
Neutrons and x-rays are complementary - neutrons...

..see magnetic atoms
..see inside materials
..see light atoms
..see atoms move
..see isotopes

Courtesy of Ian S. Anderson

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ESS - Bridging the neutron gap

ESS Overview

5 Times more powerful than SNS
30 times brighter than ILL
A European Science Project

Sweden, Denmark and Norway:
50% of construction and
20% of operations costs

European partners pay the rest
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)
# ESS Linac

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>No. of Modules</th>
<th>No. of Cavities</th>
<th>βg</th>
<th>Temp (K)</th>
<th>Cryo Length (m)</th>
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</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td>0.075</td>
<td>1</td>
<td>0</td>
<td>–</td>
<td>~300</td>
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<tr>
<td><strong>LEBT</strong></td>
<td>0.075</td>
<td>–</td>
<td>0</td>
<td>–</td>
<td>~300</td>
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<tr>
<td><strong>RFQ</strong></td>
<td>3.6</td>
<td>1</td>
<td>1</td>
<td>–</td>
<td>~300</td>
</tr>
<tr>
<td><strong>MEBT</strong></td>
<td>3.6</td>
<td>–</td>
<td>3</td>
<td>–</td>
<td>~300</td>
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<tr>
<td><strong>DTL</strong></td>
<td>90</td>
<td>5</td>
<td>5</td>
<td>–</td>
<td>~300</td>
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<tr>
<td><strong>Spoke</strong></td>
<td>220</td>
<td>13</td>
<td>2 (2S) \times 13</td>
<td>0.5 \beta_{opt}</td>
<td>~2</td>
</tr>
<tr>
<td><strong>Medium β</strong></td>
<td>570</td>
<td>9</td>
<td>4 (6C) \times 9</td>
<td>0.67</td>
<td>~2</td>
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<tr>
<td><strong>High β</strong></td>
<td>2000</td>
<td>21</td>
<td>4 (5C) \times 21</td>
<td>0.86</td>
<td>~2</td>
</tr>
<tr>
<td><strong>HEBT</strong></td>
<td>2000</td>
<td>–</td>
<td>0</td>
<td>–</td>
<td>~300</td>
</tr>
</tbody>
</table>
Prototyping the ESS accelerator

Sebastien Bousson

Pierre Bosland

CERN

Roger Barlow

Ibon Bustinduy

Santo Gammino

Søren Pape Møller

Roger Ruber

Anders J Johansson

The National Center for Nuclear Research, Swierk

ESS 2014-03-04
Applications of Cryogenics at ESS

- Cooling for the cryomodules (2 K, 4.5 – 300 K and 40 K)
- Cooling for the Target supercritical $\text{H}_2$ 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
Accelerator Cryogenics

- 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)
Elliptical Cryomodule Components

- 5-cell elliptical cavity
- Cold tuning System
- Space frame
- Power coupler
- Ti Helium tank

Diameter 1200 mm

6600 mm

Figure 4.130: Helium vessel with hanging rod
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TTC@DESY - C. Darve - 24/03/14
Spoke cavity string and cryomodule package

Diameter 1350 mm

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2900 mm
## Cryomodule Heat Load Distribution

<table>
<thead>
<tr>
<th>Static</th>
<th>Dynamic</th>
<th>Total</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others</td>
<td>Valves</td>
<td>Coupler</td>
<td>Total</td>
</tr>
<tr>
<td>3.3</td>
<td>0.2</td>
<td>3.5</td>
<td>7</td>
</tr>
<tr>
<td>1.5</td>
<td>5.0</td>
<td>6.5</td>
<td>0.092</td>
</tr>
<tr>
<td>1 Spoke</td>
<td></td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>6.3</td>
<td>0.2</td>
<td>6.8</td>
<td>13.3</td>
</tr>
<tr>
<td>3.3</td>
<td>20</td>
<td>23.3</td>
<td>0.092</td>
</tr>
<tr>
<td>1 MB</td>
<td></td>
<td></td>
<td>46.5</td>
</tr>
<tr>
<td>6.3</td>
<td>0.2</td>
<td>6.8</td>
<td>13.3</td>
</tr>
<tr>
<td>3.3</td>
<td>24.4</td>
<td>27.7</td>
<td>0.092</td>
</tr>
<tr>
<td>1 HB</td>
<td></td>
<td></td>
<td>46.5</td>
</tr>
</tbody>
</table>
Connection between Elliptical Cavity CM and Cryogenic Distribution Line

He II produced at each CM
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)
• 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)
## ACCP Capacities

### Operation modes

<table>
<thead>
<tr>
<th></th>
<th>2 K Load, W</th>
<th>4.5 K Load</th>
<th>40-50 K, W</th>
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<tbody>
<tr>
<td></td>
<td>Isothermal</td>
<td>Non-</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>isothermal</td>
<td></td>
</tr>
<tr>
<td>Nominal</td>
<td>1860</td>
<td>627</td>
<td>2478</td>
</tr>
<tr>
<td>Turndown</td>
<td>845</td>
<td>627</td>
<td>1472</td>
</tr>
<tr>
<td>Standby</td>
<td></td>
<td></td>
<td>1472</td>
</tr>
<tr>
<td>TS Standby</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal Liquefaction</td>
<td>Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal</td>
<td>2226</td>
<td>824</td>
<td>3050</td>
</tr>
<tr>
<td>Turndown</td>
<td>1166</td>
<td>824</td>
<td>1990</td>
</tr>
<tr>
<td>Standby</td>
<td></td>
<td></td>
<td>1990</td>
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<tr>
<td>TS Standby</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
ACCP Status

- Heat loads and capacities determined
- Industry studies completed
- Design choices have been made
  - No LN\textsubscript{2} precooling
  - Optimized cold compressor and turboexpander hardware for Stage 1 & Stage 2 to minimize energy consumption
- Detailed Specification and SOW complete and ITT released
- Expected placement of order in February 2015
  - Installation, LHe and GHe storage and Helium Recovery will be separate procurements
- Plant is expected to fully commissioned by June 2018
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
- Detailed design and production via IKC or commercial contract will start by Q3 2014
- 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
- 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)

Cryogenic System of the Optimus Linac

- Linac Cryoplant
- Cryogenic Transfer Line (75 m)
- Splitting box
- Auxiliary process lines
Valve box – vacuum jacket

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

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Cryogenic Distribution Line
Elliptical Cryomodules in ESS Tunnel
Target Moderator Cryoplant

• Cools the Supercritical H₂ neutron moderators that surround the target

• Provides 20 kW of cooling at 16.5 K via GHe to the He/supercritical H₂ heat exchanger
  • Moderator design is still under development and final heat load won’t be known until summer 2014
  • ESS Target Division responsible for the supercritical H₂ system

• Compressor heat is absorbed by Lund District Heating System (unique ESS feature)

• Cryoplant should be ordered in August of 2015 and fully commissioned by June of 2018
Draft Schematic of LH$_2$ Moderator Loop showing connection to the Target Cryoplant
Test and Instruments Cryoplant

- Provides cooling at 2 K, 40 K and 4.5 K liquefaction for elliptical cryomodule testing
  - 2 K operation done via warm vacuum pumps

- During ESS operations, provides up to 7500 l per month of LHe to the instruments
  - Helium is recovered, purified and reliquefied

- Sufficient LHe storage planned to allow several weeks of Science Ops in the case of cryoplant failure
Test and Instruments Cryoplant
Capacity and Status

- The plant will produce:
  - 75 W @ 2 K,
  - 422 W @ 40 K
  - 0.4 g/s at 4.5 K for coupler cooling

- A plant this size exceeds the 7500 l / month liquefaction requirement

- Cryoplant should be ordered in August 2015 and fully commissioned by July 2017
Cryomodule Test Stand Showing Connection to T&I Cryoplant

- cryo and TS control room
- cryogenic transfer line
- equipment access door
- cryomodule loading area
- test stand bunker
- 2 modulators
- 4 klystrons

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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)
    - 900 m³ - sufficient to hold all the linac inventory
  - GHe (200 Bar)
    - 12 m³ - Instrument He storage
Conceptual ESS Cold Box Room Layout

ACCP

20m3 LHe tank

TMCP

TICP

5m3 LHe tank

LHe dewar filling station
The ESS Commitment: A Sustainable Research Centre

- **Responsible**
  Energy Efficiency

- **Recyclable**
  ESS’s cooling is Lund’s heating

- **Renewable**
  Power from renewable sources
Energy Inventory ESS 2012

Total max load: 38 MW (Goal 35)
Total annual: 250 GWh

250 GWh renewable power

174 GWh re-used heat = 70% (excluding heat pumps)

49 GWh @ 20°C
34 GWh @ 40°C
91 GWh @ 90°C

Ion Source
3 MW

Accelerator incl. klystron gallery
17 MW

Cooling
8 MW

Target station
2 MW

Target cryo
3 MW

Accelerator cryogenics
4 MW

Instruments
1 MW

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Opportunities for In Kind Contributions to the ESS Cryogenic System

• There are many opportunities for IKC in the ESS Cryogenics System and we are very happy to discuss any of them.

• Possibilities include:
  
  • Cryoplants (particularly the TMCP and TICP)
  • Cryogenic Distribution System
  • He Recovery and storage
  • Assistance with installation and commissioning
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
  • Industry studies for the largest of the plants have been completed
  • Conceptual designs and technical specifications are complete or under preparation
  • Required buildings and utilities have been defined and are under detailed design
  • Sizable procurements will start in 2014 and 2015

• Significant Opportunities for IKC exist

• ESS has just received the green light to start construction