ITER Cryoplant Status
Economics of the LHe Plants

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Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization
Summary

1. ITER Cryoplant Status
   – Cryoplant Overview
   – Cryoplant Project Schedule

2. Cryoplant Specifications and Constraints

3. Economics of the LHe Plants
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Purpose of Cryogenics

- High fields magnets
- HTS current leads
- Cryogenic pumping
- Reducing of specific project cost
- Saving energy
Cryoplant Main Duties

• Basic
  – Gradual cool-down and warm-up in about one month
  – Provide and Recover Helium to Cryodistribution / Magnets / Cryopumps / Thermal Shields
    • Maintain magnets and cryopumps at nominal temperatures over a wide range of operating modes with pulsed heat loads due to nuclear heating and magnetic field variations
    • Accommodate periodic regeneration of cryopumps
  – Accommodate resistive transitions and fast discharges of the magnets and recover from them in few days
  – Enhanced mode to cool magnets at 3.7 K with an extended dwell time

• Additional
  – Ensure high flexibility and reliability
  – Low maintenance
Cryoplant System Architecture

- Main Components in the Cryoplant
  - LHe Plants – 3 x Plants //
  - 80 K helium loops - 2 x Plants in //
  - LN$_2$ Plants – 2 x Plants in // and GN$_2$ Generator and Storage
  - Recovery & Purification systems and Heaters
  - Storages – Full helium inventory in warm and cold (4.5 K and 80 K) helium tanks
Cryoplant He and $N_2$ Cooling Capacities

- **LHe Plants:** avg. 75 kW equiv. @ 4.5K in POS avg. mode
  - 87 kW in refrigeration
    - Superconducting magnet system, HTS current leads
    - Cryo-pumps with high regeneration frequency and small users
- **80K He Loops:** avg. 40 kW equivalent @ 4.5 K
  - Thermal Shields (2 x 4000 g/s in between 80K to 100K)
- **LN$_2$ Plants:** ~1300 kW @ 80 K
  - 80K He Loop, LHe Plants pre-cooling
- **GN$_2$ Generator:** ~1550 Nm$^3$/h
  - Tokamak users, Leaks, Purifier/Dryers, Air Instrument redundancy

**CERN LHC:** ~140 kW

**ITER Cryoplant:** up to 127 kW
Cryoplant Helium & Nitrogen Inventory

• Helium Storage & Inventory Management
  – Helium inventory: 27 t
  – Helium Storage
    • 5 x 400 m$^3$ of pure GHe tanks @ 300K
    • 1 x 175 m$^3$ of LHe tank
    • 2 x 360 m$^3$ of Quench Tanks (storage temperature ~80K)
    • 1 x 400 m$^3$ of impure GHe tank @ 300K
    • 7 x 120 m$^3$ of GasBags

• Nitrogen Storage & Inventory Management
  – LN$_2$ inventory: 250 t
  – GN$_2$ inventory: 4.5 t
  – Nitrogen Storage
    • 1 x 300 m$^3$ of LN$_2$ tank
    • 1 x ~100 m$^3$ of GN$_2$ tank
Cryoplant Layout – Buildings 51 and 52, Area 53

- Yellow: IO Fund (PBS 34.4H Helium Plants)
- Blue: Europe PA (3.4.P1.EU.01 – LN2 Plant and Auxiliary Systems)
- Green: India PA (3.4.P2.IN.02 – Cryolines and Warm lines & 3.4.P3.IN.01 - Cryodistribution)
## CRYOPLANT PROJECT SCHEDULE

<table>
<thead>
<tr>
<th>PBS #</th>
<th>Name</th>
<th>Resp. Procure</th>
<th>Contractor</th>
<th>1st Delivery</th>
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<tbody>
<tr>
<td>34.10</td>
<td>LN₂ Plants and Auxiliary Systems</td>
<td>F4E – Europe</td>
<td>Air Liquide Engineering</td>
<td>April 2016</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(Champigny - FR)</td>
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<tr>
<td>34.2S</td>
<td>Cryolines group Y (“simple” cryolines)</td>
<td>IN-DA - India</td>
<td>Inox India (IN)</td>
<td>Feb. 2016</td>
</tr>
<tr>
<td>34.2C</td>
<td>Cryolines Group X (“complex” cryolines)</td>
<td>IN-DA - India</td>
<td>Under Bid phase</td>
<td>March. 2017</td>
</tr>
<tr>
<td>34.2W</td>
<td>Warm lines</td>
<td>IN-DA - India</td>
<td>Under Bid phase</td>
<td>Feb. 2016</td>
</tr>
<tr>
<td>34.3Y</td>
<td>CTCB (Interconnection box)</td>
<td>IN-DA - India</td>
<td>Under Bid phase</td>
<td>Jan 2017</td>
</tr>
<tr>
<td>34.4H</td>
<td>LHe Plants</td>
<td>IO - Cadarche</td>
<td>ALAT (Sassenage-FR)</td>
<td>Dec. 2015</td>
</tr>
</tbody>
</table>

- 6 Cryogenic Contracts to manage + Interfaces (Civil work and Utilities)
- For all procurements IO is responsible for Integration and Operator
## CRYOPLANT PROJECT SCHEDULE

<table>
<thead>
<tr>
<th>PBS #</th>
<th>Interfaces</th>
<th>Ready For Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>Civil work</td>
<td>2016</td>
</tr>
<tr>
<td>63</td>
<td>Building finishing</td>
<td>2017</td>
</tr>
<tr>
<td>43</td>
<td>Electricity</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; semester 2016</td>
</tr>
<tr>
<td>26</td>
<td>Cooling water</td>
<td>End 2016</td>
</tr>
<tr>
<td>65</td>
<td>Compressed Air</td>
<td>End 2016</td>
</tr>
<tr>
<td>45 / 46</td>
<td>I&amp;C Networks</td>
<td>Mid 2016</td>
</tr>
<tr>
<td>64 / 69</td>
<td>Security, Environment monitoring</td>
<td>2017</td>
</tr>
</tbody>
</table>

- Interfaces Management and Schedule
  - Intense collaboration with interfaces
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Cryoplant Specifications and Constraints

- State-of-the-art technology adapted to large dynamic loads and parallel refrigerators operation
- High availability and reliability
  - RAMI
- Investment and personal protection
  - HAZOP
  - SIL Study
- Operation costs optimization
  - Overall process cycle and components efficiency
  - Compressors heat recovery for hot water distribution
  - Gas Nitrogen generator on site to produce and distribute GN₂
  - Liquid nitrogen pumps to regulate liquid nitrogen distribution
Cryoplant Specifications and Constraints

• Regulatory requirements
  – French Decree No. 99-1046 – Pressure Vessels
  – French Quality Order - Nuclear environment

• Codes
  – Mainly pressures vessels according to PED
    • Issues: periodic inspection and requalification, use CTP and BSEI in order to proper implement counter measures

• Standards
  – Reliability
    • E.g. Screw Compressor (ISO EN 10440-1, equivalent to API 619)
    • All rotating machineries (centrifugal compressor, pumps, etc.)
    • Heat Exchanger (TEMA and ALPEMA)
  – Standardization
    • International project
    • Minimize costly operation, maintenance and spares management
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Economics of the LHe Plants

• Economics of the ITER LHe Plants based on:
  – Contract for 3 identical LHe Plants pre-cooled with LN₂
  – Lump Sum Turn Key Contract [LSTK] ~EPCI + Commissioning
  – Excluded
    • Civil work, buildings utilities and security
    • Electricity (Main distribution board)
    • Cooling Water
    • Compressed Air

• Economics studies based on refrigeration power
Economics of the LHe Plants

- Green Formula [1997]
  \[\text{COST}[\text{M$}] = 2.6 \times (\text{Capacity}[\text{kW@4.5K}])^{0.7}\]

- CERN-LHC Formula [1999]
  \[\text{COST}[\text{1998MCHF}] = 2.2 \times (\text{Capacity}[\text{kW@4.5K}])^{0.6}\]

- Green Formula [2007]
  \[\text{COST}[\text{M$}] = 2.6 \times (\text{Capacity}[\text{kW@4.5K}])^{0.63}\]

- ITER [2014]
  \[\text{COST}[\text{M€}] = 2.6 \times (\text{Capacity}[\text{kW@4.5K}])^{0.65}\]

Coef. [2.6] not enough data to be assessed
## Economics of the LHe Plants

<table>
<thead>
<tr>
<th></th>
<th>Eq. Ref. capacity @4.5K [kW]</th>
<th>Investment cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITER LHe Plant (one Plant)</td>
<td>29</td>
<td>23.5 M€</td>
</tr>
<tr>
<td>Control Syst. (PLC &amp; PIS)</td>
<td></td>
<td>+5.0%</td>
</tr>
<tr>
<td>Machine Monitoring System (Rotating Machinery vibration, measurement and analysis)</td>
<td></td>
<td>+1.5%</td>
</tr>
<tr>
<td>Heat Recovery System – HRS</td>
<td></td>
<td>+6.5%</td>
</tr>
<tr>
<td>Test Tools (fixed for 1 or 3 plants)</td>
<td></td>
<td>+9.0%</td>
</tr>
<tr>
<td>Capital Spares – Compressors/Turbines/Oil pumps (fixed for 1 or 3 plants)</td>
<td></td>
<td>+2.0%</td>
</tr>
</tbody>
</table>

- Confirmation of Green and CERN economics up to 29kW
- Proper tool for pricing at conceptual design phase
Economics of the LHe Plants

- **Heat Recovery System [HRS]**
  - Heat recovered from compressor oil
  - Heat transferred to “Hot Water” for ITER buildings heating syst. (electrical boiler as back-up)
  - Studies and Design based on ITER scenario
    - 16 months operation (+2 for CD and WU)
    - Heaters “ON” 6 months/year

- Average estimated power recovered ~8 MW for 12MW installed
- Payback after Tokamak commissioning phase
- Highly recommended to study power recovering on large refrigeration plant

![Diagram of HRS system](image)
Thanks for Your Attention

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Particular thanks to:
• The cryogenic section colleagues
• The Domestic Agencies (F4E and ITER India)

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