ITER Cryoplant Infrastructures

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Abstract. The ITER Tokamak requires an average 75 kW of refrigeration power at 4.5 K and 600 kW of refrigeration Power at 80 K to maintain the nominal operation condition of the ITER thermal shields, superconducting magnets and cryopumps. This is produced by the ITER Cryoplant, a complex cluster of refrigeration systems including in particular three identical Liquid Helium Plants and two identical Liquid Nitrogen Plants. Beyond the equipment directly part of the Cryoplant, colossal infrastructures are required. These infrastructures account for a large part of the Cryoplants lay-out, budget and engineering efforts. It is ITER Organization responsibility to ensure that all infrastructures are adequately sized and designed to interface with the Cryoplant.

This proceeding presents the overall architecture of the cryoplant. It provides order of magnitude related to the cryoplant building and utilities: electricity, cooling water, heating, ventilation and air conditioning (HVAC).

1. Introduction
The purpose of the ITER cryoplant is to provide cooling power at 80 K, 50 K and 4.5 K for the operation of its thermal shields, current leads, superconducting magnets and cryopumps of the tokamak. The cryoplant will have the capacity to cool-down and maintain at 4.5 K over 10,000 tons of equipment. It will have an average combined refrigeration power of 75 kW of at 4.5 K and over 600 kW at 80 K. To produce this amount of refrigeration power, the cryoplant relies on a complex cluster of systems. All systems are regrouped in a single area, the cryoplant building. This proceeding provides a simplified overview of the cryoplant architecture, and orders of magnitude related to the buildings and utilities required to operate the plant.
3. The cryoplant architecture
The cryoplant is composed of two combined systems: the nitrogen and the helium systems.

3.1. The nitrogen system
The nitrogen system provides the gaseous nitrogen (\(\text{GN}_2\)) and liquid nitrogen (\(\text{LN}_2\)) required for the cryoplant operation. The nitrogen, which could be activated by neutrons, will not be used as a cooling fluid inside the tokamak, but will only serve as a utility for the tokamak cryoplant and auxiliary system.

The nitrogen system (refer to figure 1) mostly includes a gaseous nitrogen plant (\(\text{GN}_2\) plant) and two \(\text{LN}_2\) refrigeration plants (\(\text{LN}_2\) plants) plus liquid and gaseous storages.

3.1.1. \(\text{GN}_2\) plant: the \(\text{GN}_2\) plant consists in an air centrifugal compressor, a purification system and a \(\text{LN}_2\) cooled cryogenic air distillation column. It produces gaseous nitrogen for the cryoplant. It has a capacity of about 50 tons / day and is connected to the \(\text{GN}_2\) Network. 50% of the production is dedicated to external users and 50% (25 tons/day) to compensate the nitrogen wasted by the cryoplant: mostly shaft leaks from nitrogen compressors, perlite cold boxes purge and liquid and gaseous nitrogen used respectively for purifiers and dryers cooling and regeneration.

3.1.2. \(\text{LN}_2\) Plants: the two \(\text{LN}_2\) Plants consist each of a nitrogen centrifugal compressor and a vertical perlite cold box with one turbine and one turbo-booster. They have each an average capacity of 550 kW at 80 K. They supply liquid nitrogen to a 300 m\(^3\) \(\text{LN}_2\) storage, which is then fed to the \(\text{LN}_2\) network. The liquid nitrogen is used for helium precooling (90 %) and other users such as an external purifier. The \(\text{LN}_2\) storage can also be connected to the \(\text{GN}_2\) network through specific vaporizers and be used as a backup in case of \(\text{GN}_2\) plant non-availability. A 125 m\(^3\) \(\text{GN}_2\) storage is connected to the two \(\text{LN}_2\) plants to allow maintaining the cycle pressure during heat load variations.

Table 1. Nitrogen storage capacity in storage mode conditions

| \(\text{N}_2\) Storages | Quantity | Volume | Pressure | Temp. | Density | Max Mass |
|------------------------|----------|--------|----------|-------|---------|----------|
| \(\text{GN}_2\) Storage | 1x        | 125 m\(^3\) | 40 bara  | 300 K | 3.6 kg/m\(^3\) | 5 ton    |
| \(\text{LN}_2\) Storage | 1x        | 300 m\(^3\) | 5 bara   | 94 K  | 720 kg/m\(^3\) | 205 ton  |
| TOTAL                  |           | 210 m\(^3\) |          |       |         | 210 ton  |
3.3. The helium system

The helium system (refer to figure 2) provides the refrigeration power to the tokamak for the thermal shields (80 K), the cryopumps (80 K and 4.5 K), the current leads (50 K) and the superconducting magnets (4.5 K). It fully relies on LN2 for pre-cooling down to 80 K. It mainly consists of: two 80 K Loops, three Liquid Helium Plants (LHe Plants), a Cryoplant Termination Cold Box (CTCB), large gaseous and liquid storages and a helium recovery system.

![Figure 2. ITER Helium System](image)

3.3.1. 80 K Loops: The two 80 K Loops consist each in a helium centrifugal compressor and a vertical perlite cold box equipped with LN2 coolers. They circulate 80 K gaseous helium through the tokamak thermal shields and cryopumps. The heat loads are simply removed by using LN2.

3.3.2. LHe Plants: The three LHe Plants consist each in six screw compressors and a horizontal vacuum insulated cold box equipped with a LN2 pre-cooler and four cryogenic turbines. It produces the 50 K helium to be circulated in current leads and the 4.5 K helium to support the tokamak superconducting magnets and cryopumps.

3.3.3. CTCB: The cryoplant termination cold box (CTCB), allows combining respectively the cooling power of the two 80 K Loops and of the three LHe Plants. It is then connected to two multiple cryolines, one dedicated to the thermal shields, the superconducting magnets and their current leads and one to the cryopumps. The cryolines are routed through a 130 m bridge to the tokamak building.

3.3.4. Helium Storages: The helium storages allow storing the entire helium inventory, when the tokamak is shut down. They include six 400 m³ gaseous storage, one 190 m³ liquid storage and two 360 m³ quench tanks, which can be used as 80 K storages up to 18 bar. The gaseous storages are sized to handle the tokamak loads variation, the quench tanks to accommodate the magnets helium inventory in the case of a quench and, the liquid helium tank to store the remaining fraction of the total helium inventory in the event of a tokamak shut down.

| He Storages  | Qty | Volume | Pressure | Temp. | Density | Mass | Ratio |
|--------------|-----|--------|----------|-------|---------|------|-------|
| GHe Storages | 6x  | 400 m³ | 20 Bara  | 300 K | 3.6 kg/m³ | 9 ton | 25 %  |
| Quench Tanks | 2x  | 360 m³ | 18 Bara  | 85 K  | 10 kg/m³ | 8 ton | 20 %  |
| LHe Storage  | 1x  | 190 m³ | 1.3 Bara | 4.5 K | 118 kg/m³ | 21 ton | 55 %  |
| TOTAL        | -   | -      | -        | -     | -       | -    | 38 ton|

*Table 2. Helium storage capacity in storage mode conditions*
3.3.5. Helium Recovery System: The helium recovery system (not described in figure 2), allows recovering helium vented by the process during normal operation (80 K shaft seal leakage, adsorber regeneration, etc...) or in case of abnormal event (thermal expansion in case of unforeseen shutdown). It consists of an atmospheric heater, seven 115 m$^3$ gasbags, four 25 g/s recovery compressors and a 32 g/s helium purifier.

4. The cryoplant building

The entire cryoplant is regrouped in the cryoplant building, which is divided in three zones:
- B51: regroups all cryoplant compressors.
- B52: regroups the three LHe plants cold boxes and the cryoplant termination cold box. (CTCB)
- A53: regroups the 80 K Loops, LN$_2$ Plants and GN$_2$ Plant vertical cold boxes and the storages.

Figure 3. The Cryoplant Building: External view

The cryoplant building (B51 and B52), with a total area of 5 800 m$^2$, and a height of 19 m will house the most sensitive pieces of equipment of the cryoplant: the compressors, the vacuum insulated LHe Plants cold boxes, and the cold termination cold box (CTCB).

Figure 4. The Cryoplant Building: Internal view

The cryoplant building B52 is then connected to the Tokamak building via a bridge, which support the various process lines. The bridge has a section of 3.6 m x 3.6 m, it is 130 m long at an elevation of 13 m. The main process cryoline has an outer vacuum jacket of 1 m in diameter (DN 1000) and five internal process pipes (helium: 4.5 K supply/return, 50 K supply, and 80 K supply/return).
An annex building is attached to B52. It will accommodate PLCs, analysers and storage for small spare parts. While the cryoplant will be controlled from the centralized ITER control room, this building will be used as a local control room during early commissioning and maintenance of the cryoplant.

Table 3. cryoplant building main dimensions

| BUILDING                  | Area    | Length | Width | Elevation |
|---------------------------|---------|--------|-------|-----------|
| - B51: Compressors       | 2 100 m²| 75 m   | 46 m  | 19 m      |
| - B52: LHe Plants Cold Boxes | 3 500 m²| 45 m   | 46 m  | 19 m      |
| - B52: Annex             | 200 m²  | 25 m   | 8 m   | 5.5 m     |
| B51/B52: Total           | 5 800 m²| 120 m  | 46 m  | 19 m      |

EXTERNAL AREA

A53: External Area 2 300 m² 160 m 14 m /

LAND MARKS

- Storage: LN₂ / / / 26 m
- Storage: GHe / / / 24 m
- Cold box: LN₂ Plants / / / 17 m
- Cold box: GHe Plant / / / 16 m
- Cold box: 80 K Loops / / / 14 m
- Storage: Quench Tank / 34 m 4.6 m /
- Storage: LHe Tank / 26 m 3.8 m /

For maintenance, the buildings are equipped with overhead cranes, with a hook at 9 m. The compressor building (B51) is equipped with two 15 ton overhead cranes, which allows removing the largest pieces of equipment. The cold box building (B52) is equipped with two 5 ton overhead cranes mostly designed for routine maintenance.

5. The cryoplant utilities

5.1. Electrical Power

The cryoplant is powered by a total of 23 compressors and total 39 MW of installed power. The compressors are connected to the 6.6 kV electrical network, which is produced onsite from the 400 kV switch yard.

Table 3. 6.6 kV Installed Electrical Power

| INSTALLED POWER 6.6kV | Qty | Power | TOTAL | Ratio |
|-----------------------|-----|-------|-------|-------|
| - GN₂ Plant: Centrifugal Compressors: Air | 1   | 0.7 MW | 0.7 MW | 2 %   |
| - LN₂ Plants: Centrifugal Compressors: N₂ | 2   | 4.7 MW | 9.4 MW | 24 %  |
| - 80 K Loop: Centrifugal Compressors: He | 2   | 0.8 MW | 1.6 MW | 4 %   |
| - LHe Plants: Screw Compressors: He LP Stage | 12  | 1.0 MW | 12 MW  | 70 %  |
| - He HP Stage         | 6   | 2.5 MW | 15 MW  |       |
| TOTAL                 | 23  | -     | 39 MW  | -     |

At full power the cryoplant will consume up to 90% of the installed power, i.e. about 35 MW.

5.2. Cooling Water

The 35 MW of consumed power will be evacuated using cooling water supplied at 8 bara and 15–31°C. The cryoplant requires about 3 000 m³/h of cooling water, with a pressure head of 2 bar and a temperature rise of 10°C.
5.4. HVAC
The cryoplant building will be air-conditioned, and internal conditions will remain between 5 and 40°C throughout the year.

5.4.1. Air Conditioning: Out of the 35 MW consumed power, less than 2 MW are dissipated to the building. This low ratio (~5 %) is obtained by insulating all warm process pipes and by using cooling water to cool all equipment including the electrical motors. The building is equipped with seven Air Handling Units (AHU) located on the roof, which maintain the temperature below 40°C at equipment level throughout the year. They use chilled water to inject 33 000 m³/h of fresh air.

5.4.2. Heating: The heat, produced by the compression system of the Cryoplant can be turned into an opportunity. A 12 MW heat recovery system, which consists of twelve 1 MW plate and shell heat exchangers, is installed on the LHe Plants compressor station oil circuits. The heat recovery system is connected to the ITER hot water network, and will provide sufficient power to heat all ITER buildings during the coldest months of the year. The heat recovery system can be turned on and off without affecting the cryoplant operation or availability.

6. Conclusion
The ITER cryoplant consists of a complex cluster of nitrogen and helium system. The size and the quantity of equipment involved (compressors, cold boxes, storages...) require colossal infrastructures. The cryoplant building will be the size of a soccer field, the height of a six-story building. The power consumption (35 MW) will be equivalent to the electrical need of a European city of 50 000 habitants. The required cooling water flow rate (3 000 m³/h) will amount to one Olympic swimming pool per hour. For the design, installation and commissioning of the cryoplant, beyond cryogenics, solid expertise in project management, electrical, utilities and civil engineering are essential.

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

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