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ITER cryoplant status and economics of the LHe plants

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Abstract

The ITER cryoplant is composed of helium and nitrogen refrigerators and generator combined with 80 K helium loop plants and external purification systems. Storage and recovery of the helium inventory is provided in warm and cold (80 K and 4.5 K) helium tanks. The conceptual design of the ITER cryoplant has been completed, the technical requirements defined for industrial procurement and contracts signed with industry. Each contract covers the design, manufacturing, installation and commissioning. Design is under finalization and manufacturing has started. First deliveries are scheduled by end of 2015. The various cryoplant systems are designed based on recognized codes and international standards to meet the availability, the reliability and the time between maintenance imposed by the long-term uninterrupted operation of the ITER Tokamak. In addition, ITER has to consider the constraint of a nuclear installation. ITER Organization (IO) is responsible for the liquid helium (LHe) Plants contract signed end of 2012 with industry. It is composed of three LHe Plants, working in parallel and able to provide a total average cooling capacity of 75 kW at 4.5 K. Based on concept designed developed with industries and the procurement phase, ITER has accumulated data to broaden the scaling laws for costing such systems. After describing the status of ITER cryoplant part of the cryogenic system, we shall present the economics of the ITER LHe Plants based on key design requirements, choice and challenges of this ITER Organization procurement.

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1. Introduction

The purpose of the ITER cryogenic system is to provide the required operational conditions for the magnet system, vacuum system and small users like diagnostics. The magnet system consists of superconducting magnets coils, structure and current leads, and is supported by 80 K thermal shields system. The vacuum system consists of cryo-pumps for torus and cryostat, cryo-pumps for Neutral Beam Injection (NBI) and Pellet Injection System (PIS). The users of the cryogenic system require helium cryogen at temperature levels of 4.5 K, 50 K and 80 K and nitrogen at either 80 K or ambient temperature. The cryogenic system needs to satisfy all operational modes of the users at various stages of plasma operation. To satisfy the operational modes and resulting requirements, the ITER cryogenic system has been divided according to the ITER Geographical Breakdown System (GBS) in two different locations namely the cryoplant System (in cryoplant buildings and cryo-bridge) and the cryo-distribution system (in the Tokamak). In this proceeding, we will focus on the cryoplant System.

2. ITER Cryoplant Status

2.1. Cryoplant Overview

The ITER cryogenic system, see Fig. 1, has to guarantee stable operation conditions for the magnets and cryo-sorption panels over a wide range of plasma scenarios ranging from short (~100 seconds) plasma pulses with enlarged fusion power (700 MW) to long plasma burn times (3000 seconds) at reduced fusion power of 365 MW, whereas the baseline is 500 MW for 400 s.

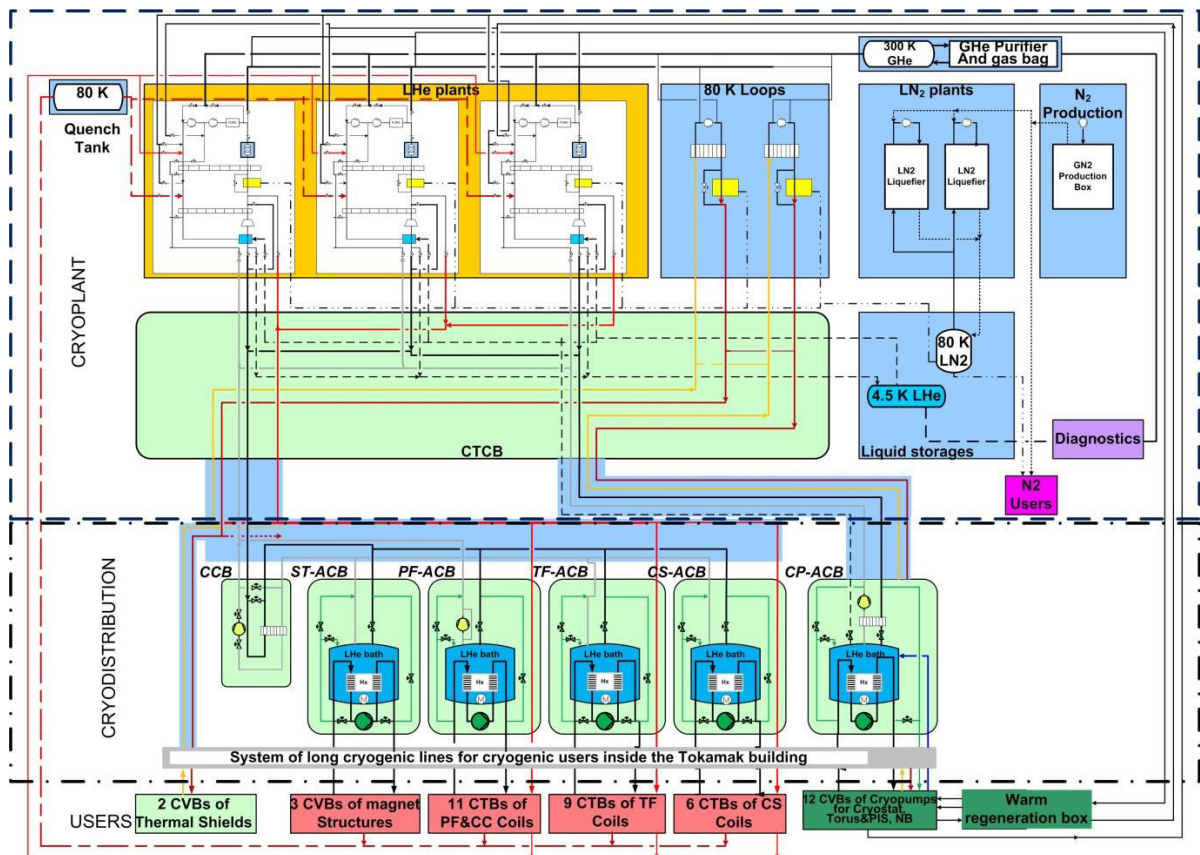


Fig. 1. Cryogenics system global architecture.

As one of the world's largest cryogenic infrastructure, see Fig. 2 and Fig. 3, the ITER cryoplant will provide an average cooling power of 75 kW at 4.5 K during plasma experiments and up to 87 kW in pure refrigeration mode through three LHe plants. For the thermal shield of the Tokamak and cryo-distribution, two 80 K helium loops with an average capacity of 40 kW equivalents at 4.5 K (2×4 kg/s loops in between 80 K and 100 K) will be installed.

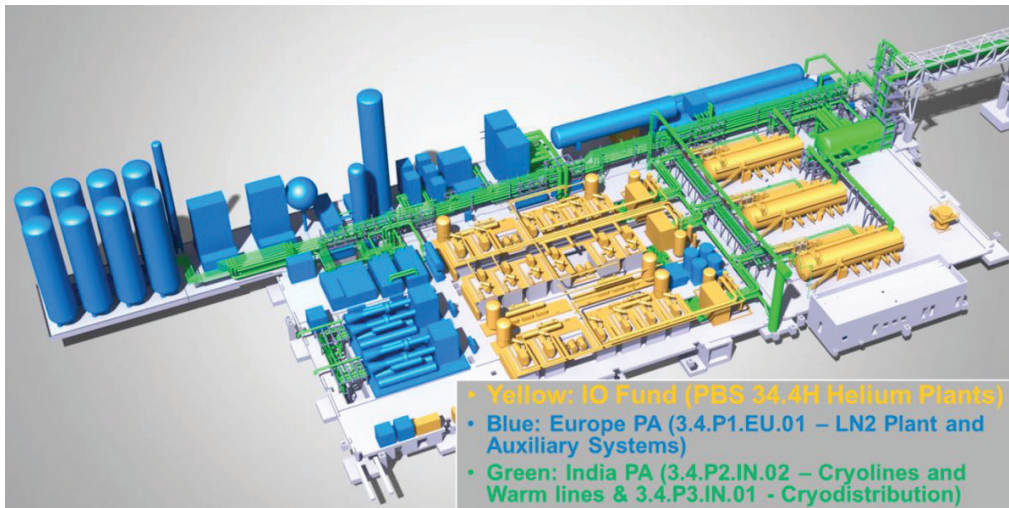


Fig. 2. Cryoplant system 3D layout.

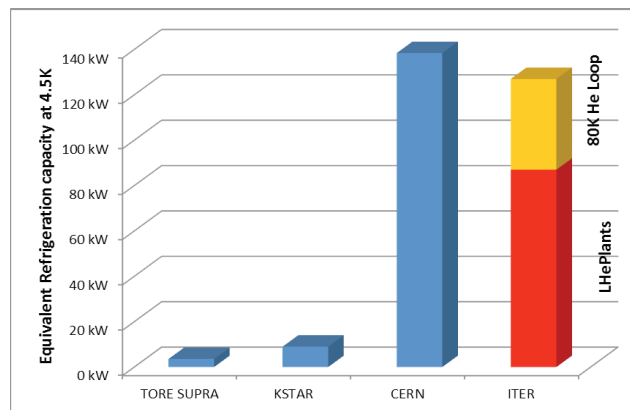


Fig. 3. Comparison of ITER cryoplant helium cooling capacities.

Two liquid nitrogen (LN_2) refrigerators with a maximum capacity of 1300 kW at 80 K will support the nitrogen pre-cooling system of all helium plants. ITER will have its own nitrogen production facility on site, provided by a nitrogen generator of $\sim 1550 \text{ Nm}^3/\text{h}$ capacity for blanketing, leaks, purifier, regeneration of dryers as well as a redundancy in case of instrument air network failure.

An impurity processing system recovers and purifies helium from safety valves and other open circuit users.

A heat recovery system (HRS) will recover up to 12 MW of heat from the cooling water circuits of the screw compressors for heating of the ITER buildings.

Storage and recovery of the helium inventory is managed via warm and cold (80 K and 4.5 K) helium tanks. ITER will have to store an overall helium inventory of 27 tons. The storage system has been optimized and its cost reduced with the replacement of part of the warm storage vessels with a 175 m^3 LHe dewar. The storages, including those for large volumes of gaseous and liquid nitrogen, are summarized in Table 1 and its layout in Fig. 2.

Table 1. Storage inventory and capacities.

	Volume [m ³]	Total volume [m ³]
Pure gas helium tanks at ambient temperature	5 × 400	2000
Impure gas helium storage at ambient temperature	1 × 400	400
LHe tank	1 × 175	175
Helium quench tanks	2 × 360	720
Helium gasbag	7 × 120	840
LN ₂ storage	1 × 300	300
Gas nitrogen storage	1 × 100	100

2.2. Cryoplant project schedule

The cryoplant system is split in between six contracts as listed in Table 2. Each contract scope covers design, manufacturing, installation and commissioning. Design is under finalization and manufacturing has started with first deliveries scheduled by end of 2015. The construction of the cryoplant system on ITER site will be spread over the years of 2016 and 2017. The test of the components will start in 2017 and will be completed in 2018 with the test of the three LHe plants working in parallel while connected to a test cryostat via the cold termination cold box (CTCB).

Table 2. Cryoplant project contracts and deliveries.

PBS #	Name	Responsible for procurement	Contractor	First delivery
34.10	LN ₂ Plant and Auxiliary Systems	F4E – Europe	Air Liquide Engineering	April 2016
34.2S	Cryolines group Y (“simpler” cryolines)	IN-DA – India	Consortium Inox India and AS Scientific	February 2016
34.2C	Cryolines group X (“complex” cryolines)	IN-DA – India	Under bid phase	March 2016
34.2W	Warm lines	IN-DA – India	Under bid phase	February 2016
34.3Y	Cold Termination Cold Box (CTCB)	IN-DA – India	Under bid phase	January 2017
34.4H	LHe Plants	ITER Organization	Air Liquide Advanced Technology	December 2015

3. ITER cryoplant specifications and constrains

For the first time a large and distributed cryogenic system has to consider the constraint of a nuclear installation while aiming at maximizing the efficiency, flexibility, availability and reliability of operation required to demonstrate the economic viability of fusion for future energy production.

As a nuclear installation, the ITER project is under the French Quality Order 1984 (French decree relating to the quality of design, construction and operation) which has been rolled-out to contractors and sub-contractors.

Codes (mainly for pressure vessels) are imposed and strictly followed unless proper counter measure could be implemented. One of the main issue for IO as a nuclear operator is maintenance of all vacuum insulated pressure vessels which forces the design to take all measure to assure or avoid such activities of periodic inspections and re-qualifications.

A Reliability Availability Maintainability Inspectability (RAMI) analysis is developed and detailed along all design phases, with contractors and re-integrated to IO overall RAMI analysis.

For protection of investment as well as personal, Hazard and Operability (HAZOP) and Safety Integrity Level (SIL) studies are systematically conducted.

In order to meet RAMI, HAZOP and SIL requirements, the cryoplant technical specification refers to the European or International standard such as EN ISO 10440-1 for rotary-type positive-displacement compressor or EN ISO 10438 for lubrication, shaft-sealing and control-oil systems and auxiliaries. All rotating machineries have to follow either an ISO standard or its equivalent from the American Petroleum Institute (API). The heat exchanger

will follow the TEMA (Tubular Exchanger Manufacturer Association) or ALPEMA (Aluminium Plate Fin Exchanger Manufacturer Association) standards.

4. Economics of the LHe plants

IO has signed in December 2012 with industry the LHe plants contract and data, see Fig. 4 and Table 3, to broaden the scaling laws for the cost of such systems have been accumulated. Economics of the ITER LHe plants are based on Lump Sum Turn Key Contract [LSTK], however it does not cover the cost for building, civil work, electrical distribution board, cooling water and compressed air systems.

The studies from Strobridge² who correlated the capital cost of helium refrigerator according to installed compressor power, followed by M.A. Green^{4,5}, as well as CERN³ who correlated it to the refrigeration capacity, see Fig. 5. ITER LHe plants confirm that the Green [2007] formula (Equation (1)) up to the 29 kW refrigeration capacities can be used for initial cost estimation during conceptual design.

$$\text{Green Formula [2007]} \quad \text{Cost}(M\$) = 2.6 \times (\text{Capacity}[kW@4.5K])^{0.63} \quad (1)$$

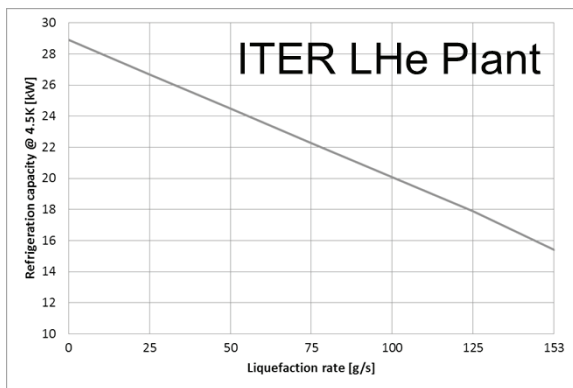


Fig. 4. Liquefaction rate vs. refrigeration capacity at 4.5 K.

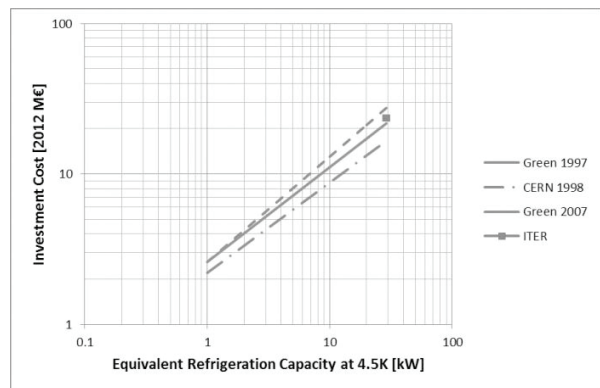


Fig. 5. Investment cost of LHe plant vs. equivalent capacity.

Table 3. LHe plant cost breakdown.

	Refrigeration capacity at 4.5K	Investment cost
ITER LHe plant (one plant)	29 kW	23.5 M€
Control system (control and interlock system)		+5.0%
Machine monitoring system (vibrations measurements and analysis)		+1.5%
Heat recovery system – HRS		+6.5%
Test tools (fixed for 1 or 3 plants)		+9.0%
Capital spares – compressors/turbines/oil pumps (fixed for 1 or 3 plants)		+2.0%

4.1. Economics of the LHe plants heat recovery system – HRS

ITER will recover part of the heat produced by the helium compression, for the building heating system, using additional oil-water heat exchangers. Those exchangers will be arranged in parallel to the standard oil-water heat exchanger in order to keep the high availability of the system and in any case to respect the oil temperature injected into the compressors independent of the load on the HRS hot water loop.

The typical flow scheme of the oil system of the screw compressor is represented in Fig. 6. ITER concept includes the way to control the oil system. A three way valve will control the oil temperature downstream the

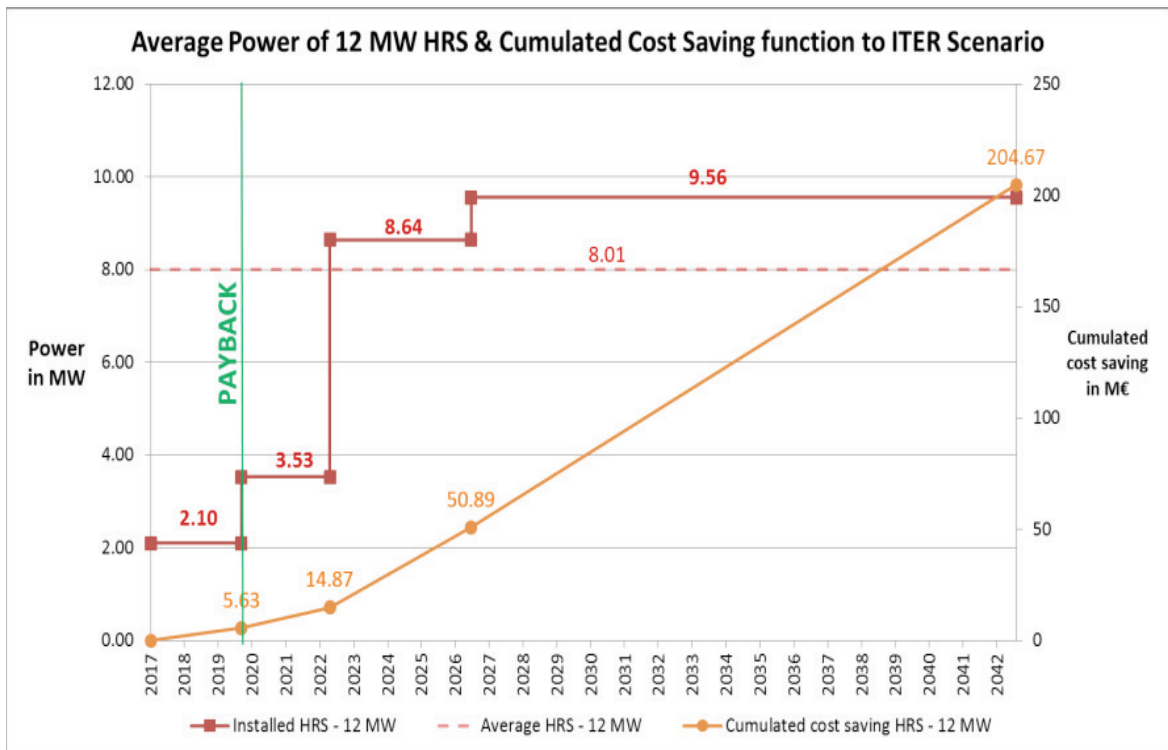


Fig. 7. ITER scheme of heat recovery from screw compressor oil system.

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Disclaimer

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

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