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Conceptual design and main requirements of the divertor tokamak test (DTT) cryogenic system / Angelucci, M.; Migliori, S.; Frattolillo, A.; Iaboni, A.; Bonifetto, R.; Lisanti, F.; Froio, A.; Michel, F.; Duri, D.. - In: FUSION ENGINEERING AND DESIGN. - ISSN 0920-3796. - ELETTRONICO. - 227:(2026). [10.1016/j.fusengdes.2026.115700]

Publisher:

Elsevier Ltd

Published

DOI:10.1016/j.fusengdes.2026.115700

Fusion Engineering and Design 227 (2026) 115700

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Conceptual design and main requirements of the divertor tokamak test (DTT) cryogenic system

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ARTICLE INFO

Keywords:
DTT
Tokamak
Fusion
Cryogenic system
Cryogenic requirements
Operational states

ABSTRACT

The Divertor Tokamak Test (DTT) facility (https://www.dtt-project.it/), currently in initial phase of construction at the ENEA Frascati Research Centre, is designed to explore critical components of tokamak, such as the divertor, in plasma regimes that are relevant for ITER and DEMO (as far as power loads are concerned), and where plasma core and edge properties are fully integrated. To achieve this goal, considerable amounts of plasma heating will be injected in DTT, whose ambitious program is spread over several years and different operational phases.

The DTT facility is designed to produce sufficiently long plasma pulses, thus requiring the adoption of a superconducting magnet system. This latter includes 18 Toroidal Field (TF) coils, 7 Central Solenoid (CS) modules and 6 Poloidal Field (PF) coils. All superconducting coils are supported by a cold structure with thermalized gravity supports and thermally protected in a cryostat with actively cooled thermal shields. The coils and their structures need to be cooled by supercritical helium supplied at about 4.5 K. The thermal shields (TS) have to be cooled with pressurized helium at 80 K. The superconducting coils are connected to the power supply by means of superconducting feeders which need to be maintained at around 4.5 K. High Temperature Superconducting (HTS) current leads (CL), which operate between ambient and cryogenic temperatures, require cold helium gas flow at 50 K. To allow helium and hydrogen adsorption, cryopumps behind the divertor targets are employed, requiring two cryogenic helium streams, one at around 4.5 K for the cryopump panels and one at 80 K for cryopump baffles.

The Cryogenic System has to cool-down the cryogenic users and to keep them at their design temperatures during different operation modes and plasma scenarios. The overall cryogenic capacity is estimated to be around 10 kW equivalent power at 4.5 K.

This paper gives a general overview of the Cryogenic System requirements, the proposed conceptual design, and a description of the main layout.

Introduction

The DTT facility is a new tokamak under construction at ENEA Frascati research centre (Italy). The main objective of this project is to investigate the power exhaust problem in a Tokamak in core/edge plasma physics parameters relevant for DEMO. An ambitious program is spread over several years, in order to test different divertor concepts, under multiple magnetic configurations, and plasma exhaust approaches [1,2].

For this purpose, the machine has been conceived to be flexible and with up-down symmetry so that, in addition to the conventional Single Null (SN) scenario, the X-divertor (XD), Double Null (DN) and negative triangularity (NT) configurations can also be tested. The main

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https://doi.org/10.1016/j.fusengdes.2026.115700
Received 16 December 2025; Received in revised form 10 February 2026; Accepted 2 March 2026

Acronyms

BAK	Baking
CB	Cold Boxes
CC	Cold Circulator
CL	Current Leads
CODAS	Control Data and Acquisition system
CR	Cryostat
CS	Central Solenoid
CTB	Coil Terminal Boxes
CVB	Cryogenic Valve Boxes
DTT	Divertor Tokamak Test
ECRH	Electron Cyclotron Resonance Heating
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
GSTA	Gravity Supports Thermal Anchor
HCS	Helium Compression Station
HTS	High Temperature Superconducting
IBVV	In-Board Vacuum Vessel
ICRH	Ion Cyclotron Resonance Heating
LBAK	Light Baking
LNS	Liquid Nitrogen System
LTS	Low Temperature Superconducting
MLI	Multi-Layer Insulation
NNBI	Negative Neutral Beam Injection
OBVV	Out-Board Vacuum Vessel
PO	Pulsed Operations
POS	Plasma Operation State
PF	Poloidal Field
PR	Ports
QHX	Quench Heat eXchanger
QL	Quench Line
SBAK	Strong Baking
STS	Standard Stand-by
TF	Toroidal Field
TFC	Toroidal Field Coils
TS	Thermal Shields
WGS	Warm Gas Storage
WL	Warm Lines

parameters of the tokamak are: 2.19 m major radius, 0.70 m minor radius, a toroidal field of 5.85 T, a plasma current of 5.5 MA, and a pulse duration of 100 s. Additional power is a key feature to fulfil the challenging plan of experiments: DTT will be equipped with 3 MW of ICRH, 14.5 MW of ECRH and 7.5 MW of NNBI for the initial plasma operations phase; further, up to a total of 45 MW of additional heating will be installed at a later time [3].

Central to the design of the DTT tokamak reactor is a superconducting magnet system that require ultra-low-temperature cooling (4.5 K) to maintain their operational efficiency. The DTT magnet system is supported by an actively cooled structure with thermalized gravity supports and is thermally protected in a cryostat with TS cooled with pressurized helium at 80 K. The superconducting coils are connected to the power supply by means of HTS-Current Leads, which operate between ambient and cryogenic temperatures. Further, DTT employs cryopumps behind the divertor targets, which require 4.5 K helium for the cold panel and helium at 80 K for its chevron baffle.

The above-mentioned requirements in terms of low temperature demand a big and complex Cryogenic System, with customized design of the refrigerator and of the distribution system. Considering appropriate contingency factors, the overall capacity of the Cryogenic System is currently estimated to be around 10 kW equivalent power at 4.5 K. DTT cryogenic system shares very similar power requirements to another superconductive fusion machine [4].

More information on the scope of the DTT project, its main characteristics and scientific program preparation of the DTT facility can be found in [5], whereas and a detailed overview of the progress in the design and procurement of the DTT machine are reported in [6].

The Cryogenic System is a cornerstone of this machine, ensuring stable magnet performance while managing challenging pulsed thermal loads. This paper outlines the main requirements of the Cryogenic System, focusing on its conceptual design and some tailored technical solutions underpinning the DTT’s CryoPlant.

DTT cryogenic users and requirements

The Cryogenic System must meet stringent features to support the operation of the DTT’s cryogenic users, which operate in a high-stress environment characterized by intense magnetic fields and plasma-induced thermal fluctuations. It is responsible for cooling down several users, preserve their thermal stability during different operation modes and plasma scenarios, and warming them up to ambient temperature during the shutdown phase of the machine. However, the Cryogenic System shall deliver the necessary cooling power at three different operating temperatures, which are reported below with the detailed list of the components to refrigerate.

Supercritical helium at 4.5 K is required to:

- 18 superconducting TF coils,
- 6 superconducting power cables (feeders) to the toroidal magnets,
- 15 superconductive power cables between the TF coils electrically connected in series (jumpers),
- 18 casing structures of the TF coils,
- 18 thermal anchors made in the gravity supports (GSTA),
- 6 Low-temperature superconducting (LTS) central solenoid modules plus 1 HTS central solenoid module,
- a Central Solenoid structures,
- 14 superconductive feeders to the central solenoid modules,
- 6 superconductive poloidal magnets,
- 12 superconductive feeders to the poloidal magnets,
- 10 cryopump panels.

Helium at 50 K is required to:

- 6 HTS-Current Leads for the toroidal magnets,
- 12 HTS-Current Leads for the central solenoid modules,
- 12 HTS-Current Leads for poloidal magnets.

Helium at 80 K is required to:

- 9 sectors of the In-board vacuum vessel thermal shield (IBVV-TS),
- 9 sectors of the Out-board vacuum vessel thermal shield (OBVV-TS),
- 6 sectors of the cryostat thermal shield (CR-TS),
- 18x5 sectors of the thermal shield of the ports (PR-TS),
- 10 Chevron Baffles of the cryopumps,
- 18 80K-thermal anchors made in the gravity supports,
- Radiation shields of 5 Coil Terminal Boxes (CTB),
- Radiation shields of 4 Cryogenic Valve Boxes (CVB).

DTT cryoplant architecture and layout

A preliminary design of the DTT cryogenic system has been developed and its architecture is shown in Fig. 1. The main sub-systems have been identified, and a conceptual design was developed to achieve

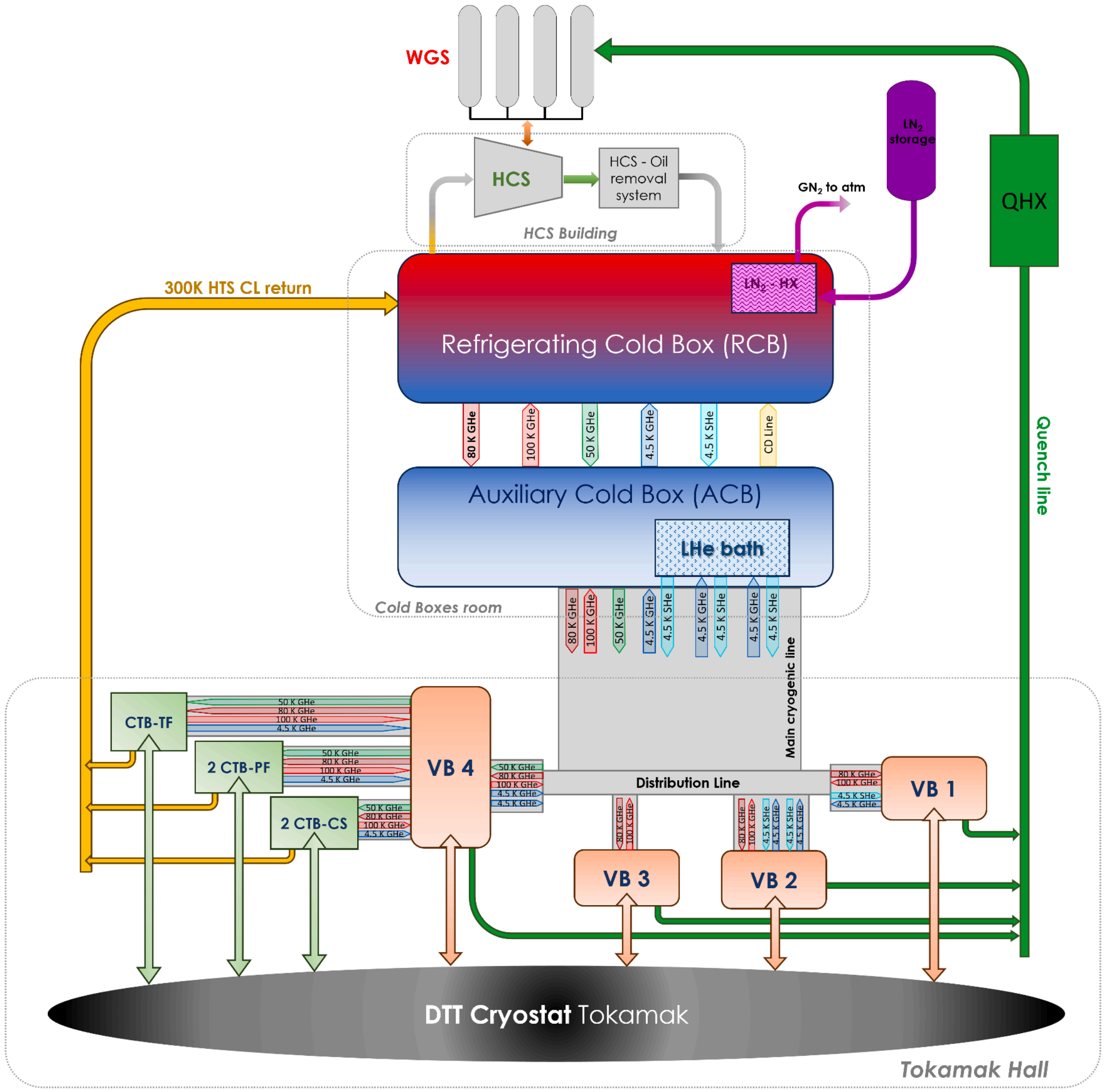

Fig. 1. Preliminary functional scheme of the DTT Cryogenic System.

efficient helium refrigeration, distribution, and recovery. Nevertheless, the details of the cryogenic process and the final design of the refrigerator will be optimized together with the expertise of the final supplier, with the aim of obtaining the most efficient solution for the needs of DTT.

The preliminary layout of the DTT cryogenic system, developed by DTT cryogenic team is shown in the 3D isometric view of Fig. 2. It has been practically divided into nine sub-systems, summarized below:

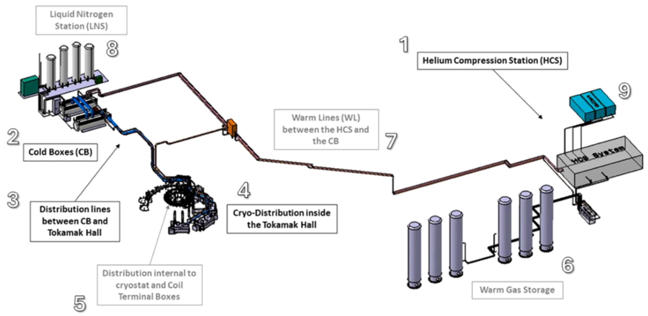

Fig. 2. 3D CAD view of the CryoPlant in the DTT Frascati Centre.

1. Helium Compression Station (HCS): it is the system necessary to pressurize around 1kg/s of warm helium from around atmospheric pressure to around 20–23 bar, to feed the refrigerator. Moreover, the HCS shall be capable of filling the overall helium inventory in the storage volume available, when the CryoPlant goes in the shut-off phase. The HCS is equipped with charcoal adsorbers for oil removal and with a helium dryer to eliminate residual humidity.
2. Cold Boxes (CB): two Cold Boxes of about 4 m diameter and 12 m length can be arranged in the dedicated room of the DTT site. In this system, the helium refrigeration process takes place. The main components for this purpose include: high effective counterflow exchangers for LN_2 pre-cooling, plate fin exchangers, 80 K and 20 K adsorbers, expansion turbines, valves. Additional critical components may include cold circulators (CC), cold compressors, and a liquid helium bath, which should serve as a thermal buffer to absorb peak heat loads.
3. Distribution between Cold Boxes and Tokamak Hall: this system includes one Main Cryoline (one or more Multi-Transfer cryolines containing 9 cryogenic pipes) and two further warm helium lines, which connect the Cold Boxes to the distribution system in the Tokamak. The estimated length of these pipes is around 55 m.
4. Distribution inside Tokamak Hall: the sub-system responsible for the distribution of the helium inside the Tokamak Hall up to Cryostat. It

includes one Distribution Cryoline which allows the delivery of cryogenic helium to the 4 CVBs, these latter which allow the distribution, flow and temperature control of the helium to the cryogenic users, and the CVB cryogenic ducts, which arrive to the interfaces with the DTT cryostat base.

5. Distribution internal to the DTT tokamak cryostat and CTBs: this sub-system refers to the network of manifold and pipes which delivers helium from the CVBs to the DTT cryogenic users and gather back helium from the users to the CryoPlant.
6. Warm Gas Storage (WGS): It is the sub-system devoted to the recovery and storage of the entire helium inventory (warm and in pressure) during the stand-by of the cryogenic system. Up to six tanks of around 240 m^3 capacity are currently considered for this purpose. One or more WGS tanks shall also be devoted to containing the helium evacuated in case of Quench or Fast Discharge Events.
7. Warm Lines (WL): which connect the Helium streams from HCS room and WGS to Cold Boxes room. It comprises: a High-Pressure line and a Low-Pressure line between the HCS room and the Cold Boxes, the Quench Heat eXchanger (QHX), i.e., an atmospheric heater to warm up cold helium released in case of over-pressurization in the cryogenic circuits, and the Quench Line (QL) Section from QHX to the WGS. The length of the warm lines from the HCS to the Cold boxes is around 250 m.
8. Liquid Nitrogen System (LNS): this system provides Liquid Nitrogen for the pre-cooling of helium from ambient to 80 K. Four 30 m^3 storage tanks are made available by DTT in the external area of the Cold Boxes building for this purpose. A dry and hot N2 gas service shall be also provided by LNS to CryoPlant and DTT for conditioning, drying and regeneration needs.
9. Water Chillers: necessary for cooling the helium compressors.

All these sub-systems span a large area and several buildings of the DTT site as displayed in Fig. 3, but still must respect the dedicated areas, which are often limited in terms of available space. For instance, a major effort was made by the CRYO-DTT team to develop the layout and a preliminary design of the Cryo-Distribution system inside the Tokamak Hall within the very limited available space. Four CVBs have been considered at least necessary to host all the necessary cryogenic valves, filters and instrumentation which ensure adequate flow control to the magnets and the other cryogenic users. The final design of the CVBs shall preserve the accessibility for component replacement and maintenance, requiring a very tailored solution.

Another key feature of the DTT Cryogenic system is the cooling

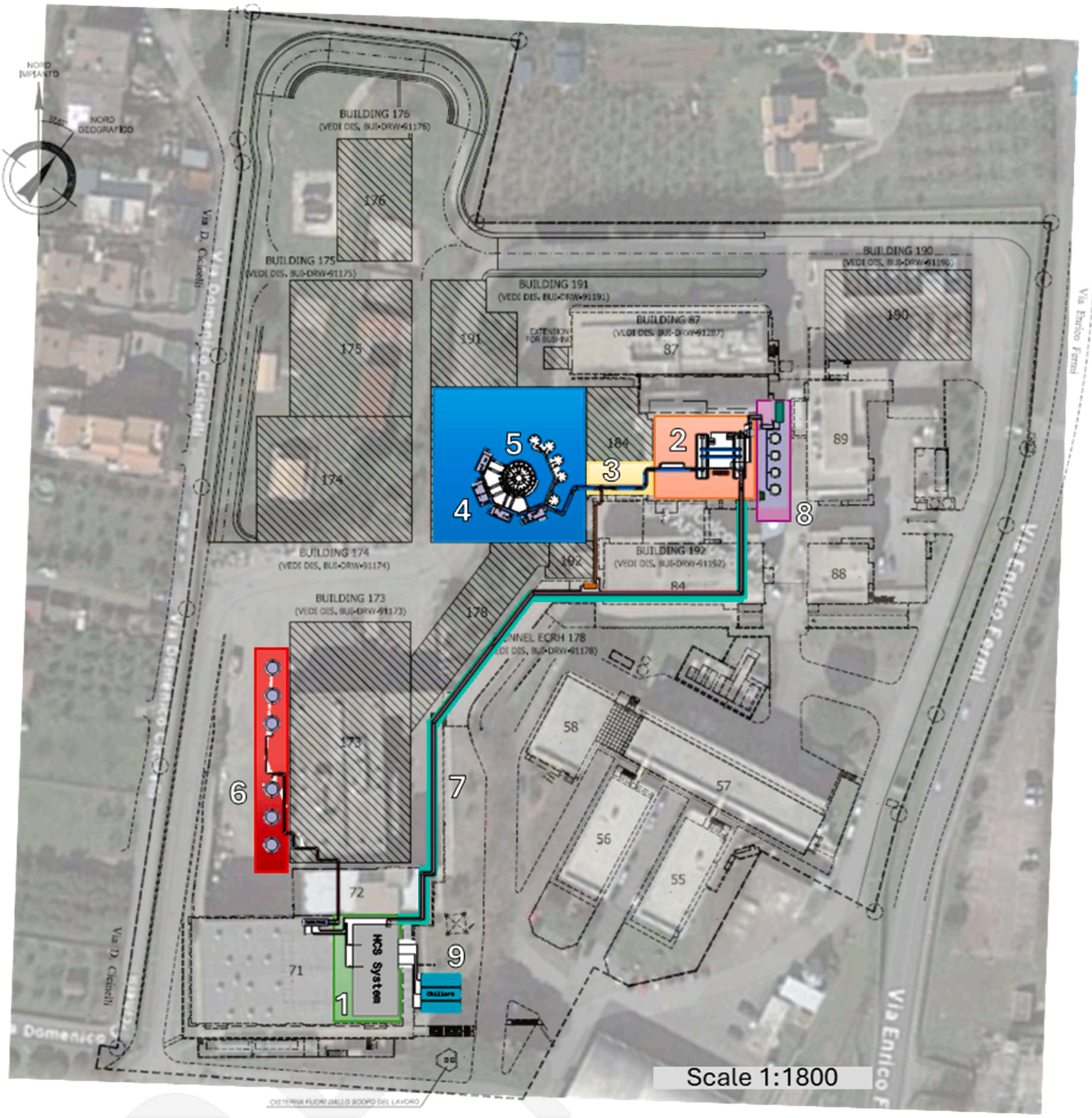

Fig. 3. Distribution of the CryoPlant sub-systems in DTT Frascati centre.

pattern: the cryogenic users are supplied with helium by means of 5 different distribution loops, schematically represented in Fig. 4. Loop 1 and Loop 2 provide helium in two closed loops, respectively to TF magnet system and both PF magnets and CS modules by means of two independent cold circulators and dedicated heat exchangers to transfer heat from the cooling loops to a liquid helium bath. Loop 3 provides helium (at about 4.5 K) to the 10 cryopump panels. Loop 4 supplies the 80 K pressurized helium to the TS, cryopump Chevron Baffles and 80K-GSTA. Finally, loop 5 provides 50 K helium to the 30 HTS Current Leads. Preliminary study performed for the optimization of the cooling loops (e.g., for TF magnet system) is presented in reference [7]. All the cooling loops will be equipped with specialized cryogenic instrumentation, such as adequate cryogenic temperature sensors, pressure transducers, flow meters, identified through extensive market surveys and the selection of dedicated, high-performance components. A comprehensive description of the cryo-distribution system inside the DTT tokamak hall will be presented in a successive, dedicated manuscript.

The DTT Cryogenic System will be equipped with its own integrated Control Data and Acquisition system, called Cryo-CODAS, which will be designed to control the Cryoplant during all the operational modes of the system and, most important, the transient phases and the passages between two different modes, among the ones described in paragraph 4. The Cryo-CODAS should be designed with specific architecture in order to communicate with DTT-CODAS through defined protocols. The peculiar functions to be handled are: synchronization of DTT state machines with the Cryo-CODAS state machine, the transmission of CryoPlant data to DTT archives, the transmission of Cryo-CODAS equipment status to DTT CODAS and also of CryoPlant alarms in case some of the process parameters are overcoming the threshold values.

Main operational states

To estimate the CryoPlant capacity, it has been necessary to evaluate the required heat load of all cryogenic users in all the operational states. The operational states of the DTT cryogenic system, along with the heat loads and requirements for each cryogenic user, are detailed in the following paragraphs. These operational states are shared between many fusion machines [8,9]. A preliminary comparison of the refrigerating power required for the most relevant operational states is provided in Fig. 5, which accounts for the heat loads of cryogenic users, but not of the further amount due to cold circulators. Finally, considering appropriate contingency, the overall cryogenic capacity currently needed is estimated at approximately 10 kW equivalent power at 4.5 K.

Pulsed operations (PO)

The most demanding phase for the CryoPlant is the Pulsed Operations (PO), i.e., the actual DTT experimental campaign. This state consists in a sequence of alternating the Plasma Operation State (POS) and Dwell periods. During the whole PO cycle, cryogenic users are subjected to static heat loads such as conduction, radiation, and resistive losses. During POS, which lasts about 100 s, the magnets are subjected in addition to large pulsed heat loads, originated from AC losses (including hysteresis and eddy currents during plasma current ramping) and nuclear heating. The pulsed heat loads are handled by the evaporation of a huge amount of liquid Helium from the Cold Boxes bath. Following POS, the system enters the Dwell period, lasting approximately 3500 s, where the CryoPlant must restore the thermal conditions required to initiate the next plasma pulse.

An overview of the main heat loads and helium flow parameters required during POS is reported in Table 1. In this table, the heat loads due to radiation (both for magnets and thermal shields) have been calculated with Stefan-Boltzmann law with the assumption of two grey-body surfaces forming an enclosure. Emissivity and view factor depended on the material and geometry of the examined component. Conduction heat loads on the gravity support thermal anchor are calculated

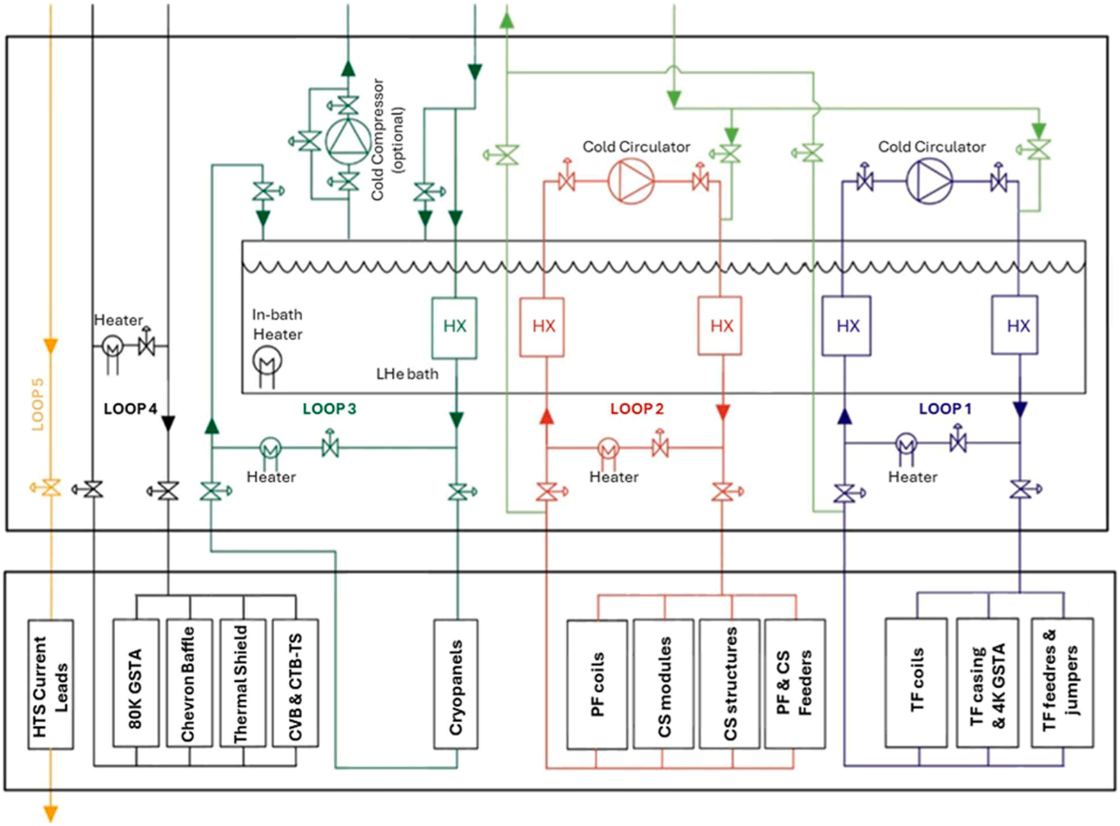

Fig. 4. Simplified representation of the DTT cryogenic cooling scheme.

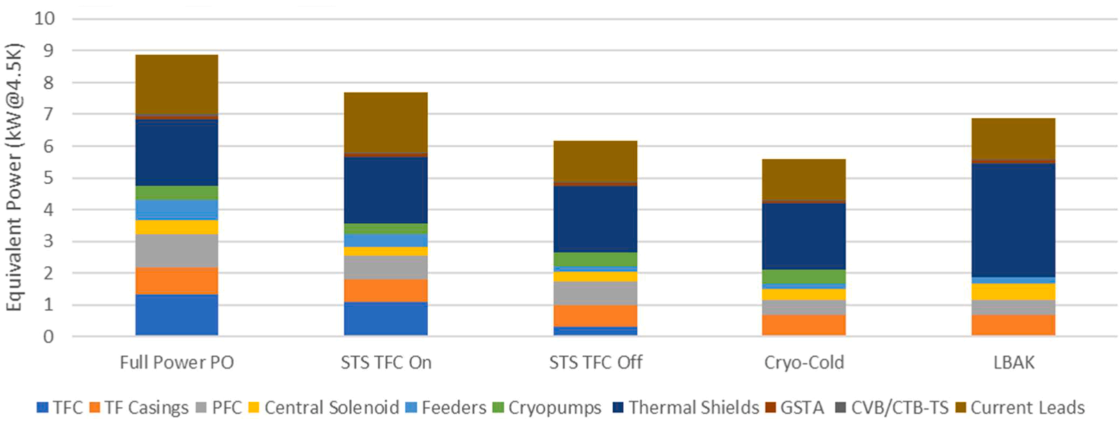

Fig. 5. Comparison of the equivalent heat loads at 4.5 K between the main DTT operational states.

Table 1
Cryogenic users heat loads and helium flow parameters provided by the CryoPlant during PO.

Cryogenic User	Supply Temperature (K)	Supply Pressure (bar)	Design Pressure Drop (bar)	Mass rate (g/s)	Static Heat Load (W)	Pulsed Heat Load (kJ)	Equivalent Load @4.5 K (kW)
TF Coils	< 4.6	4.5	1	400	1100	800	1.32
TF Structures + 4 K GSTA	< 4.6	4.5	0.2	145	700	300	0.8
TF Jumpers + Feeders	< 4.6	4.5	0.1	105	275	0.7	0.28
CS Modules	< 4.6	5	1	360	450	570	0.61
CS Structures	< 4.6	5	1	10	10	0	0.01
PF Coils	< 4.6	5	1	380	950	1100	1.26
CS/PF feeders	< 4.6	5	0.1	48	391	0	0.39
Cryopanels	< 4.6	5	0.11	200	66	5.6	0.07
Chevron Baffles	80	16	0.1	50	7210	0	0.36
Thermal Shields	80	16	0.7/0.1	400	41,900	0	2.09
80 K GSTA	80	16	<1	36	1800	0	0.09
CVB-TS*	80	16	<1	20	1600	0	0.1
CTB-TS*	80	16	<1	12.5	1200	0	0.04
TF-CLs	50	4.0	3.0	24	31,000	0	0.93 ± 0.19
CS-CLs	50	4.0	3.0	12	15,500	0	0.48 ± 0.10
PF-CLs	50	4.0	3.0	12	15,500	0	0.48 ± 0.10

*Heat load preliminary estimate since the detailed design of the CVB and CTB need to be still addressed; it is considered the use of Multi-Layer Insulation (MLI) between the CVB/CTB external cryostat and the CVB/CTB-TS to reduce the radiation heat loads.

with 1D model, as presented in [10]. Pulsed loads are mainly due to nuclear heating, computed in [11], AC losses and Eddy Currents, calculated following the model presented in [12]. Other loads on superconductive magnets are due to Joule dissipation on resistive joints and are static on TF coils and pulsed on PF and CS coils. A preliminary estimate of the mass flow rates necessary for the HTS-CL have been calculated based on the experience of previous machines [4,13]. However, slightly conservative values have been considered since the design of the CL for DTT is not yet available.

The equivalent load at 4.5 K has been calculated by means of exergetic method applied to a cryogenic helium refrigeration plant as reported in [14]. In particular, exergy loss W is calculated as:

$$W = \dot{m}\ \Delta e = \ \dot{m}\ (\Delta h - T_0\ \Delta s)$$

Where Δh and Δs are calculated for expected helium parameters (temperature and pressure) across the related cryogenic user, whereas T_0 is the reference temperature of 300 K. Helium parameters are taken from NIST thermophysical properties database [15]. The equivalent load at 4.5 K is then evaluated as:

$$Q_{eq,4.5K} = W\frac{4.5\ K}{(4.5\ K - 300K)}$$

Due to the cryogenic users' thermal inertia and the thermo-hydraulic cooling schemes, the heat loads are typically released to the Liquid Helium bath, located in Cold Boxes, within 10 min, as shown in Fig. 6. Liquid Helium bath could be operated at constant or variable pressure depending on the design strategy, which will be selected during the detailed design phase. CCs must remain operational during both POS and dwell phases to ensure an adequate mass flow rate and the related heat loads need to be handled through the liquid Helium bath too.

Standard stand-by (STS) and cryo-cold

The STS operational state is typically scheduled overnight and during weekends throughout the experimental campaign. In this phase, cryogenic users are only subjected to static heat loads; however, CCs remain in operation, contributing to an overall gross heat load of approximately 2 kW. Depending on whether the TF magnets are energized, a further decrease of about 1.5 kW heat load is expected. A breakdown of the estimated heat load during the STS phase is shown in Table 2. Furthermore, cryopump regeneration may be performed overnight. To avoid impacts on the experimental campaign, the whole regeneration process, involving evacuation of the helium in the circuits, heating up of the cryopanels and final re-cooling, shall last less than 12 h in total.

Cryo-Cold operational state foresees cryogenic users kept cold, close to their reference temperature. However, CCs are not in function with helium directly supplied by the HCS in a closed loop. For this reason, reduced mass flow rates are supplied to the magnets and cryopanels, as

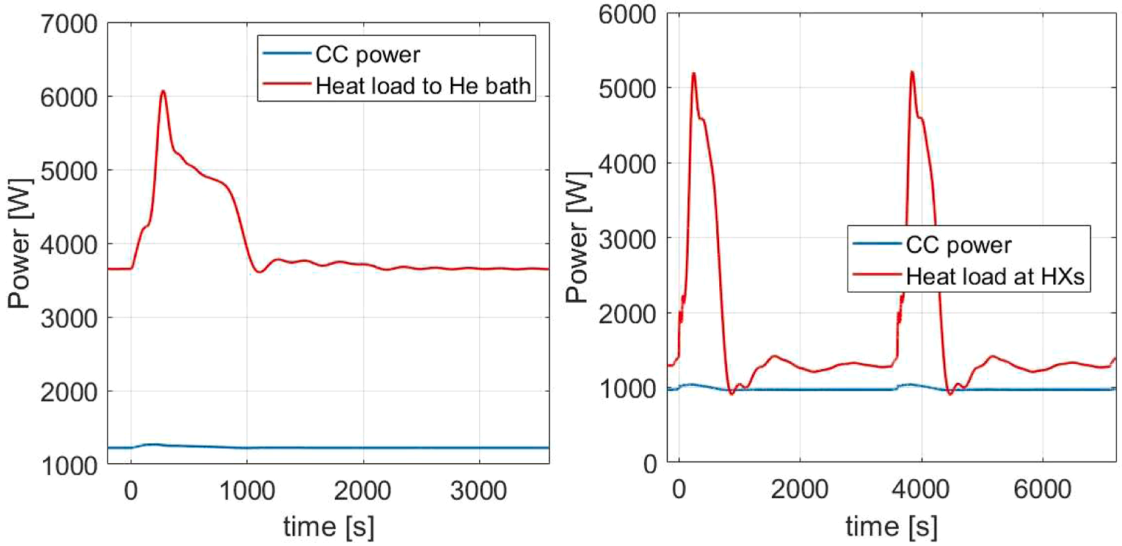

Fig. 6. Simulation of the heat load to Liquid Helium bath during a PO cycle from [7].

Table 2
STS heat loads summarized per loop.

	Mass Rate (g/s)	Static heat load (W)	Equivalent power @4.5 K (kW)
Loop 1	650	2075 (TFC On) 1085 (TFC Off)	2.075 (TFC On) 1.085 (TFC Off)
Loop 2	800	1138	1.138
Loop 3	200	66	0.066
Loop 4	530	52,090	2.617
Loop 5	48 (TFC On) 32.4 (TFC Off)	63,000 (TFC On) 43,000 (TFC Off)	1.890 (TFC On) 1.290 (TFC Off)

reported in the summary of Table 3.

Baking (BAK)

Another critical operational state is the baking (BAK), where the in-vessel components of the tokamak are warmed-up, leading to an increase of the radiation loads to the thermal shields of the vacuum vessel and the ports, and where the cryopumps need to undergo the regeneration process. HTS-CLs are not cooled is this state as well. To avoid over-design of the CryoPlant capacity, CCs are switched off and the temperature in the cryogenic user can be relaxed up to be close to environment conditions. Two kinds of BAK operational phases are defined, differing in heating temperature and duration: Light Baking (LBAK) performed approximately every weekend, involving vacuum vessel and ports heat up respectively to 373 K and 383 K; Strong Baking (SBAK) carried out at the beginning and at the end of each experimental campaign, when the vacuum vessel and ports are heated up respectively to 473 K and 438 K. The BAK operating conditions are summarized in Table 4. A preliminary estimate of the LBAK requirements is summarized in Table 5. The most effective strategy, for managing the two baking operational states from a cooling point of view, is still under assessment.

Table 3
Cryo-cold heat loads summarized per loop.

	Mass Rate (g/s)	Static heat load (W)	Equivalent power @4.5 K (W)
Loop 1	220	785	0.785
Loop 2	270	888	0.888
Loop 3	200	66	0.066
Loop 4	530	52,090	2.617
Loop 5	32.4	43,000	1.290

Table 4
LBAK and SBAK operating conditions and time durations.

	Port Temperature (K)	Vacuum Vessel Temperature (K)	Duration (h)	Frequency
LBAK	373	383	24	Up to once a week
SBAK	438	473	/	Once/Twice a year

Table 5
LBAK heat loads summarized per loop.

	Mass Rate (g/s)	Static heat load (W)	Equivalent power @4.5 K (W)
Loop 1	250	785	0.785
Loop 2	270	888	0.888
Loop 3	/	/	/
Loop 4	420	75,390	3.746
Loop 5	/	/	/

Quench

Quench and fast discharge events involve a sudden warming of the helium inventory contained in the magnets, which leads to system over-pressurization. This condition must be managed through dedicated quench valves, releasing helium via the quench line to the quench tank. Additionally, disruption mitigation experiments are expected to heat the helium contained in the cryopumps. To address these, QHX has been designed to warm the released helium before it reaches the quench tank.

Cool down and warm up

The cryogenic system shall be capable of cooling the cryogenic users from room temperature to cryogenic temperatures during Cool Down operational state and warming them back up during Warm-Up, which are foreseen at the beginning and at the end of each experimental campaign. This process is expected to last approximately 30 days, with a controlled cool-down rate for each cryogenic user. An overview of the involved cold masses is provided in Table 6. As reference strategy for this phase, the cool down speed is maintained <1 K/h and temperature difference between inlet and outlet of superconducting devices is maintained below 40 K. Cool Down could be divided into the following phases:

Table 6
Breakdown of the DTT cold masses.

Cryogenic user	Cold mass (ton)
TF Coils	82
TF Casings	367
TF Feeders and Jumpers	4
CS Modules	45
CS Structures	15
PFC	65
CS/PF Feeders	1.5
Cryopanels	0.1
Chevron Baffles	0.4
Gravity Support Thermal Anchors	Negligible
CTB-TS	Negligible
HTS-CLs	11
Total	580

- Cool down of the CryoPlant and of the Loops 1, 2 and 4 (except for Chevron Baffles) from room temperature to around 100 K. This phase is expected to be characterized by greater LN2 consumption.
- Cool down of the CryoPlant and of Loops 1 ,2 and 4 (except for chevron baffles) from 100 K to the Cryo-Cold reference temperatures (around 5–10 K for Loops 1, 2 and 80 K for Loop 4). Once the cryogenic users of Loops 1 and 2 had reached the temperature of 50 K, the cool down of HTS-Current Leads should start in order to limit the conduction heat loads on the TF, CS and PF feeders. Cool down of chevron baffles can be operated once the TS sectors are cooled at their reference temperature (80 K).
- Cool down of cryopumps from 300 K to 4.5 K. Due to the smaller thermal inertia, this phase is expected to require around a day.

Conclusions and perspectives

The DTT cryoplant is a key system to underpin the DTT's mission to resolve critical fusion challenges, by enabling stable operation in the tokamak's magnets. The conceptual and preliminary engineering design of this plant have been developed after that the main heat loads, and the main requirements were consolidated. Then, the main layout of the Cryogenic System inside the DTT site was arranged considering the limited space available. The cryo-distribution system features strategical choices for helium flow regulation and quench management, aiming at reducing the total number of necessary cryogenic valves. This choice allows to reduce costs and simplify the control of the entire Cryogenic System during the operation. The Cryo-CODAS control system should be developed to handle the different operational states of the CryoPlant and the transition between them, in coordination with the Control Data and Acquisition System of the DTT Tokamak. Some other characterizing aspects will be designed by the final supplier during the first year of supply contract. The main requirements and the conceptual design of the DTT Cryogenic System have been collected and reported on the technical specification, which is ready for the tender publication.

CRediT authorship contribution statement

M. Angelucci: Conceptualization, Methodology, Investigation, Writing – original draft, Visualization, Supervision. **S. Migliori:** Conceptualization, Investigation, Supervision, Project administration. **A. Frattolillo:** Conceptualization, Investigation, Writing – review & editing, Supervision. **A. Iaboni:** Methodology, Investigation, Writing – original draft, Visualization. **R. Bonifetto:** Methodology, Investigation, Writing – review & editing. **F. Lisanti:** Methodology, Investigation, Writing – review & editing. **A. Froio:** Methodology, Investigation, Writing – review & editing. **F. Michel:** Conceptualization, Writing – review & editing, Supervision. **D. Duri:** Conceptualization, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors acknowledge the support and the coordination activities related to the DTT Tokamak and Magnets areas efficiently managed by G. M. Polli and G. Ramogida. The authors are also very grateful to the contributions of E. Boz, G. Biava, V. Prandelli, and M. Micheletti to the development of the 3D CAD model of the cryogenic system.

Data availability

No data was used for the research described in the article.

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