Cryogenics for fusion

A brief look at cryogenics for fusion from the ITER perspective.

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ITER ORGANIZATION - CSP

Disclaimer: The views and opinions herein do not necessary reflect those of the ITER Organisation.

Introduction

ITER fusion reactor is an experimental research reactor

Objectives:

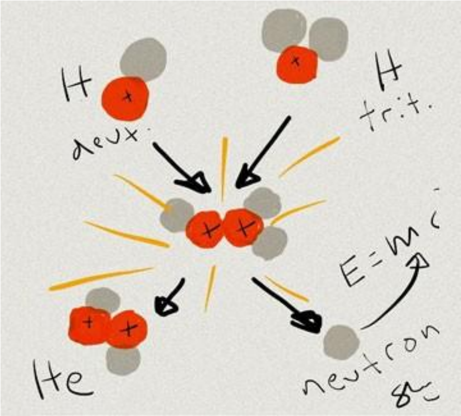
1) Achieve a deuterium-tritium plasma in which the fusion conditions are sustained mostly by internal fusion heating

2) Generate 500 MW of fusion power in its plasma for long pulses

3) Contribute to the demonstration of the integrated operation of technologies for a fusion power plant

4) Test tritium breeding

5) Demonstrate the safety characteristics of a fusion device

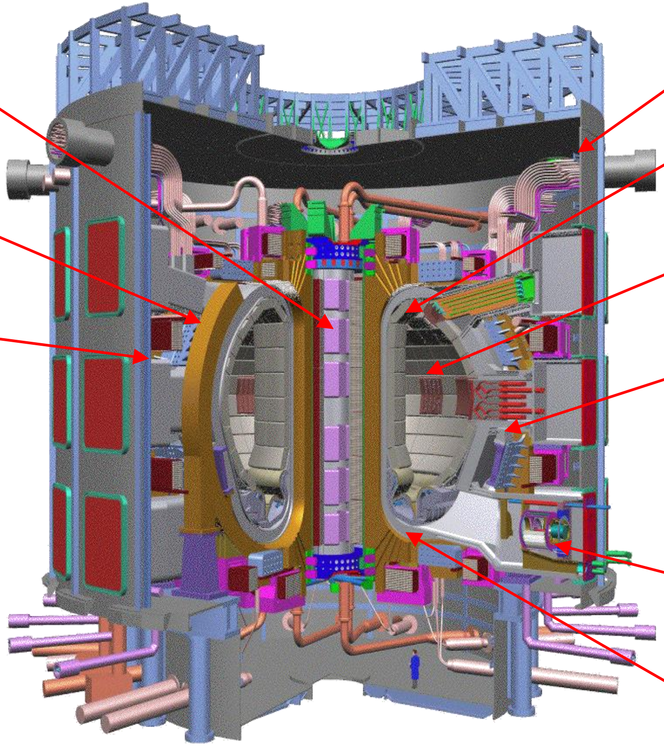


The Core of ITER

Central Solenoid
Nb_3Sn, 6 modules

Toroidal Field Coil
Nb_3Sn, 18, wedged

Poloidal Field Coil
Nb-Ti, 6



Cryostat
29 m high x 28 m dia.

Vacuum Vessel
9 sectors

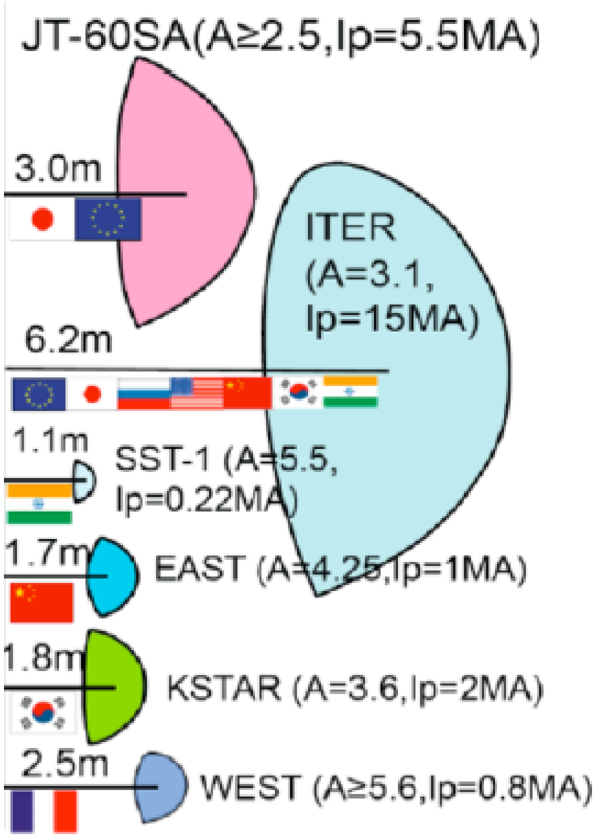
Blanket
440 modules

Port Plug
heating/current drive, test blankets limiters/RH diagnostics

Torus Cryopumps
8 Pumps

Divertor
54 cassettes

The latest Tokamaks - KSTAR, JT-60SA, ITER

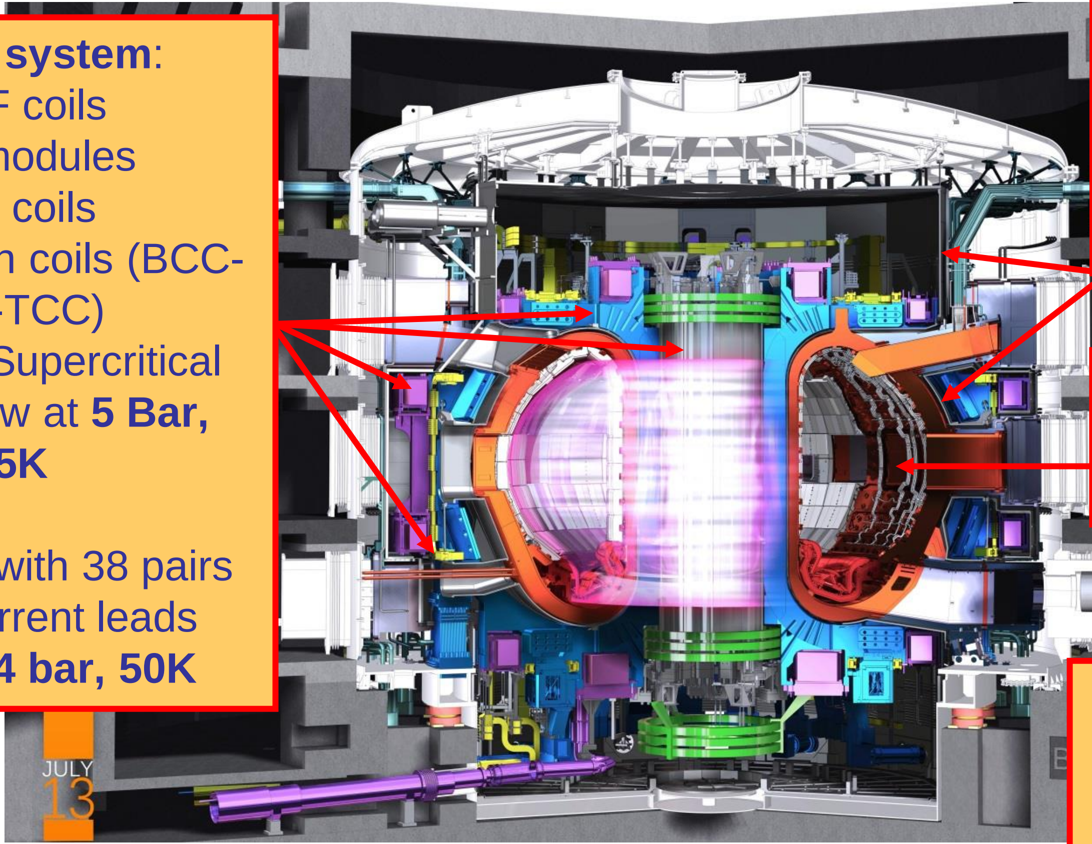


PARAMETERS	KSTAR Operation since 2008	JT-60SA Construction FP 2019	ITER Construction FP 2025
Plasma R major radius [m]	1.8	2.95	6.2
Plasma a minor radius [m]	0.5	1.18	2.0
Plasma Ip [MA]	2	5.5	15
Toroidal Field Bt [T]	3.5	2.7	5.3
Plasma Volume [m^3]	17.8	140	830
Superconductors	CICC Nb3Sn/NbTi	CICC Nb3Sn/NbTi	CICC Nb3Sn/NbTi
Size of the tokamak	H 8.6m D 8.8m	H 16m D 12m	H 24m D 28m
Magnet system total weight (Ton)	270	700	10 135

The main cryogenic users

Magnet system:
18 TF coils
6 CS modules
6 PF coils
18 Correction coils (BCC-SCC-TCC)
Cooled by Supercritical Helium Flow at **5 Bar, 4.5K**

Associated with 38 pairs of HTS current leads supply at **4 bar, 50K**

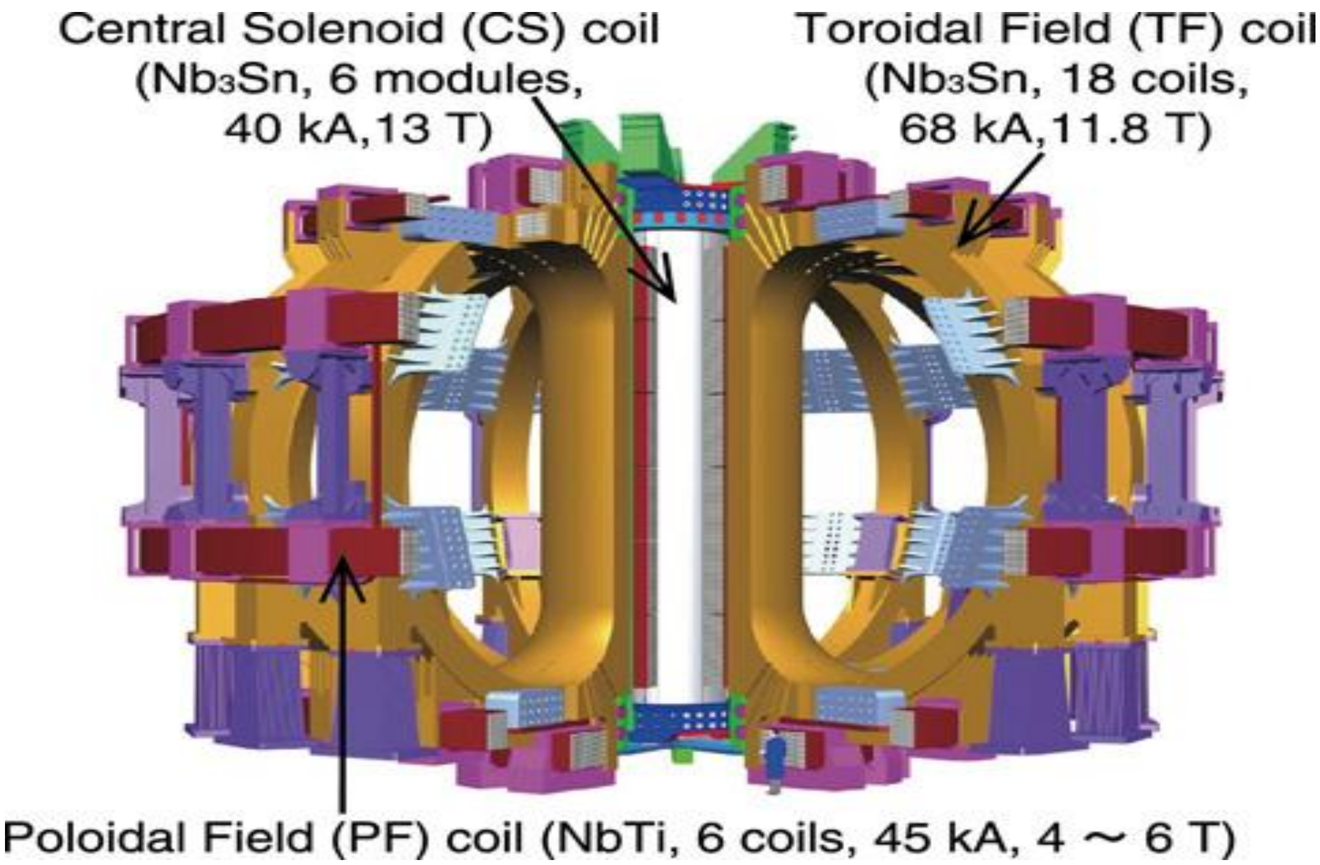


Thermal Shields cooled between **80K and 100K with 18 bar**
Composed of Cryostat TS And Vacuum Vessel TS

Plasma Fueling
Pellet Injection system
4.5K + 80K needs

CryoPumps 4.5K, 5 bar
and baffles **80K-100K**
2CP for Cryostat pumping
6CP for Torus pumping (VV)
For NBI (max. 4 CP)

The main cryogenic users - Magnet System

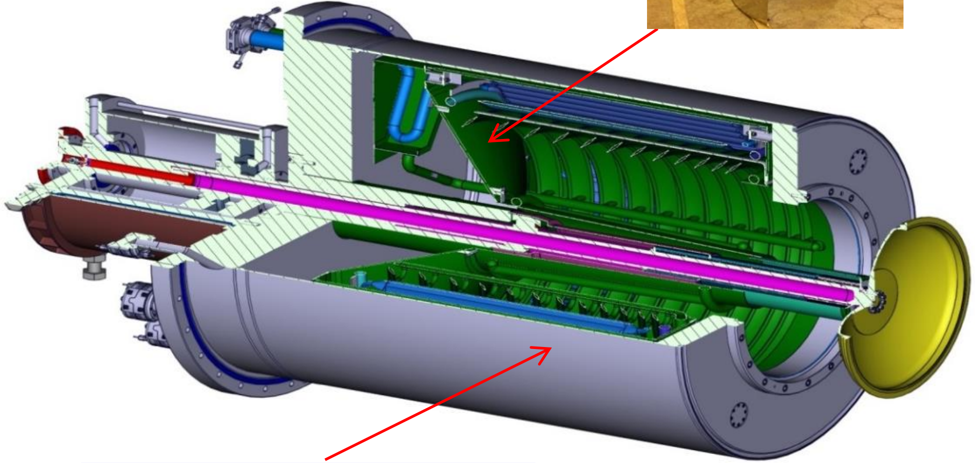


TF Coil

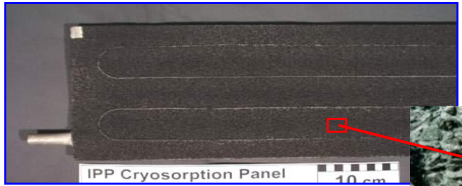
PF coil 3

The main cryogenic users – part of Thermal shield

The main cryogenic users - Cryopumps



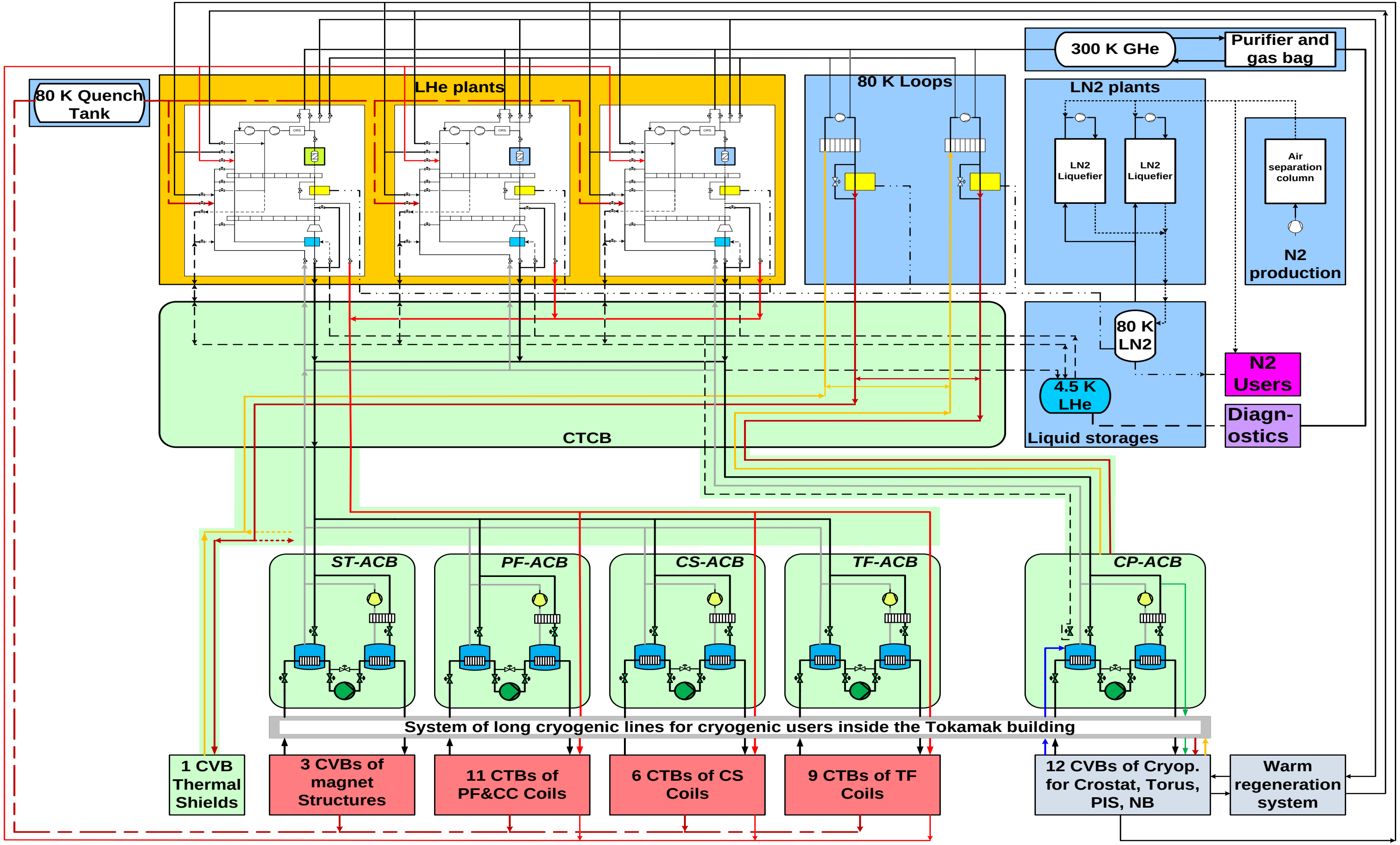
Pumping by charcoal on surfaces:
Efficiently Helium at T< 5 K
Efficiently all hydrogen isotopes at T < 10 K



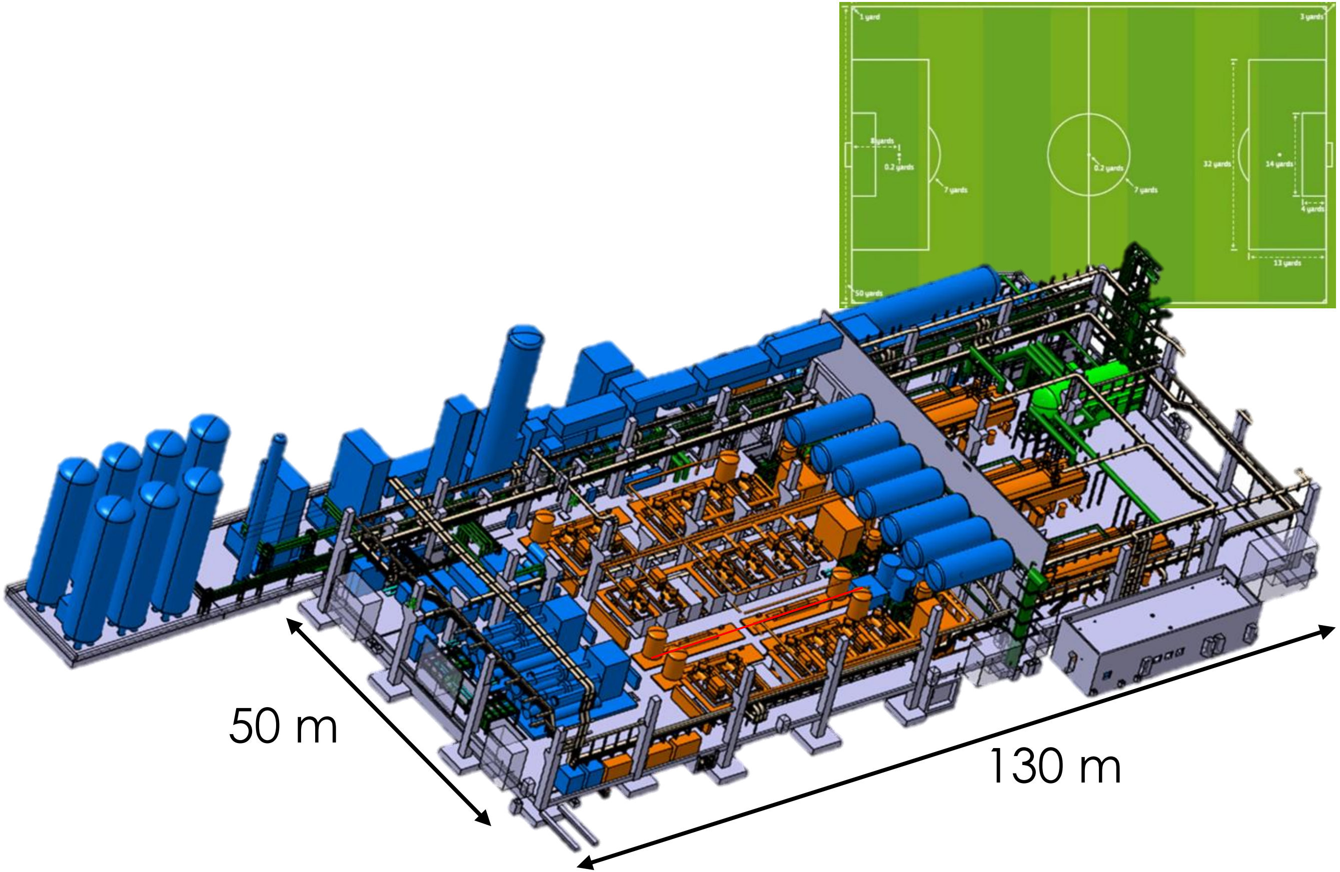
Regeneration:

100K to release He, Ne and Hydrogen isotopes
300K to release Ar, O2, N2, CO, CH4, CO2
470K to release higher hydrocarbons

Cryogenic system - schematic



Cryogenic system - CRYOPLANT



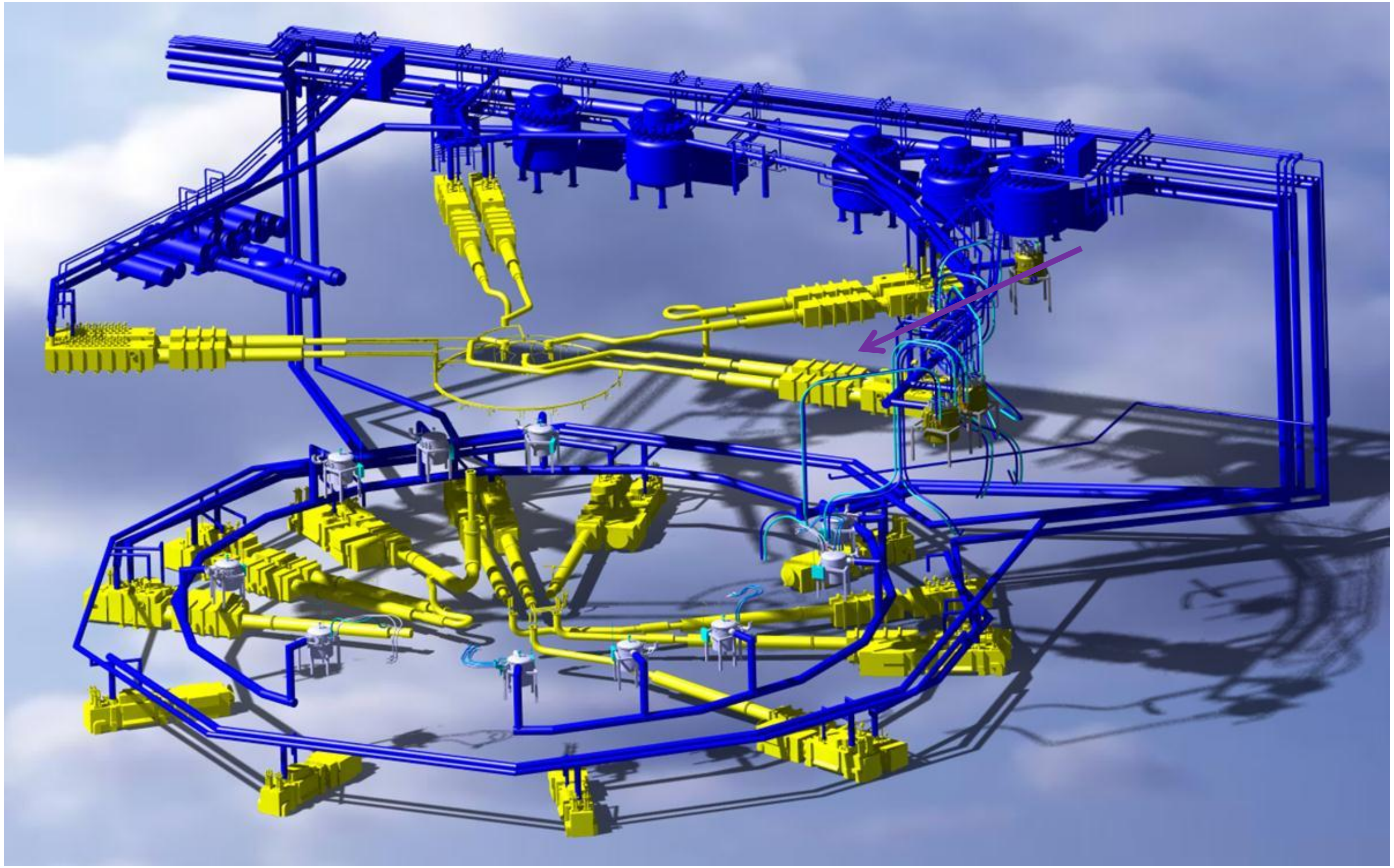
Cryogenic system - Compressor building - Helium Compressors

Cryogenic system - Compressor building - Nitrogen Compressors

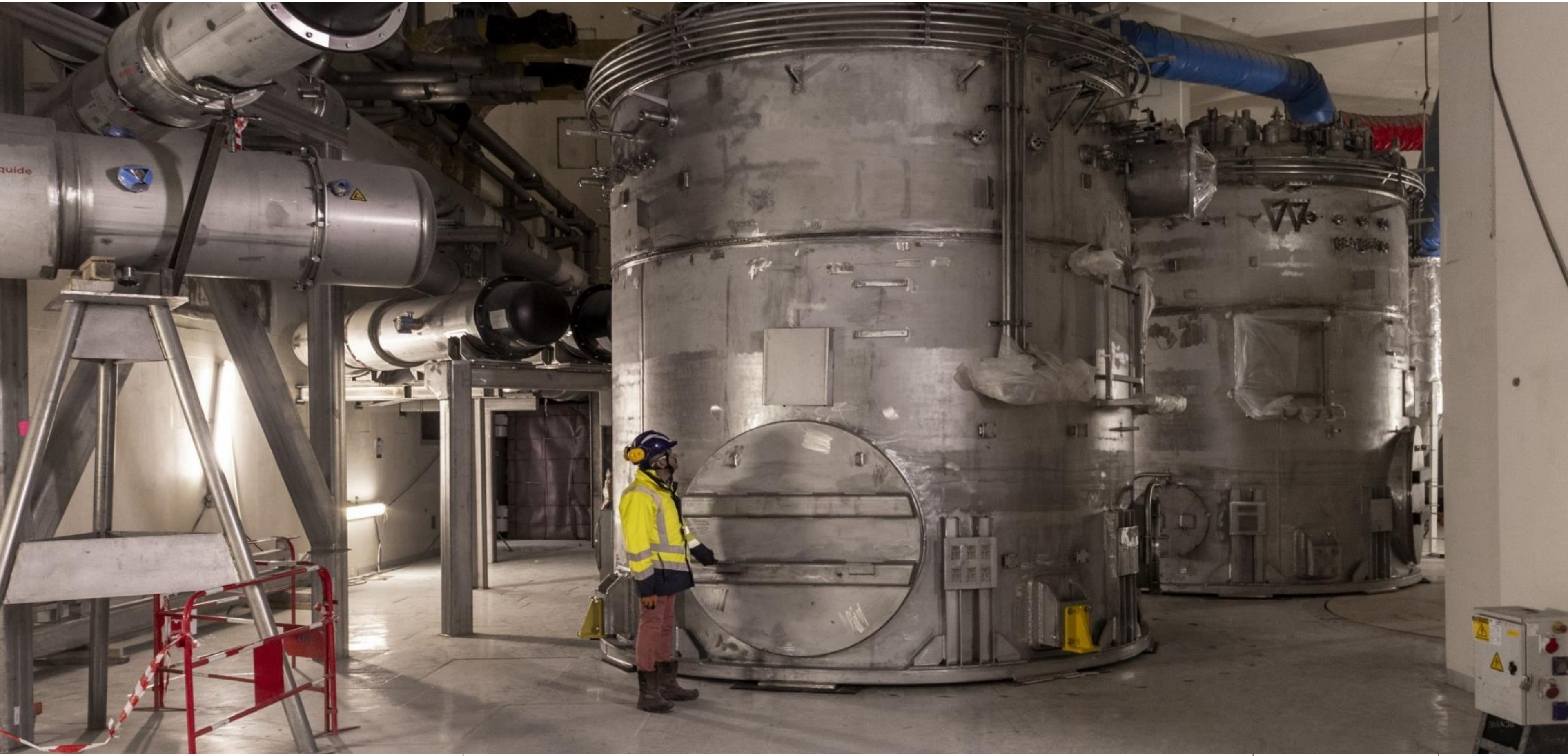
Cryogenic system – Cold box building – Helium Cold Boxes

Cryogenic system - Cryoplant area outside

Cryogenic system - Tokamak Building - Cryodistribution



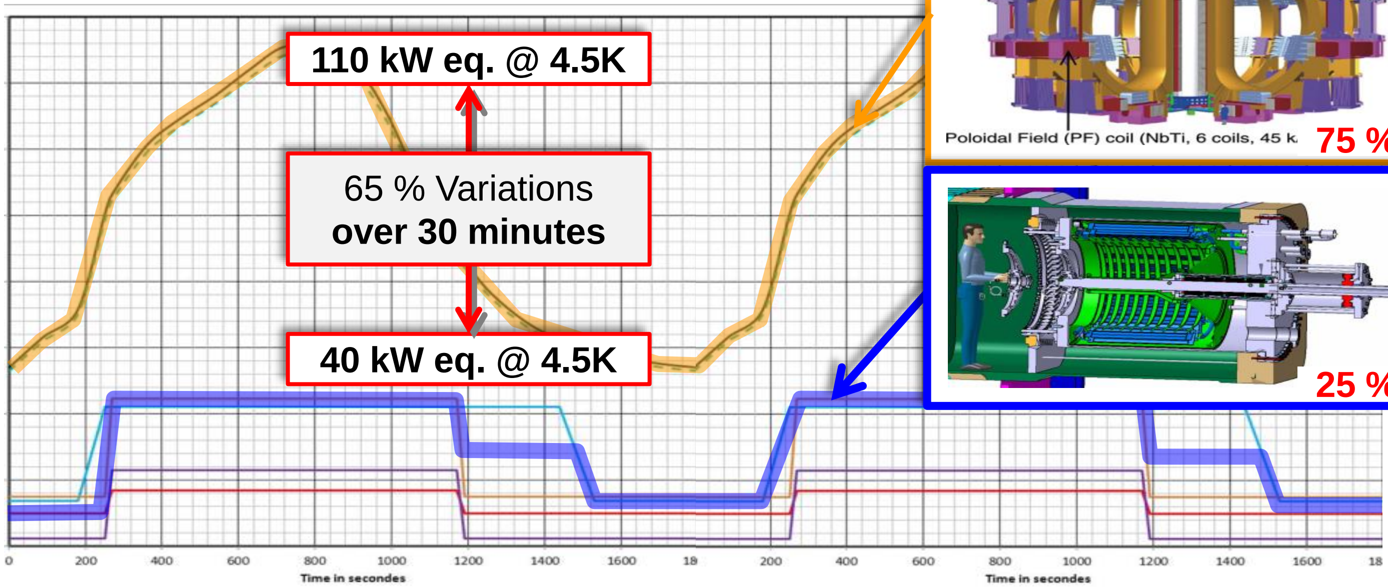
Cryogenic system - Auxiliary Cold Boxes



Cryogenic system - Main duties

- Cool-down of the cryostat and torus cryopumps
- Gradual cool-down and filling of the magnet system and the 80 K thermal shield in about one month
- Cool-down of the NB cryopumps, pellet units and gyrotrons
- 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

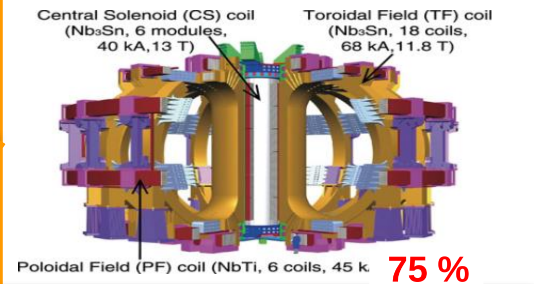
Cryogenic system - Particular large heat load variations



110 kW eq. @ 4.5K

65 % Variations
over 30 minutes

40 kW eq. @ 4.5K



75 %

25 %

Cryogenic system - Important heat loads due to high helium flow

- The magnet system is the main cryogenic users for tokamak ~70-80% of the cryogenic cooling power
- Recent Tokamak magnet system use CICC cooled by Supercritical Helium flow in the conductor jacket
- The conductor lengths are important and at about 1K temperature difference, the mass flow through the CICC creates important pressure drop.


JT-60SA TF CICC

PARAMETERS	KSTAR	JT-60SA	ITER
Mass flow rates for magnet system	2 loops of 300g/s	2 loops (900g/s - 1000g/s)	4 loops (btw 2000-2700g/s)
Pressure drop in magnets	~2.5 bar	~0.8 – 1.4 bar	~0.5-1.1bar
Approximative power dissipation from the ciculation pumps	1800 W	2200 W	10000 W

Important impact of cold circulators on the heat loads (≤30%)
Transit time of SHe flow inside coils ~ 1000s

Perspectives

- The commissioning of the Cryoplant has been started and will be completed in 2026.
- Following by the cryo-distribution and the commission together with the clients of the cryogenic system
- Test Facilities for cryopumps and magnets are currently in preparation.