Introduction to ITER

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ITER Organization

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Joint ICTP-IAEA Fusion Energy School
Trieste, Italy

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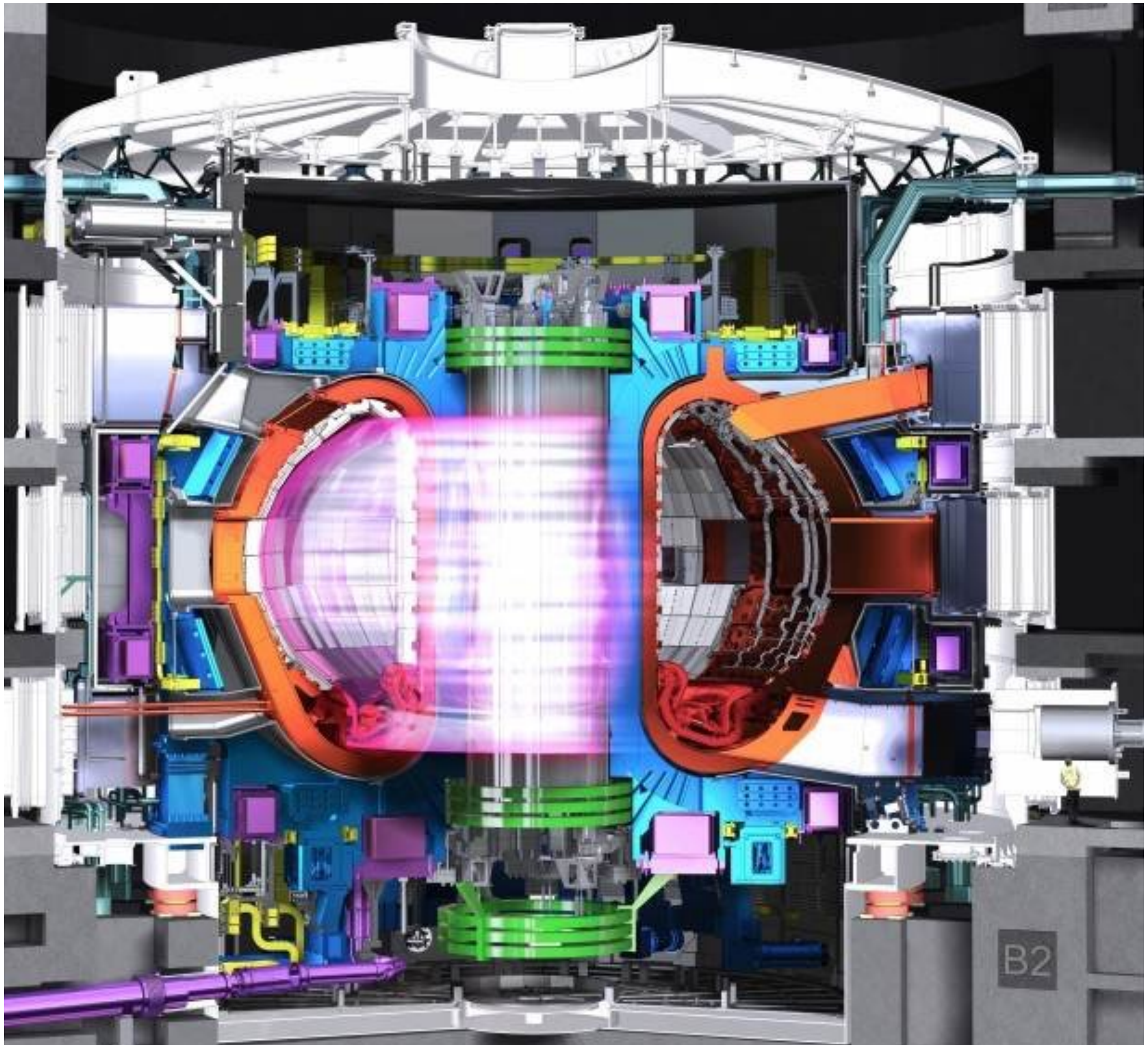
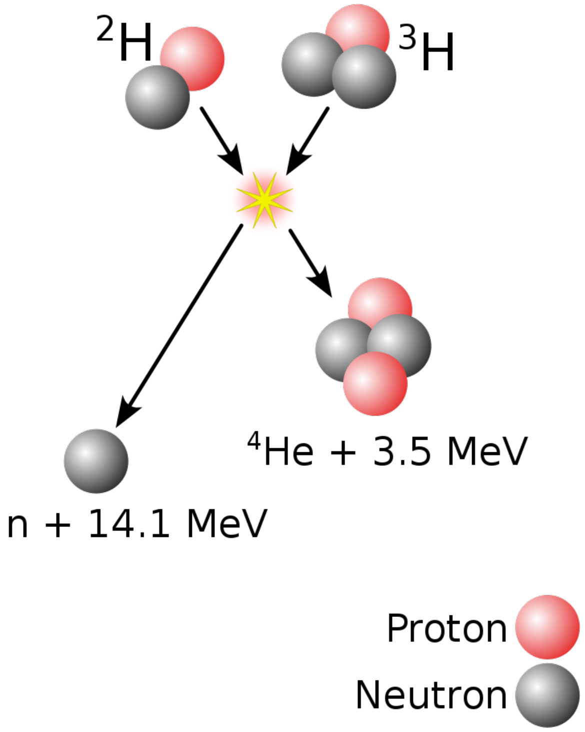
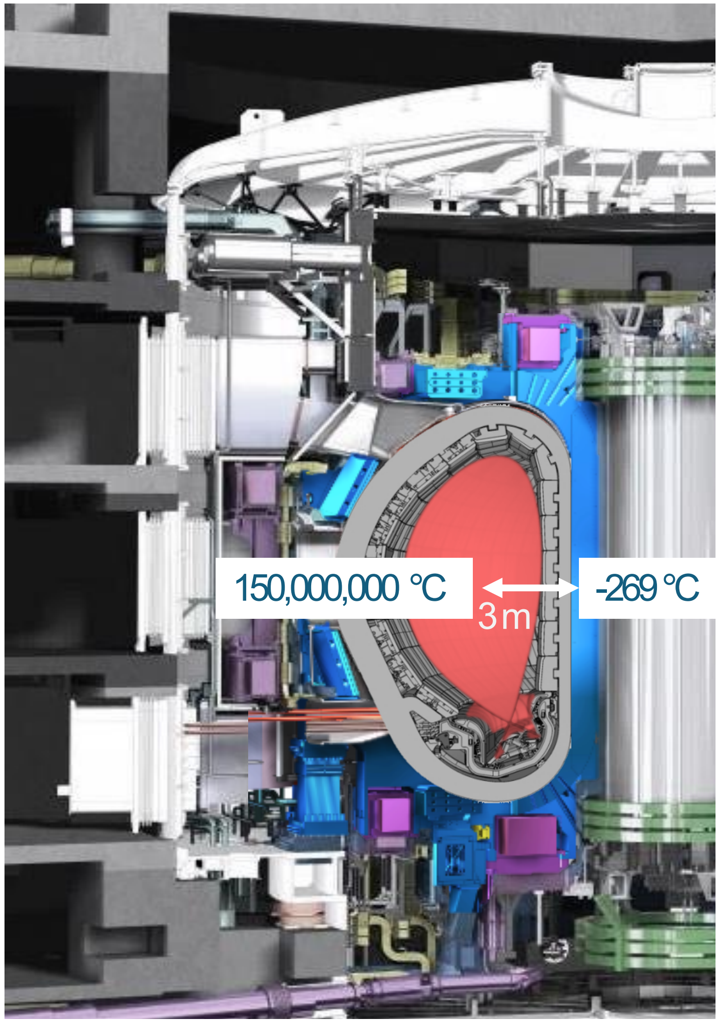
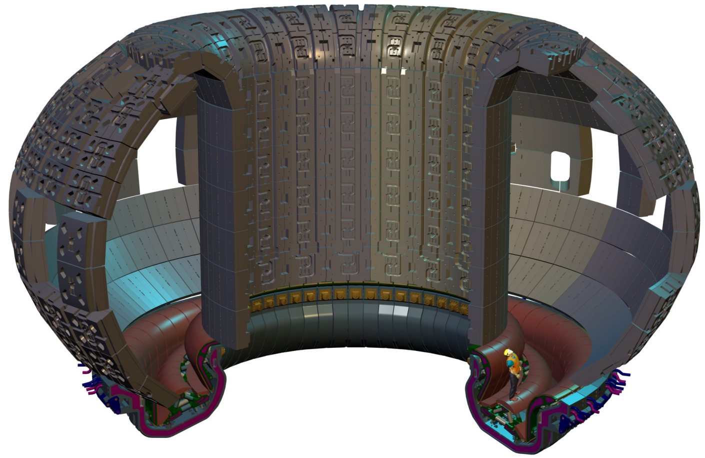
iter
china eu india japan korea russia usa



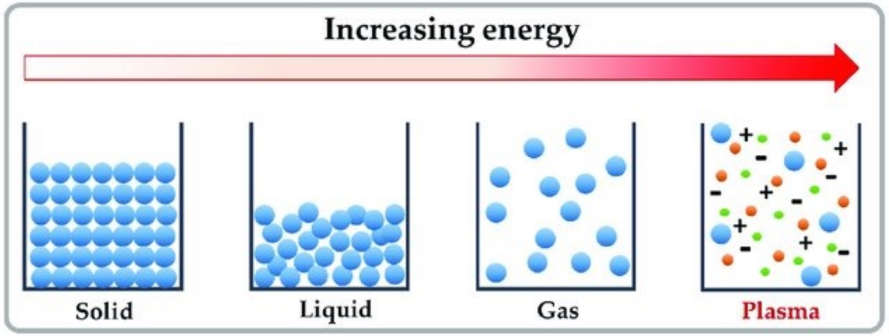
This presentation follows heat transfer processes in ITER.







Plasmas span a large range of Temperatures and densities

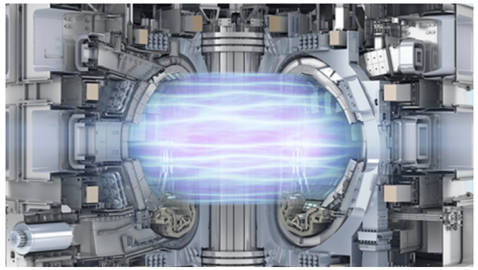


Cold plasma : neutrals >> ions ≈ electrons

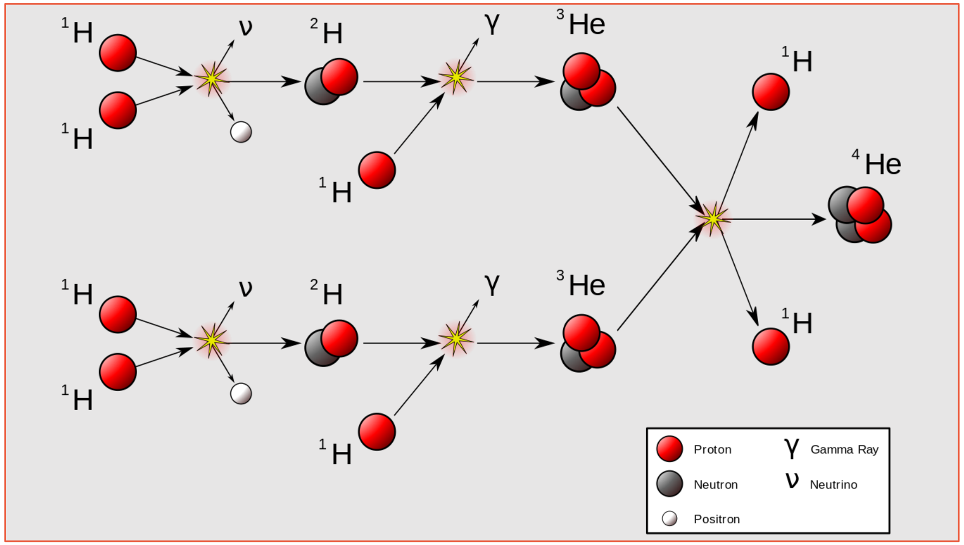
- **Aurora Borealis: 10^7 e^-/m^3, < 0.1 eV**
- **Gas discharge lamp: 10^{17} e^-/m^3 < 0.5 eV**

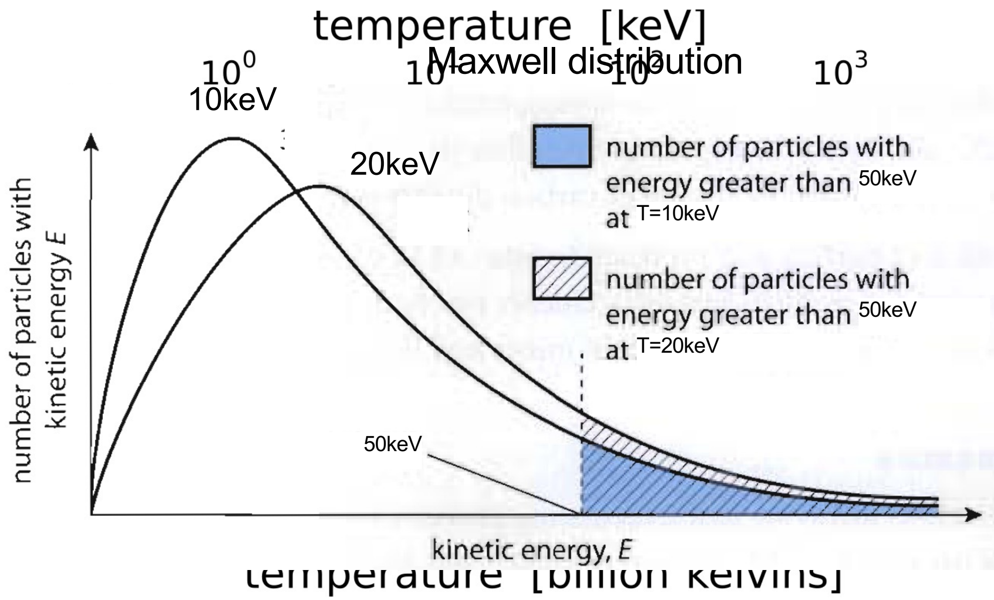
Hot plasma : neutrals << ions ≈ electrons

- **Sun (core): 10^{32} e^-/m^3, 1.2 keV**
- **ITER (core): 10^{20} e^-/m^3, 25 keV**



ITER plasmas are twenty times hotter than the Sun's core





Sun (core): 10^{32} e-/m3, 1.2 keV

- **Proton (^{1}H) fusion reaction chain**
- **Gravitational confinement: 28 g**

ITER (core): 10^{20} e-/m3, 25 keV

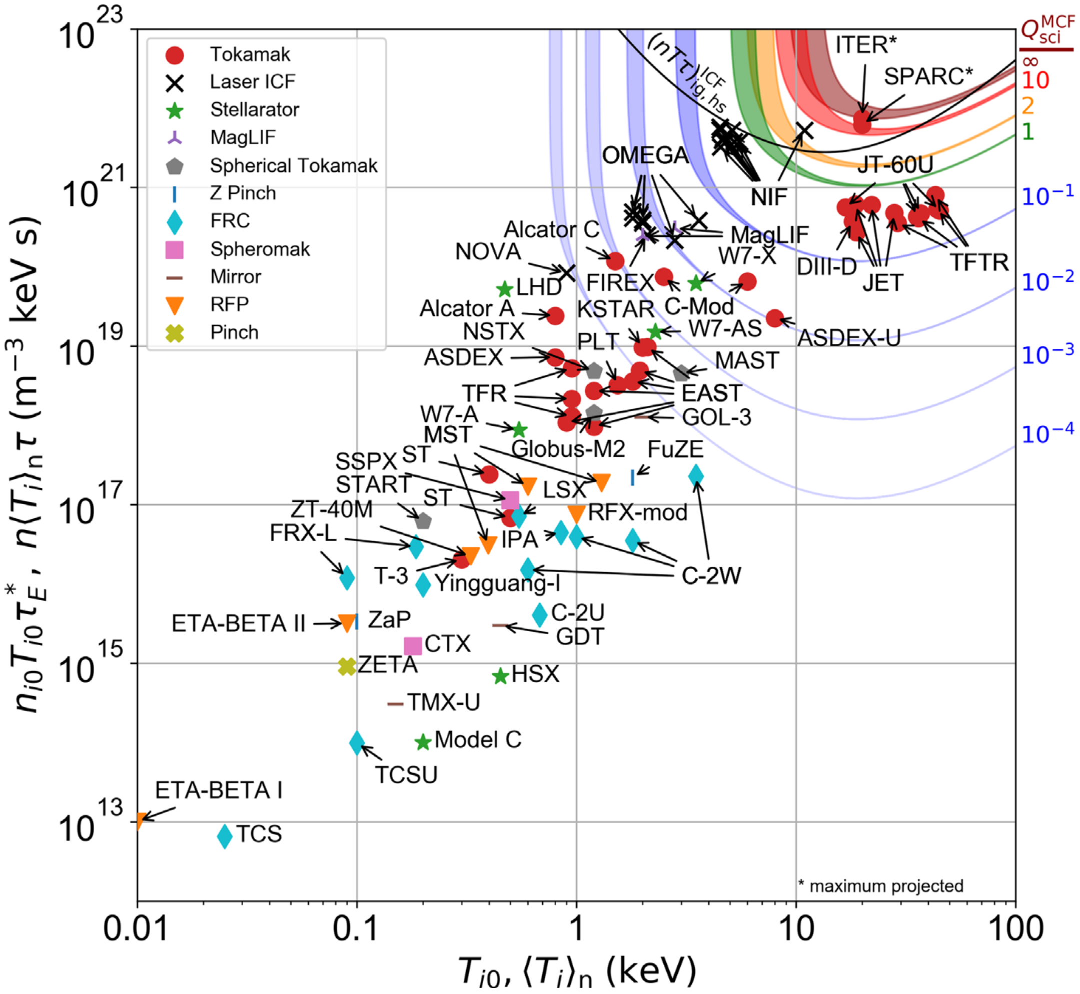
- **Deuterium (^{2}H) -Tritium (^{3}H) fusion**
- **Magnetic confinement: 5.3 T**

Fusion performance is characterized by the triple product of density, temperature and confinement time.

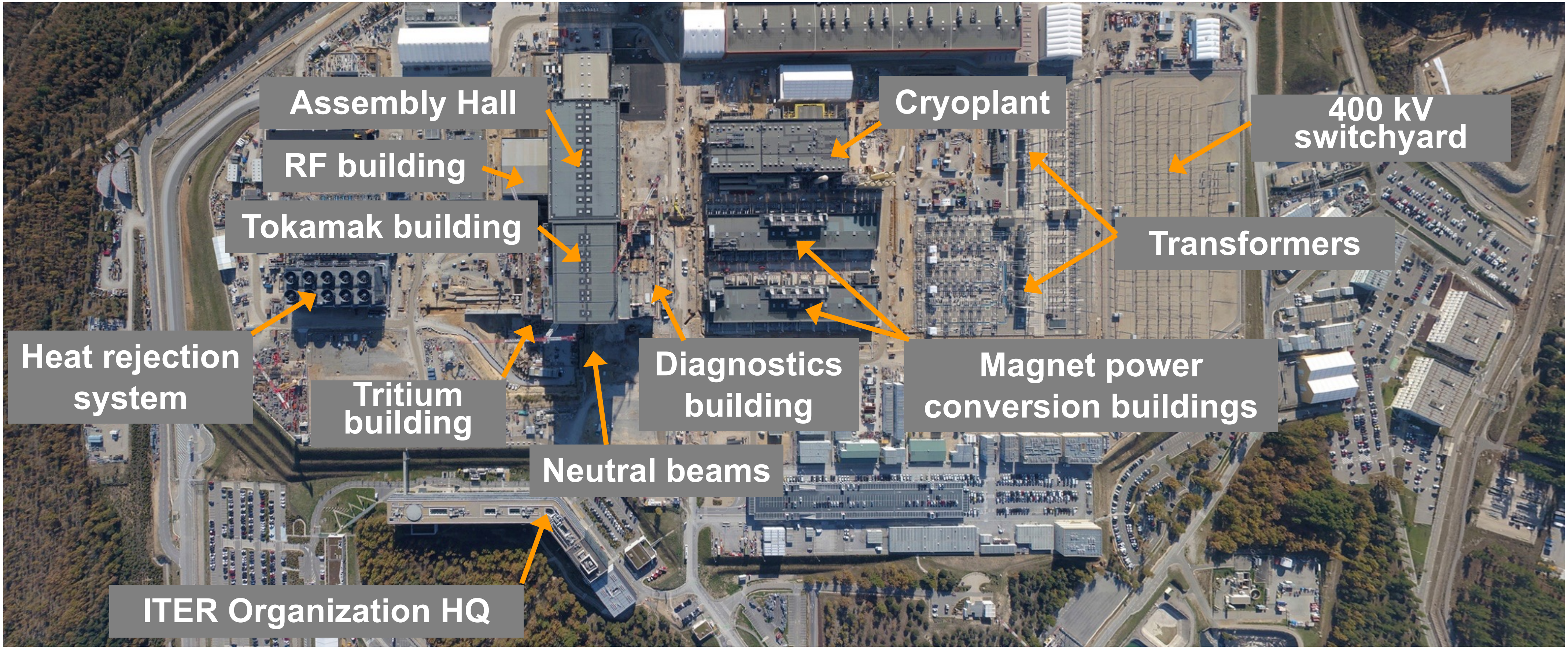
To achieve high Q >5 requires hot >10 keV plasmas with sufficient density that keep energy for sufficiently long time

Fusion technology demonstration:

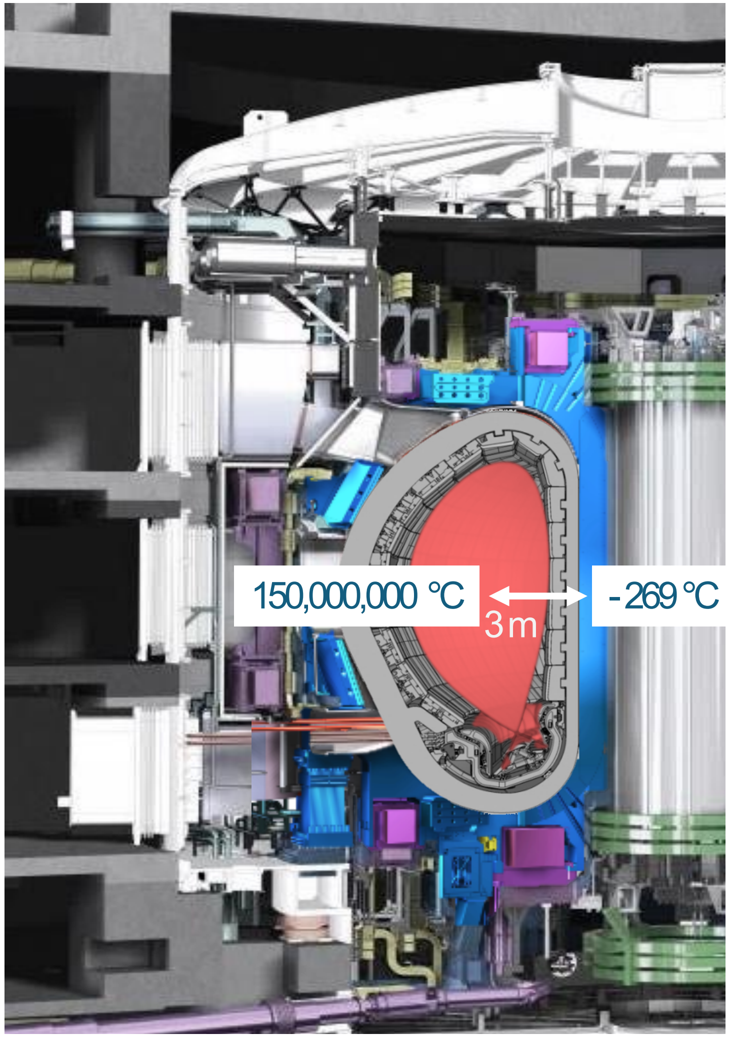
- Superconducting magnets
- Plasma facing components
- H&CD
- Tritium breeding



Our mission is to demonstrate the scientific and technical feasibility of fusion power for peaceful purposes.



ITER will see the largest *steady* temperature gradient in the universe.



Plasma core: 150,000,000 °C

Blanket / Divertor: 550 °C

Vacuum Vessel : 100 °C

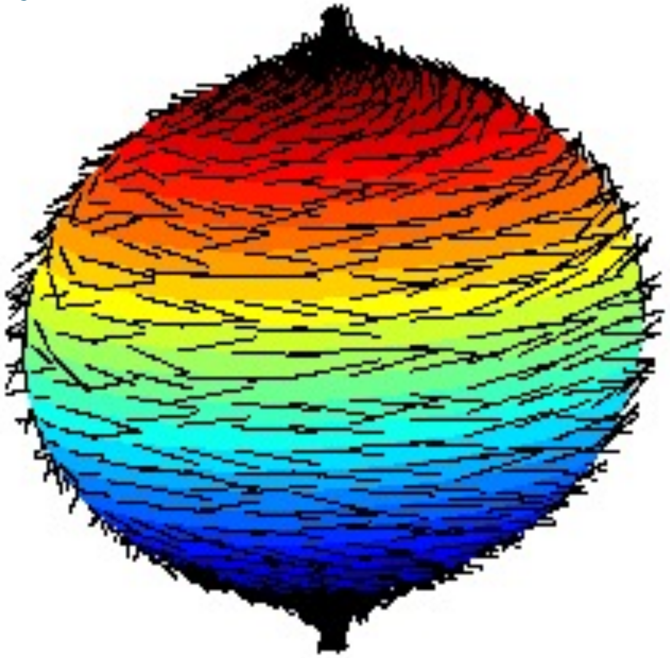
Thermal Shield : -193 °C

Superconducting Magnet : -269 °C

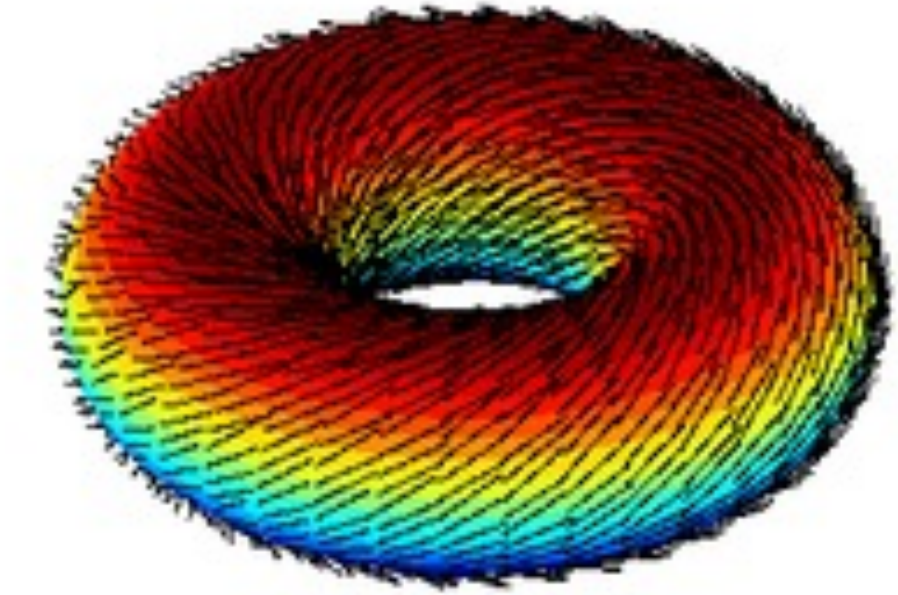
Toroidal magnetic topology used to confine charged particles.

At high temperatures Deuterium and Tritium atoms ionize to form a charged plasma which may be contained by magnetic fields.

Hairy ball

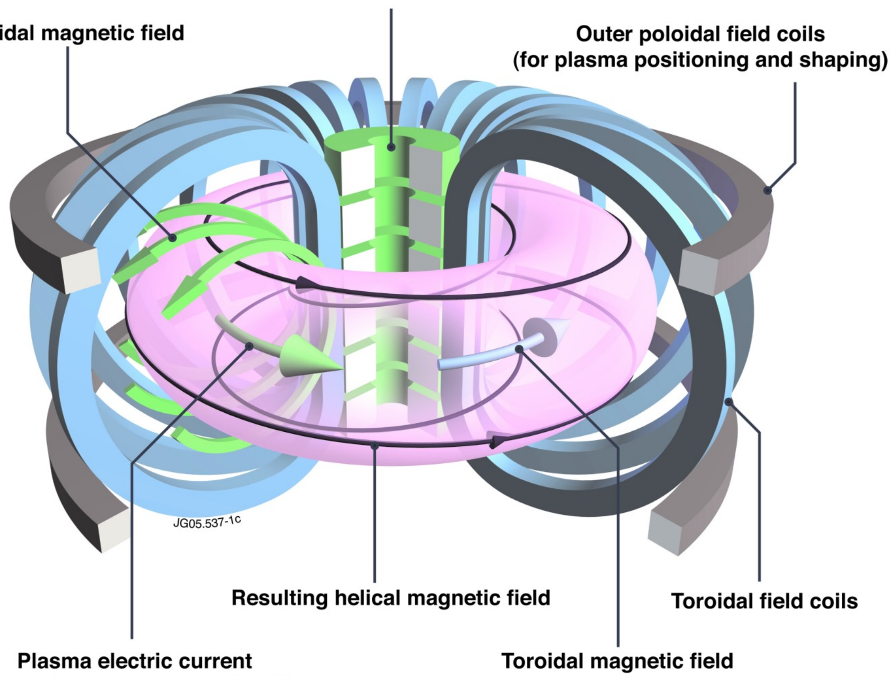


Hairy torus



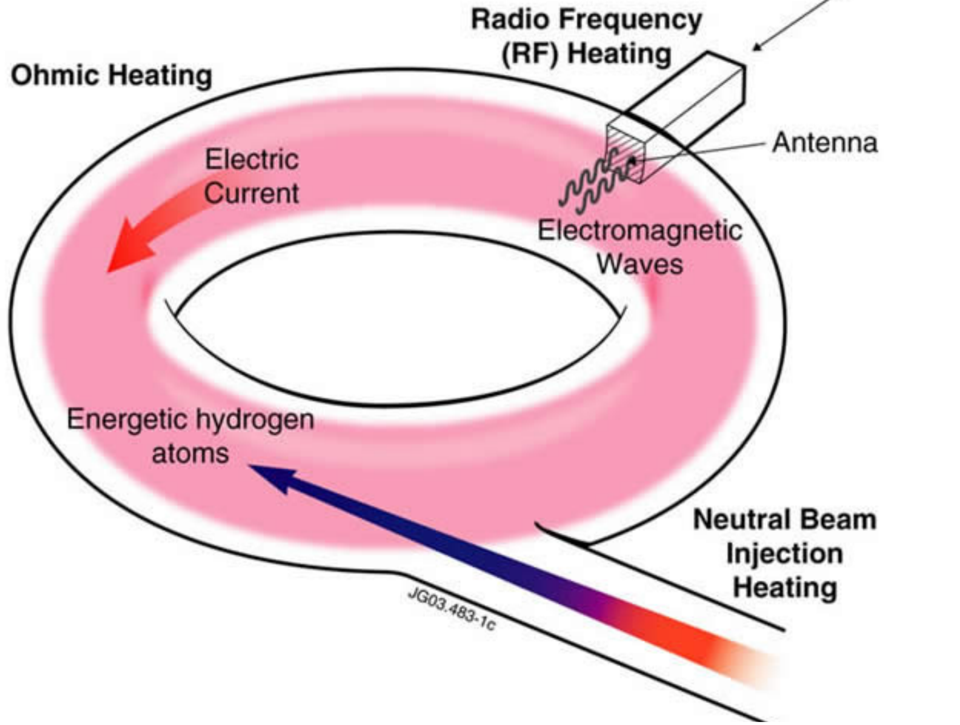
External heat sources are required to attain target plasma temperatures of 150,000,000 °C.

Ohmic heating is insufficient at high temperatures

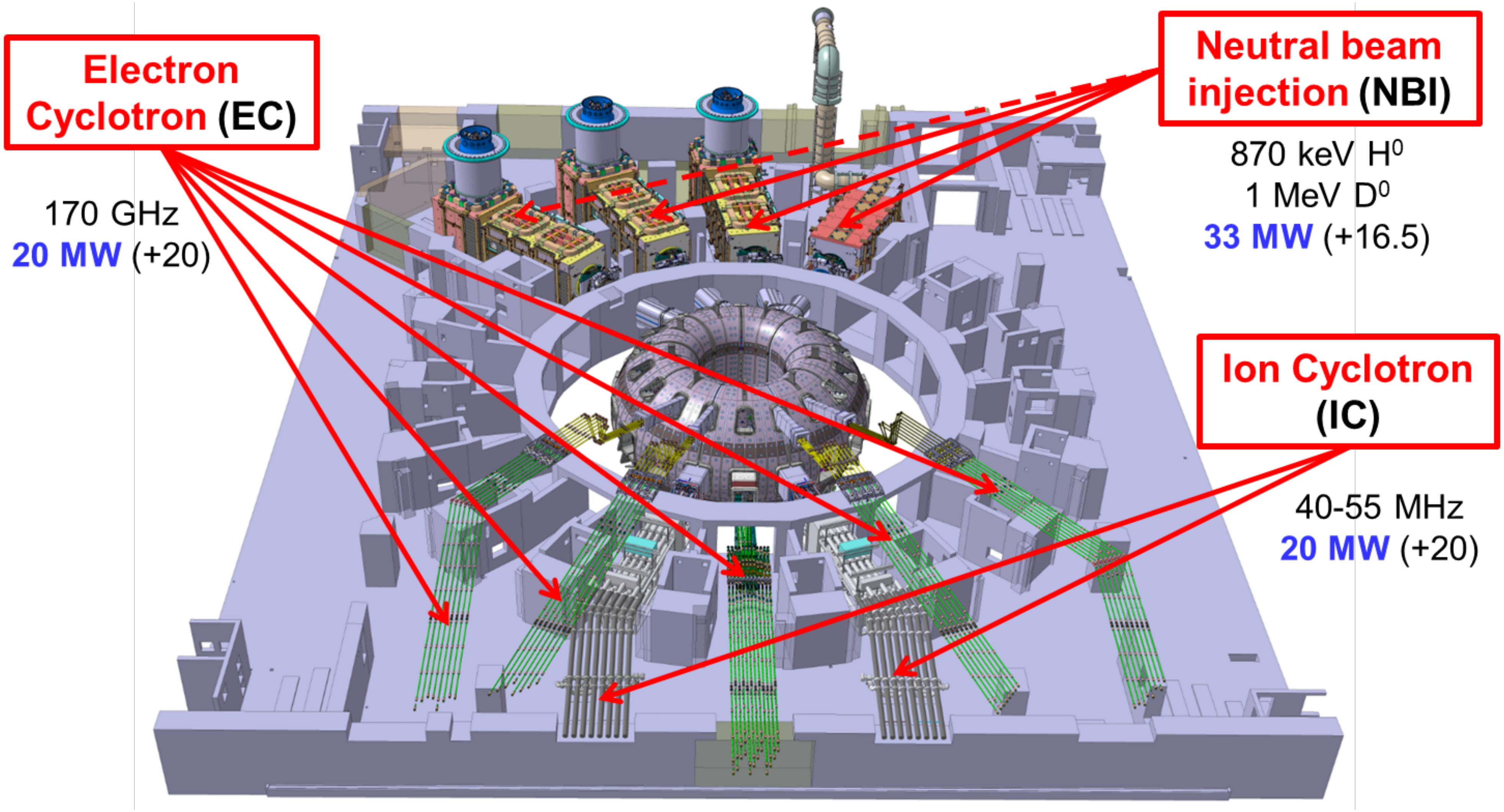


R. A. Pitts et al., Physics World 19 (2006) 20

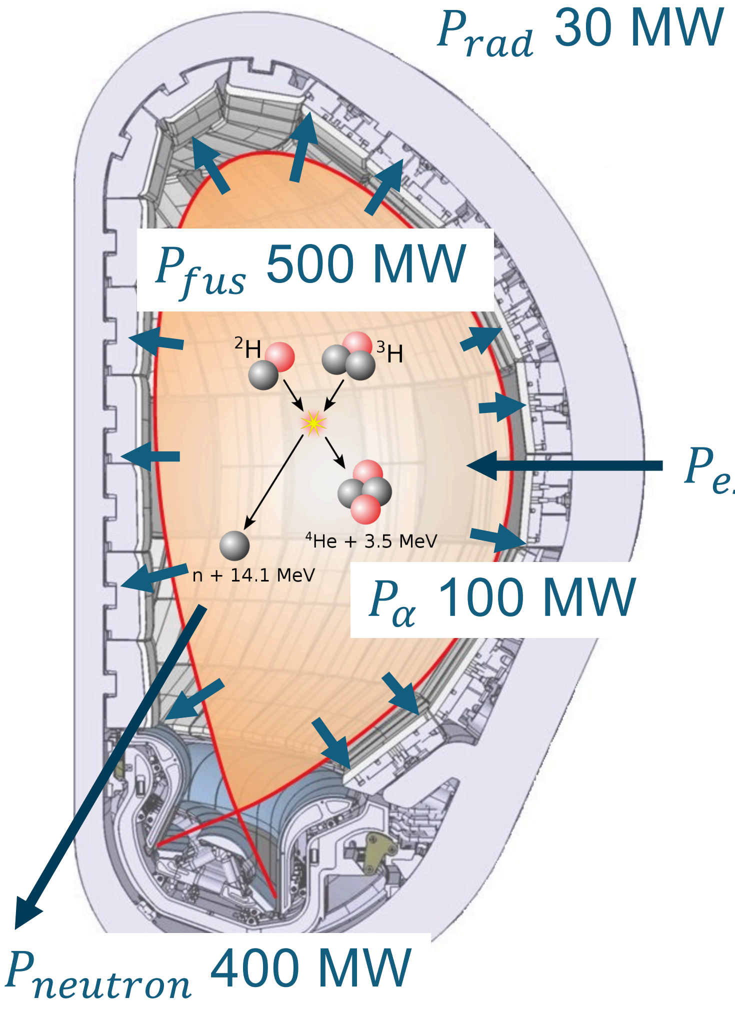
Complement with neutral beams and RF heating

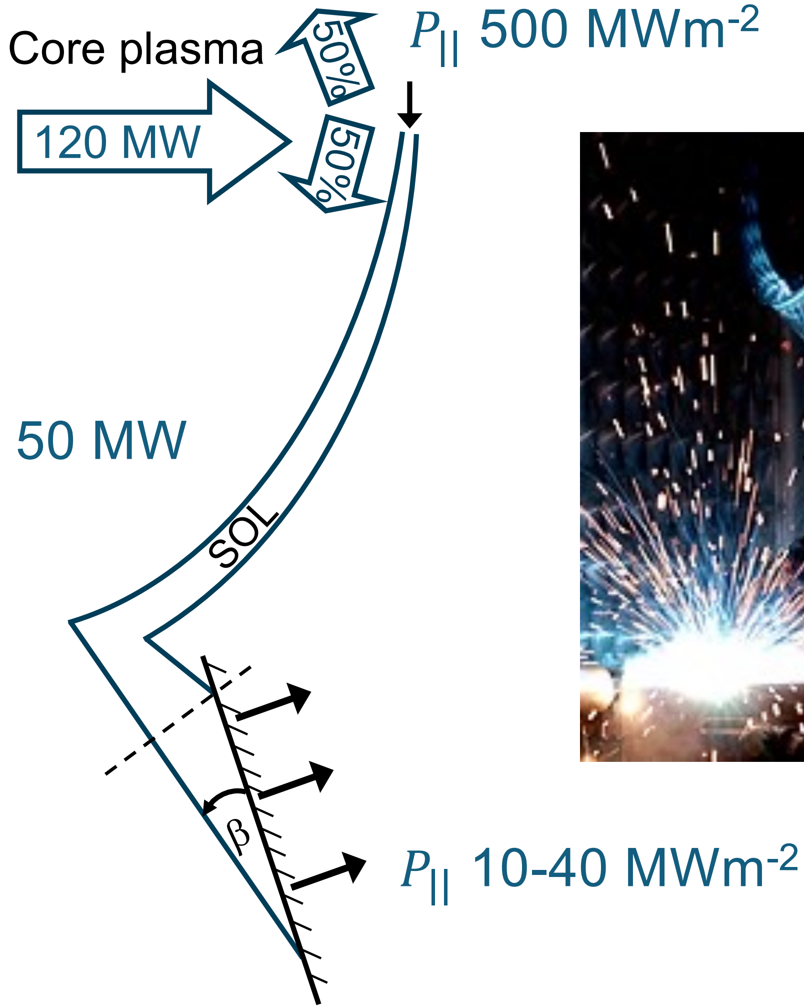


Neutral beams and EC and IC provide additional heat sources.

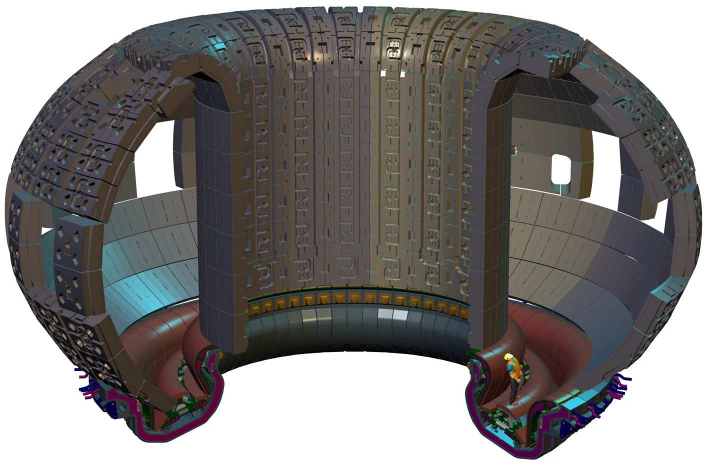


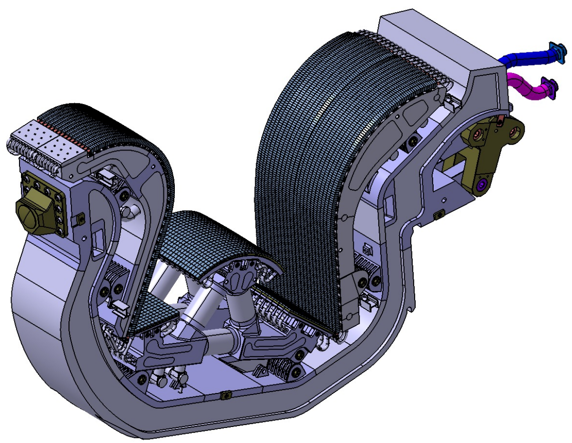
Controlling the flow of heat from the plasma is crucial.

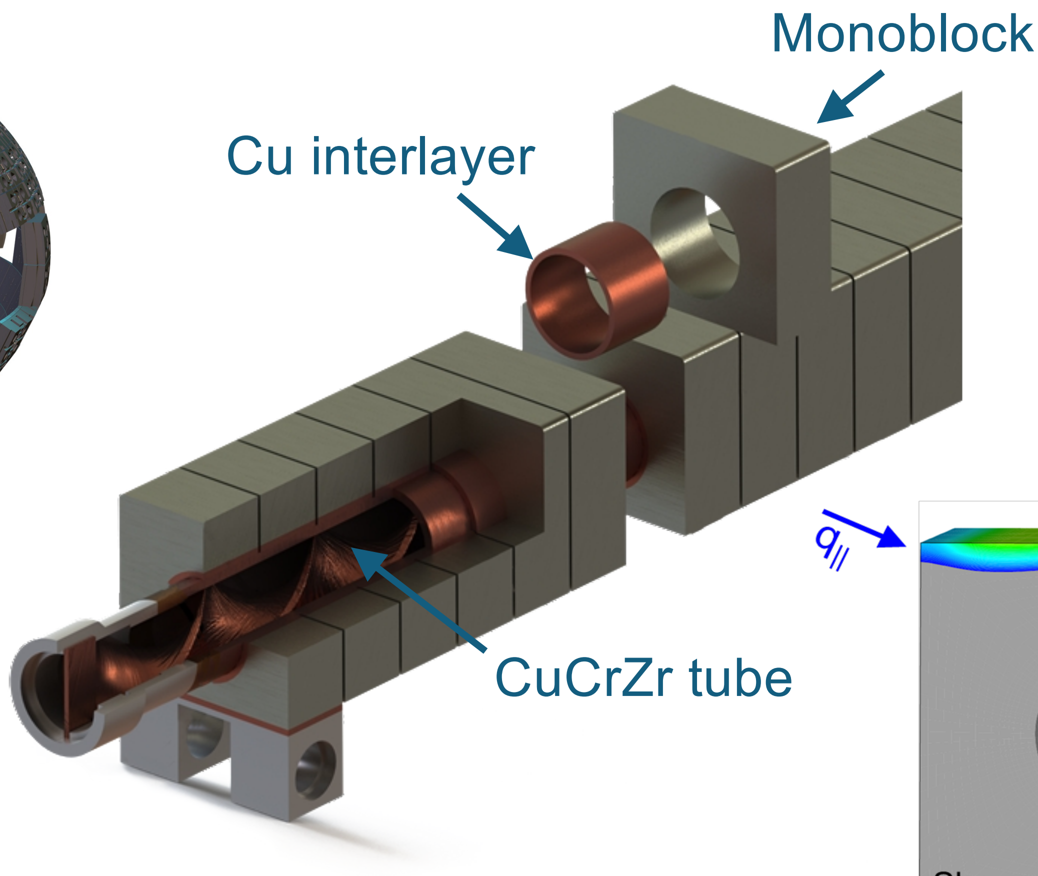


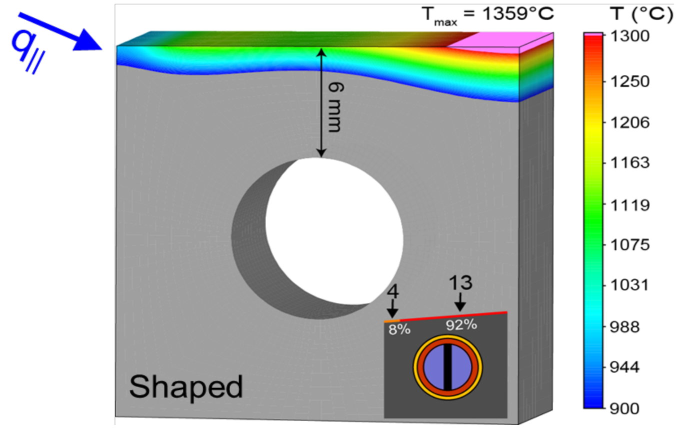


Components designed to handle high heat fluxes line the divertor.



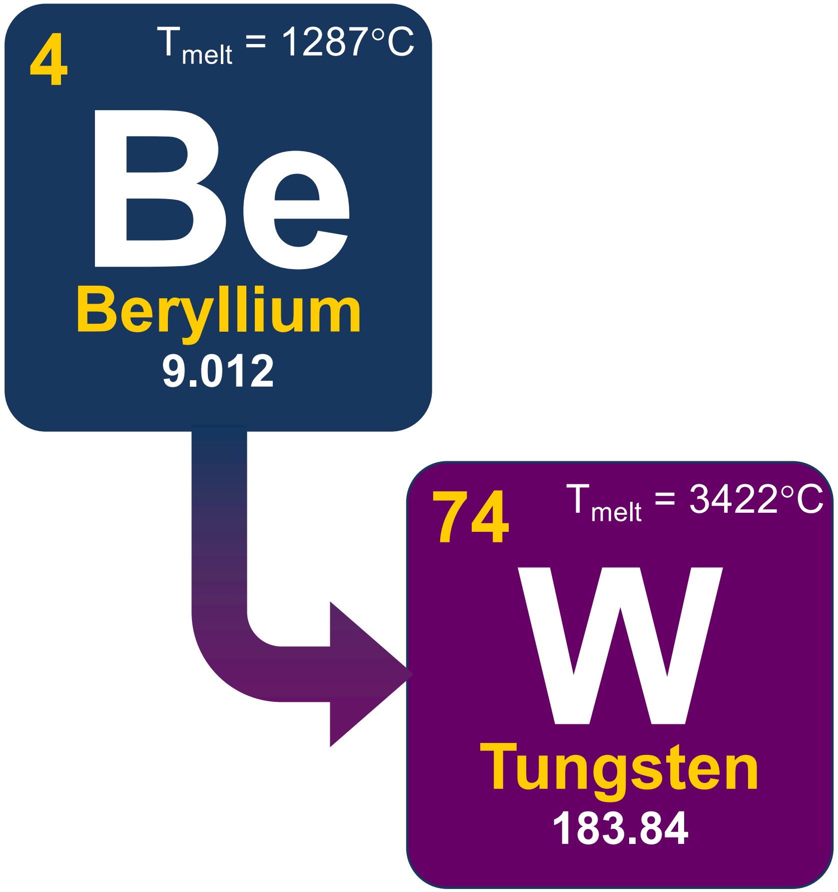






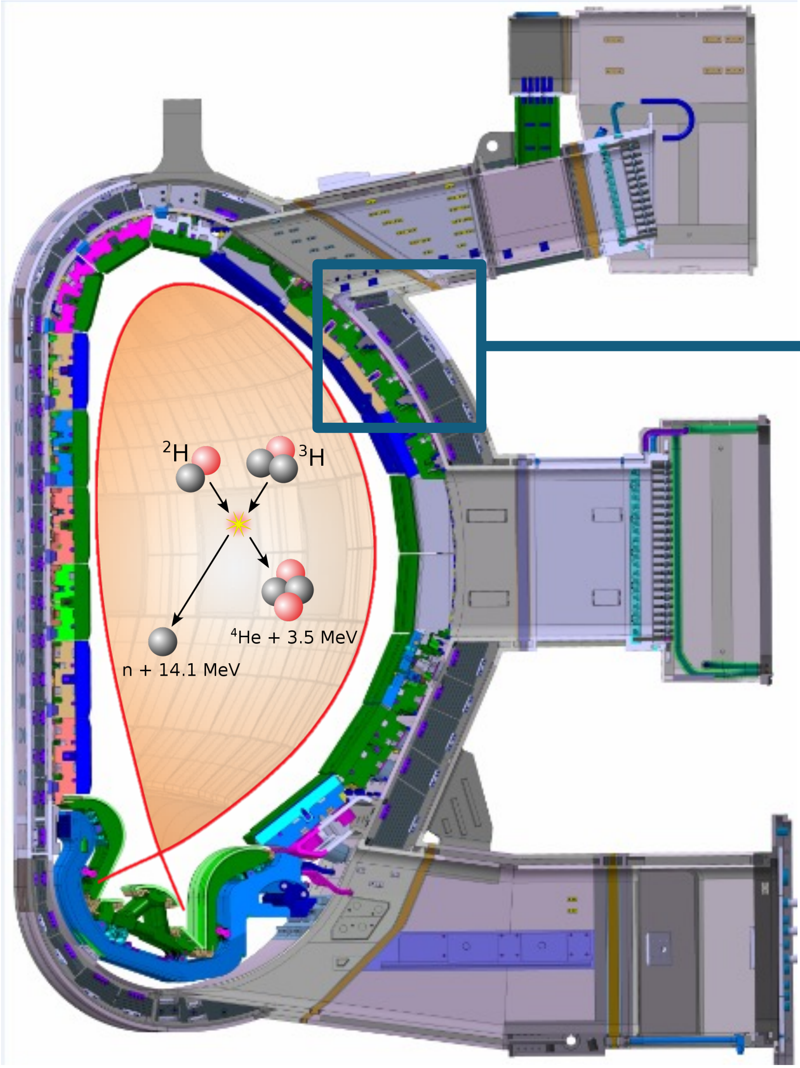
Why change to a tungsten first wall?

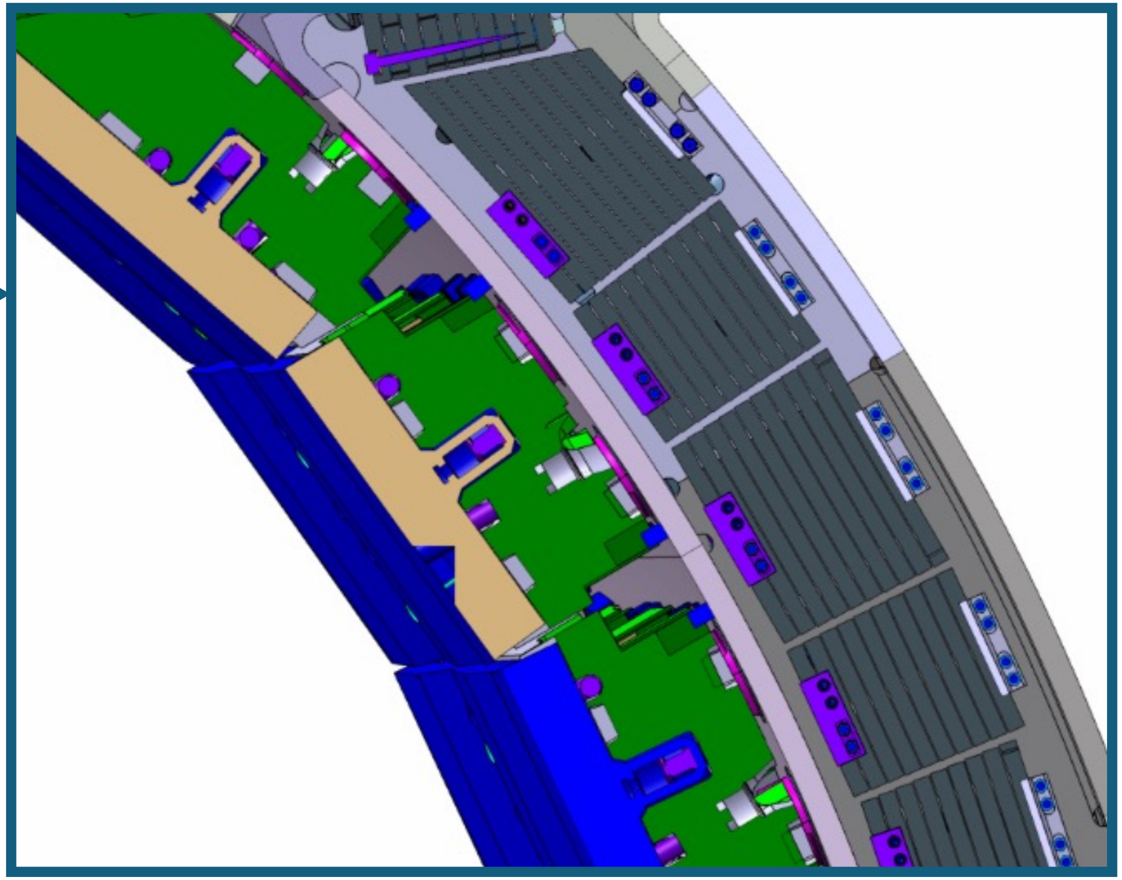
- Physics basis for tokamak operation with W walls is much stronger than it was at start of ITER construction
- Several issues with Be as PFC:
  - Erosion lifetime
  - Tritium retention in co-deposits
  - Low melting point → lower margin in I_p before potential “gap bridging” on FW panels (disruption current quench)
- Major benefit in assembly complexity and avoid costly later wall changeout



R.A. Pitts NME 2025

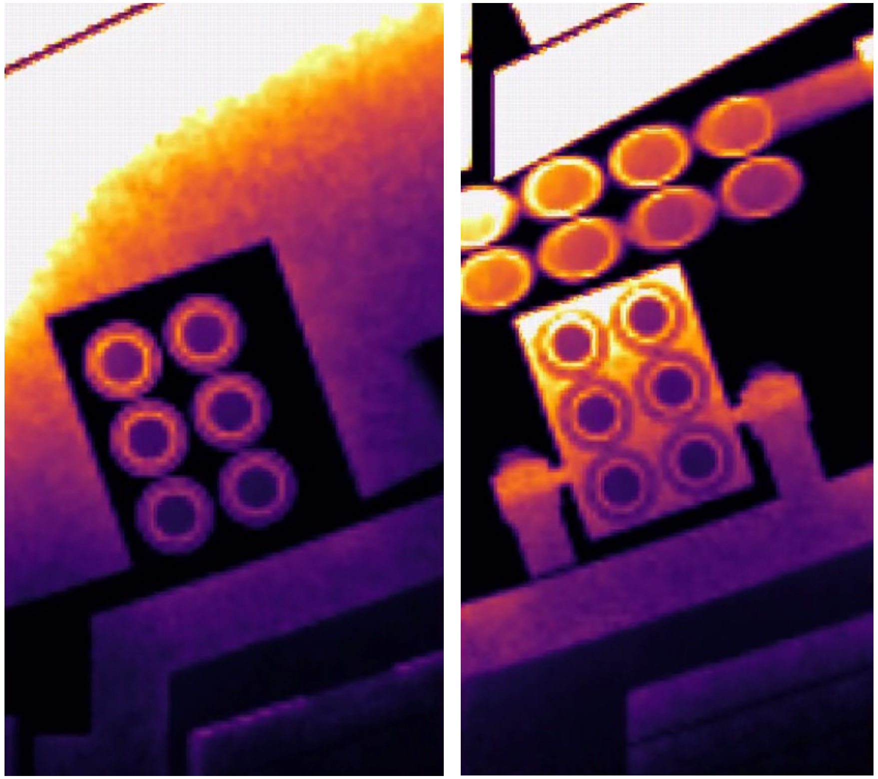
Neutronic shielding protects superconducting coils and diagnostics.



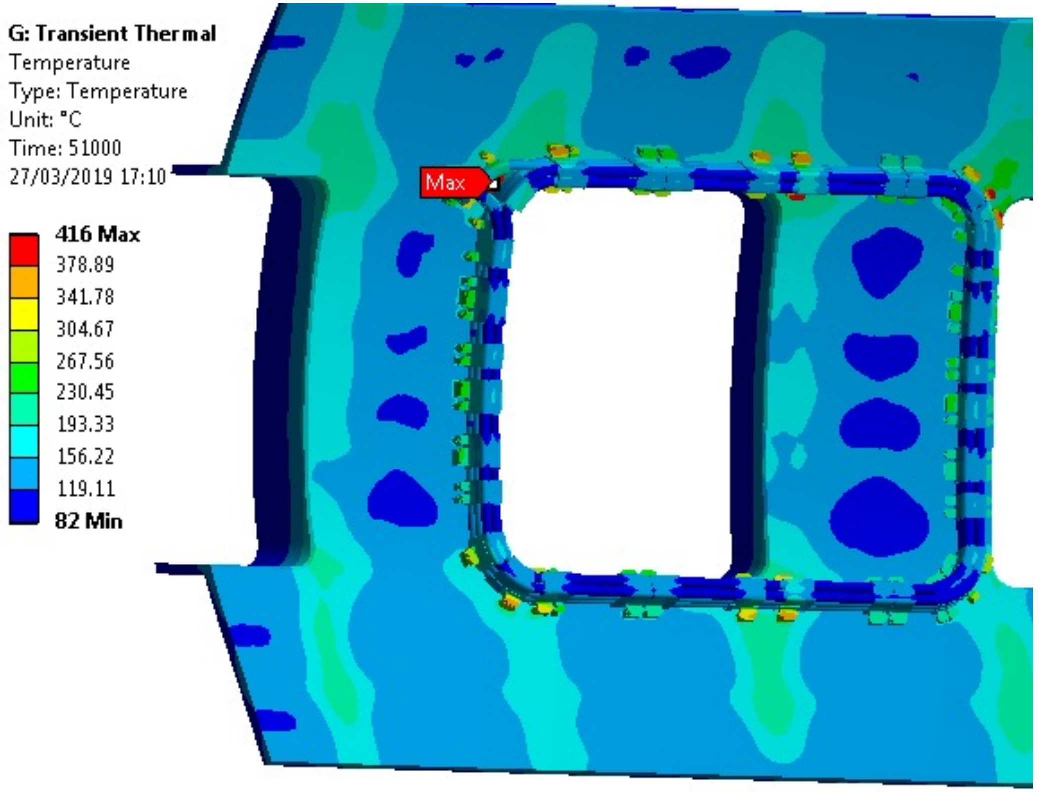


Gaps in blanket shield blocks generate inhomogeneous heat loads.

Neutron heat source maps across two poloidal slices of an ELM coil (right)

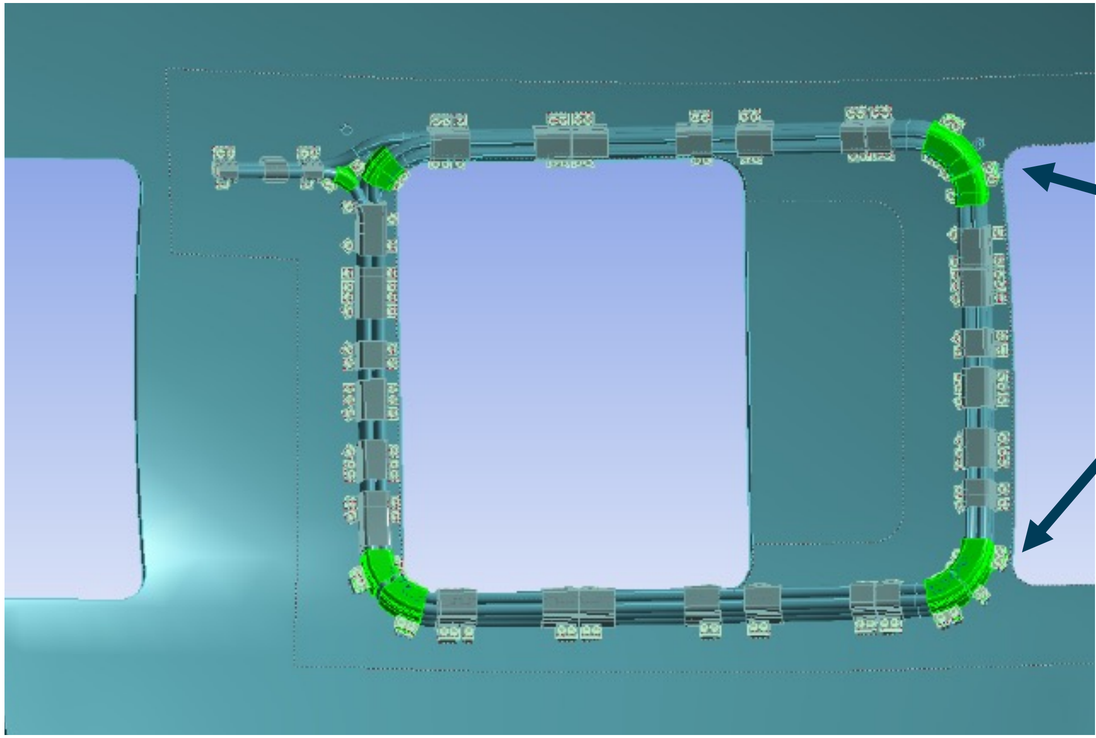


Vessel and ELM coil temperature map

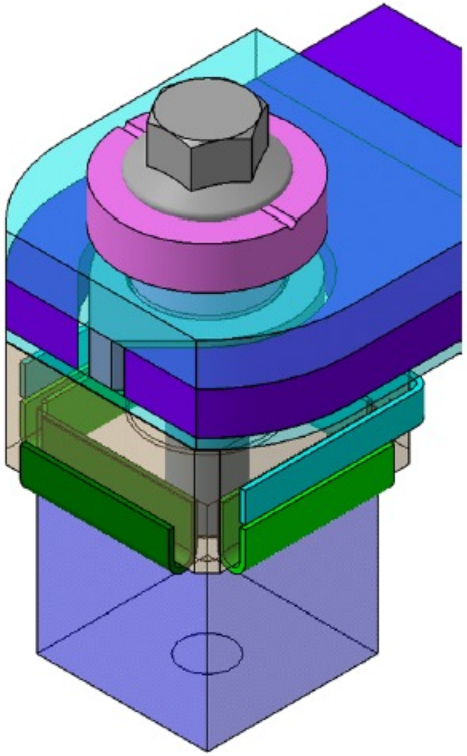


Thermal loads drive the design of many in-vessel components.

ELM coil mounted to inner vessel shell

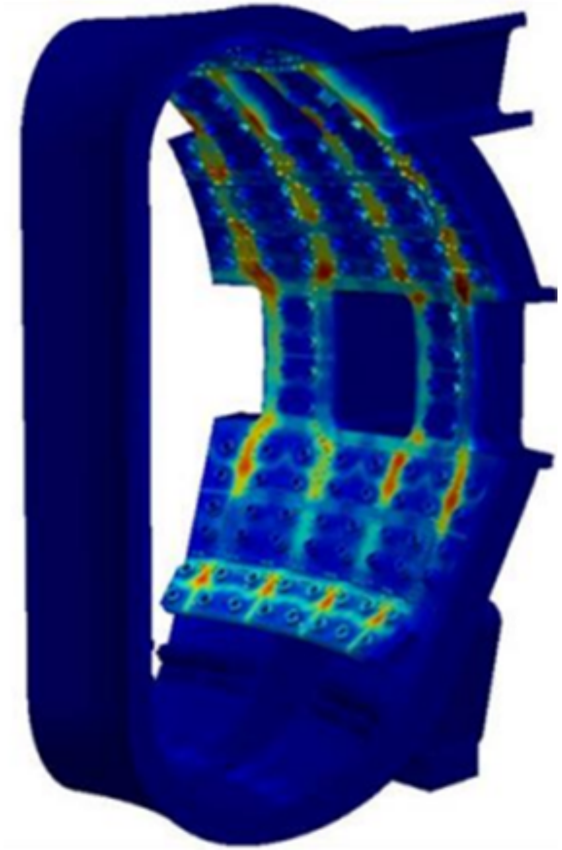


Ccompliant fixings developed to handle heat loads



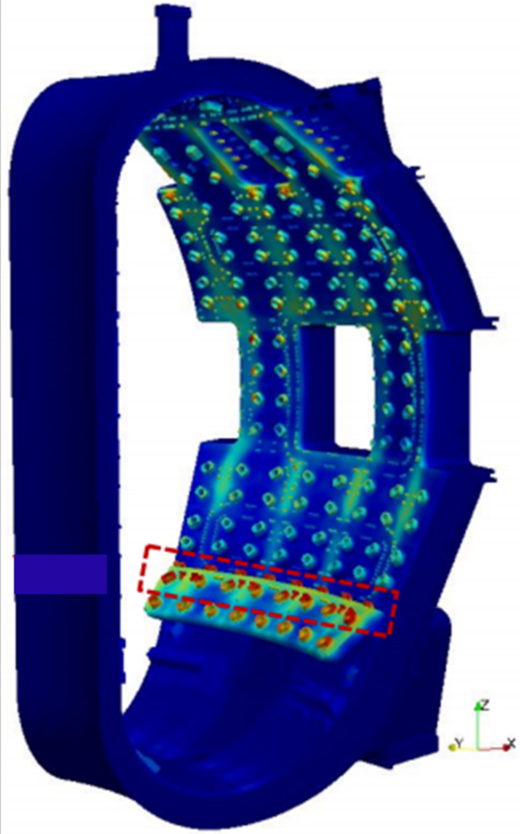
Active water cooling removes neutronic heat loads from the vessel .

Neutronic heat source

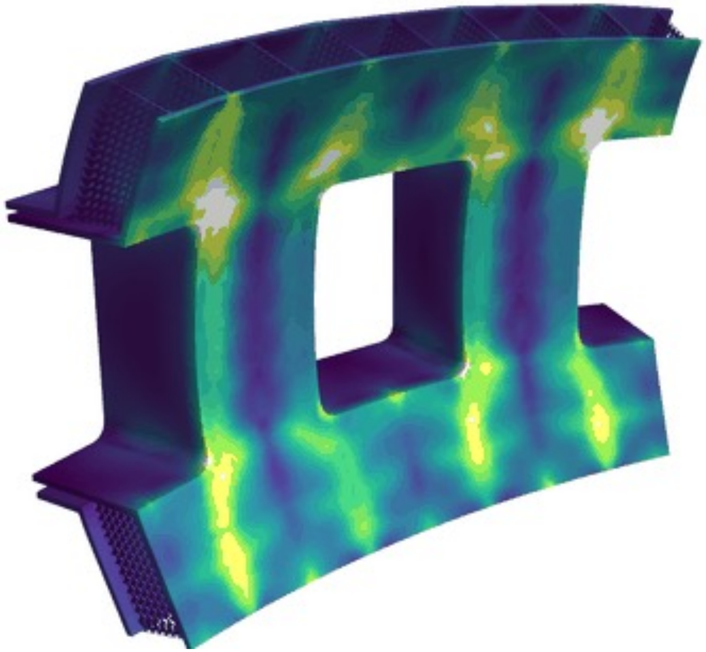


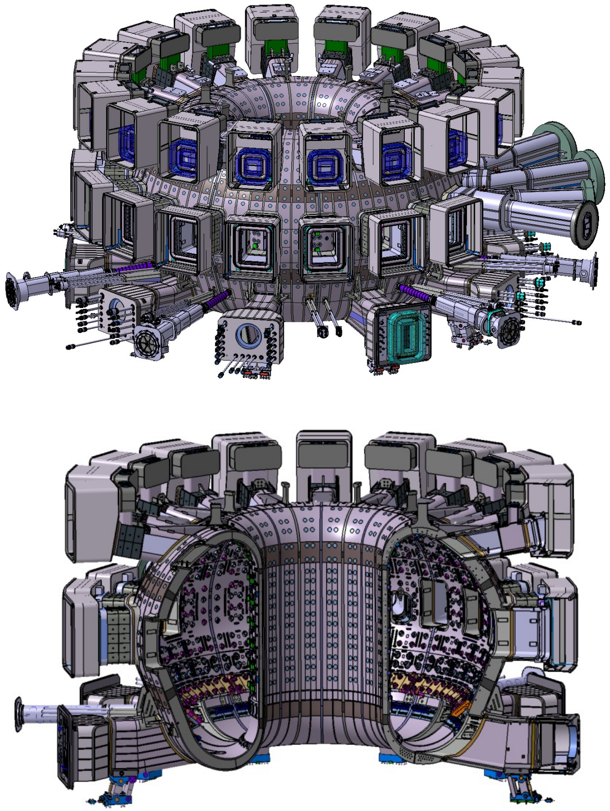
Active water cooling

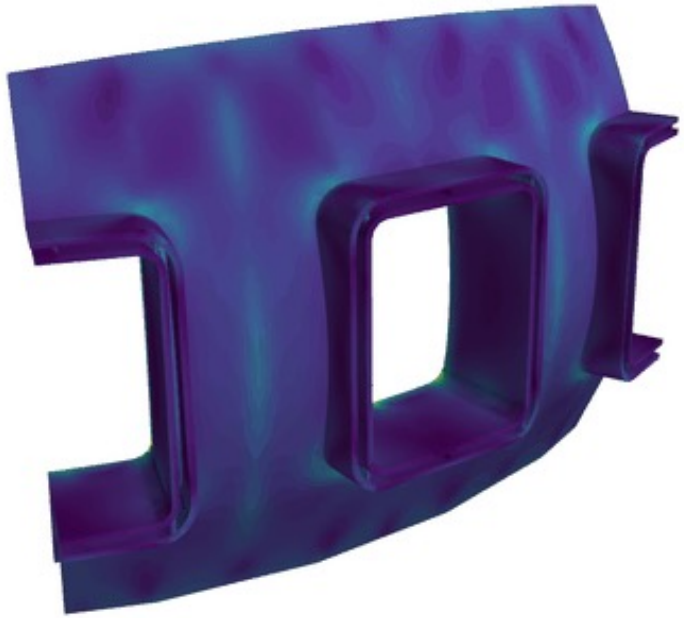
Vessel temperature



Differences in neutronic heat generation between inner and outer vessel shells generate large thermally generated vessel loads.





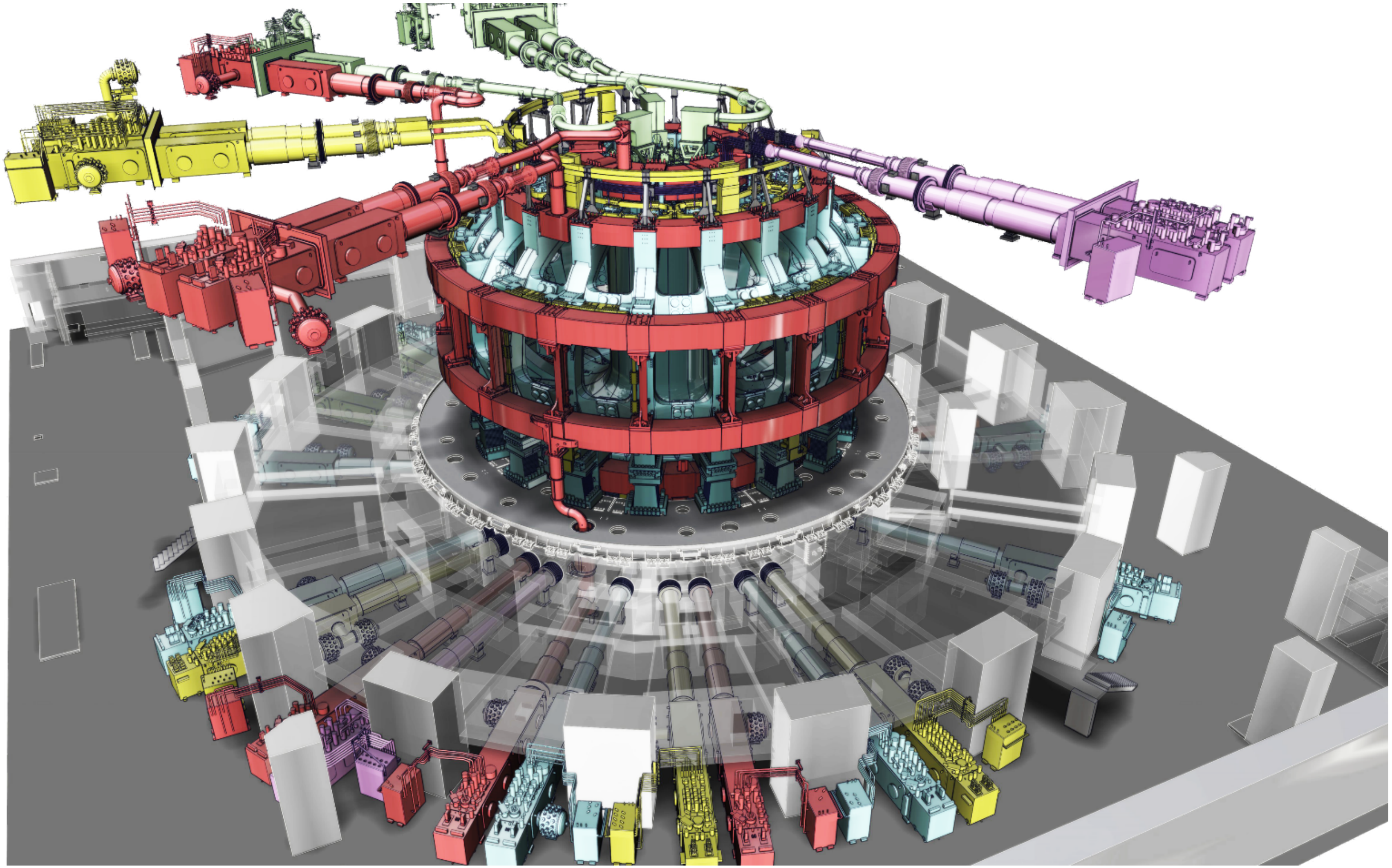


magnification x200

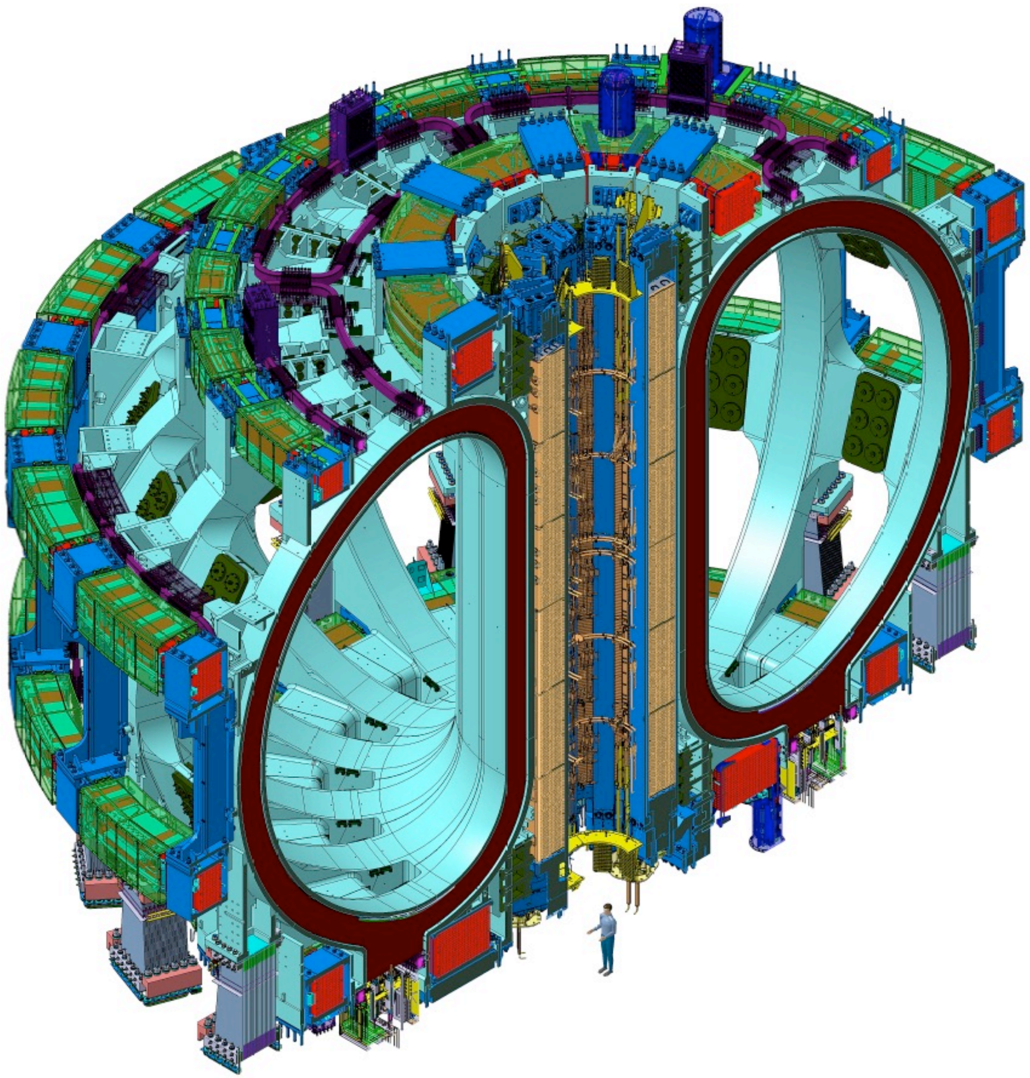
Thermal shields protect magnets from vessel, pipe, and cryostat radiation

Thermal shields are cooled to 80K and manufactured with a low emissivity surface.

Superconducting magnets will be necessary for any future plant.

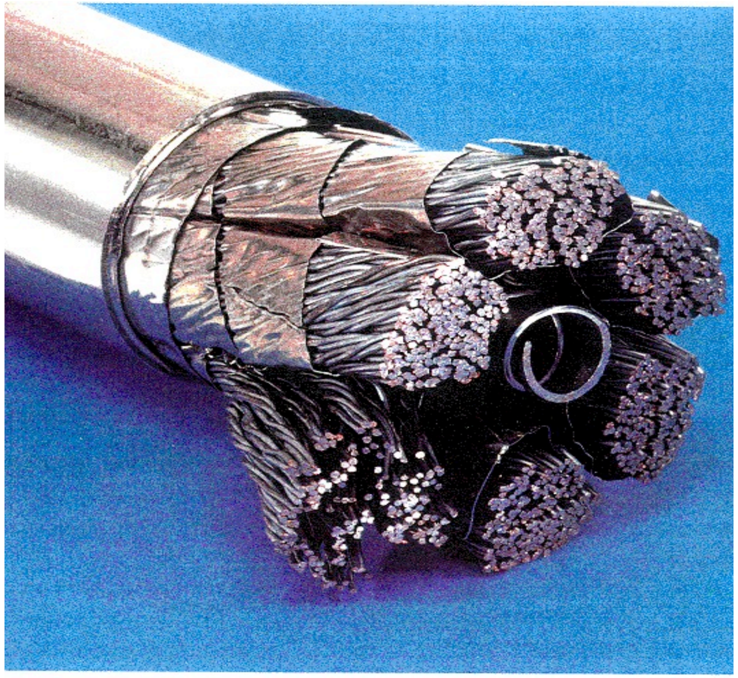


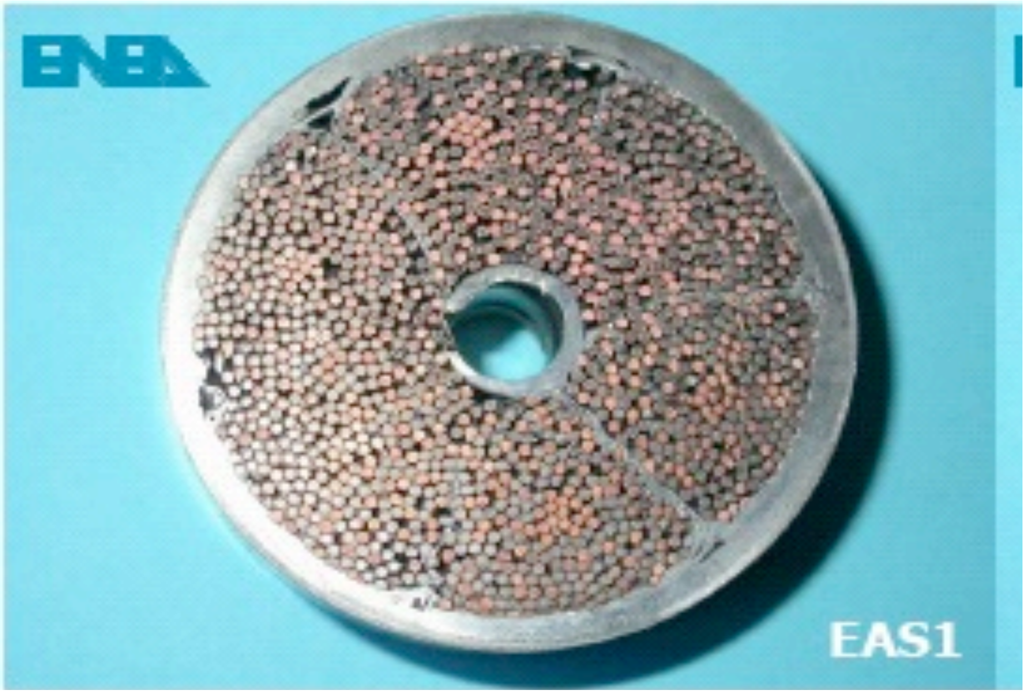
The ITER superconducting magnet system comprises 48 separate coils.



Superconducting strand is actively cooled using supercritical He.

Fluctuating fields and Ohmic losses at conductor joints generate unwanted heat which must be removed to maintain low strand temperatures.



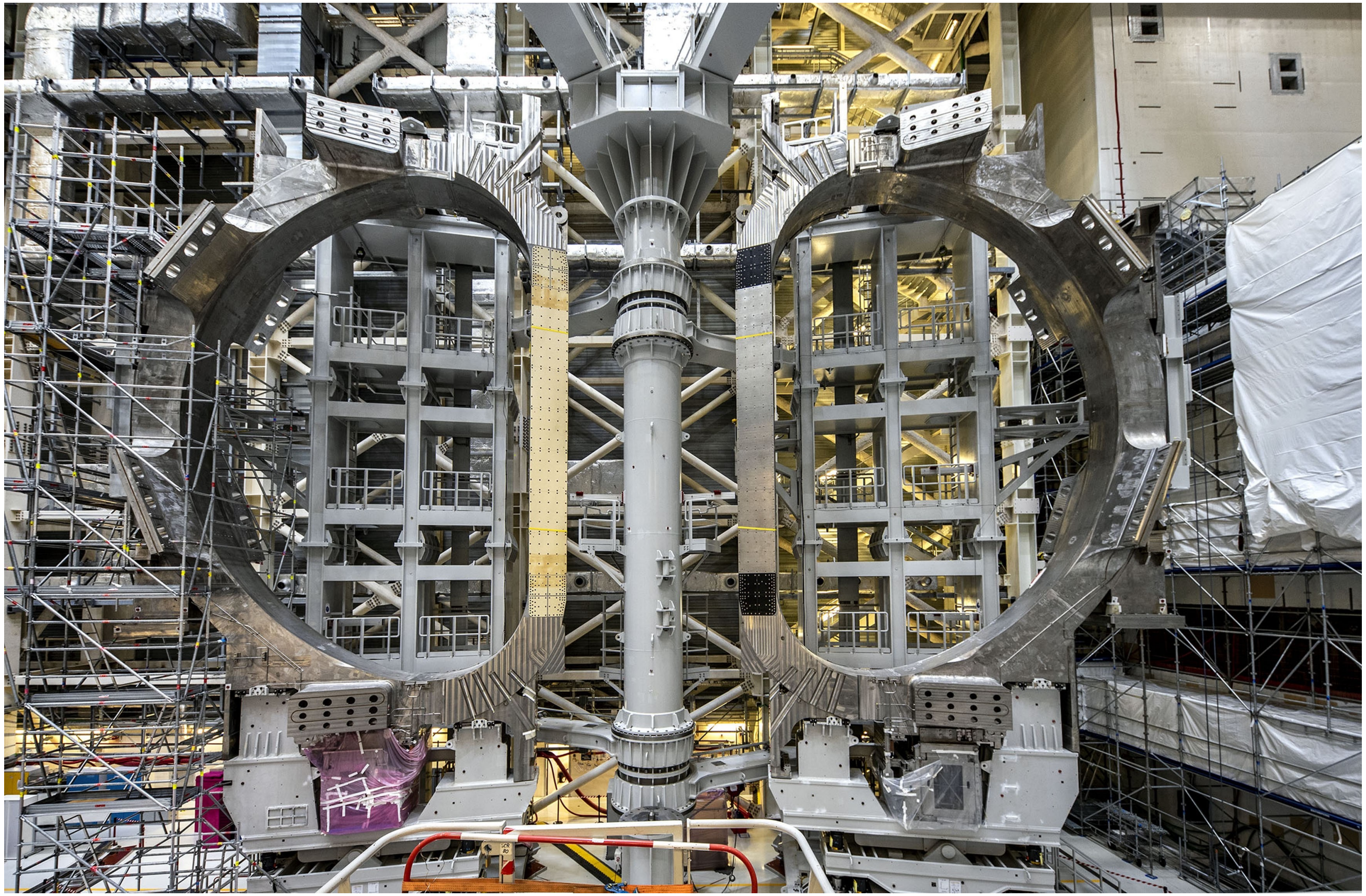


Grooved ‘radial plates’ locate 5km of conductor for each toroidal field coil.

Pancakes are stacked and insulated to form a coil winding-pack.

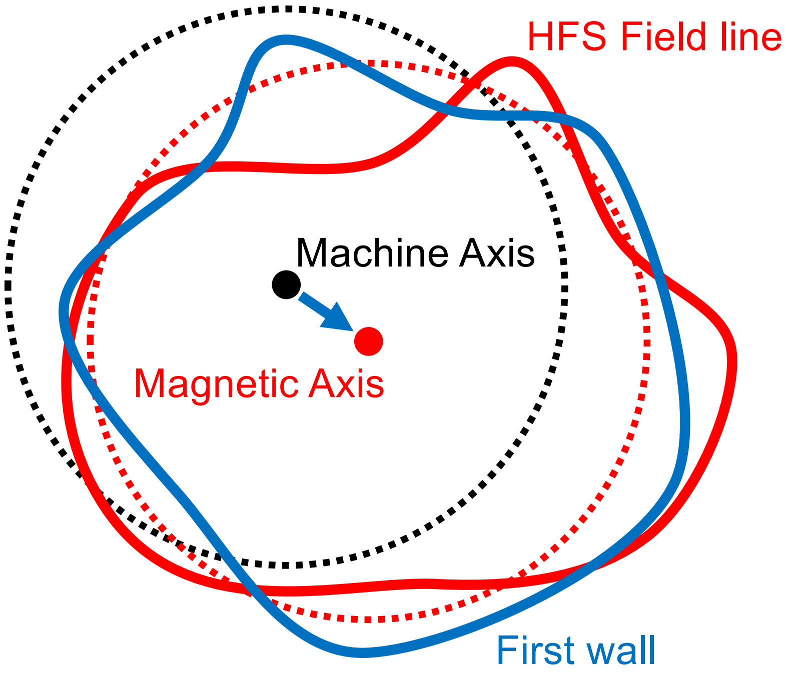
The alignment of ITER’s 17 meter high, 360 tonne D-shaped Toroidal Field magnets is a feat of precision engineering.

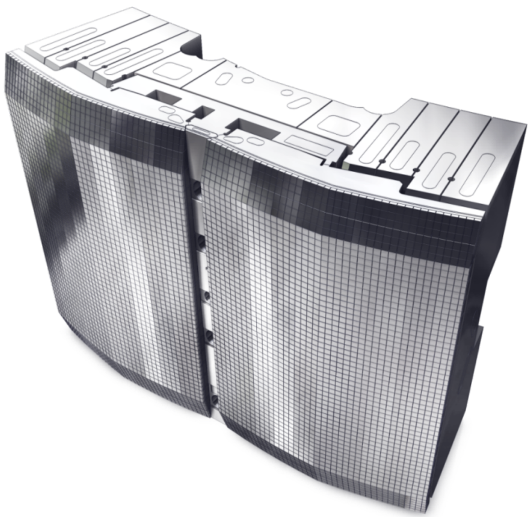
Exceptionally low tolerances that are repeatable and stable over time.

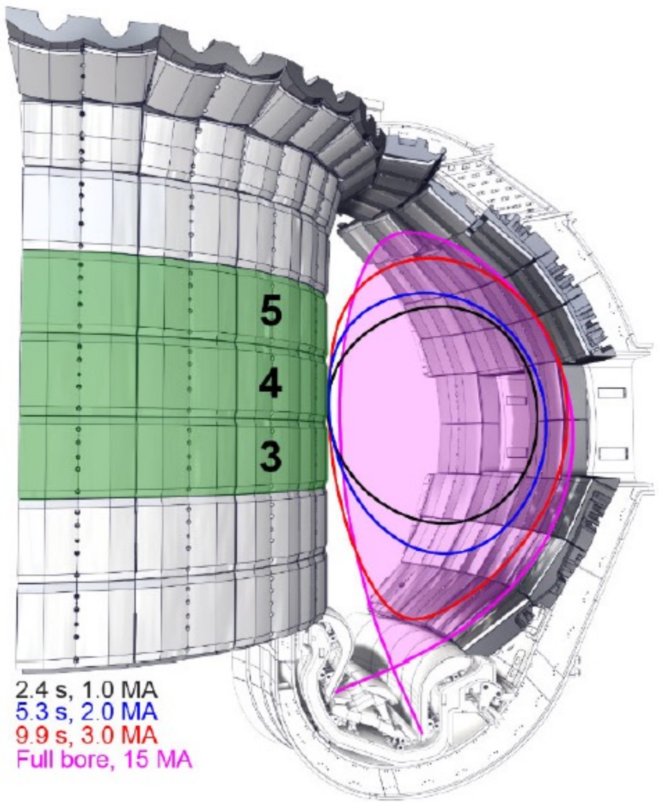


Field line deviations with resect to the first wall generate high start-up heat loads.

Field lines and first wall should be approximately concentric and circular with a long wave peak-peak misalignment $H <$ 6mm .

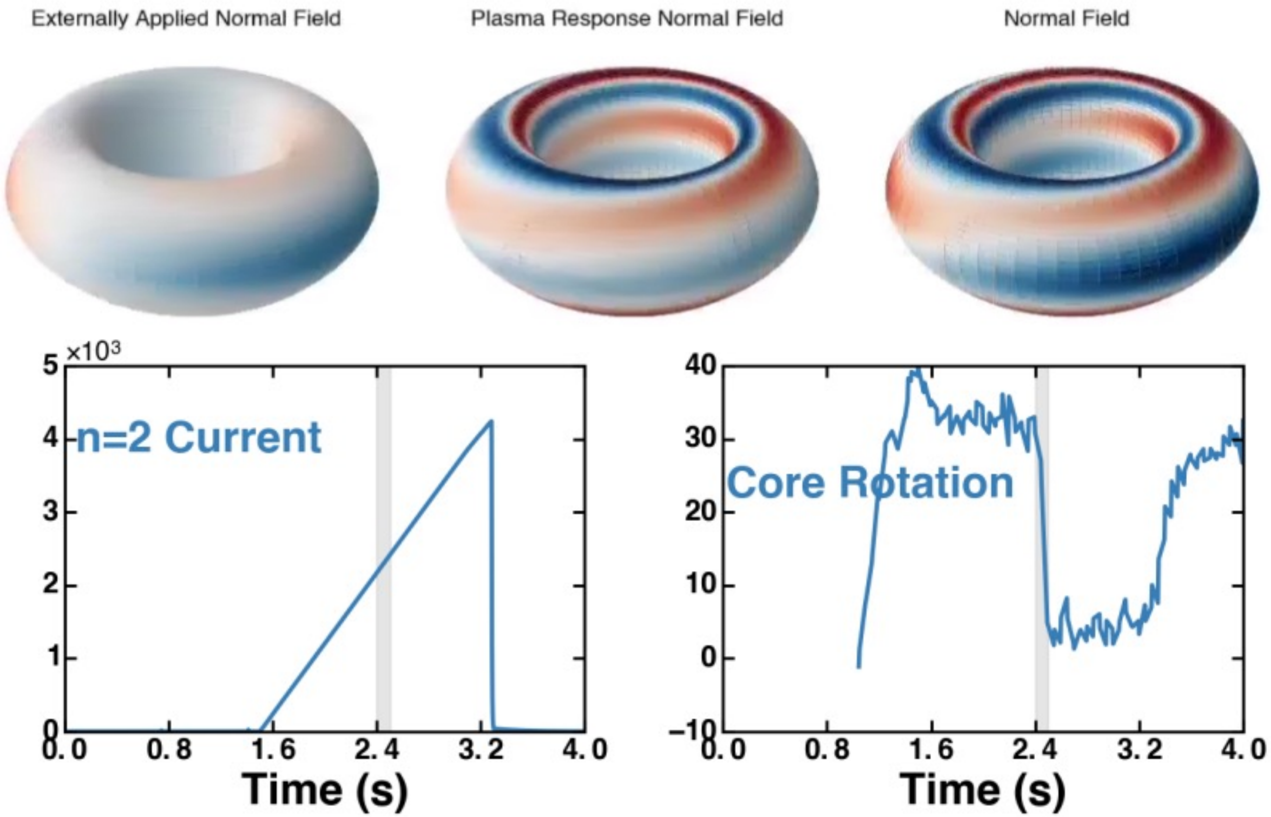


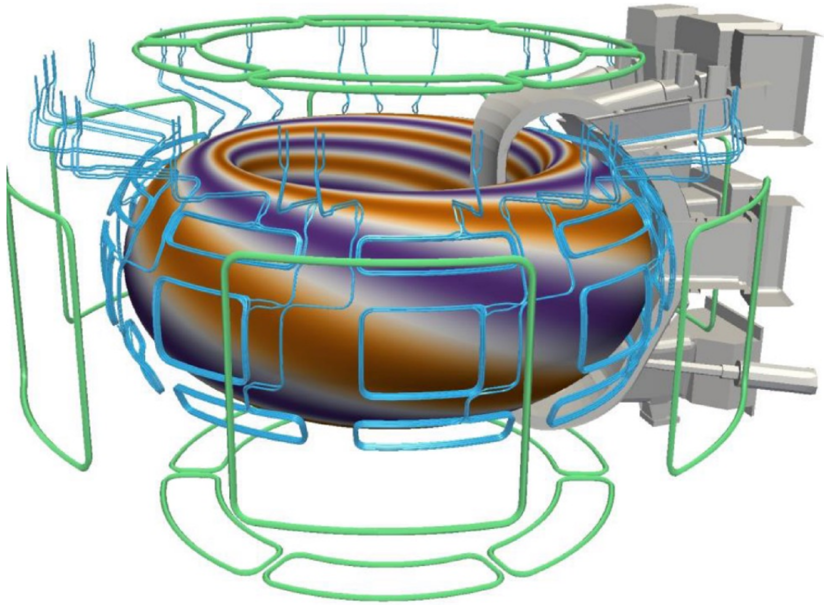




Error fields slow plasma rotation and increase disruptivity.

Overlap error field limits are defined via a semi-empirical scaling for n=1 & n=2 modes (GPEC) .

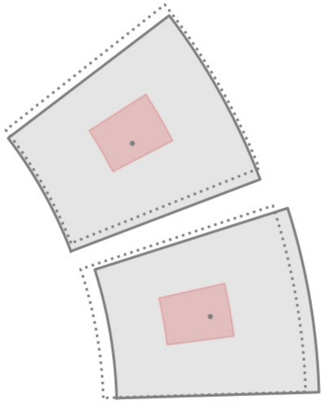


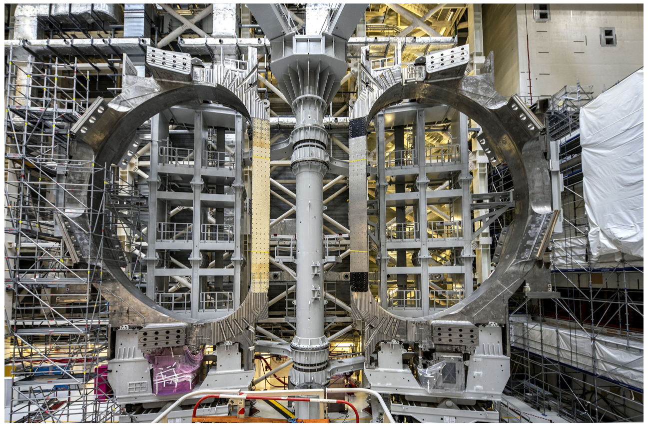


DIII-D L-mode discharge (Logan et al., 2020)

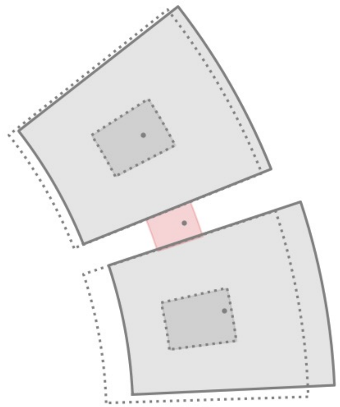
Component alignment is governed by targets and tolerances.

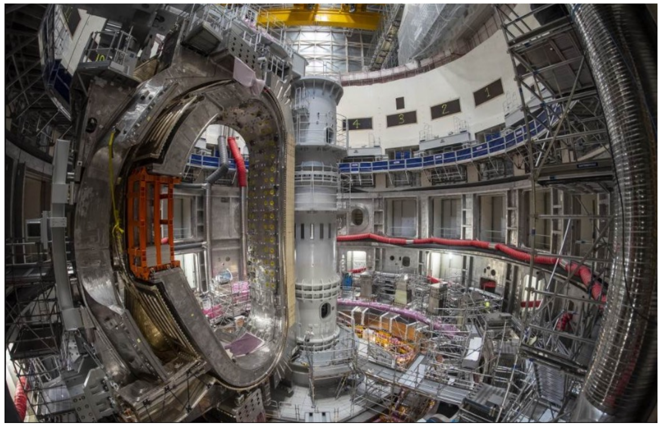
Subsector assembly tool



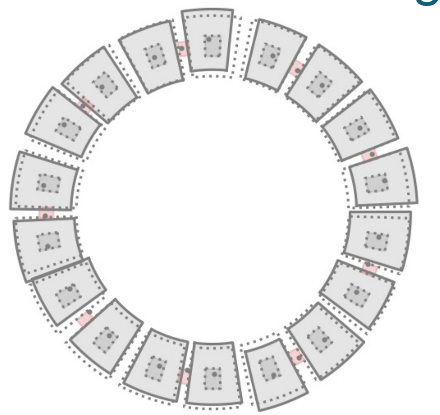


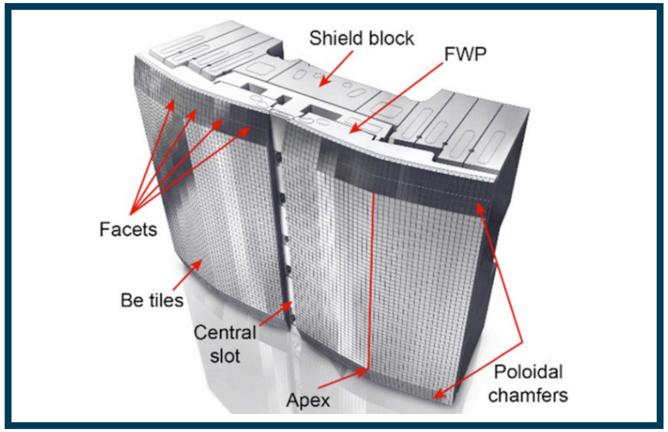
In-pit sector alignment





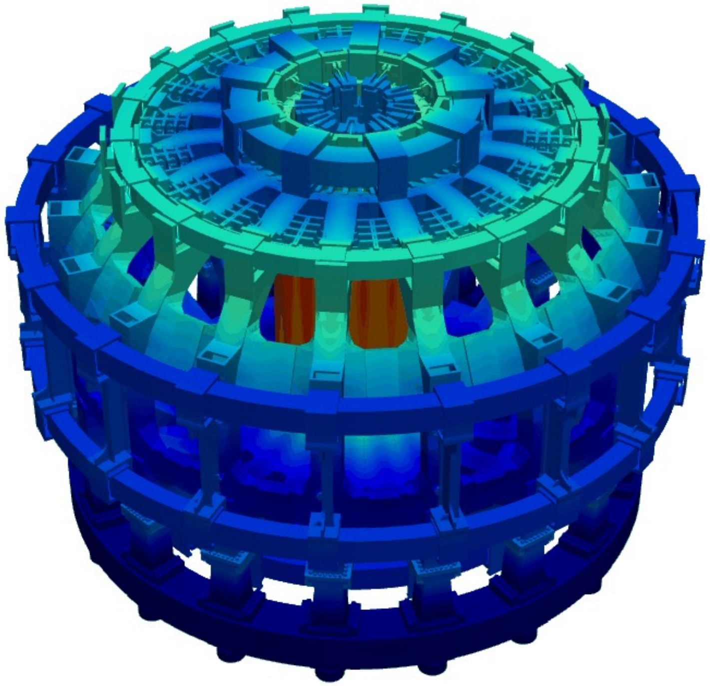
Torus closure & coil energization





Coil energization aligns the toroidal field coil vault.

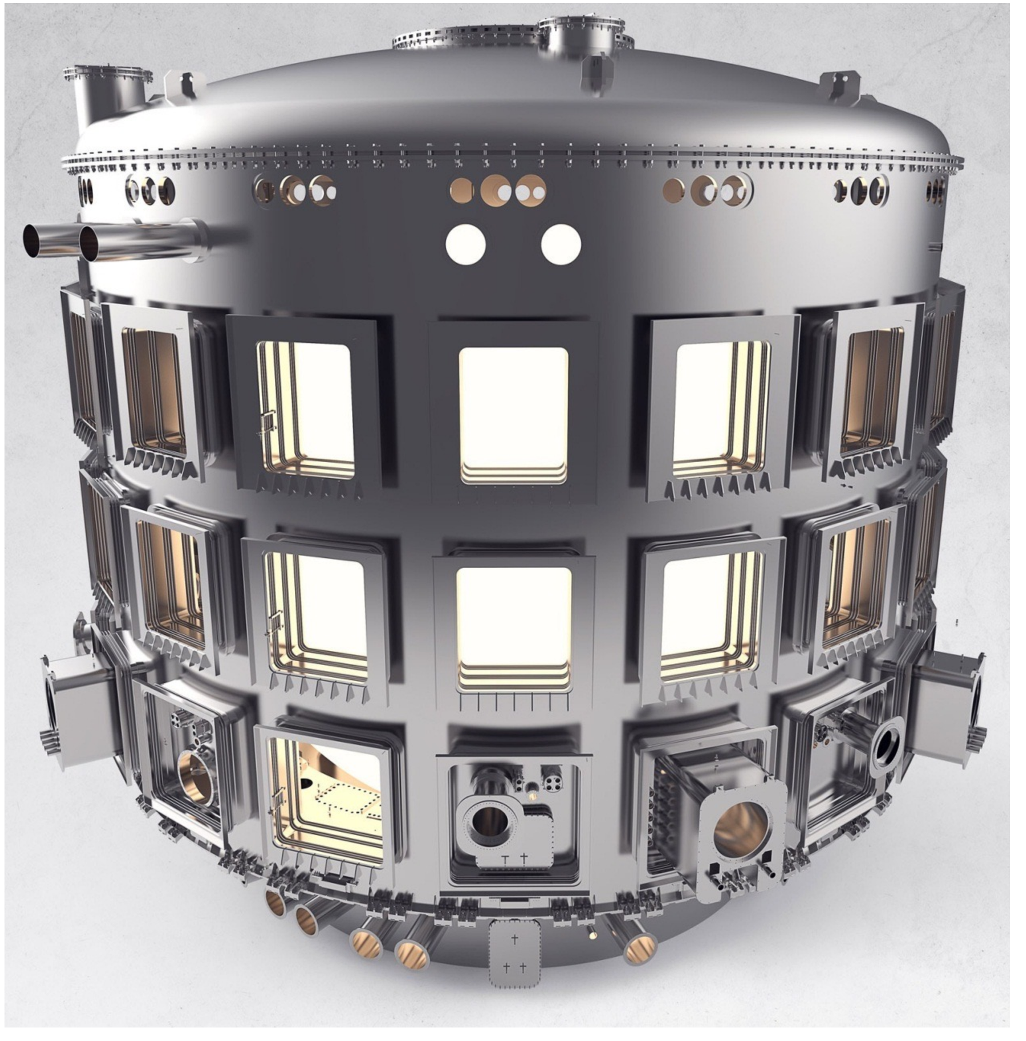
High-field and low-field sides of the TF coils are structurally decoupled.



magnification x50

A cryostat maintains a good vacuum around all SC magnets.

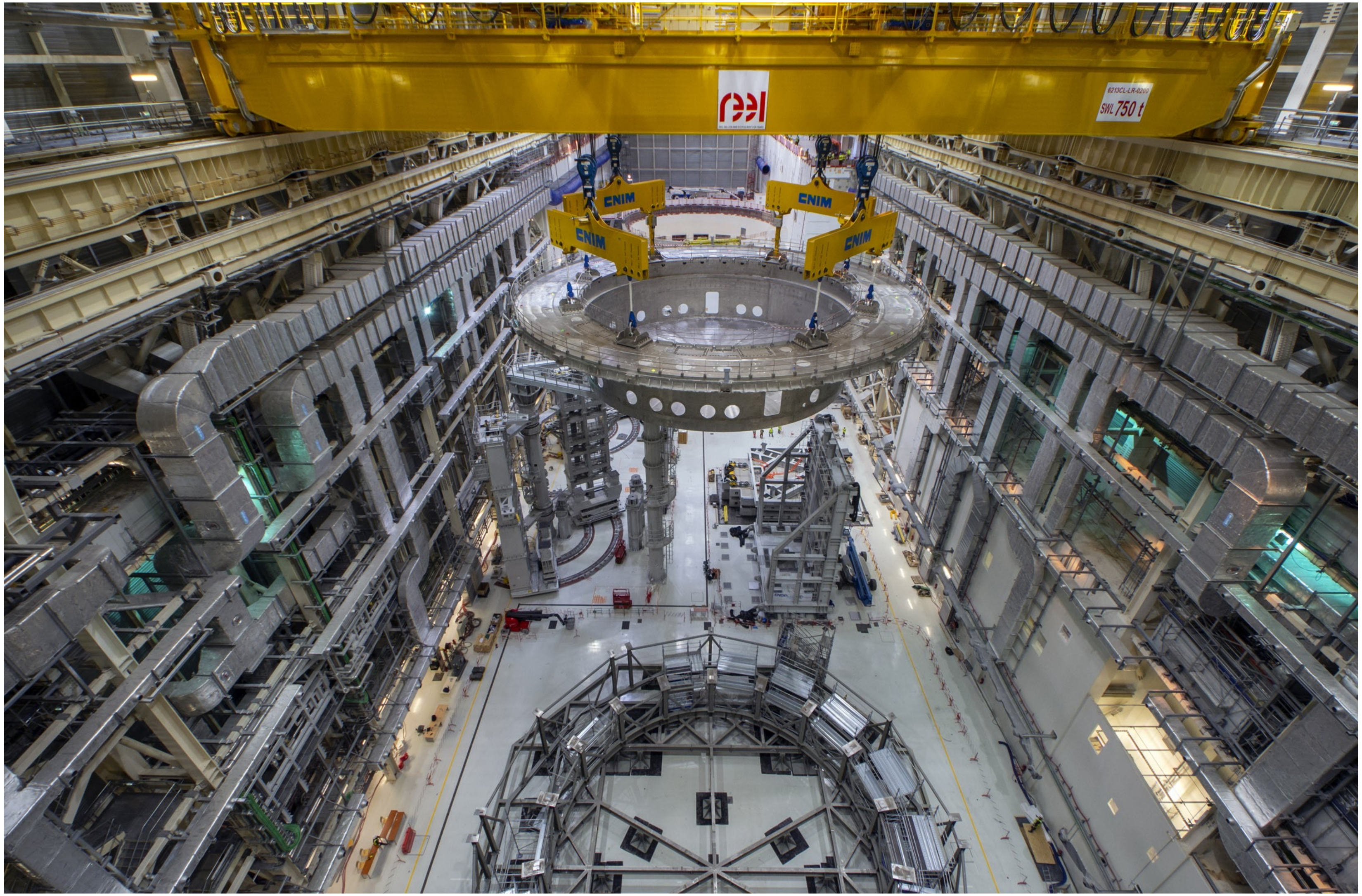
A vacuum suppresses convective heat transfer.



The Tokamak pit ready to receive its first large components

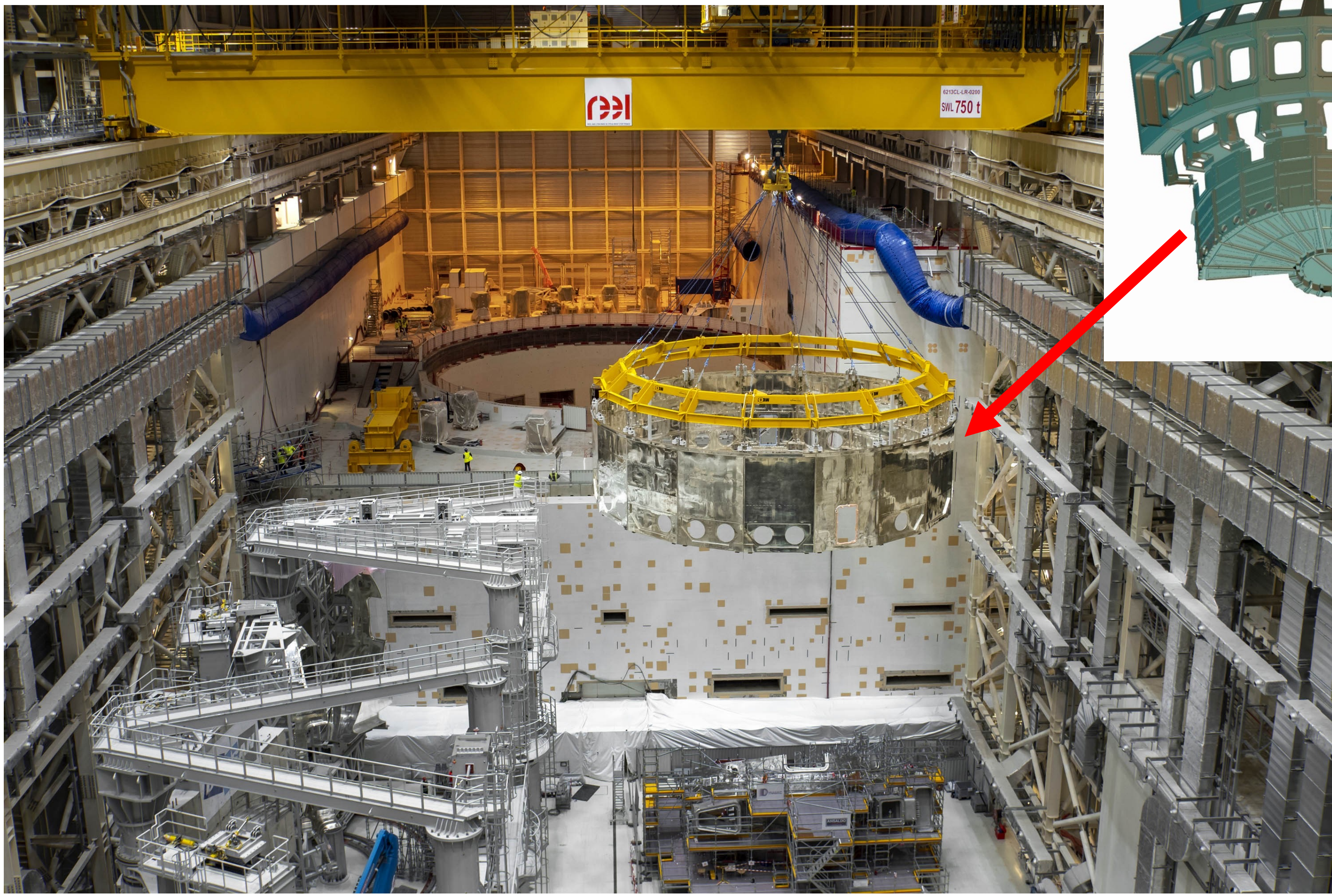
All ITER components pass through the assembly hall before being hoisted into the Tokamak pit

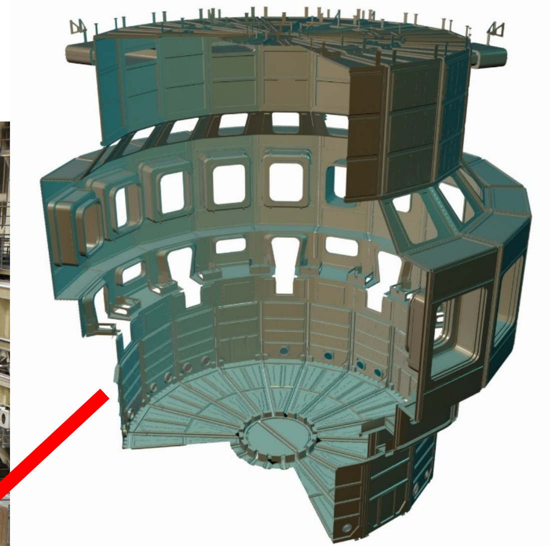
The cryostat base on its way to the pit



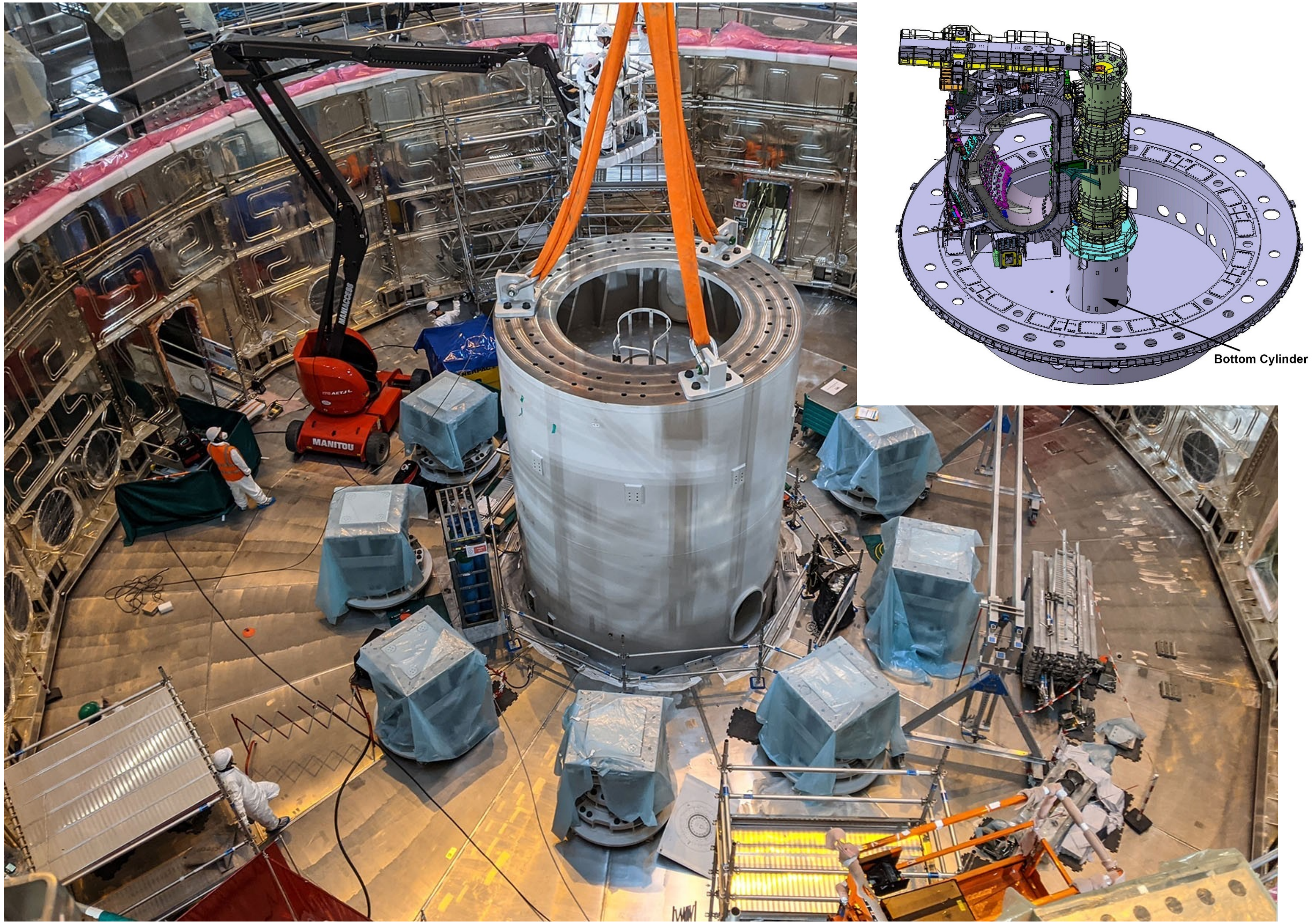
The cryostat is assembled in four sections

An outer thermal shield lines the cryostat.

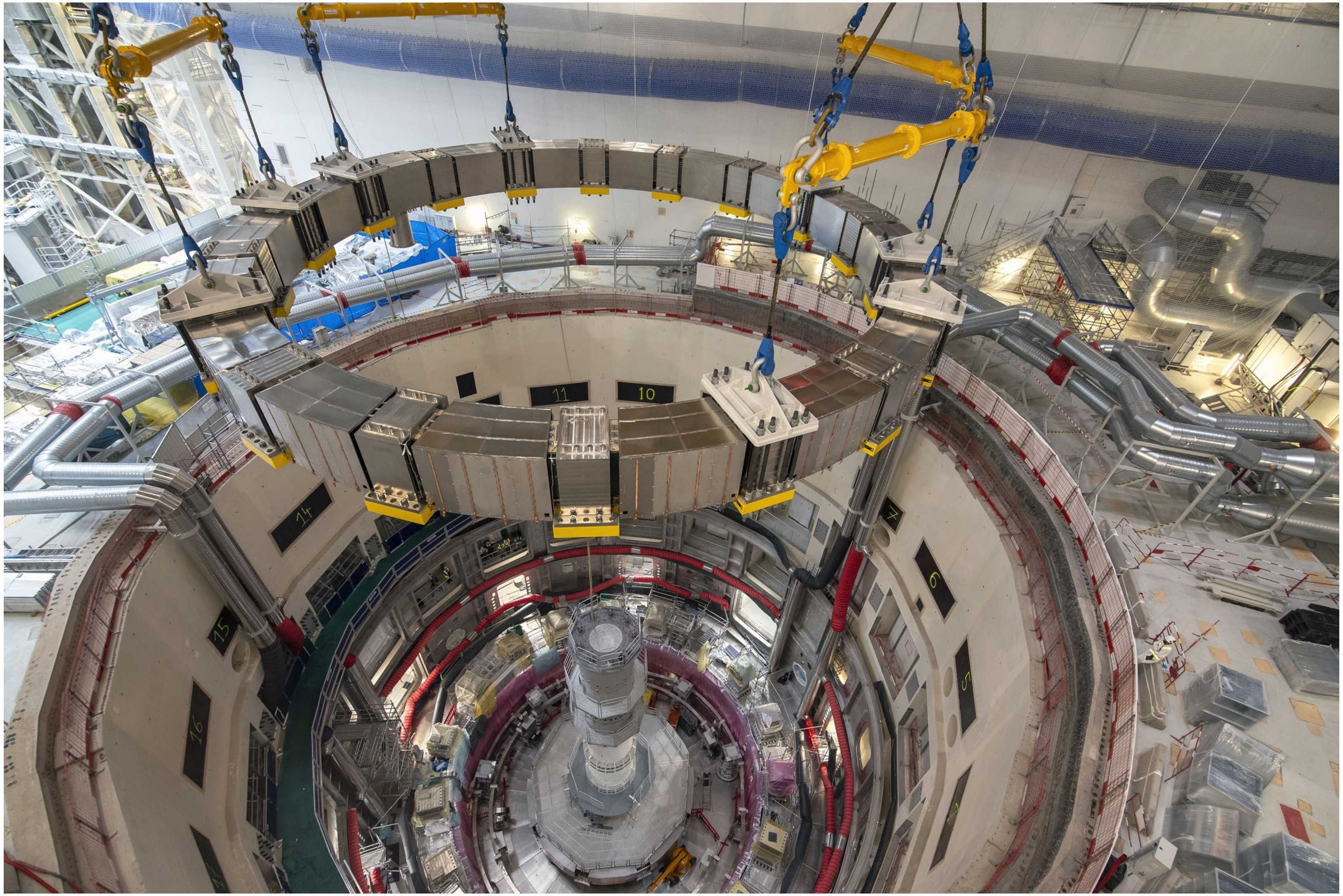




Special tooling supports in-pit assembly and alignment



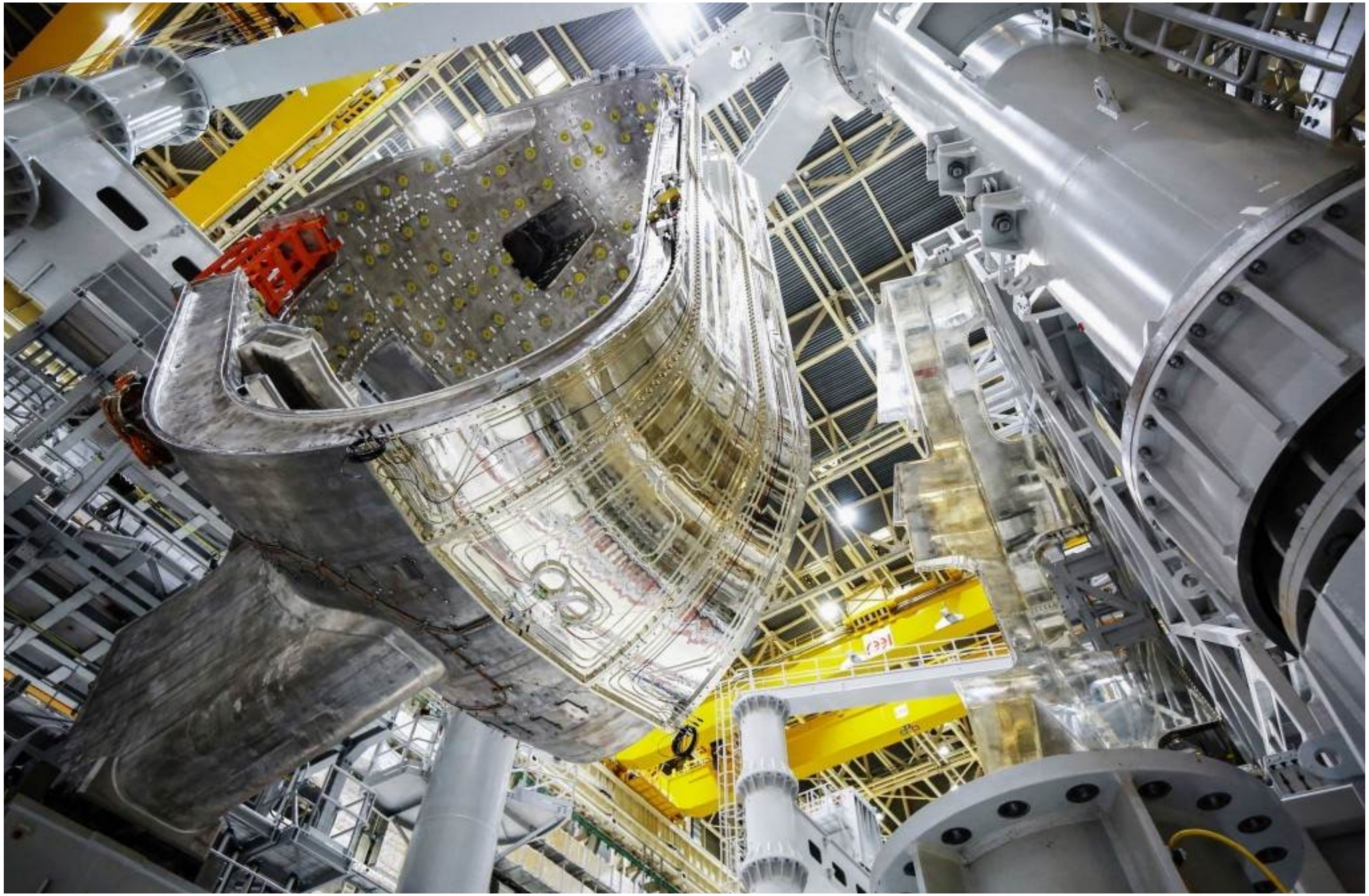
Captive coils are lowered into the pit before the first sector.



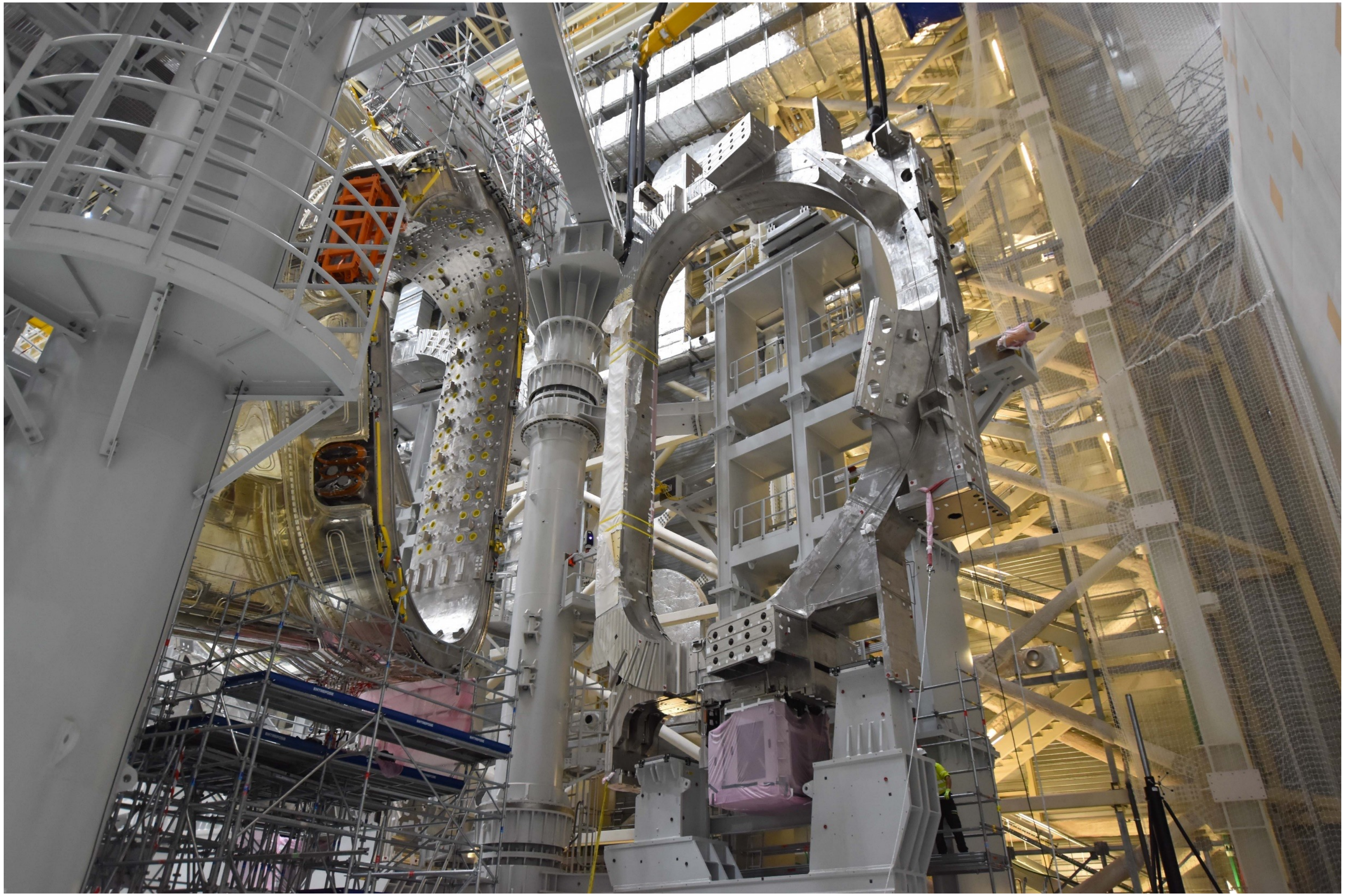
Sector components are upended…

And transferred to the sub-sector assembly tool.

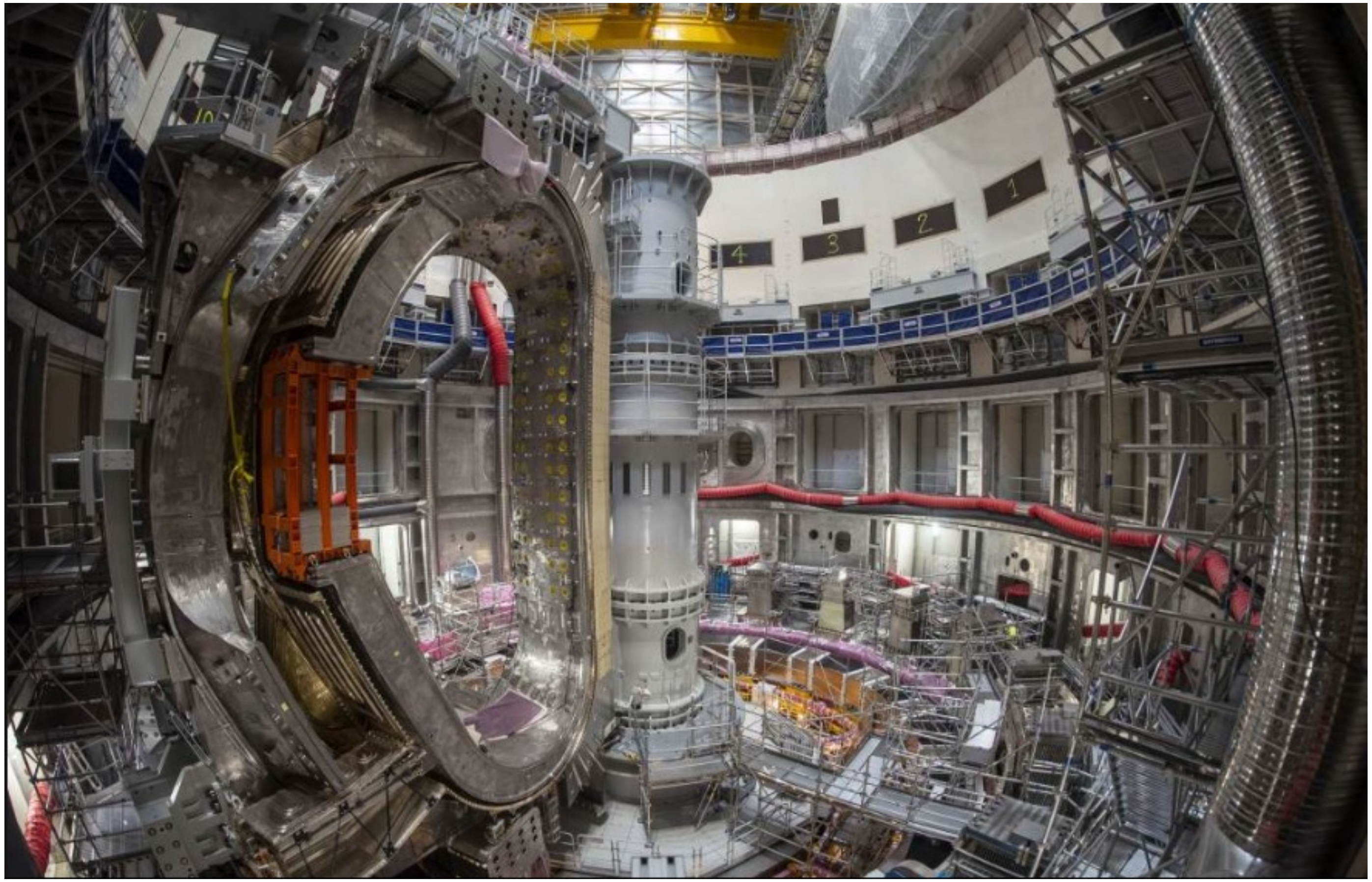
The vessel is wrapped in an actively cooled thermal shield.



A pair of TF coils are swung over each side of the vessel sector.



Successful demonstration of in-pit sector alignment.



cylindrical fiducial	r	rphi	z
A	-0.58	-0.44	
B	-2.06	0.13	
C		2.18	3.12
D		0.67	0.70
E		0.47	3.10
F		0.92	2.31
G		-1.19	
H	-1.18	0.23	
A	0.37	2.16	
B	-1.70	1.36	
C		3.21	3.17
D		2.69	0.10
E		0.63	0.31
F		1.57	0.80
G		2.34	
H	-0.62	-0.09	

In summary the control of heat transfer is critical to the successful fulfilment of the ITER’s scientific and technical goals