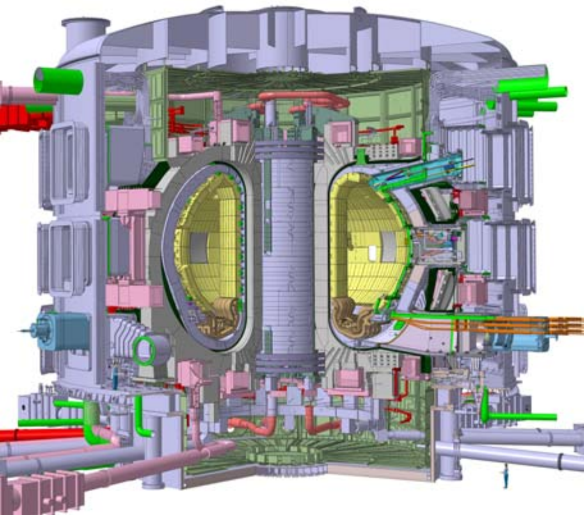
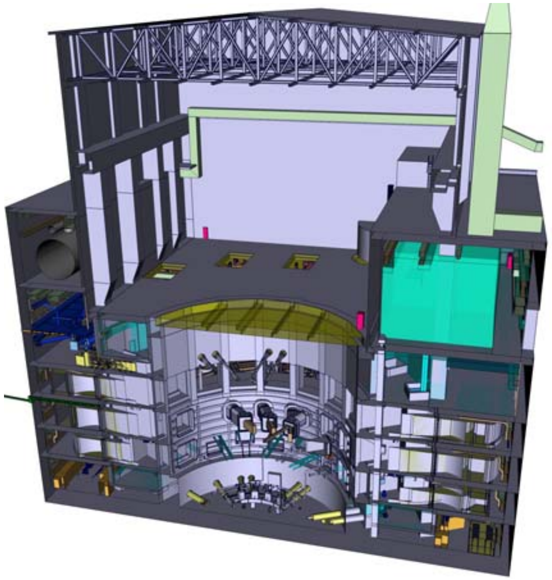
ITER - the decisive step towards Fusion Energy



DPG

Bonn

March 15th 2010



Guenter Janeschitz

Senior Scientific Advisor for Technical Integration (SSATI) to the PDDG

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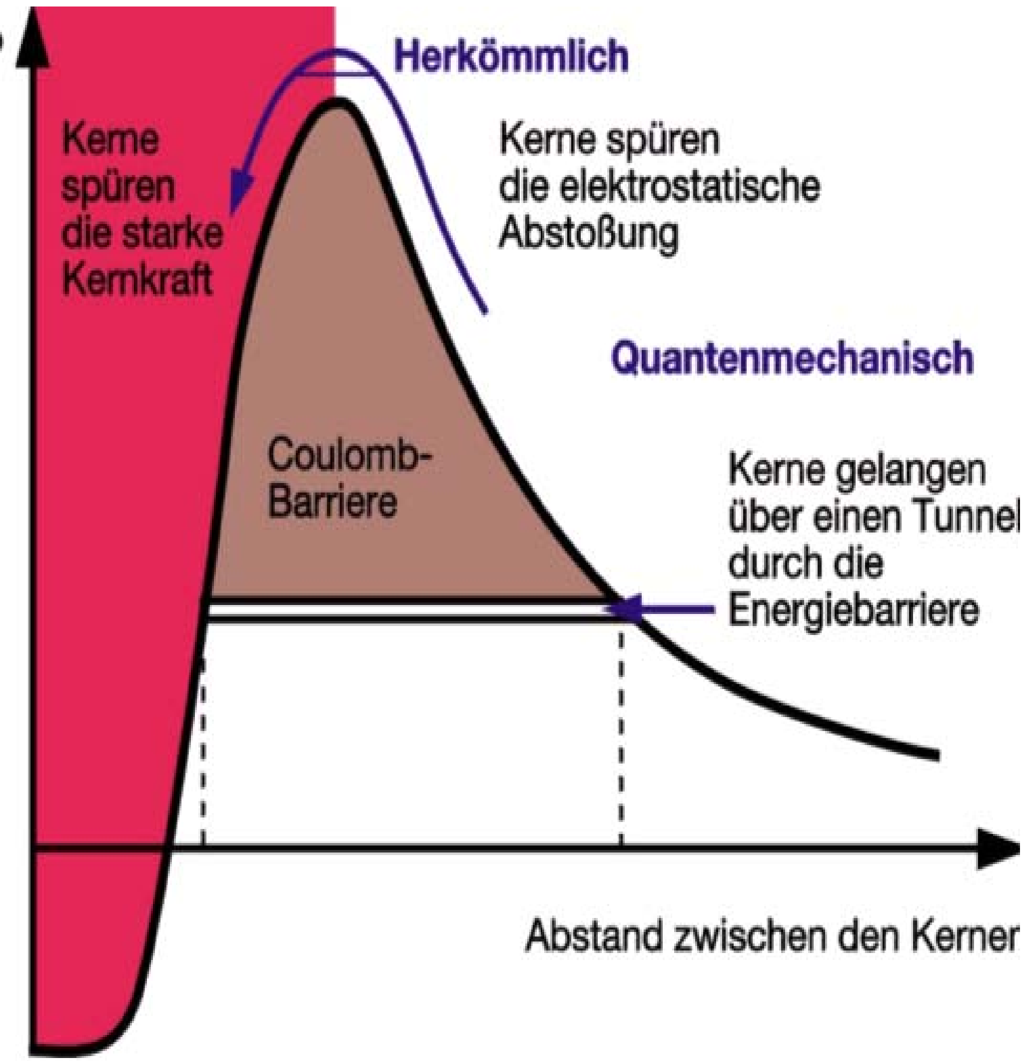
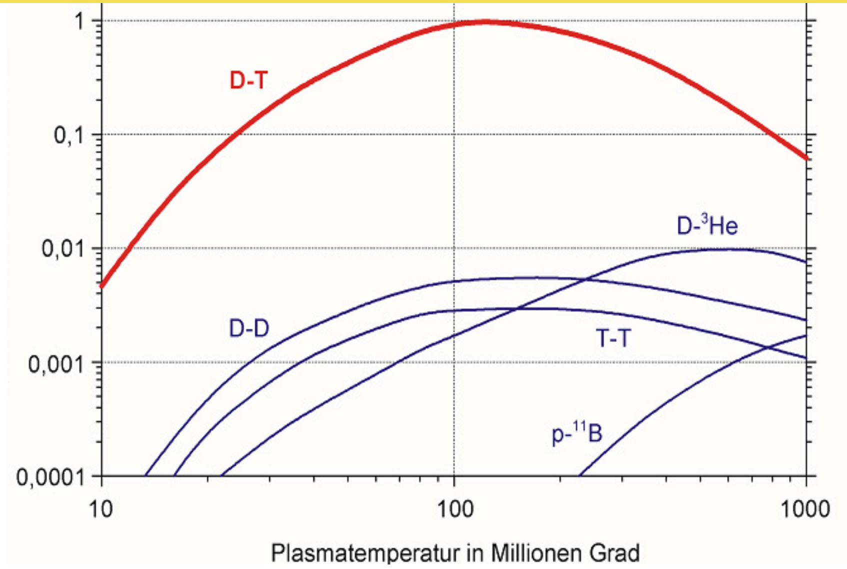
Outline

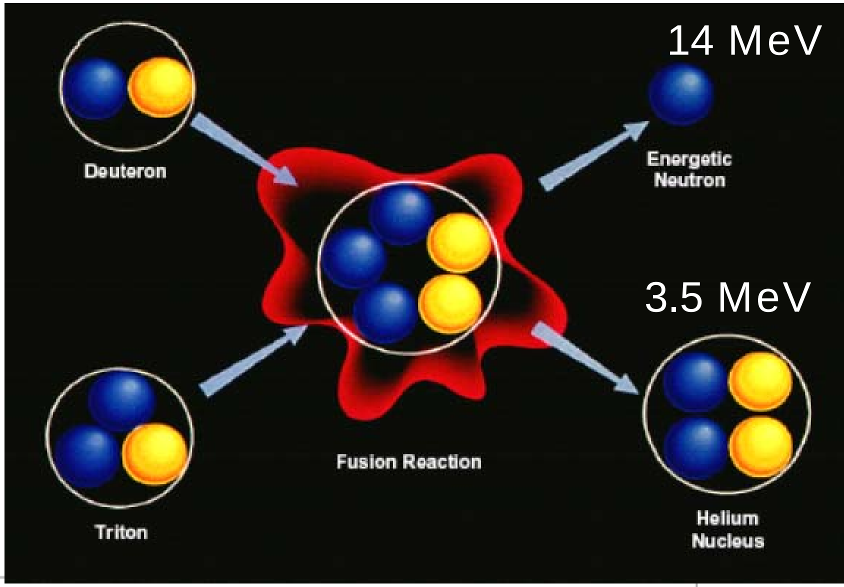
- **Fusion Basiscs**
- **ITER's technical Challenges** (highlights) **and Status**
- **The path to DEMO**
- Conclusion

The Quantum mechanic tunnel effect makes fusion possible



The DT reaction is the most promising





Needed resources for one year operation of a D-T-Fusion Power Plant, ~1000 MW electrical :

Deuterium D_2: ~ 100 kg/a → in $5 \cdot 10^{16}$ kg Oceans

Sufficient for 30 billion years !!

Tritium T_3: ~ 150 kg/a

breeding with Lithium reaction →
Only <u>300 kg Li6</u> needed per year

$^{6}Li + n \rightarrow {}^{3}T + {}^{4}He + 4.8\ MeV$

⊕⊕⊕ ○ ⊕ ⊕⊕
○○○ ○○ ○○

About 10^{11} kg Lithium in landmass
Sufficient for 30'000 years

About 10^{14} kg Lithium in oceans
Sufficient for 30 million years !!

Considering all energy is produced by fusion

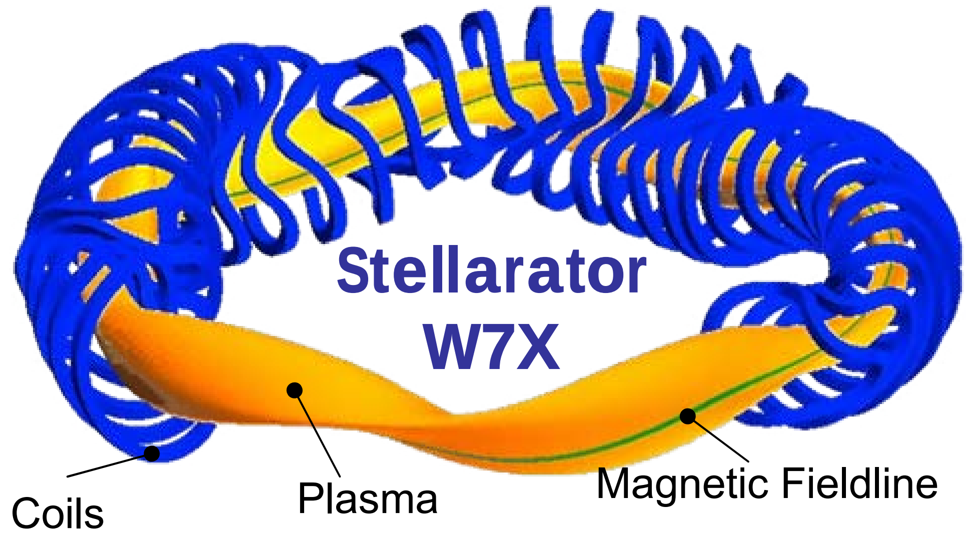
Magnetic Confinement of a plasma with 10 to 20 keV

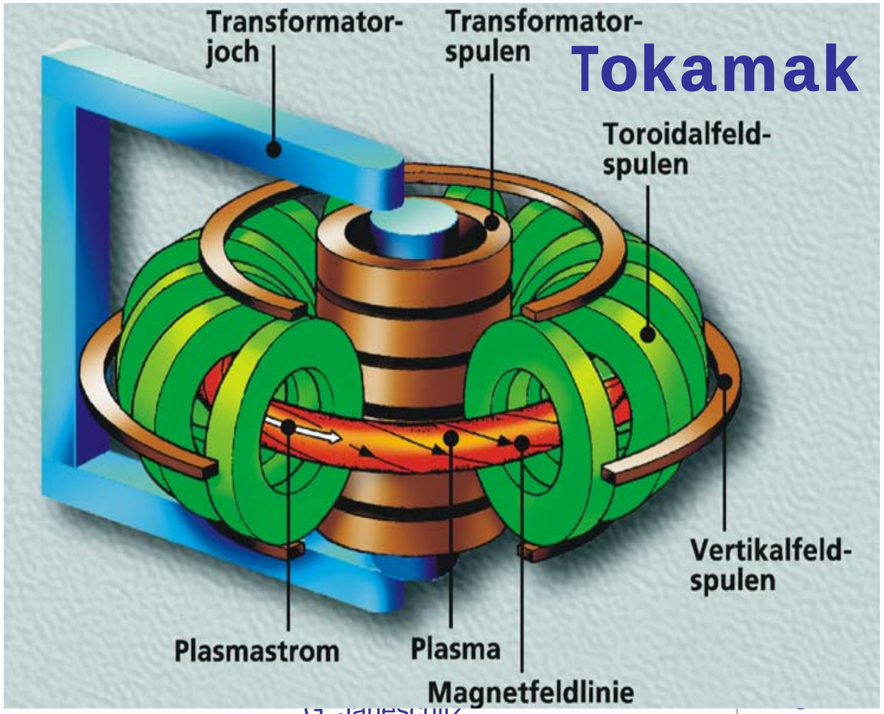
A toroidal magnetic system needs:

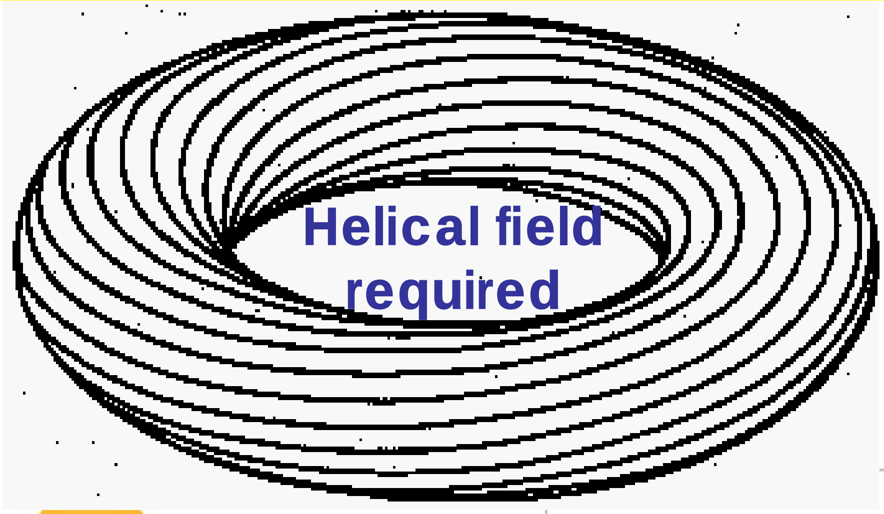
- a helical field configuration to compensate drifts
- a magnetic well

Two successful systems:

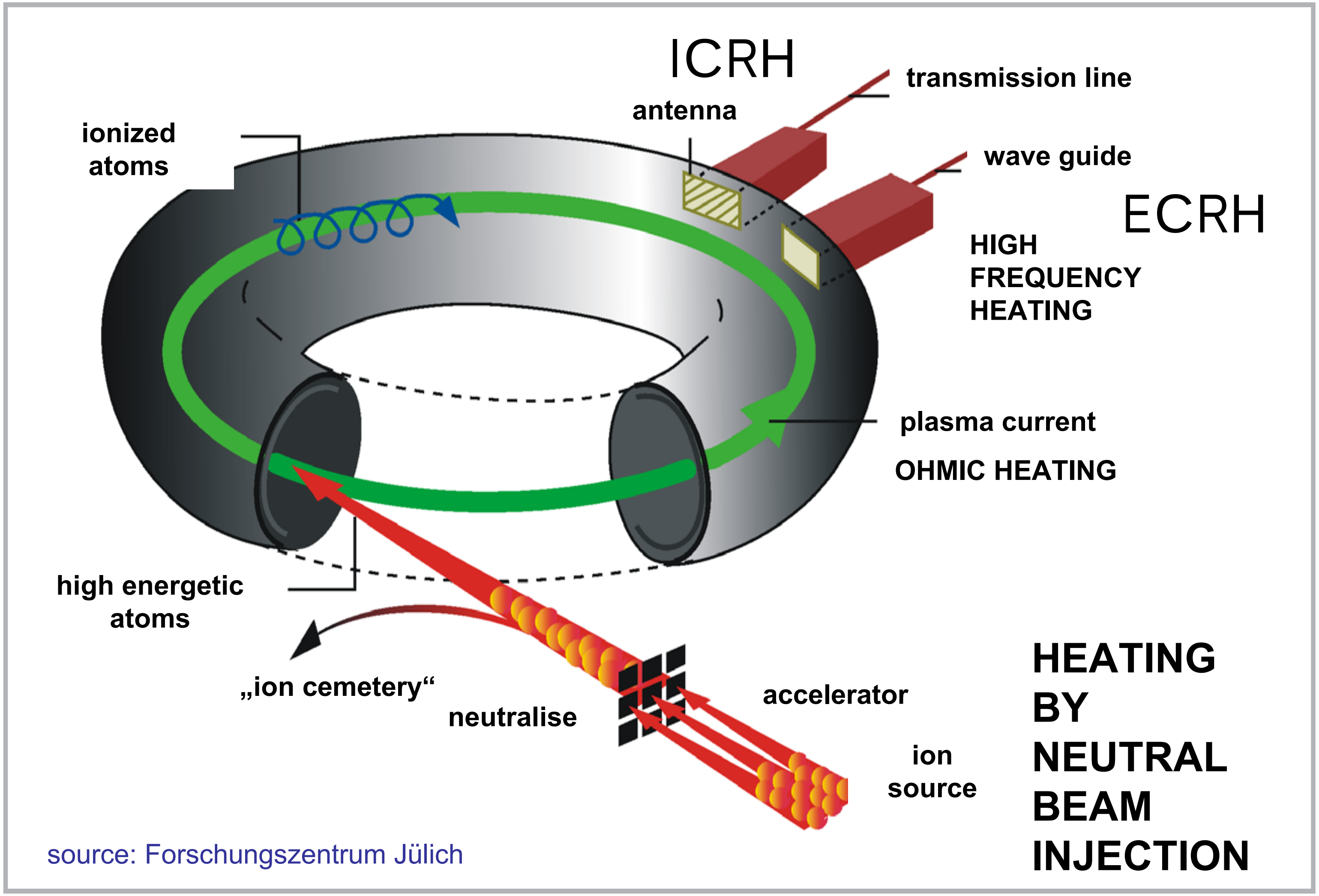
Stellarator / Tokamak - ITER





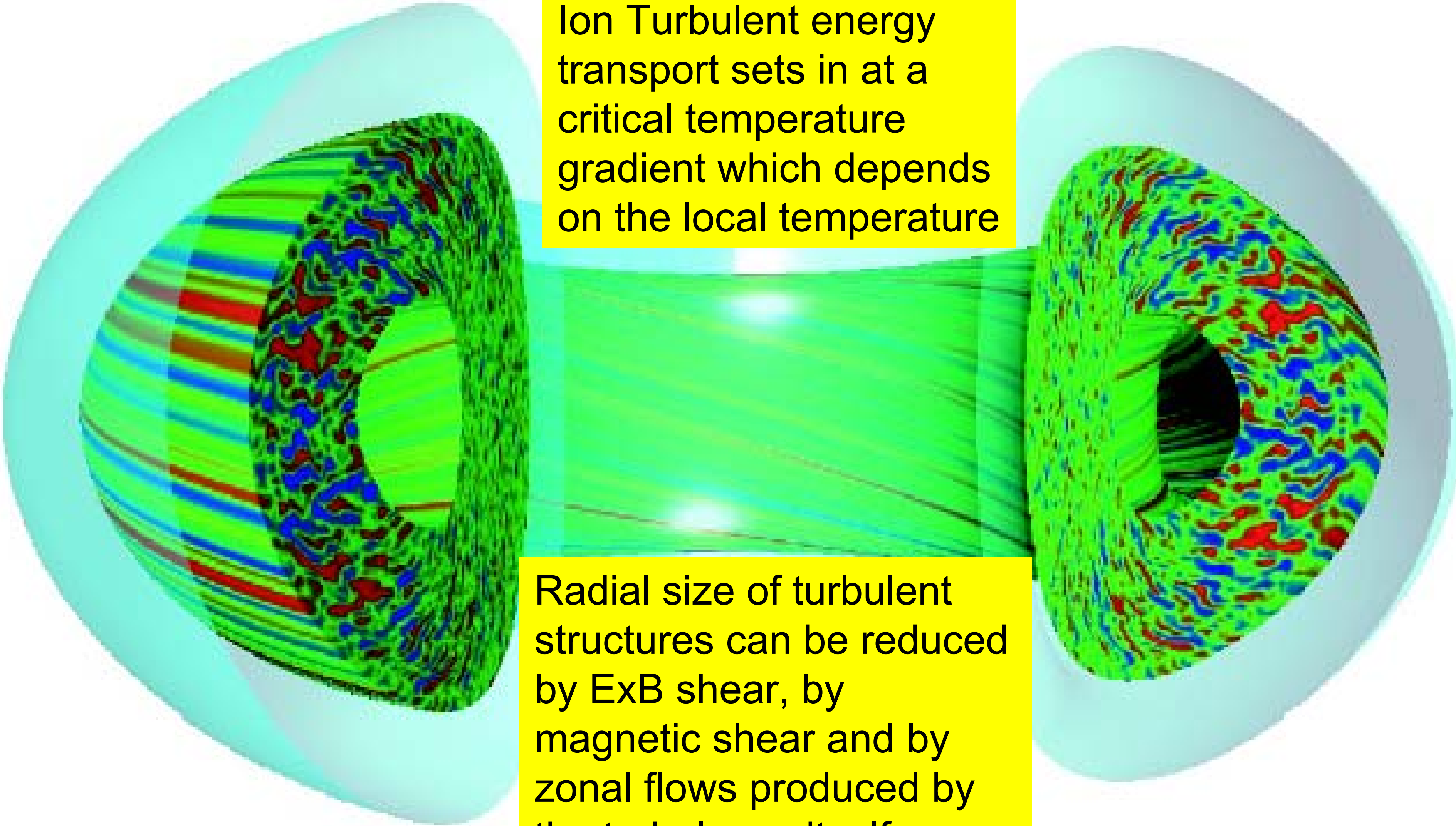


Methods for the heating of a tokamak plasma



source: Forschungszentrum Jülich

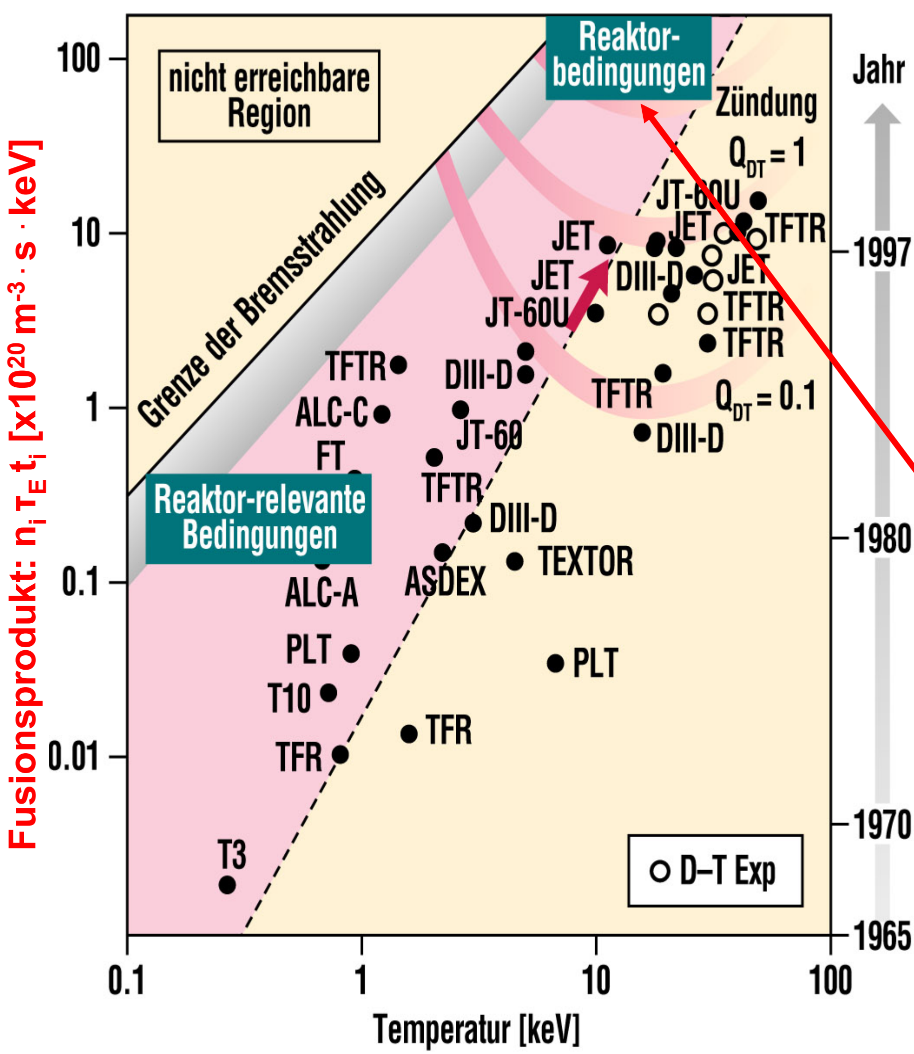
Energy and particle Transport is governed by turbulence

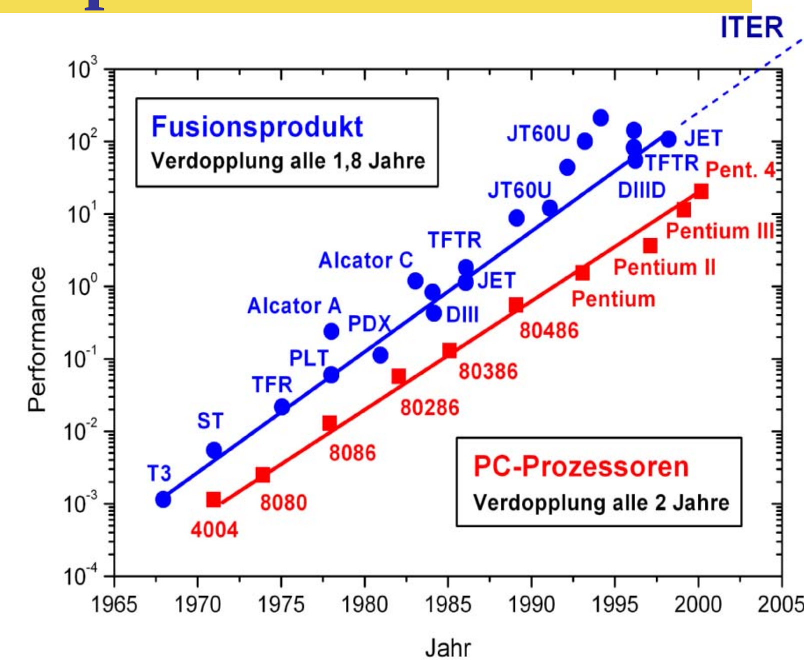


Ion Turbulent energy transport sets in at a critical temperature gradient which depends on the local temperature

Radial size of turbulent structures can be reduced by ExB shear, by magnetic shear and by zonal flows produced by the turbulence itself

Progress in Fusion Tripple Product similar to Progress in Microprocessor Development





Fusion Reactor Class in the area of 3 to 6 10^{21}

- Ti > 10 keV

  => $n_e \times \tau_E \sim 6.0\ 10^{20}\ m^{-3}s$

  => $n_e \sim 1.0\ 10^{20}\ m^{-3}$

  => $\tau_E \sim 6.0$ s

=> Energy Confinement time between 3 and 6 sec

What is ITER ?

ITER is a major international collaboration in fusion energy research established in the 80th by Reagan - Gorbachev involving

the EU (plus Switzerland), China, India, Japan, the Russian Federation, South Korea and the United States

Physics Goals:

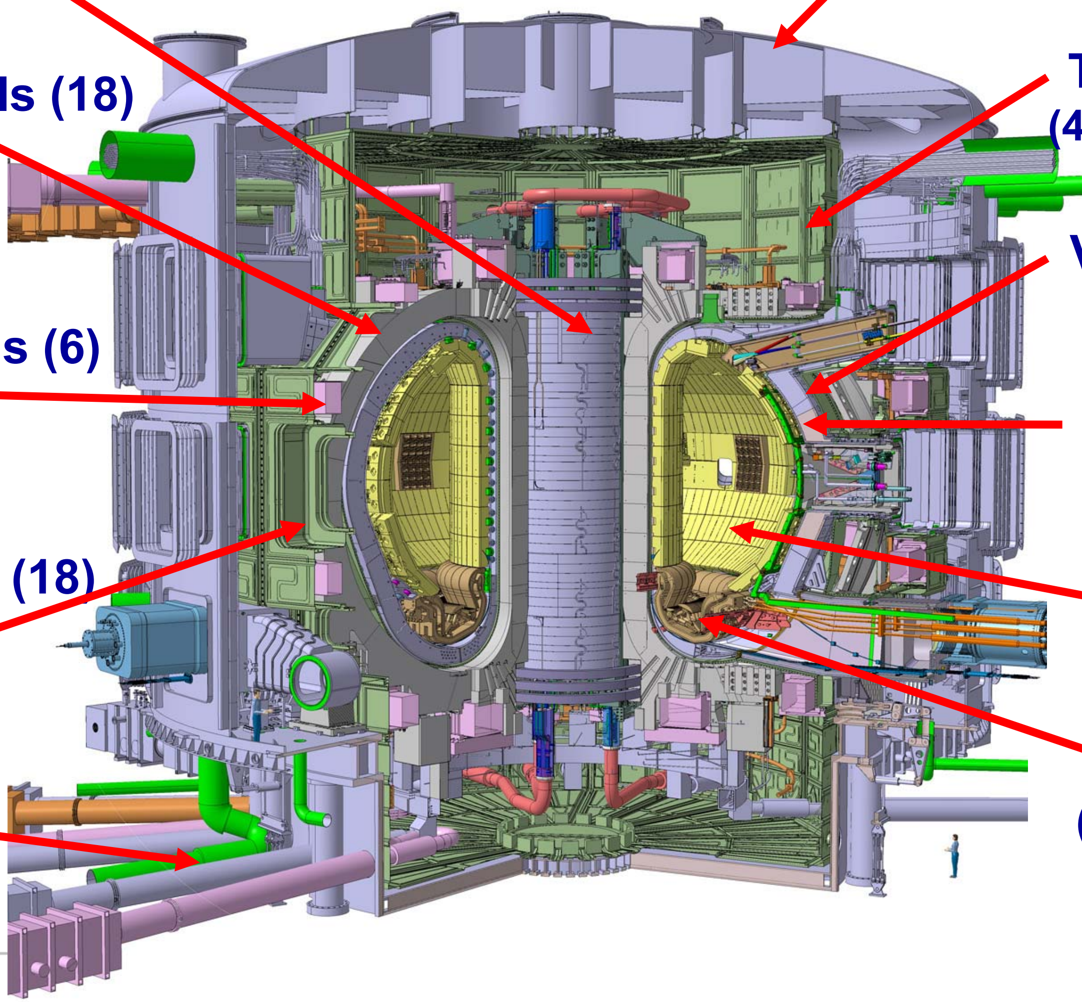
- ITER is designed to produce a plasma dominated by α-particle heating
- produce a significant fusion power amplification factor ($Q \geq 10$) in long-pulse operation
- aim to achieve steady-state operation of a tokamak ($Q = 5$)
- retain the possibility of exploring 'controlled ignition' ($Q \geq 30$)

Technology Goals:

- demonstrate integrated operation of technologies for a fusion power plant
- test components required for a fusion power plant
- test concepts for a tritium breeding blanket

The ITER Machine

Fusion gain Q = 10, Fusion Power: ~500MW, Ohmic burn 300 to 500 sec
Goal Q=5 for 3000 sec



Central Solenoid (6)
(Nb_3Sn)

Toroidal Field Coils (18)
(Nb_3Sn)

Poloidal Field Coils (6)
(NbTi)

Correction Coils (18)
(NbTi)

Feeders (31)
(NbTi)

Cryostat
(29 m high x 28 m dia.)

Thermal Shield
(4 sub-assemblies)

Vacuum Vessel
(9 sectors)

In-Vessel Coils
(2-VS & 27-ELM)

Blanket
(440 modules)

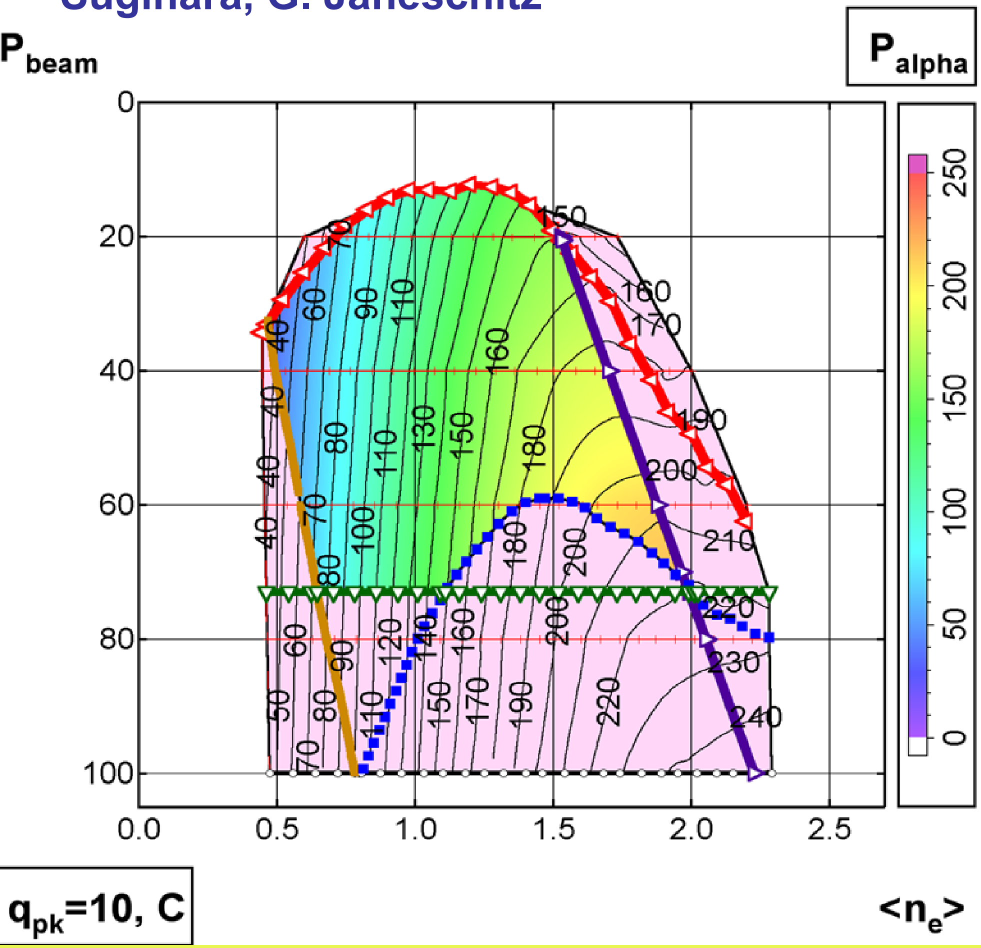
Divertor
(54 cassettes)

What were / are the major Challenges in Physics ?

- The solution to the divertor peak heatflux problem (solved / ongoing)
  - The development of the radiative divertor heatflux from 40 MWm^{-2} to < 20 MWm^{-2}
- The prediction of the ITER Energy Confinement and thus the definition of its size (solved / ongoing) –> major radius = 6.2 m
  - Shortfalls of scaling as a predictive tool => Physics understanding needed !
- The impact of magnetic ripple on energy confinement (solved / ongoing)
  - Impact low at ripple < 0.7% at separatrix, however, not understood !!
- The developing understanding of ELMs and RWM and their stabilisation (solved / ongoing)
  - In vessel coils foreseen in ITER – physics not understood – risk !
- The definition of a credible steady state scenario (solved / ongoing)
  - Development needs new generation of Tokamaks (EAST, KSTAR, JT60SA, ITER)

ITER Operation Space in H-mode -> Integrated Plasma Model

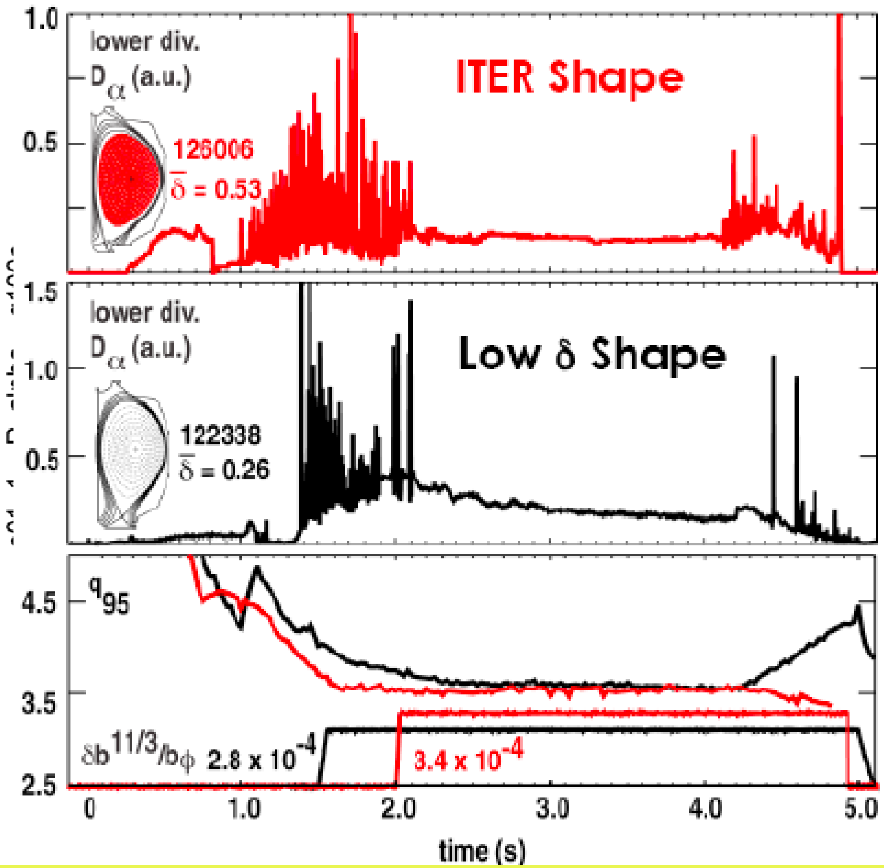
G. Pacher, H. Pacher, Y. Igitkhanov, M. Sugihara, G. Janeschitz



Q=5, **LH transition**, **low temperature limit on alpha power**, **auxiliary power**, **edge density limit**

ELM Control / Mitigation

ELM Mitigation by edge ergodization by RMP coils



see foreseen ELM- coil layout below

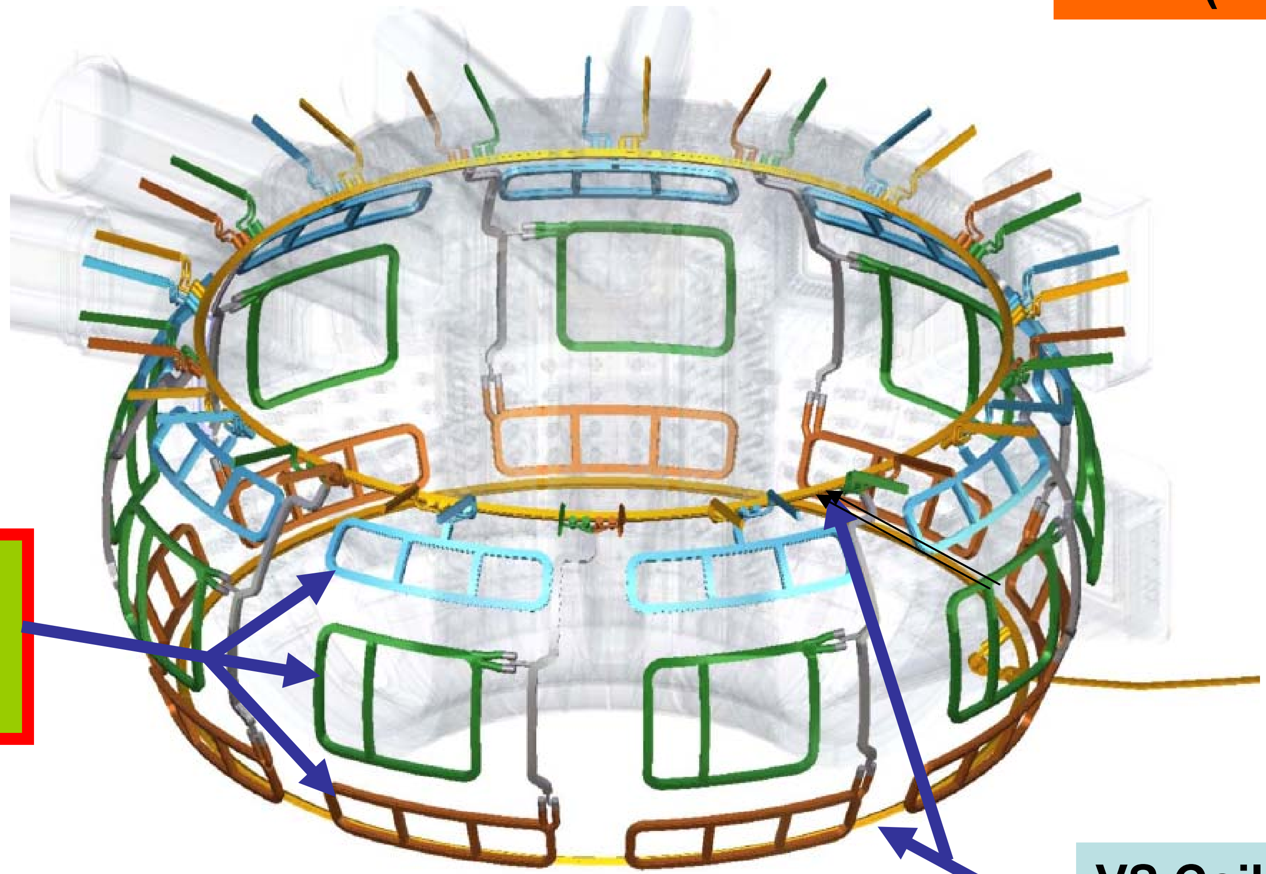
ELM- and VS- coils in ITER

ELM Control

Resistive Wall Mode (RWM) Control

Vertical Stabilization (VS)

ELM/RWM Coils (9 groups of 3)



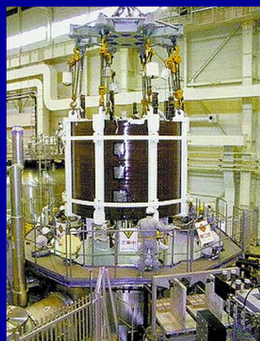
VS Coils (upper & lower ring coils)

ITER Technology Challenges / Developments

- **The development of high field large superconducting magnets**
  - Requirements seemed unfeasible 20 years ago
- **The development of Divertor High Heatflux Components**
  - A large step in development to achieve 20 MW/m^2
- **The development of Remote Maintenance**
  - Thought to be impossible by engineers from nuclear industry
- **The development of the DT fuel Cycle**
  - A key for ITER and DEMO – major components demonstrated in Labs
- **The development of Heating and Current Drive systems**
  - A challenge for all systems envisaged, not fully solved today
- **The development of ITER compatible Diagnostics**
  - A step from laboratory type systems to a reliability similar to space

The ITER Design and Technology has been underpinned by R&D

CENTRAL SOLENOID MODEL COIL

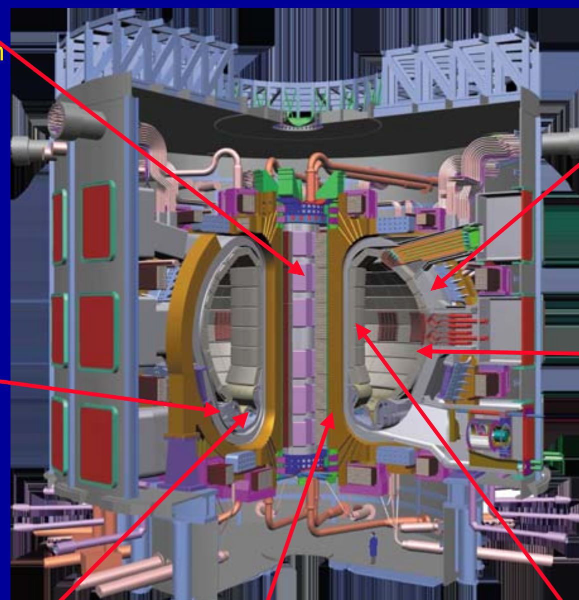


Radius 3.5 m
Height 2.8m
B_{max}=13 T
W = 640 MJ
0.6 T/sec

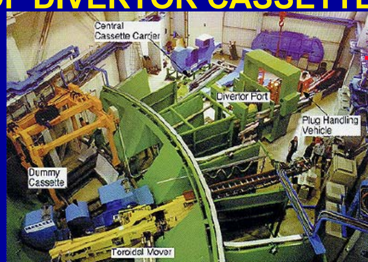
Completed R&D Activities by July 2001.

VACUUM VESSEL SECTOR

Double-Wall, Tolerance ±5 mm



REMOTE MAINTENANCE OF DIVERTOR CASSETTE



Attachment Tolerance ± 2 mm

BLANKET MODULE

HIP Joining Tech
Size : 1.6 m x 0.93 m x 0.35 m

DIVERTOR CASSETTE

Heat Flux >15 MW/m^2, CFC/W

TOROIDAL FIELD MODEL COIL

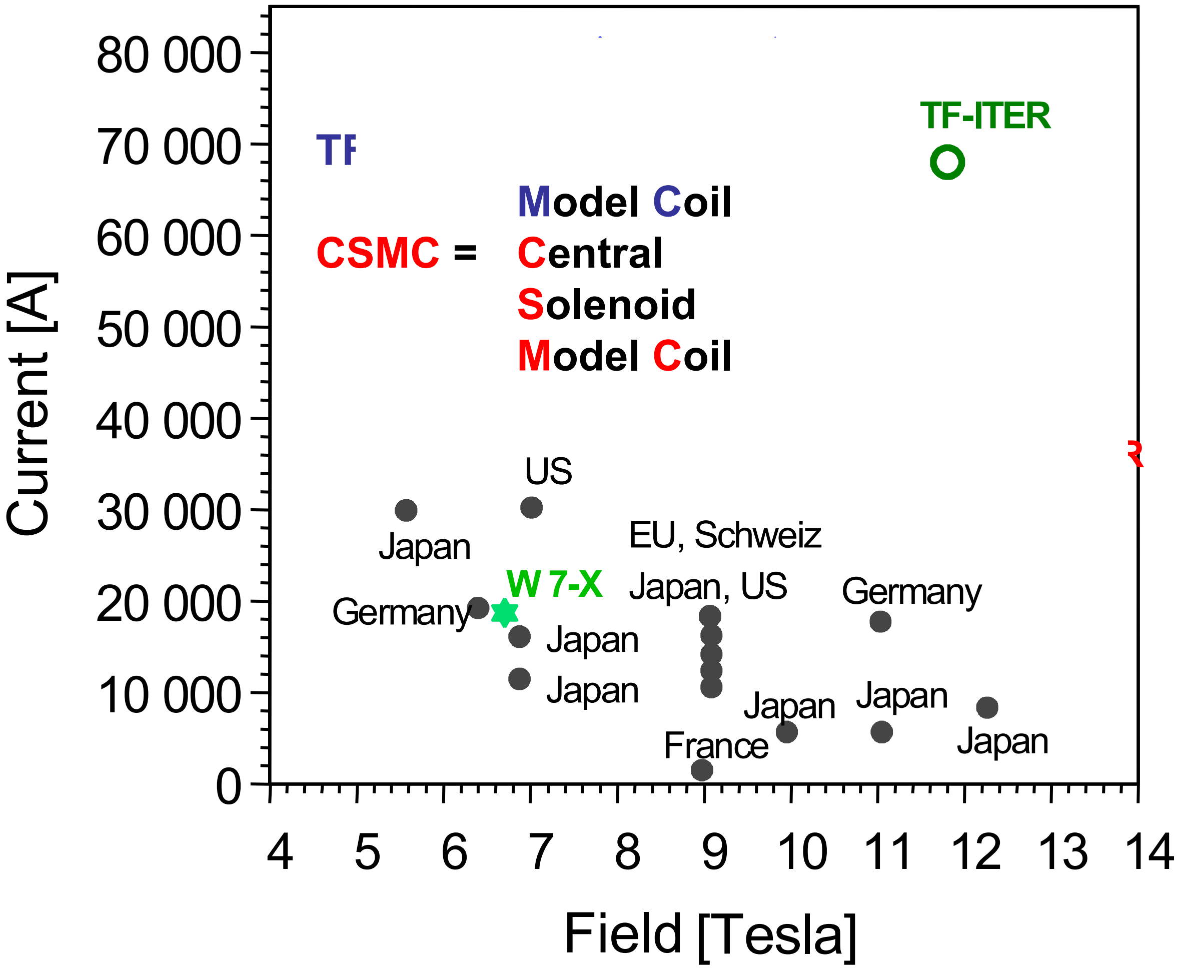
Height 4 m
Width 3 m
B_{max}=7.8 T
I_{max} = 80kA

REMOTE MAINTENANCE OF BLANKET

4 t Blanket Sector
Attachment Tolerance ± 0.25 mm

Magnet Development: Current-Field-Chart (Lorentz-Force)

Situation today – gives confidence to be able to built the ITER magnets



Situ
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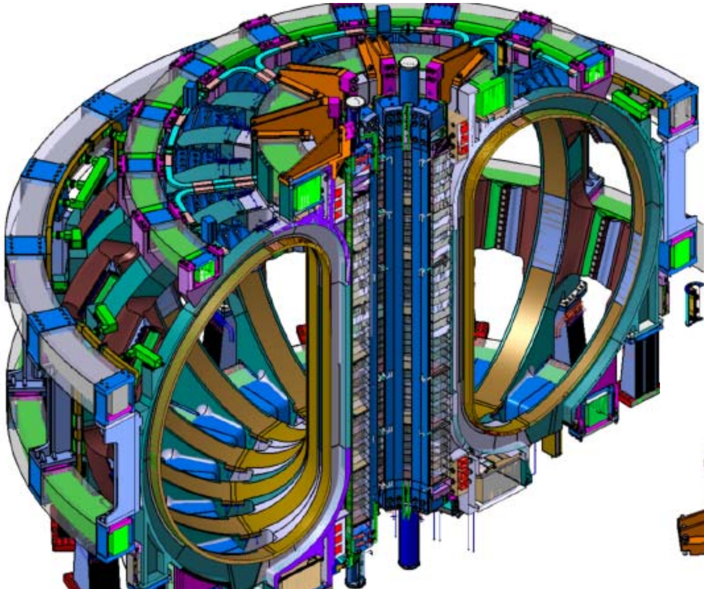
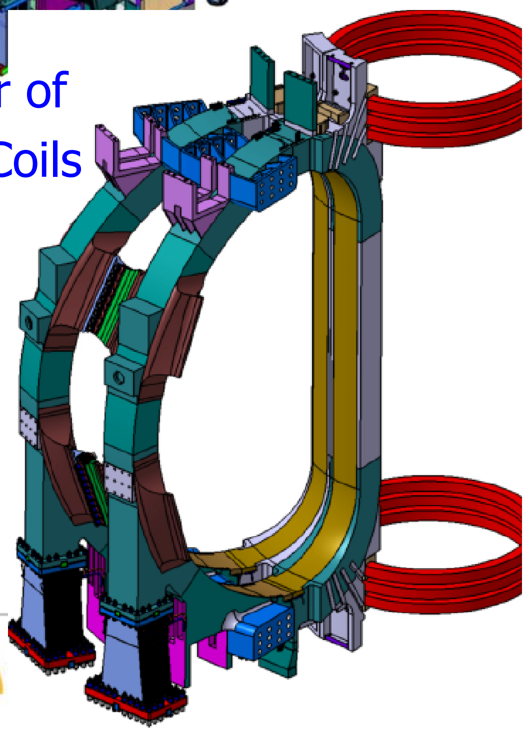
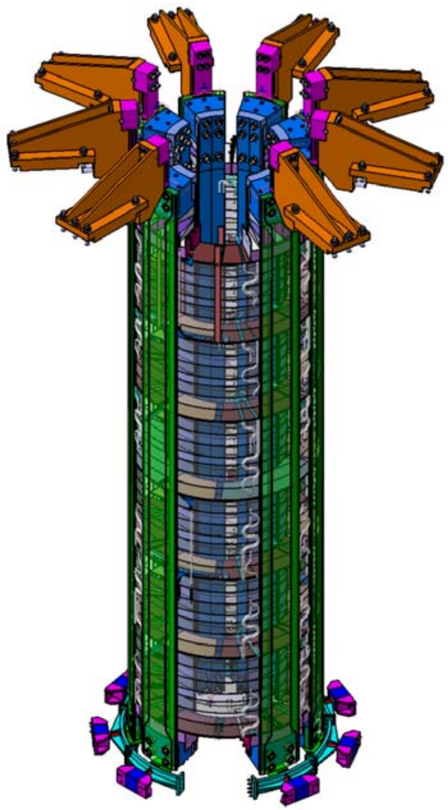
ITER Magnet System



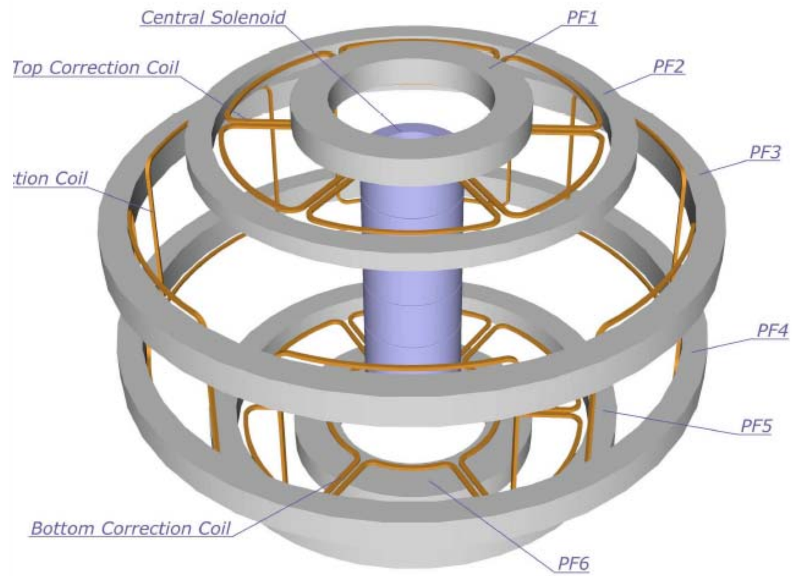
- The ITER magnet system is made up of
  - 18 Toroidal Field (TF) Coils,
  - a 6-module Central Solenoid (CS),
  - 6 Poloidal Field (PF) Coils,
  - 9 pairs of Correction Coils (CC).



Pair of TF Coils

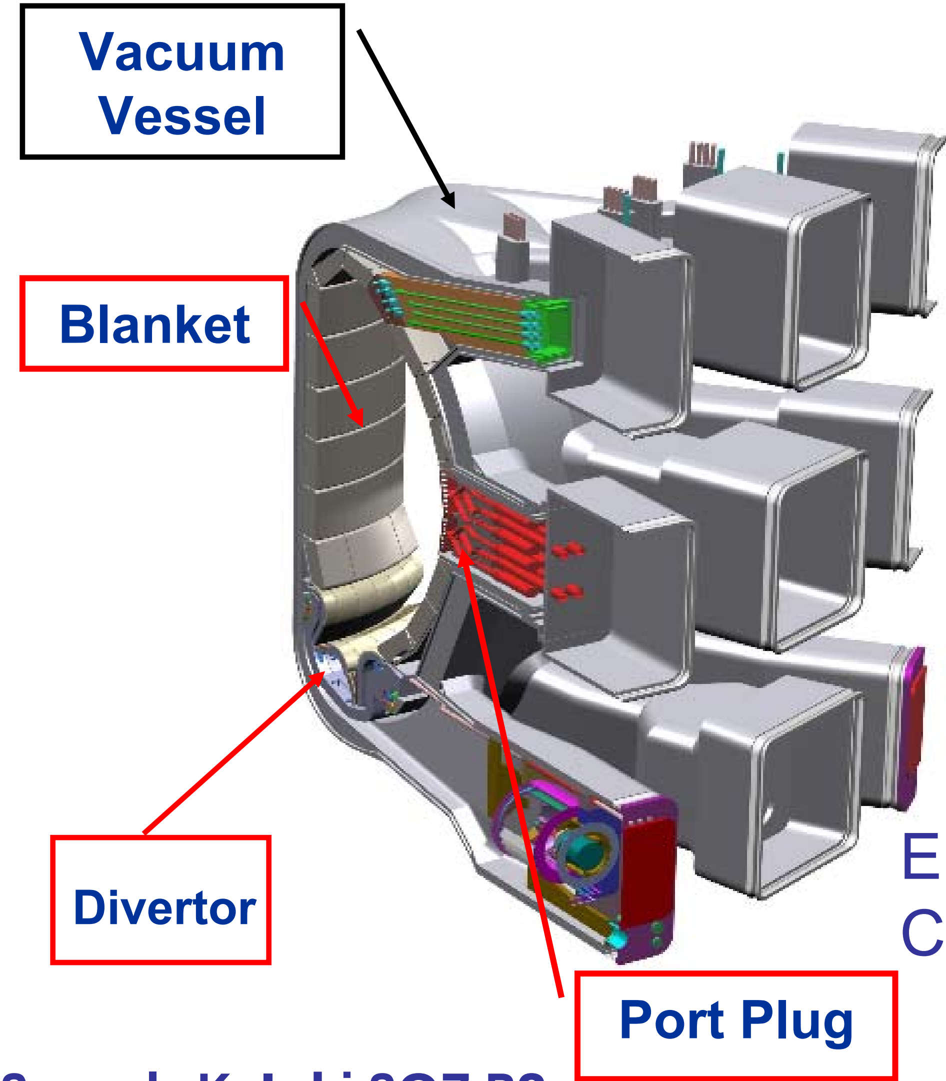


CS Coil

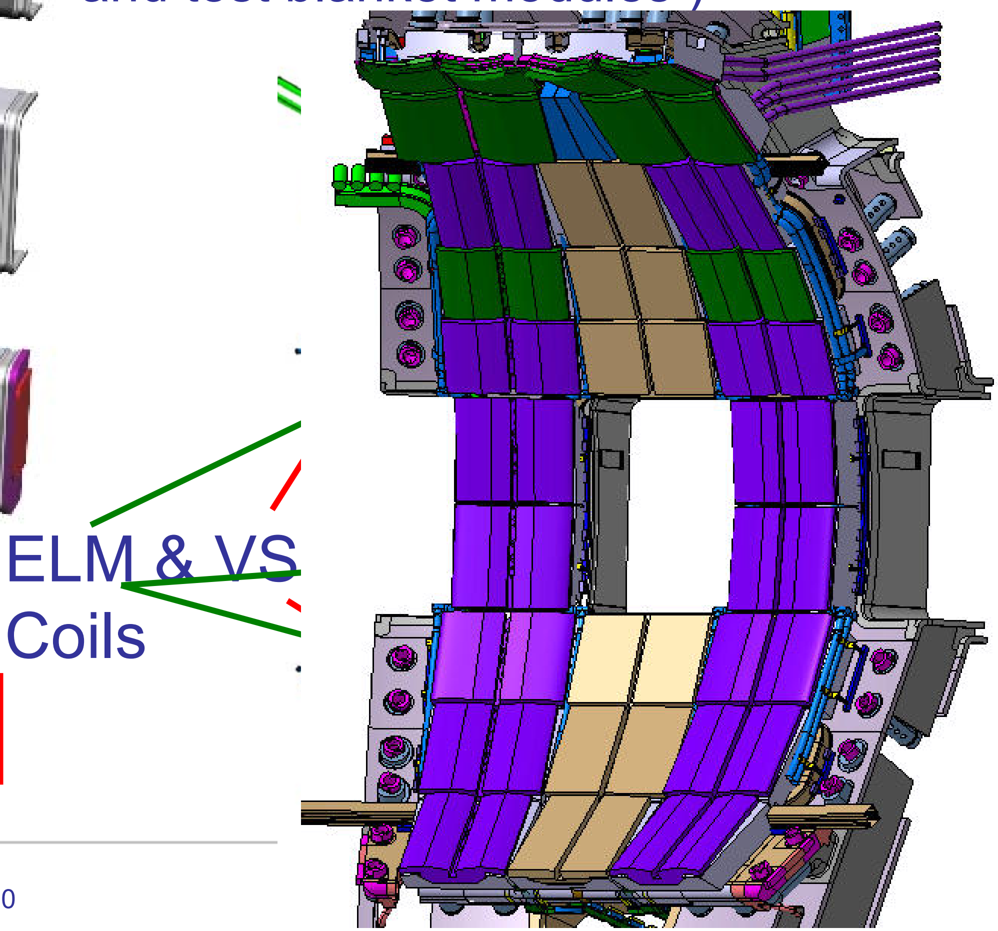


PF & CC Coils

ITER Vacuum Vessel supports all In-Vessel Components



- The vacuum vessel is lined by modular removable components: : **blanket modules, divertor cassettes, ELM / VS coils** and **port plugs** (heating antennae, diagnostics and test blanket modules)



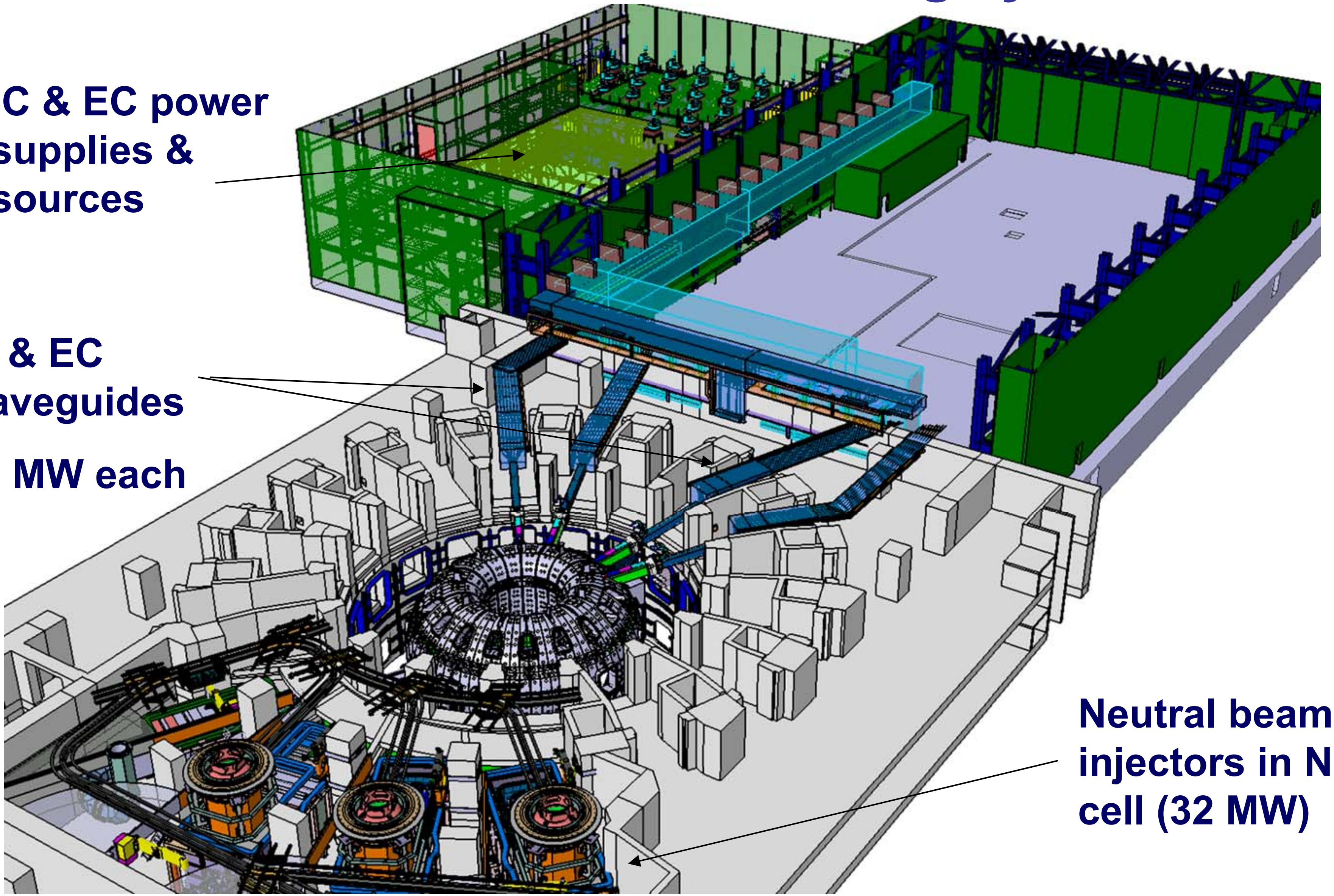
See als K. Ioki SO7 B2

Overview of the 70 MW ITER heating systems

IC & EC power supplies & sources

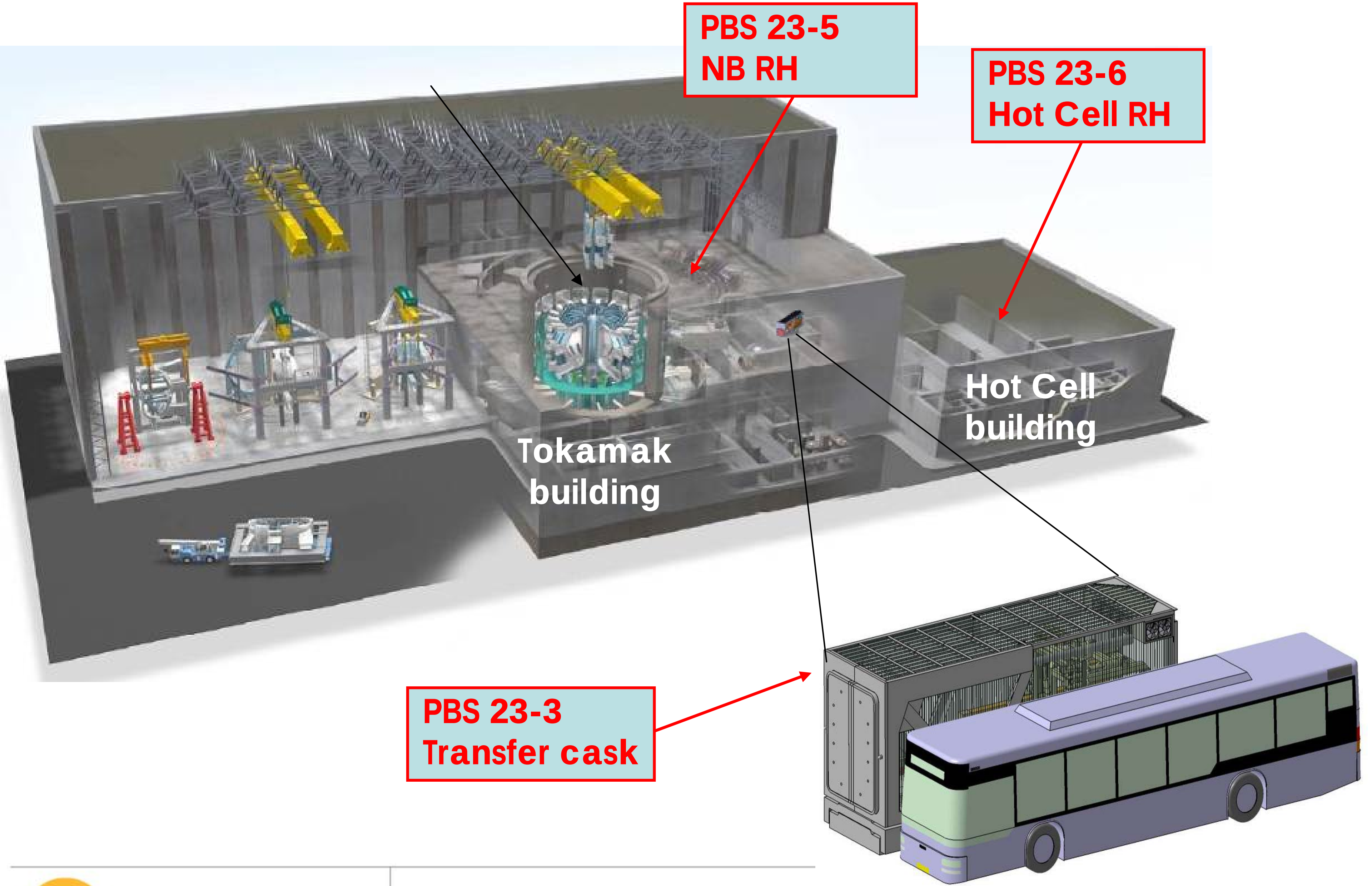
IC & EC waveguides

20 MW each

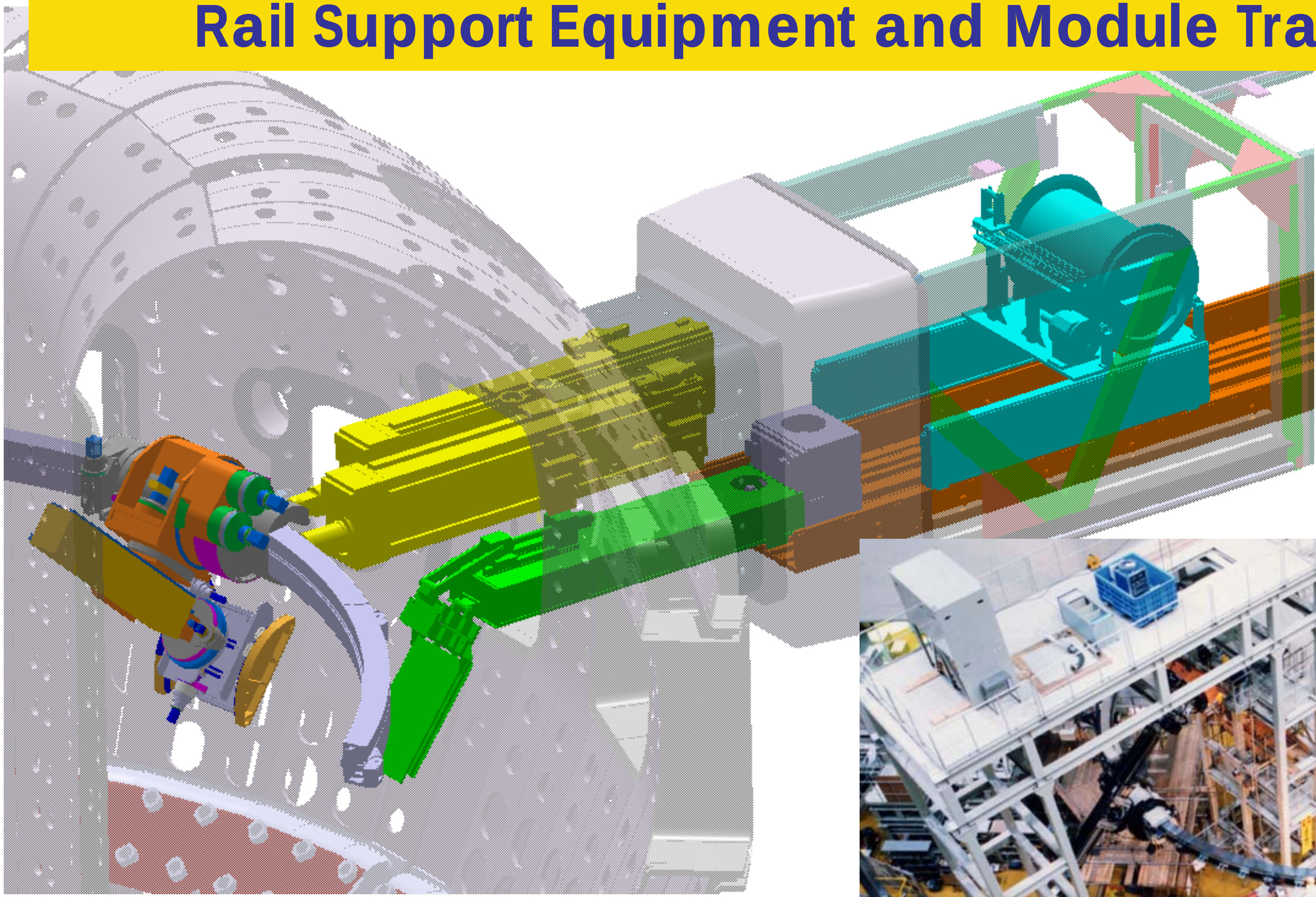


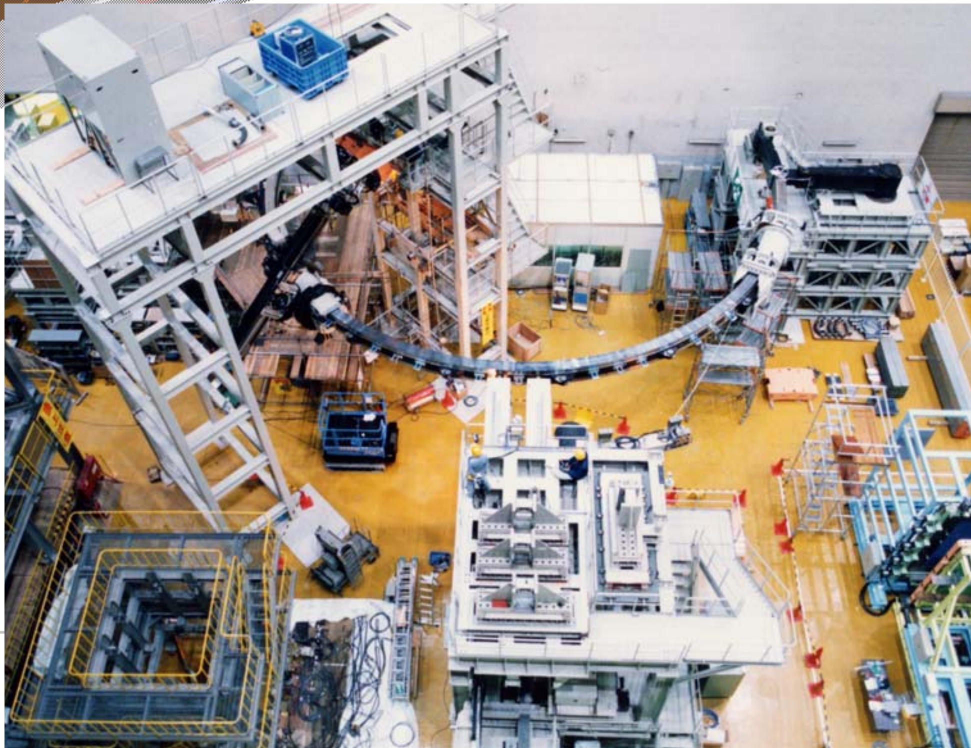
Neutral beam injectors in NB cell (32 MW)

ITER Remote Handling / Hot Cell

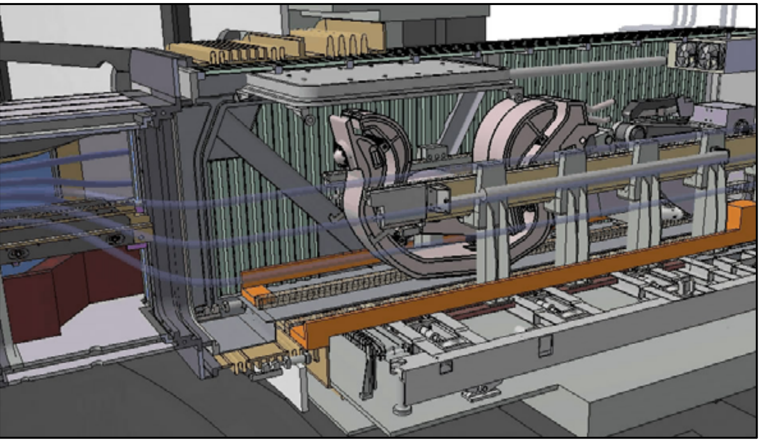


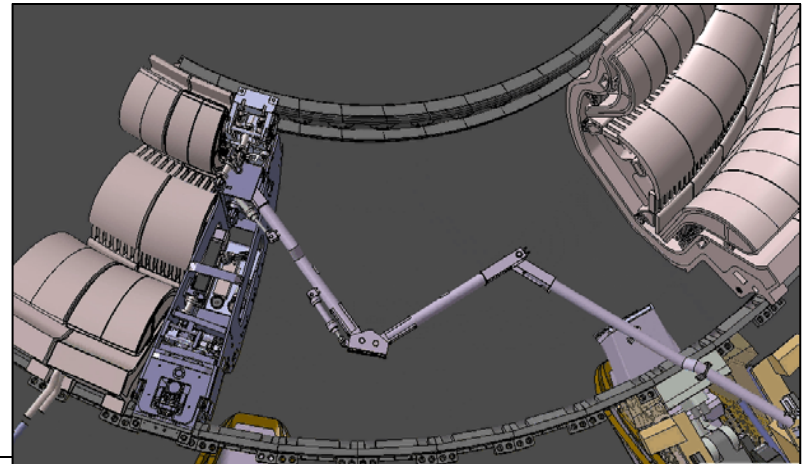
Blanket RH System
Rail Support Equipment and Module Transporter

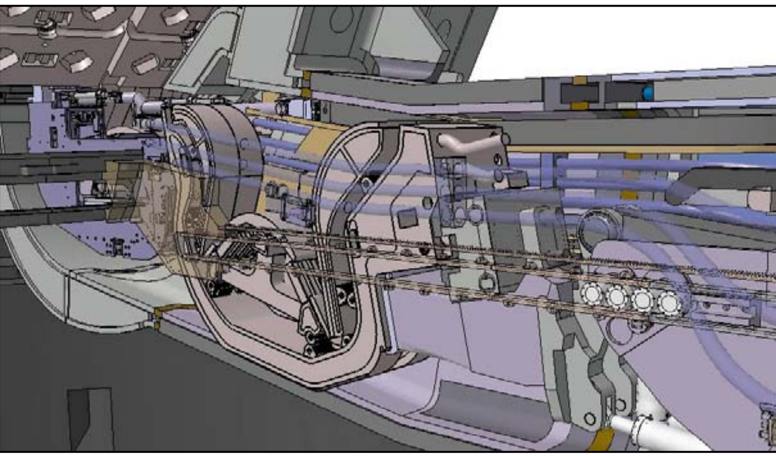




Divertor RH Equipment demonstrated to work



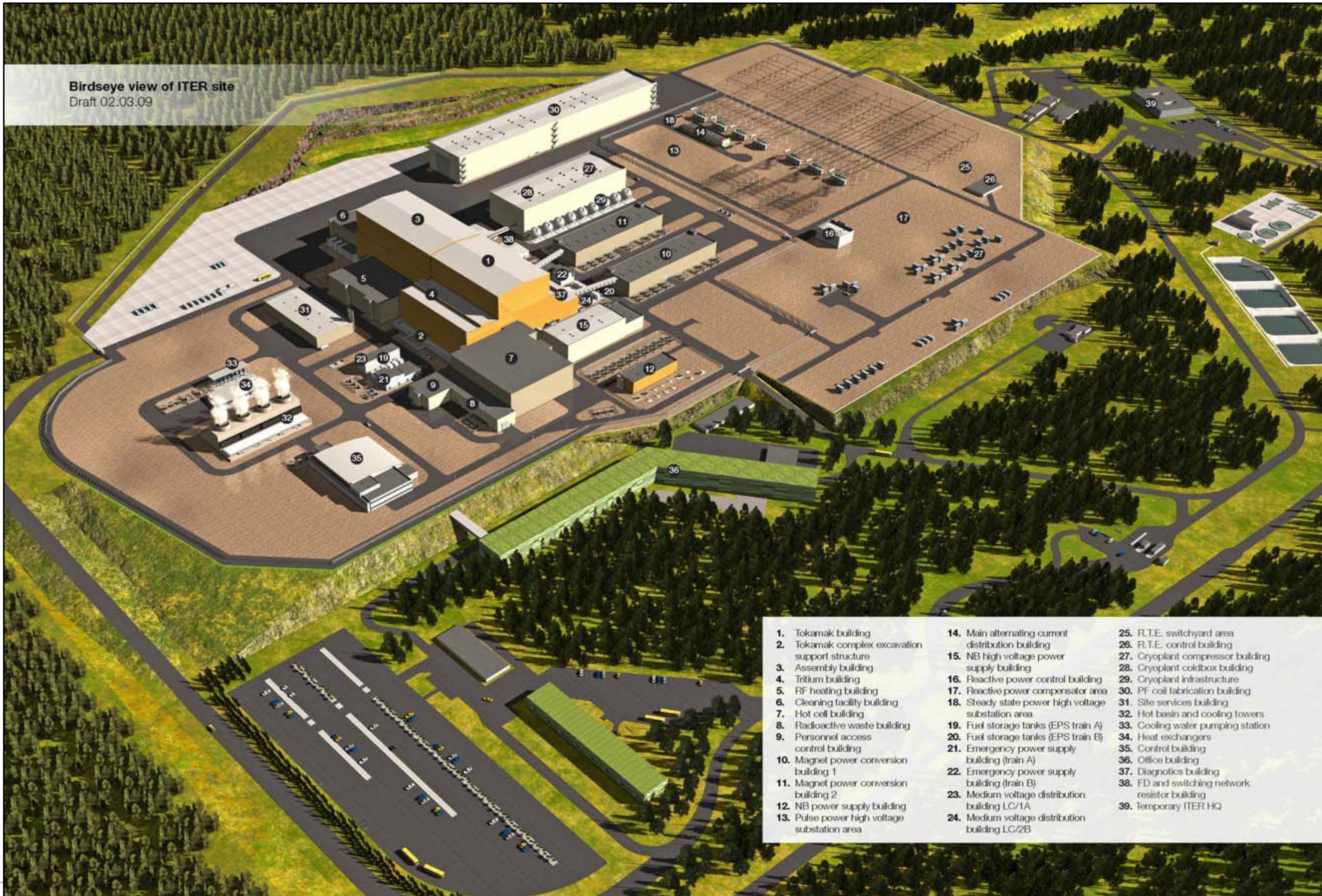




Divertor RH equipment is comprised of
Two main types of “cassette mover”:

- **Cassette Multi-functionl Mover (CMM)**
- **Cassette Toroidal Mover (CTM)**

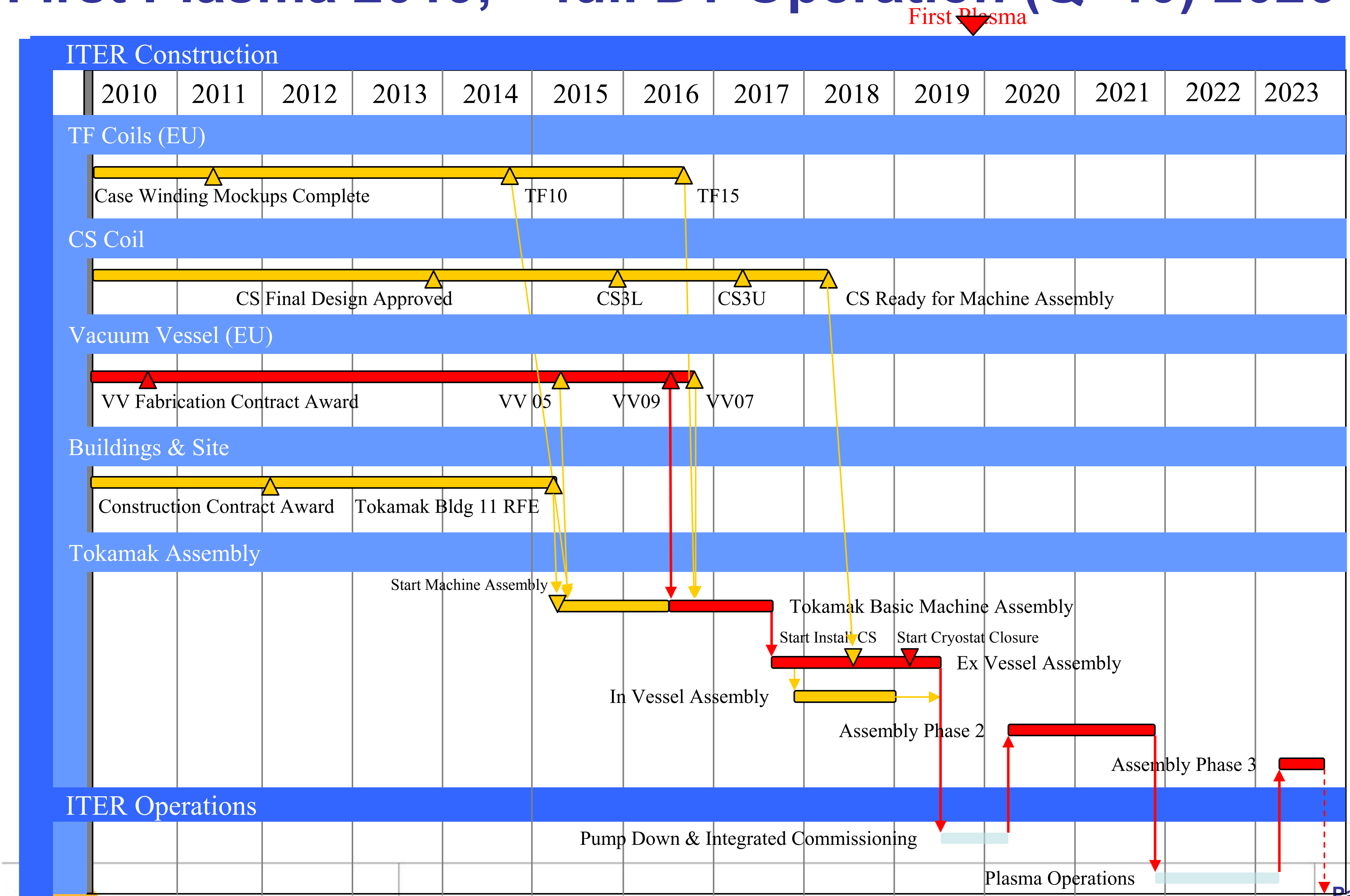
ITER Project Site Layout: 3-D graphics view



Present ITER Construction Site

The creation and improvement of 106 kilometres of access roads from Fos harbour to Cadarache have been finished by February 2010.

Overview of Construction Schedule
First Plasma 2019, full DT Operation (Q=10) 2026

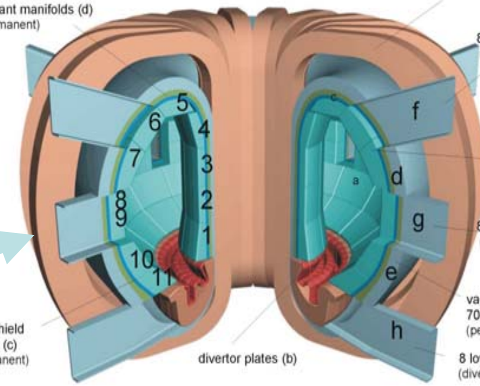


Fusion Energy Development

Energy Conversion Technology

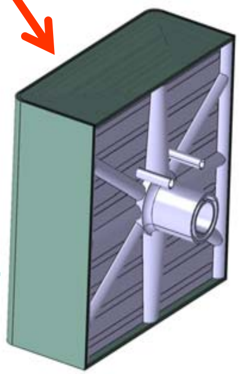
H_2 Production ?

IFMIF



EU DEMO > 2025

Materials

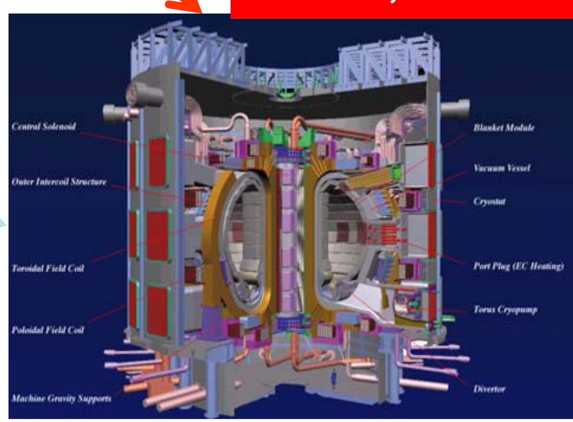


Technology

TBM, TDM

now

Physics & Technology



ITER 2019

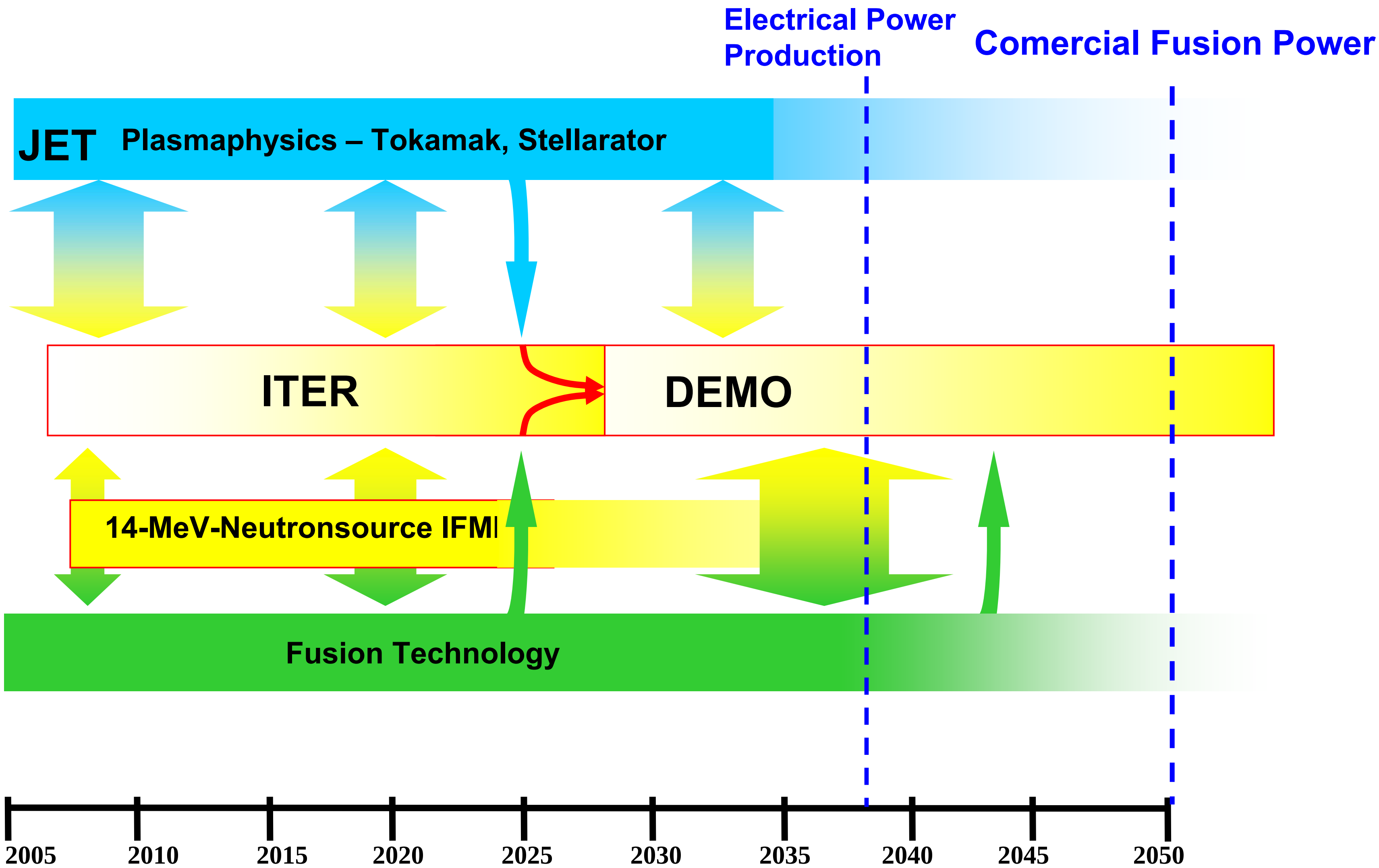
Conclusions

ITER is the key step towards the realization of fusion energy with magnetic confinement

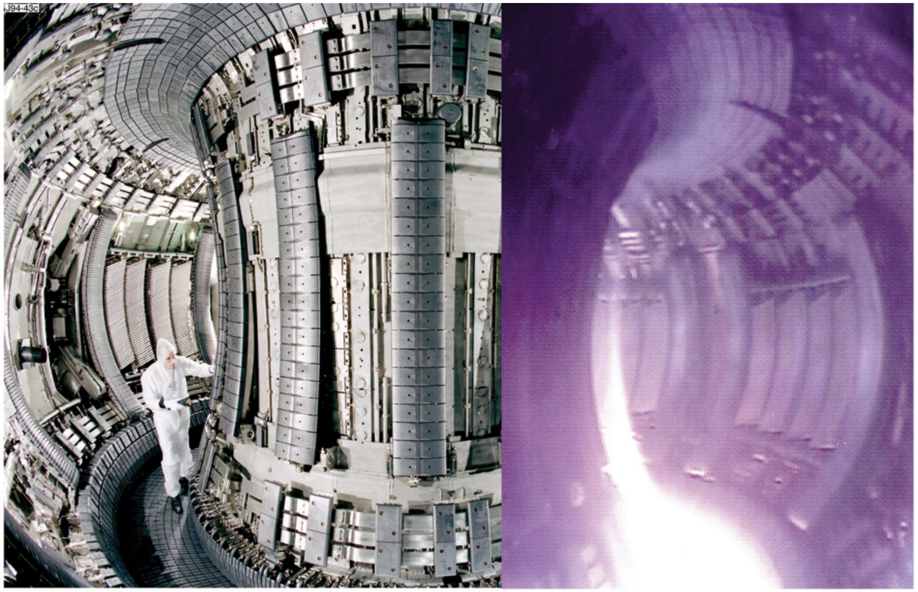
- All the Physics and Technology Challenges have been met to a large extend
  - **The Physics Basis is stable since several years**
  - **All systems are underpinned by R&D and by industrial qualification processes ongoing at the moment**
  - **The few outstanding issues and challenges are to be solved in the near to mid term future – in time for procurement and installation**
- The licensing process is well under way
- While ITER is the decisive step to fusion energy, technologies and materials for DEMO need to be developed in parallel in order to keep the momentum for fusion energy as major contributor within this century

Backup Material

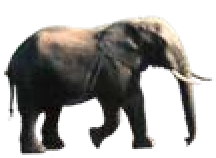
Road Map to the Fusion Reactor (Fast Track - EU)

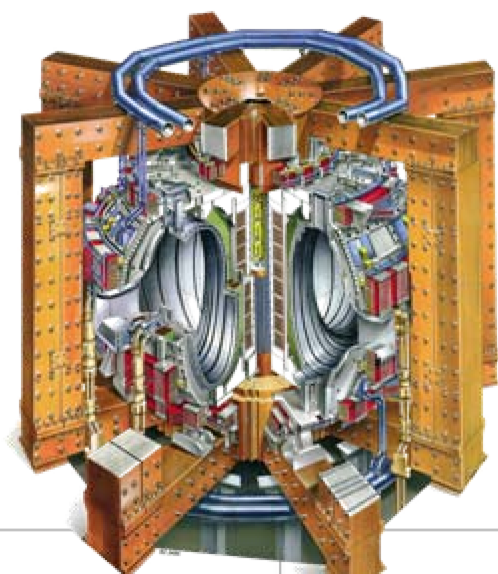


Family of Tokamaks defined the ITER Physics Basis

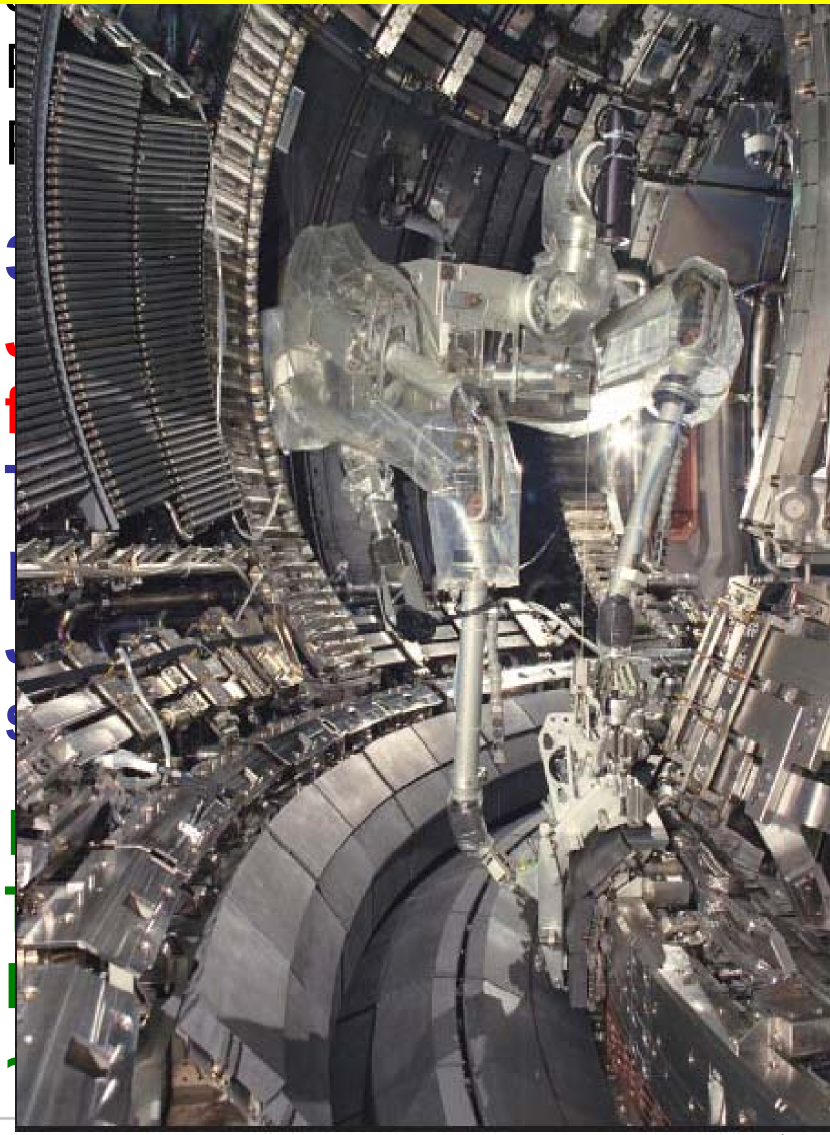


JET – Internals & Plasma

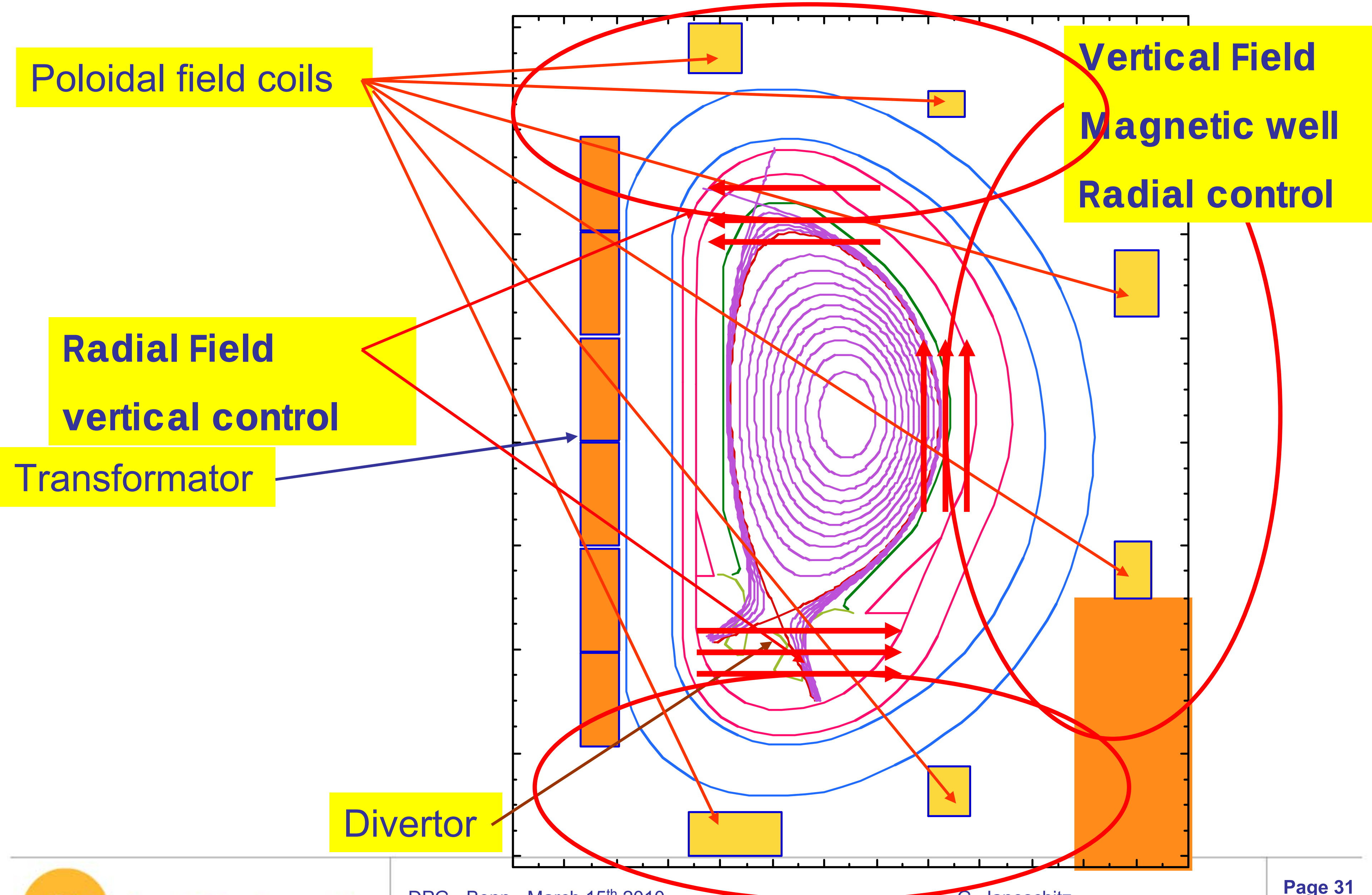




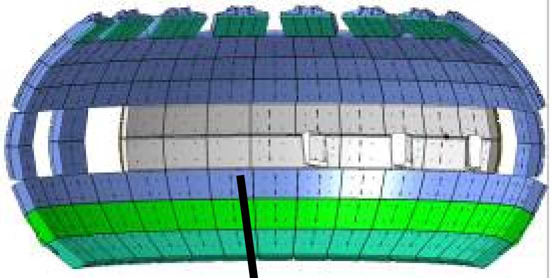
Remote Handling in JET

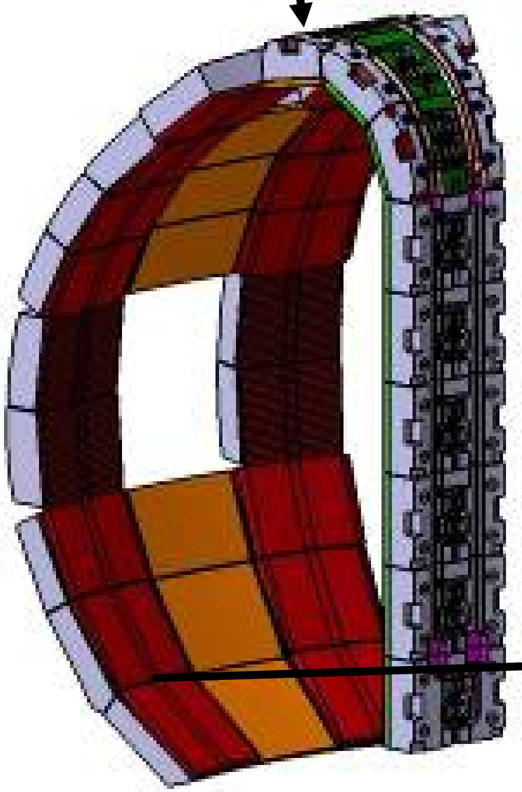


A modern Tokamak – Vertical-, Radial-, Divertor Fields



Blanket System

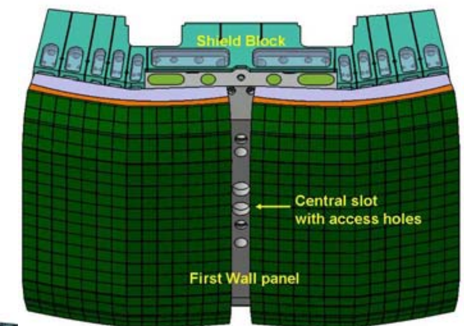




Challenge EM Forces, FW heatflux

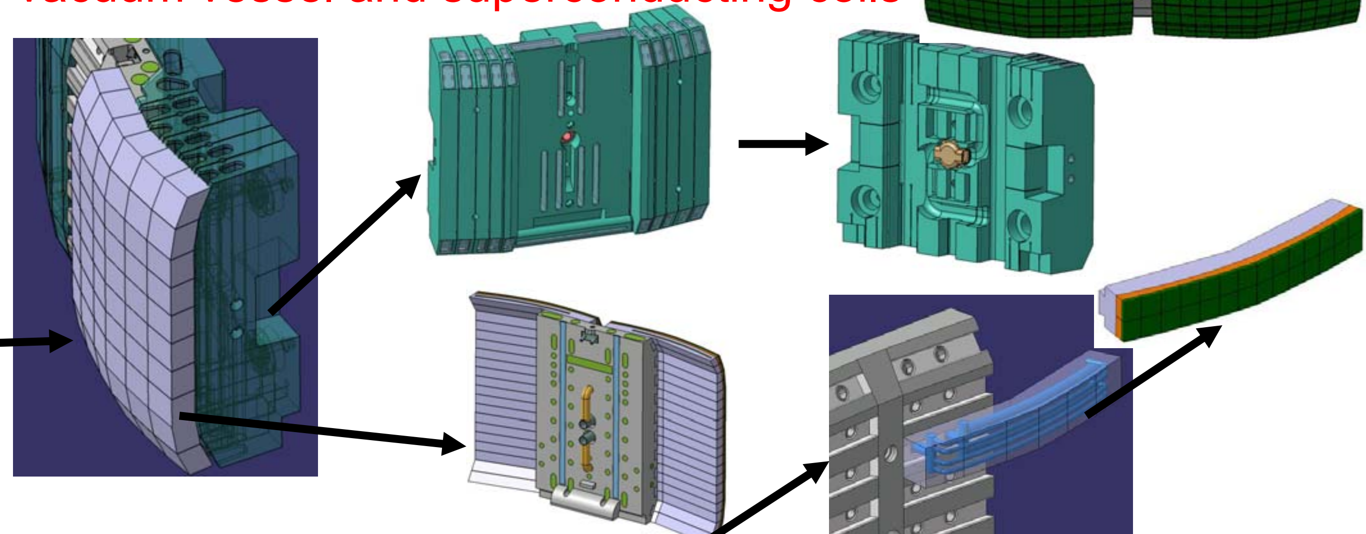
Scope

- 440 blanket modules at ~4 ton each
- ~40 different blanket modules



Blanket system main functions :

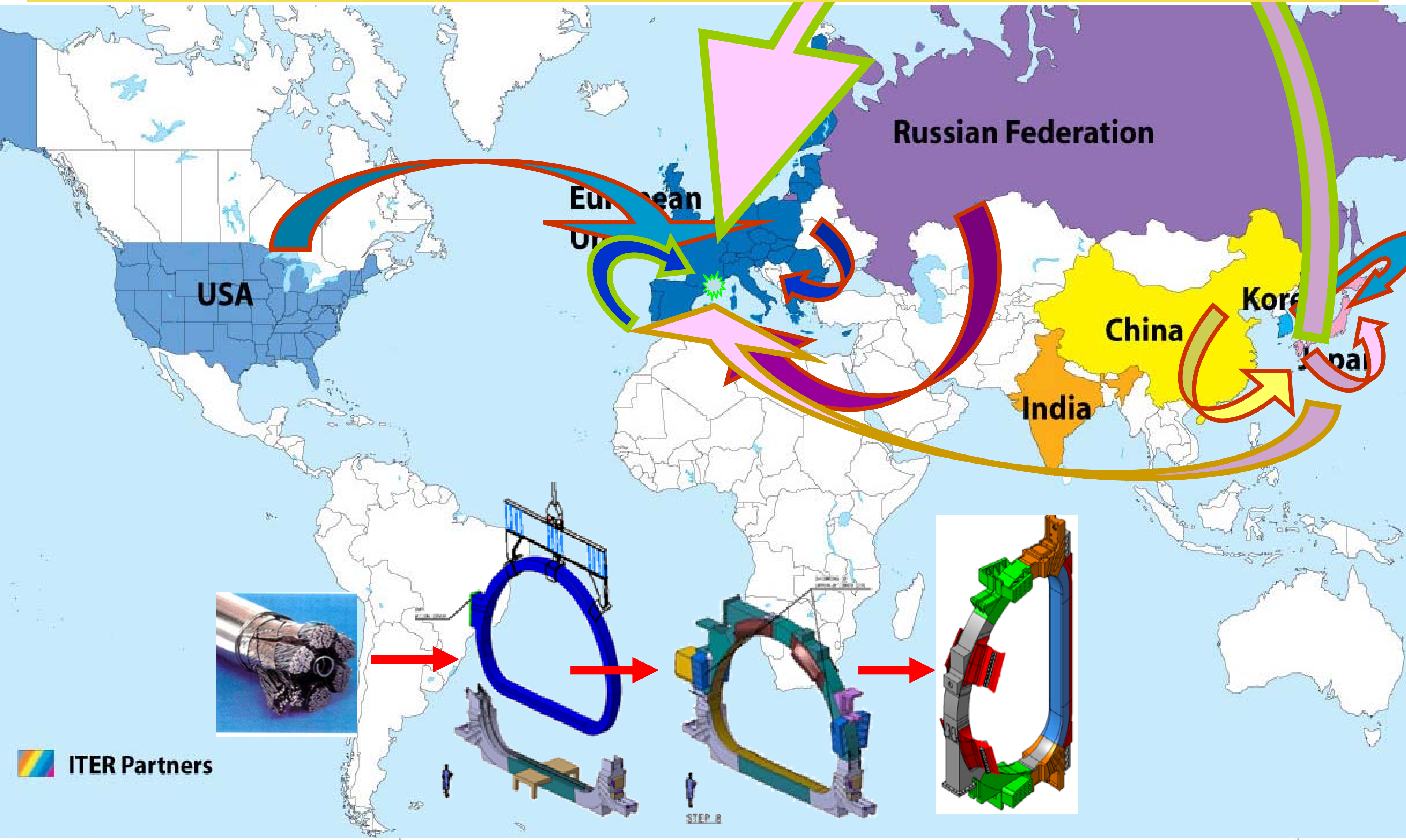
- Exhaust the majority of the fusion power
- Reduce the nuclear responses in the vacuum vessel and superconducting coils



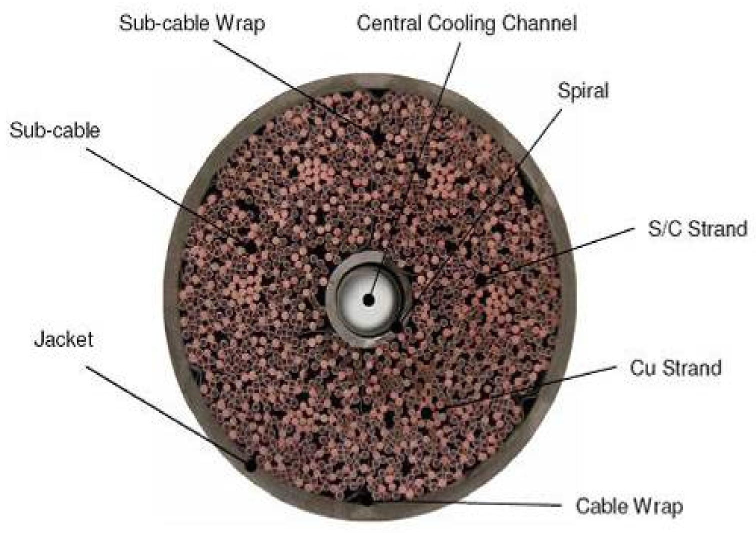
FW shaped – avoid edges – 5 MW/m^2 in 60% of area

Separable FW module, shield module slotted to reduce EM forces

ITER Procurement - a Worldwide Collaboration
Example: TF Coils



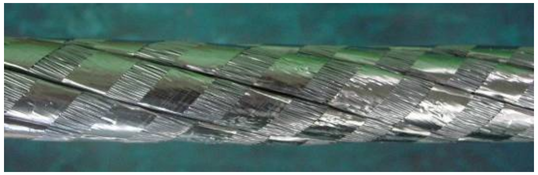
ITER Conductors



X-section of 70kA ITER TF Conductor (CEA)

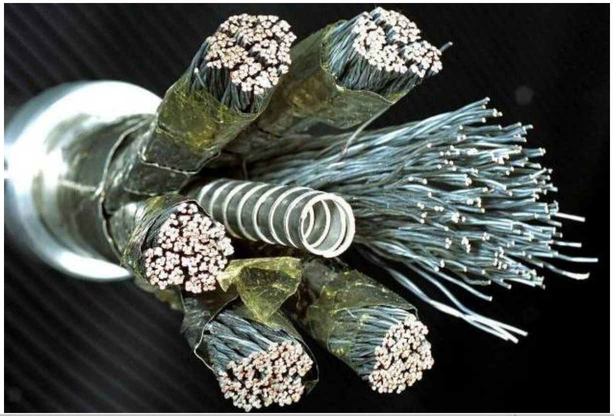
- ITER coils are wound from Cable-In-Conduit Conductors (CICC's), relying on superconducting multifilament composite strands mixed with pure Cu strands/cores.
- The strands are assembled in a multistage rope-type cable around an open central cooling spiral.
- The cable and its spiral are inserted inside a stainless steel conduit which provides helium confinement.

Cooling Spiral



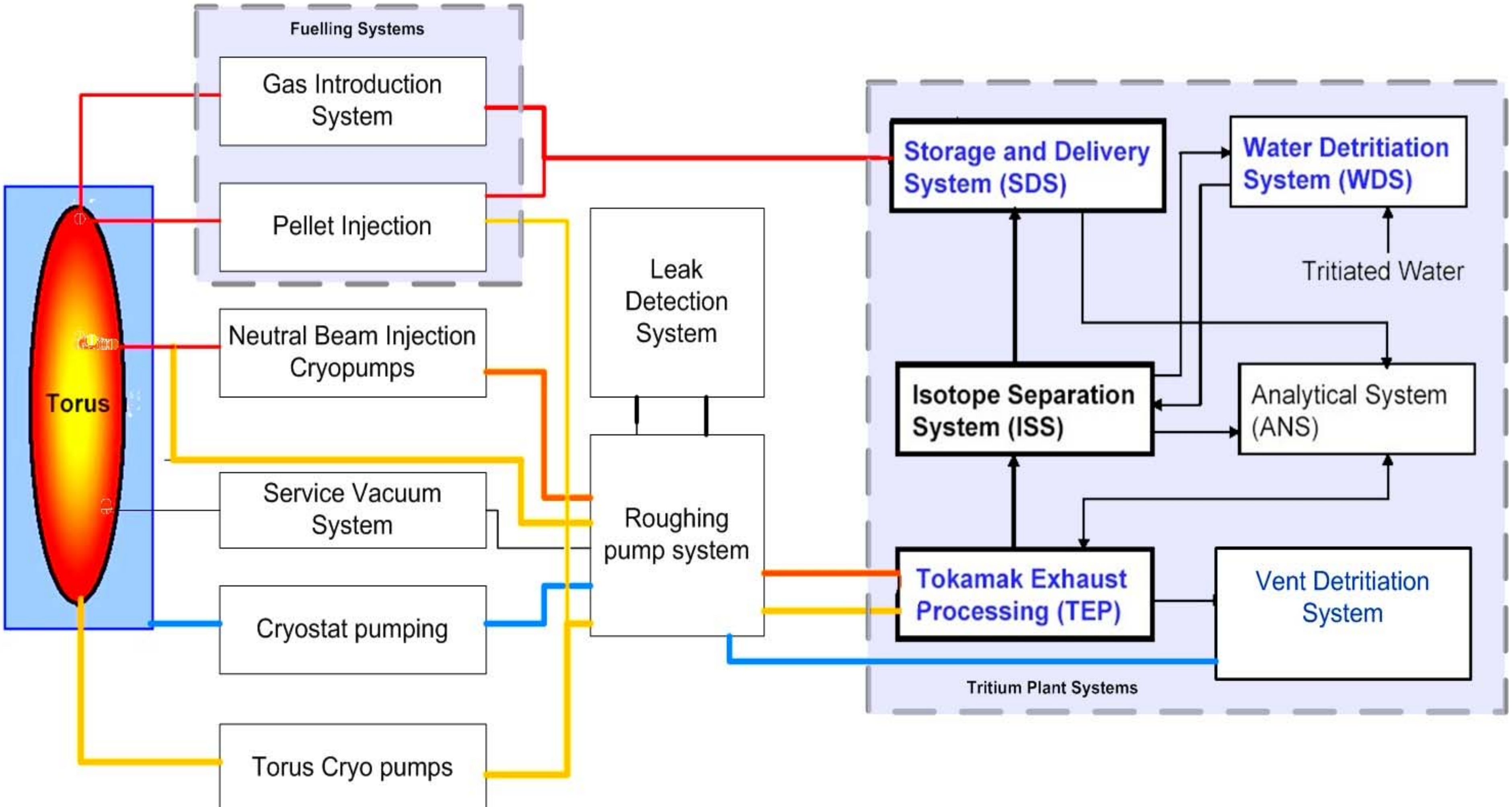
Final-Stage Cable (NFRI)

Stainless Steel Conduit (ASIPP)



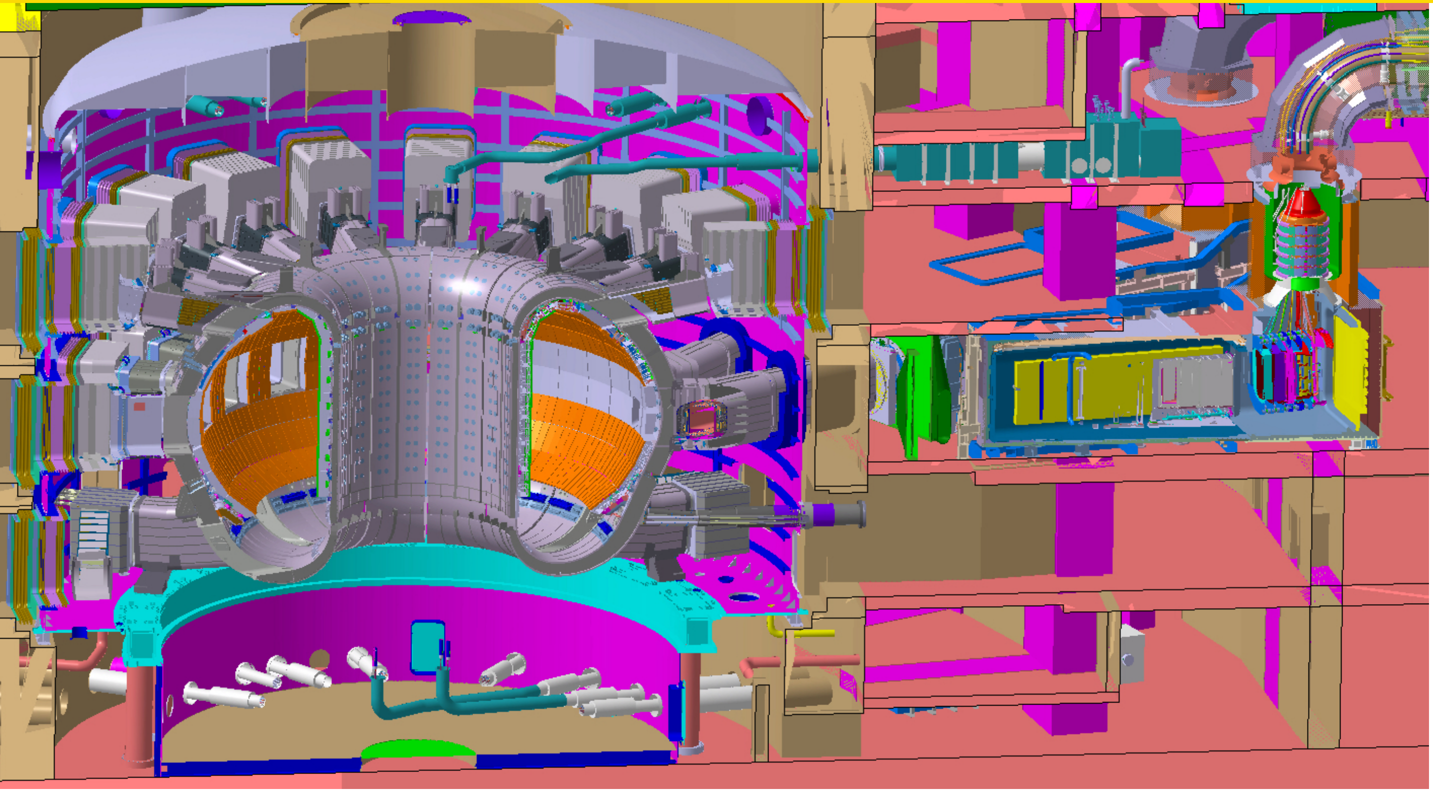
ITER Fuel Cycle

T-Plant handles all exhaust gases – release limits !!



Apart from the cryogenic guard vacuum – exhausts are centralized and controlled

ITER Vacuum Systems



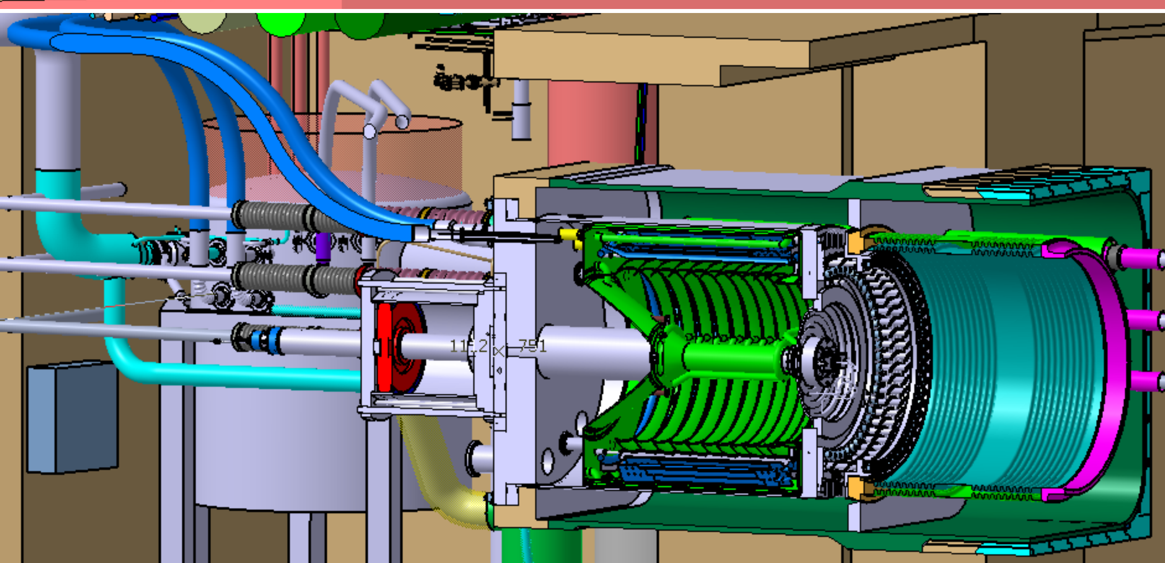
Cryostat vacuum(<10-4 Pa) 8500 m3

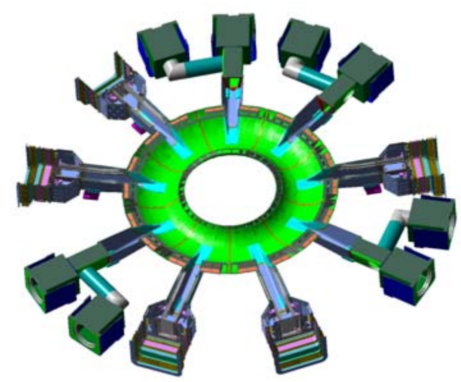
Torus vacuum(~10-6 Pa) 1400 m3

Neutral Beam vacuums(~10-7 Pa) 630 m3 (for 4)

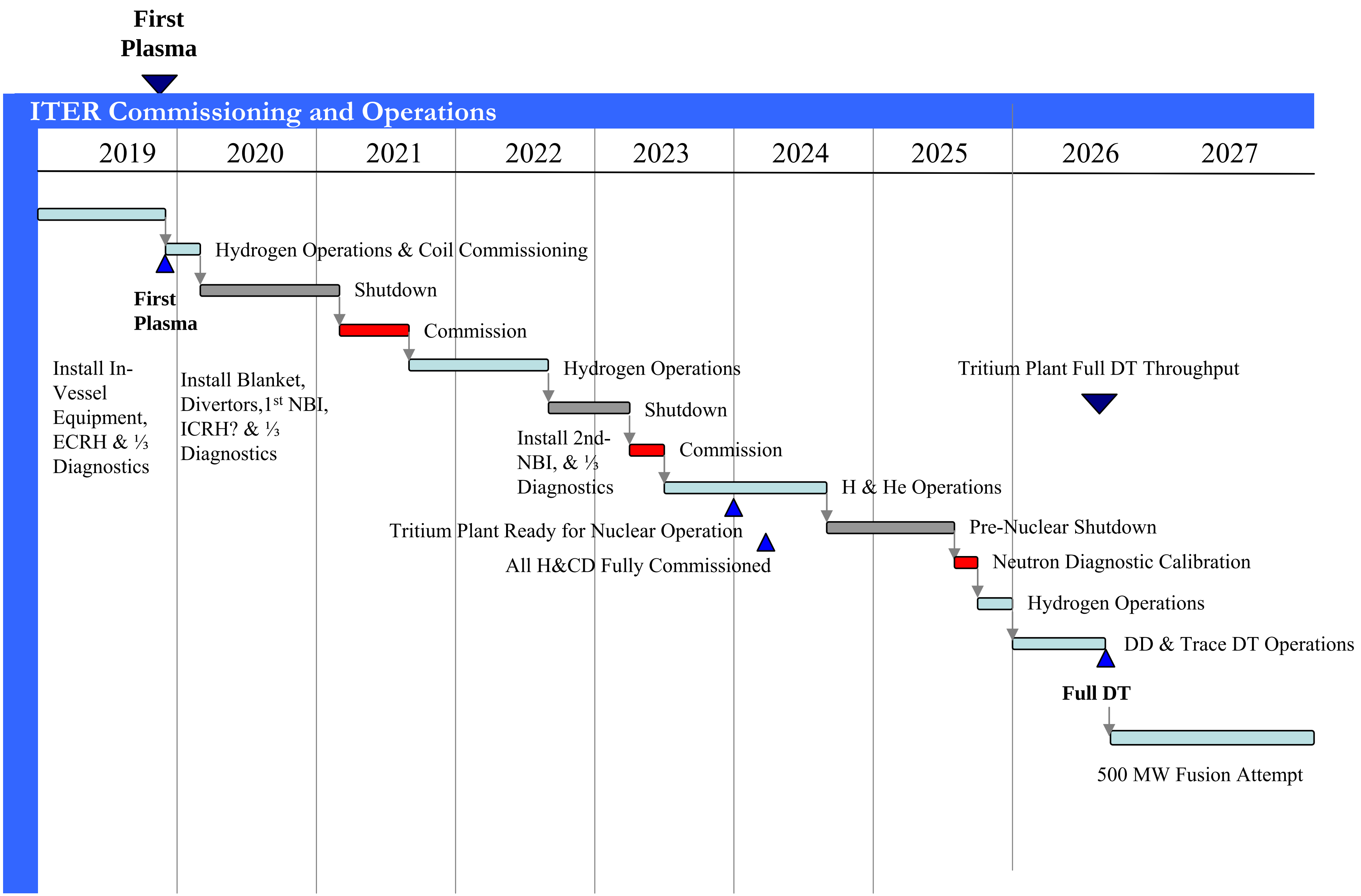
Cryogenic Guard Vacuum

Service Vacuum System (Inc diagnostics)
ICRH and ECRH Vacuums



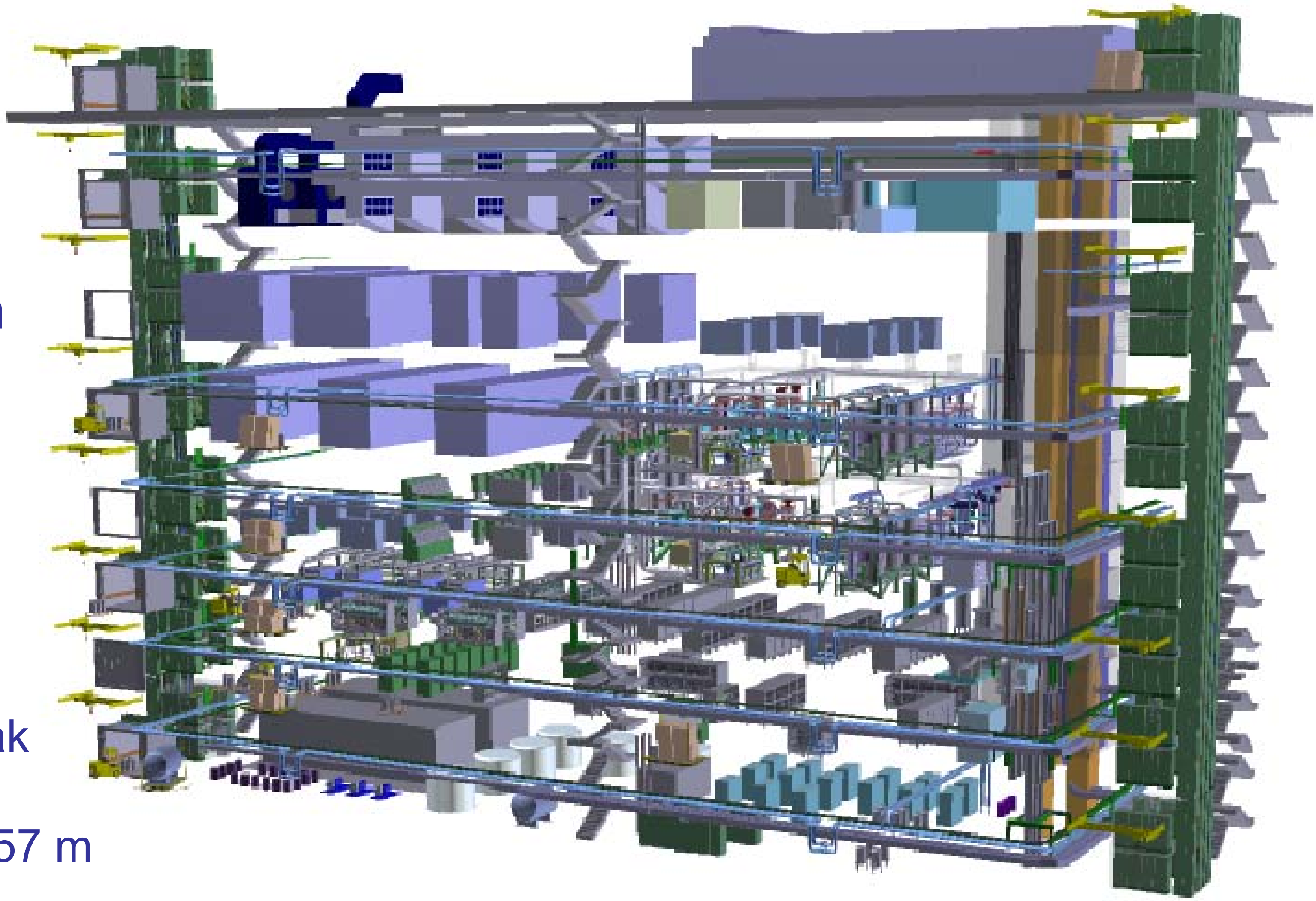


ITER Schedule Following First Plasma: Path to DT in 2026

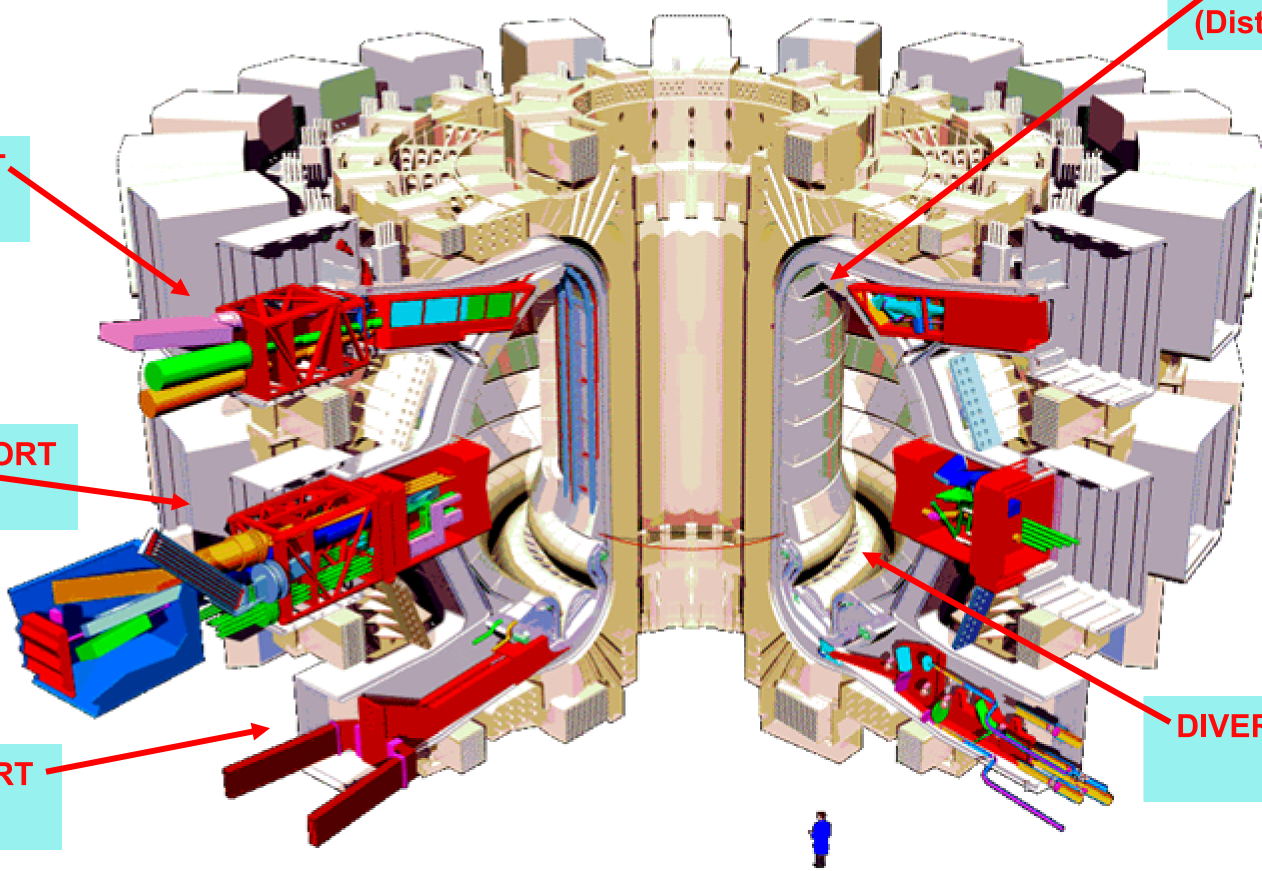


Tritium Plant Building Systems Layout

- 7 Floors
  - 2 below grade
- L = 80 m
- W = 25 m
- H = 35 m
- Release point elevation: 60 m
  - Tokamak building height: 57 m

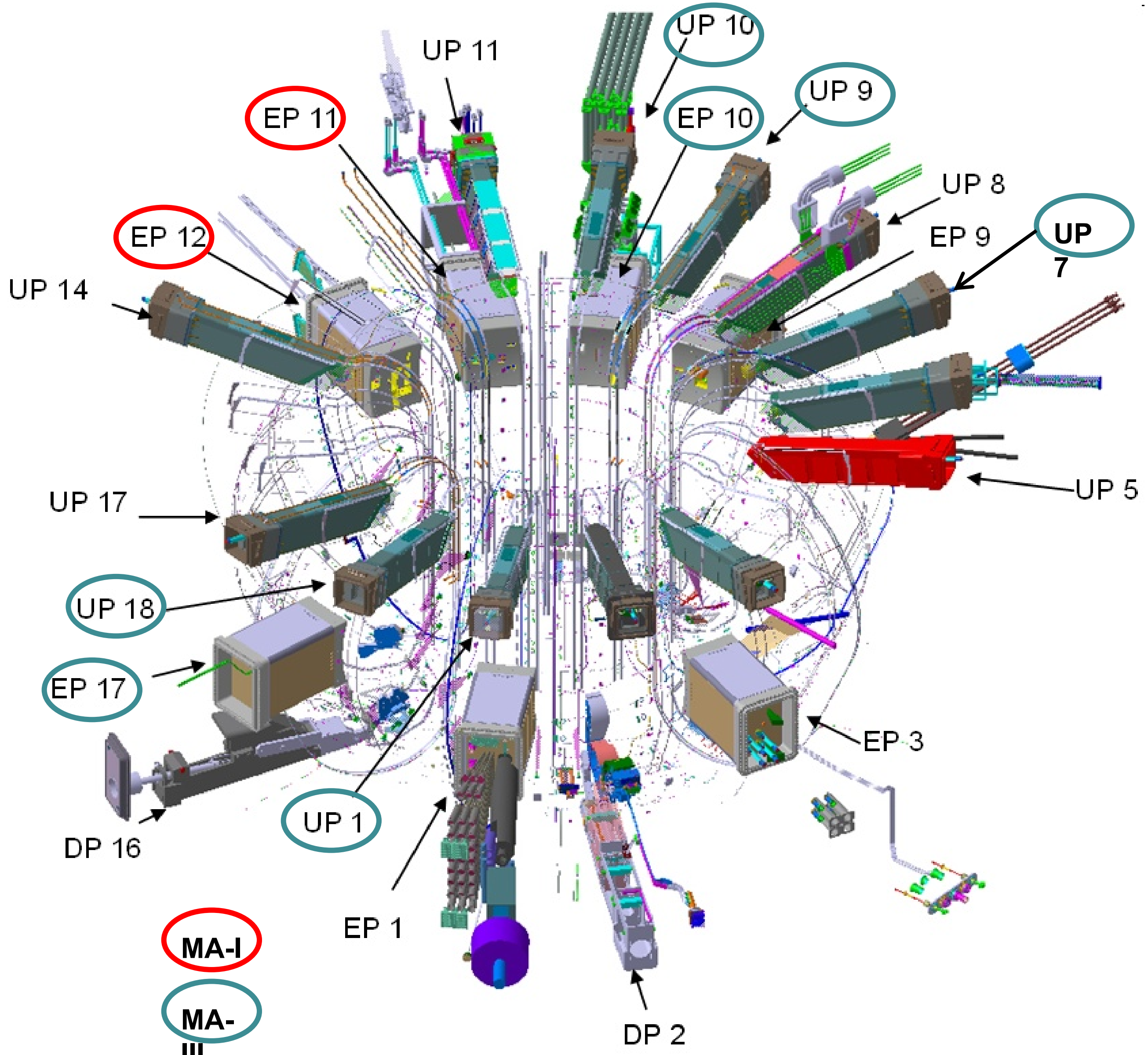


ITER Diagnostics



- **About 40 large scale diagnostic systems are foreseen:**
  - Diagnostics required for protection, control and physics studies
  - Measurements from DC to γ-rays, neutrons, α-particles, plasma species
  - Diagnostic Neutral Beam for active spectroscopy (CXRS, MSE ….)

Vessel & Port-based Diagnostic subsystems – installation phases



Machine Assembly Phase

MA-I
- All in-ex vessel
- Magnetics
- Bolometry
- Waveguides
- Eq ports 11 & 12

MA-II
- All lower ports
- Most Eq and Up ports

MA-III
- Remaining ports

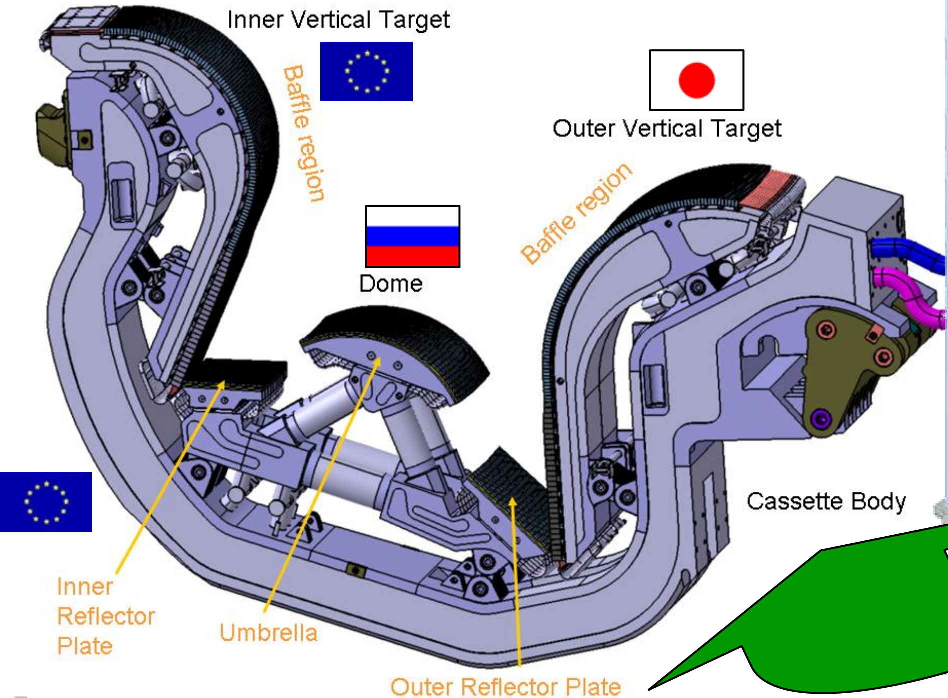
Divertor

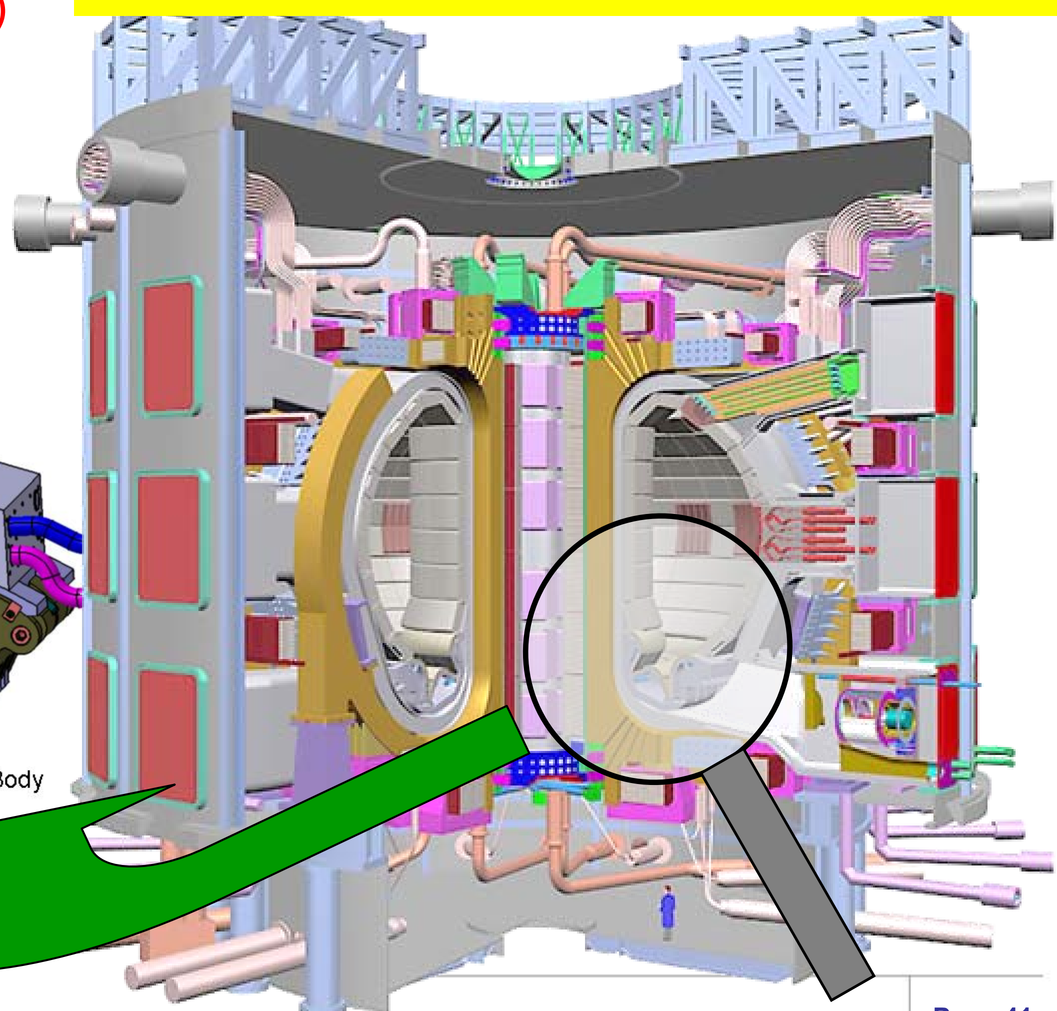
Divertor system main functions :

• Exhaust the major part of the plasma thermal power (including alpha power)

• Minimize the helium and impurities content in the plasma

Challenge to develop HHF Componets capable of 20 MW/m²





Divertor Qualification Prototypes

A qualification is "*…needed for the critical procurement packages shared by multi-Parties…*", including the divertor

All the 3 DAs have qualified to start procurement