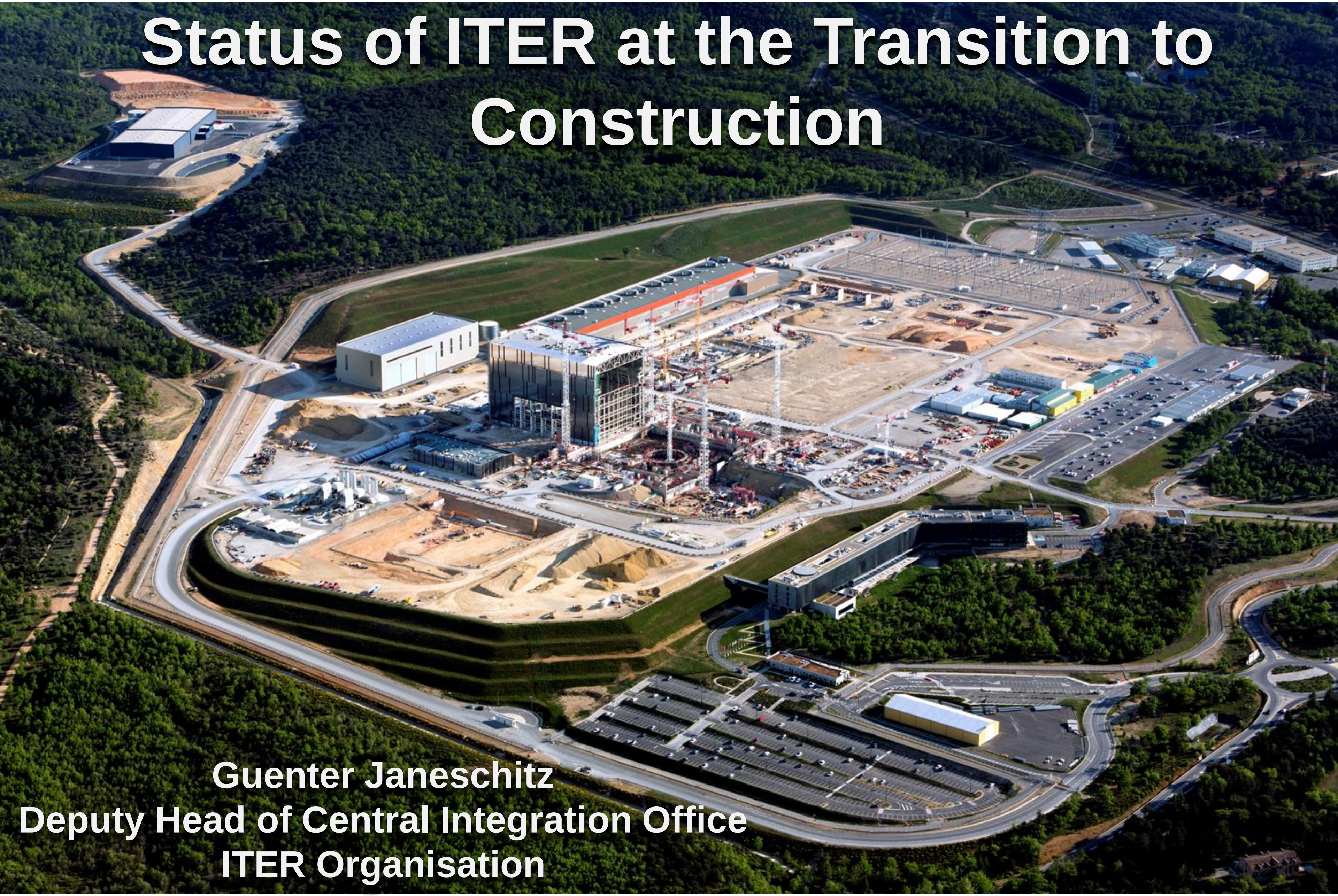
Status of ITER at the Transition to Construction

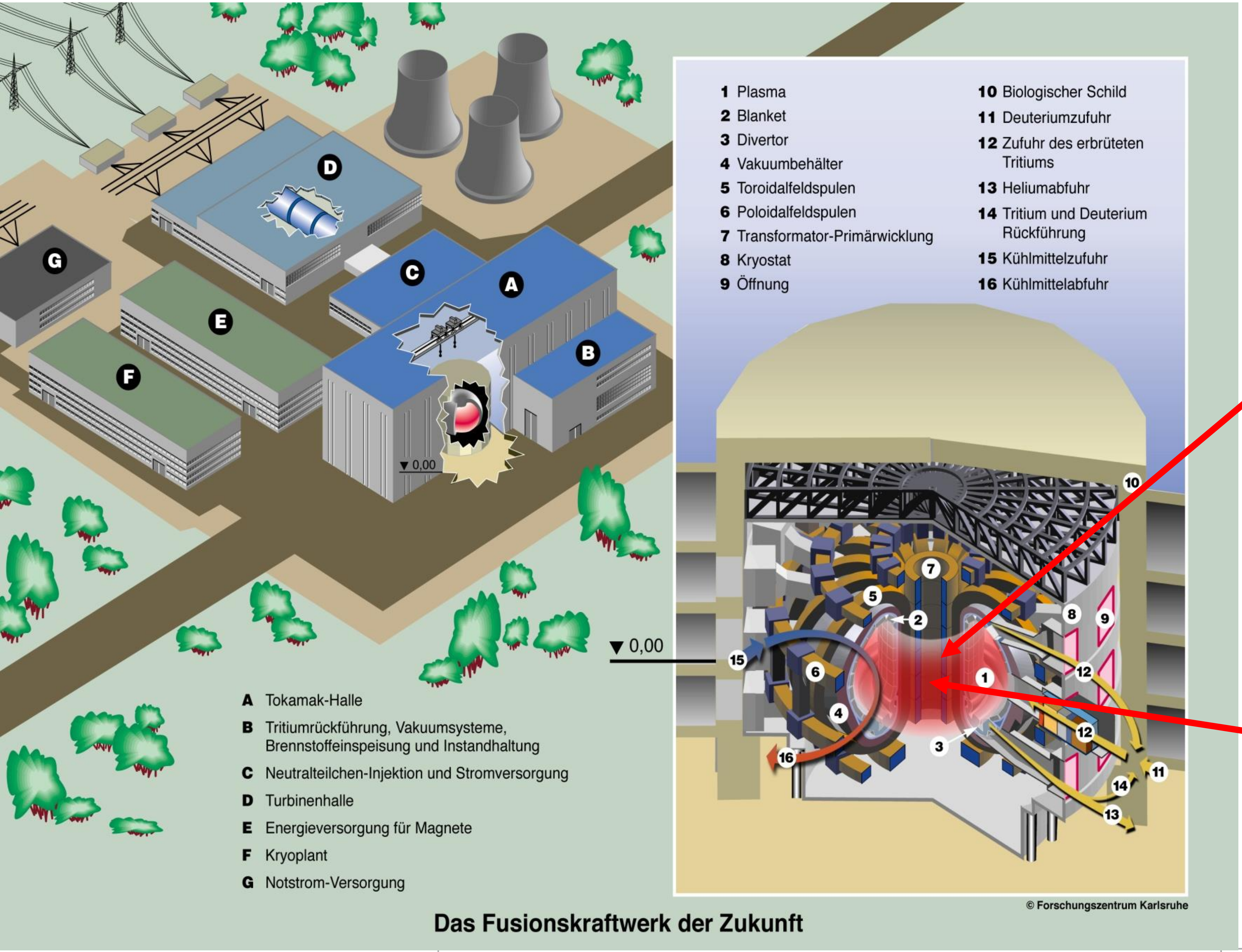


Guenter Janeschitz
Deputy Head of Central Integration Office
ITER Organisation

Outline

- Fusion Basics and History of ITER (very brief):
- ITER and its mission, Status of Construction
- Road-map and Technologies needed for DEMO (very brief)
- Conclusion

Schematic View of a future Fusion Power Reactor



Fusion can be a long term solution not a short term fix

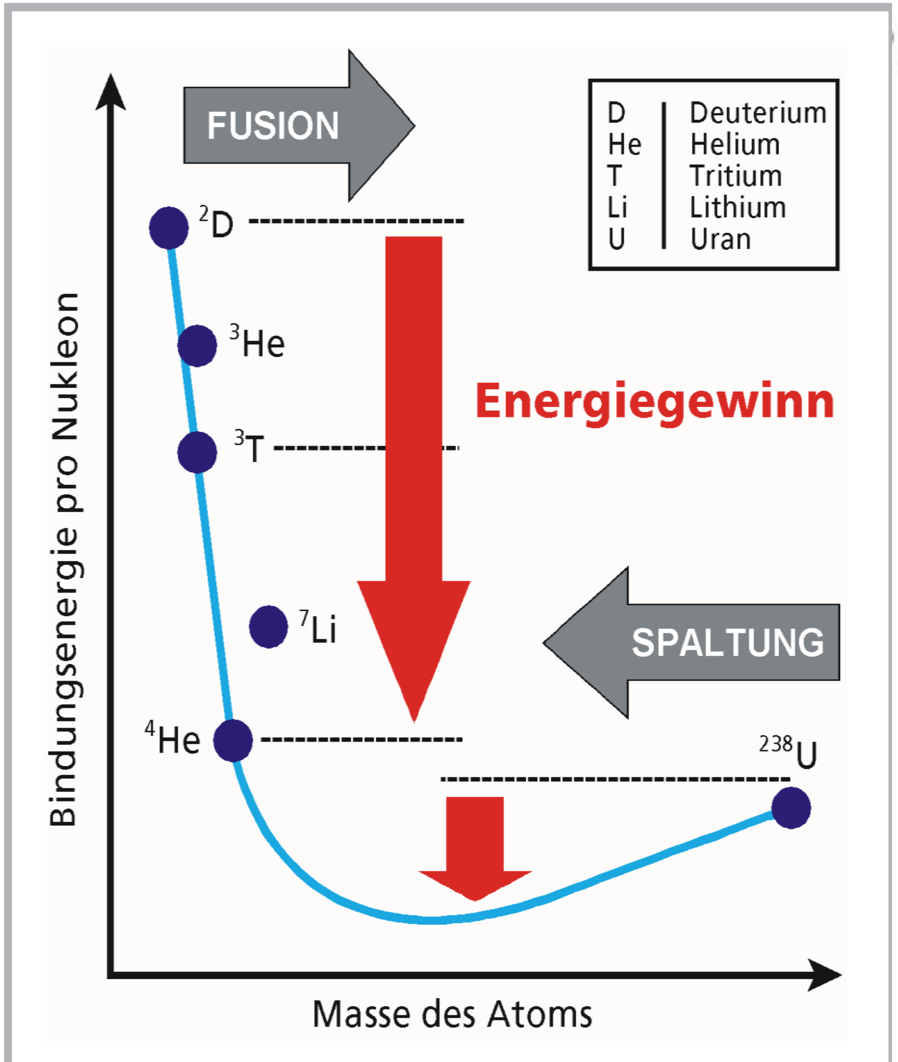
Power generated by hot plasma

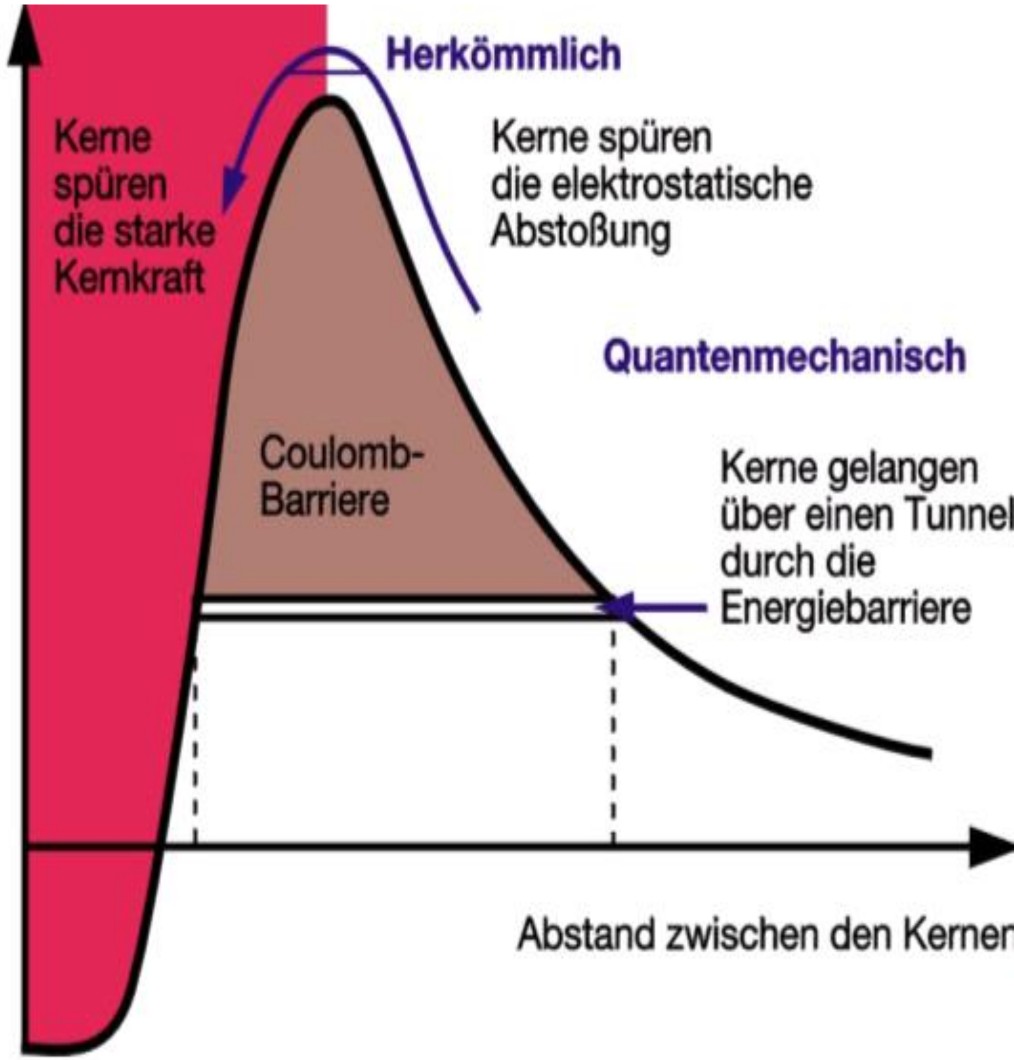
(20 keV = 200 Mio °C)

4/5 th of Power transported by 14 MeV Neutrons

Energy Gain from Nuclear Reactions

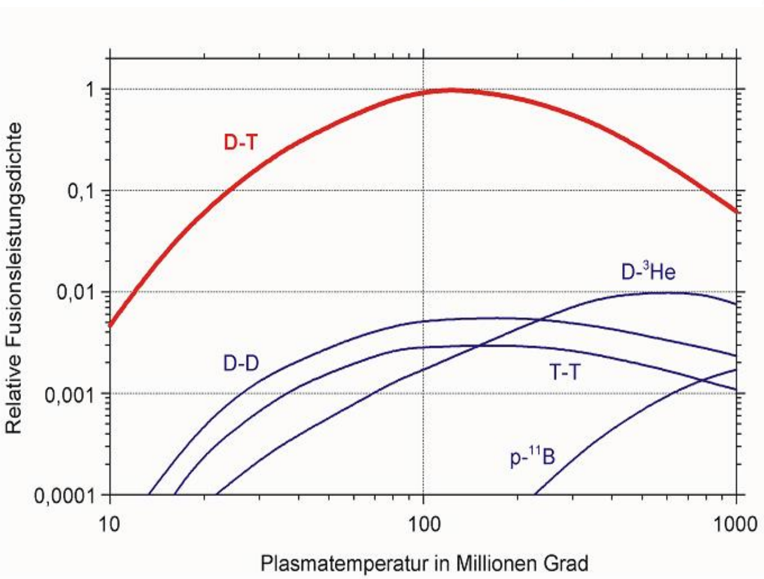
The Quantum mechanic tunnel effect makes fusion possible

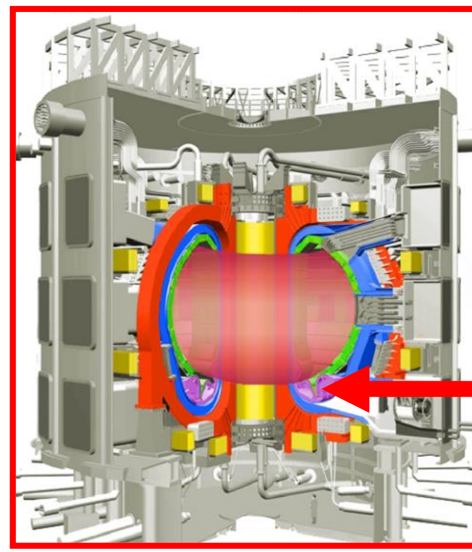




- Which
- Fusion
- reaction ?

Reaction: Fuel	Reaction: Product	Ignition Temperature (millions of °C)	Ignition Temperature (keV)	Output Energy (keV)
D + T	^4He + n	220	20	17,600
D + ^3He	^4He + p	350	30	18,300
D + D	^3He + n	400	35	~4,000
	T + p			~4,000





Needed resources for Fusion energy production

1. one year operation of a D-T-Fusion Power Plant, ~1000 MW electrical

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

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

Considering all energy in the world is produced by fusion

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

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

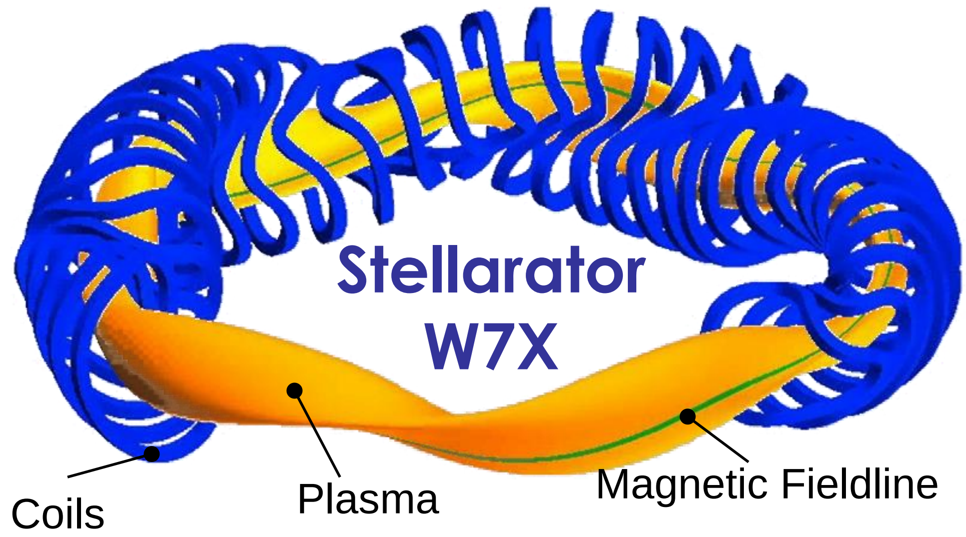
Magnetic Confinement of a plasma with 10 to 20 keV

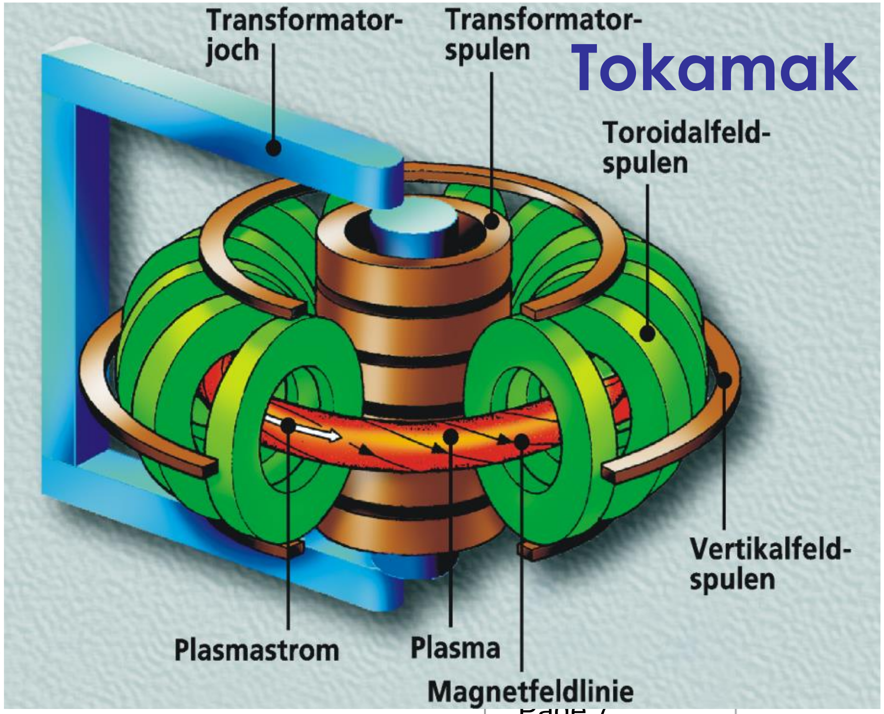
A toroidal magnetic system needs:

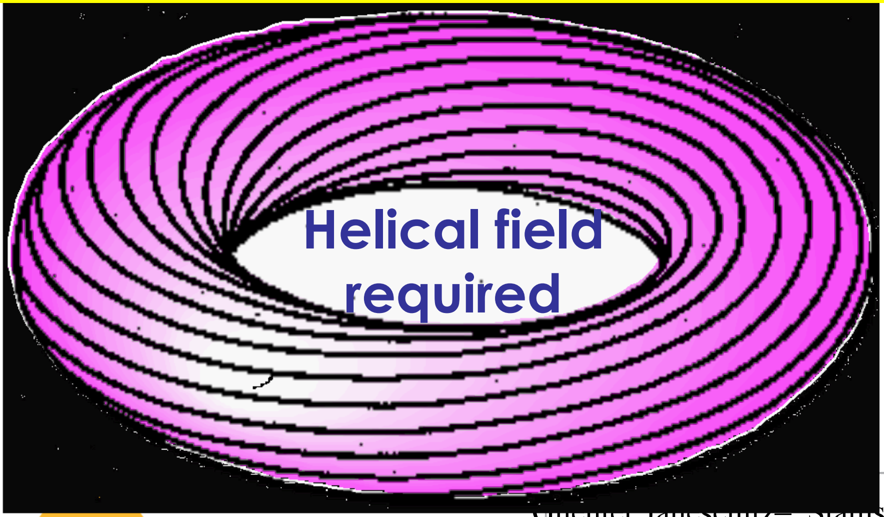
- a helical field configuration to compensate drifts
- a magnetic well

Two successful systems:

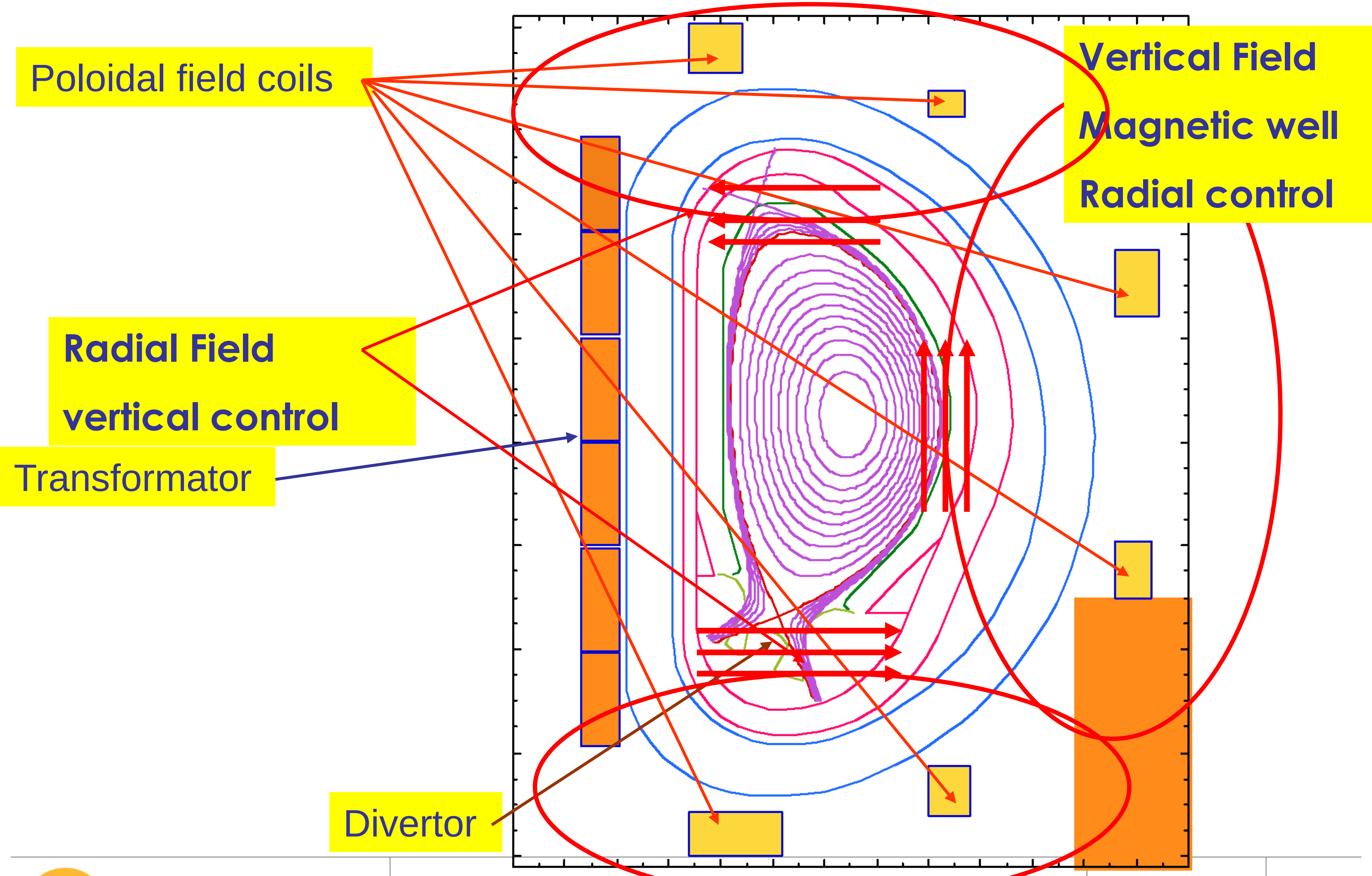
Stellarator / Tokamak - ITER



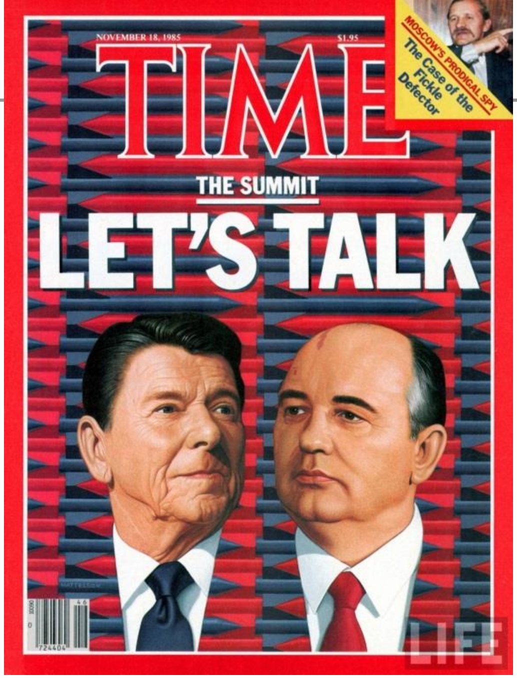




A modern Tokamak – Vertical-, Radial-, Divertor Fields



ITER Cooperation



- **1978 (November): First "Steering Committee of the INTOR Workshop" convenes in Vienna. INTOR was the first attempt at building a truly international fusion programme. INTOR was very close to ITER in its concept.**

- **1985 (November): At Geneva Superpower Summit in 1985 US president Reagan and <u>Secretary General Gorbatchev</u> propose an international effort to develop fusion energy... "as an inexhaustible source of energy for the benefit of mankind". This is the first political step to the ITER programme**

21/11/2006: ITER Agreement Signed

The ITER Machine

- V: 840m^3

R/a: 6.2m /2m

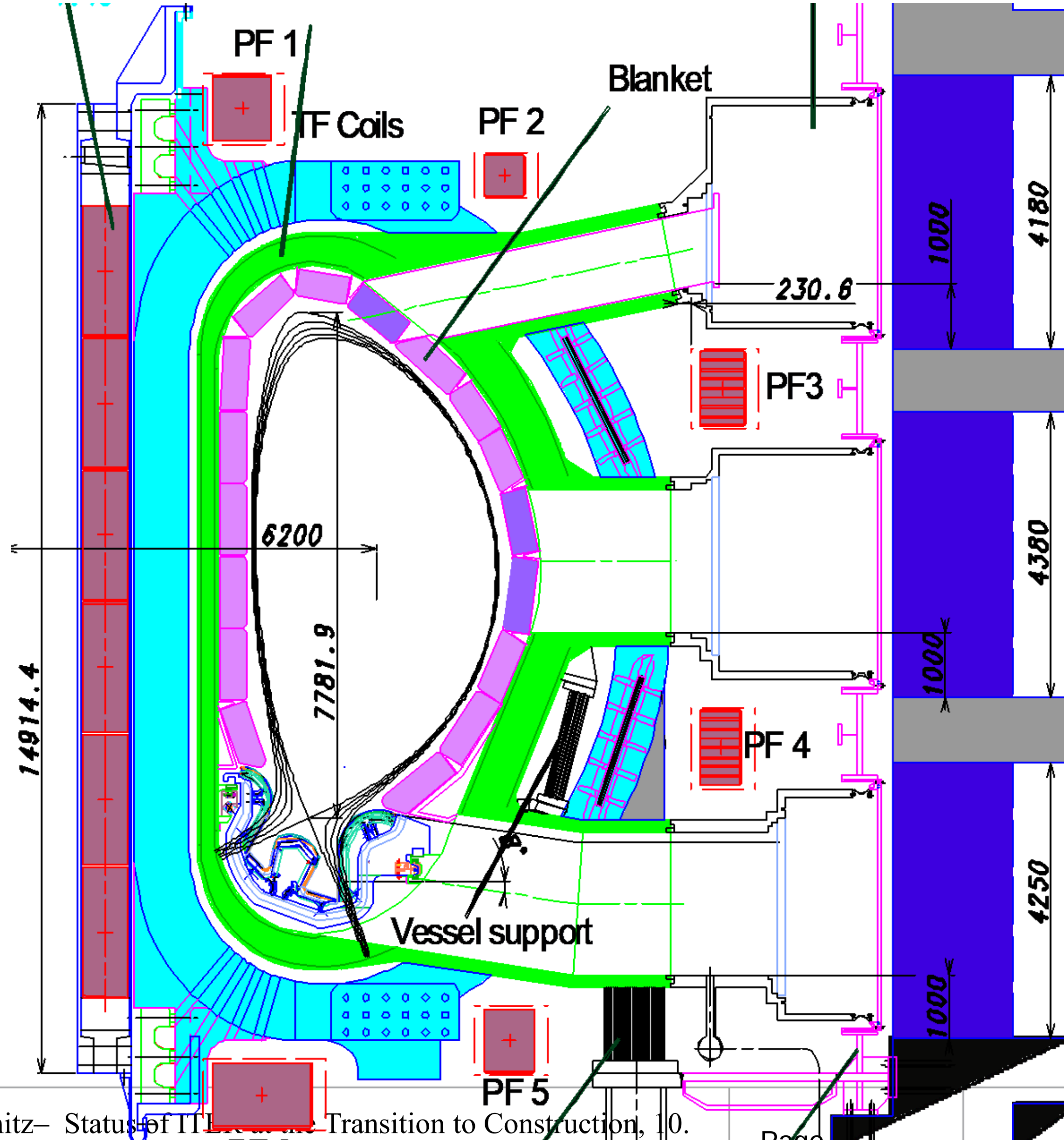
Vertical elongation: 1.85
Triangularity: 0.45

- Density: $10^{20}m^{-3}$
- PeakTemperature:17keV

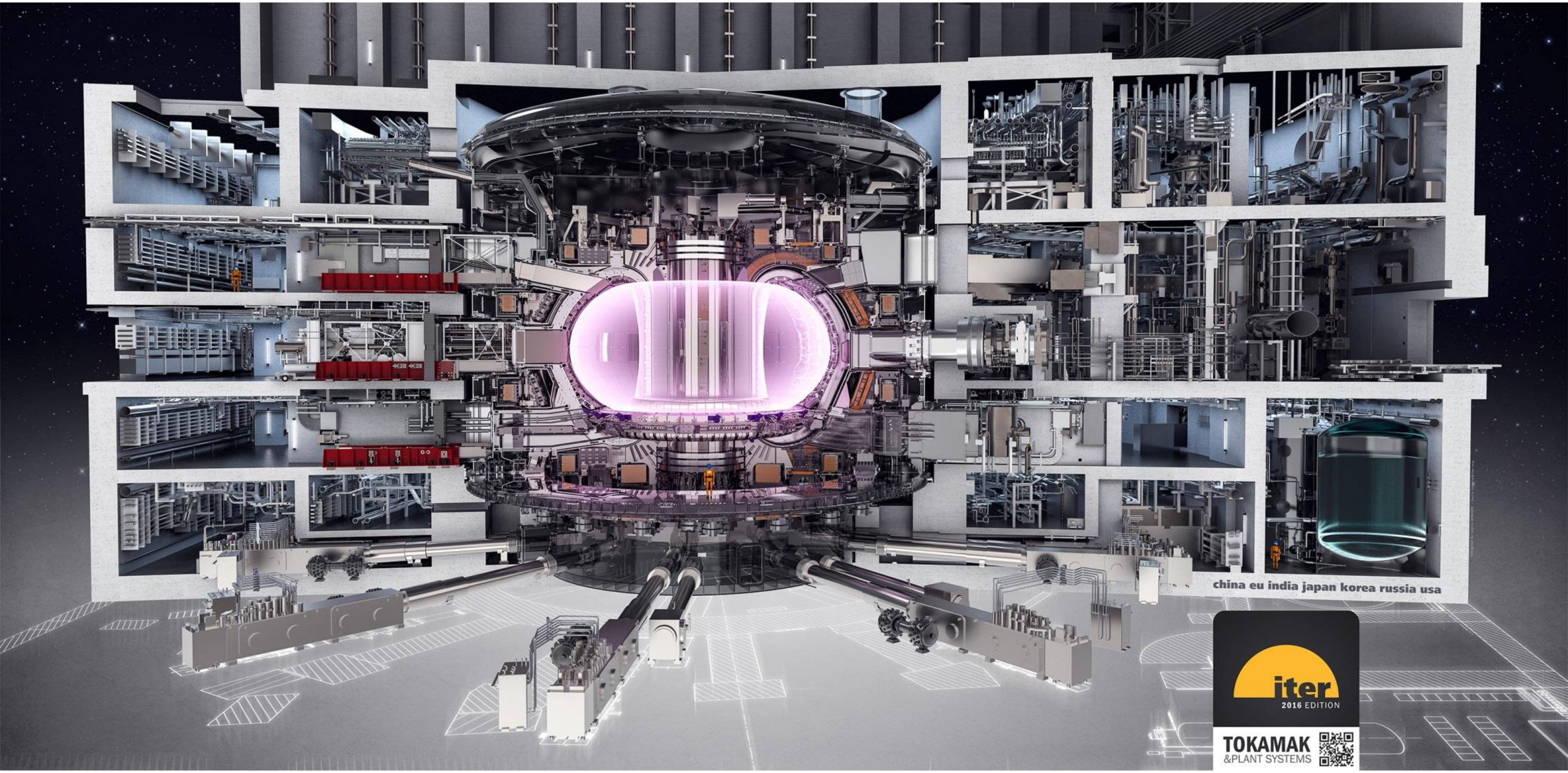
-Fusion gain Q = 10
-Fusion Power: ~500MW
-Ohmic burn 400 sec

-Goal Q=5 for 3000 sec

- Plasma Current : 15MA
- Toroidal field: 5.4T

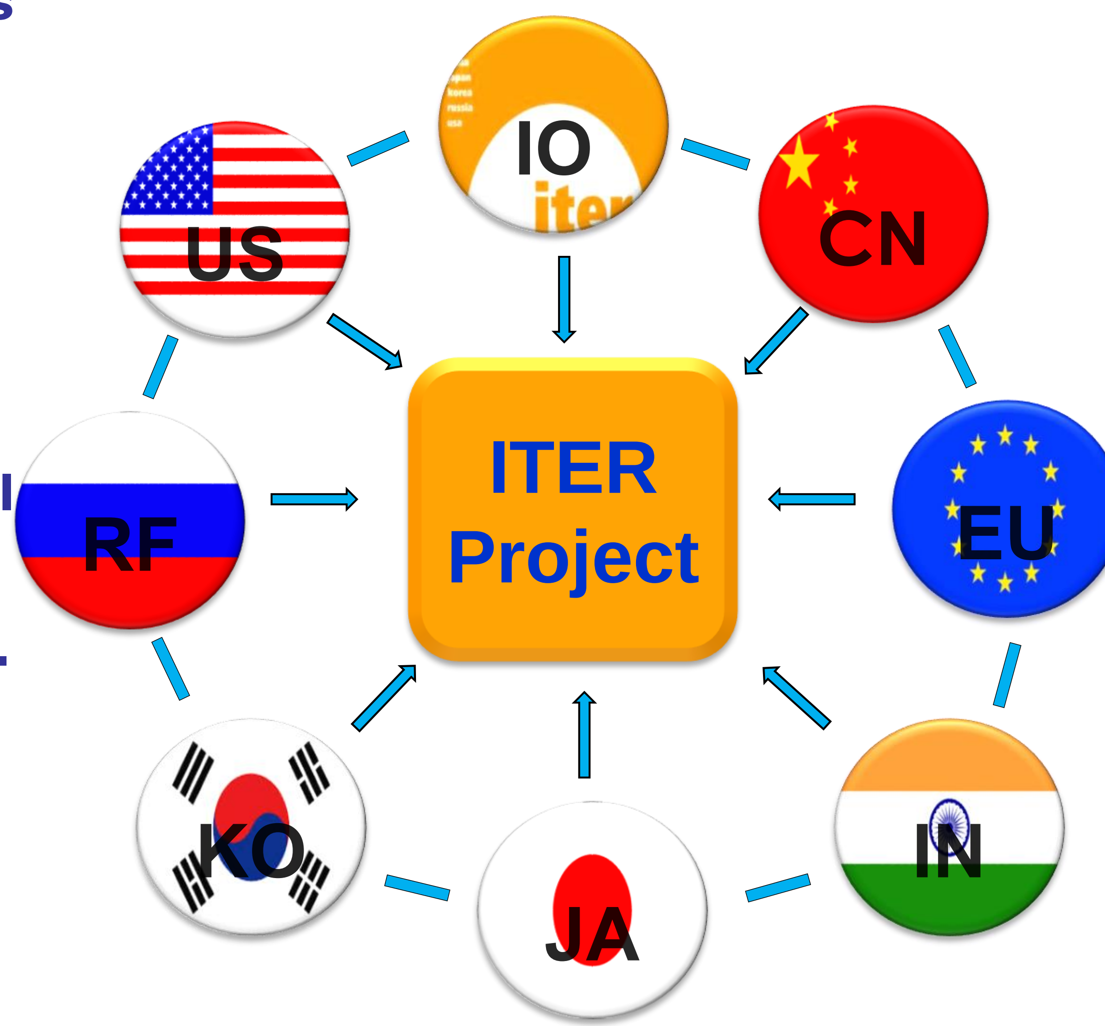


Tokamak Machine and Complex

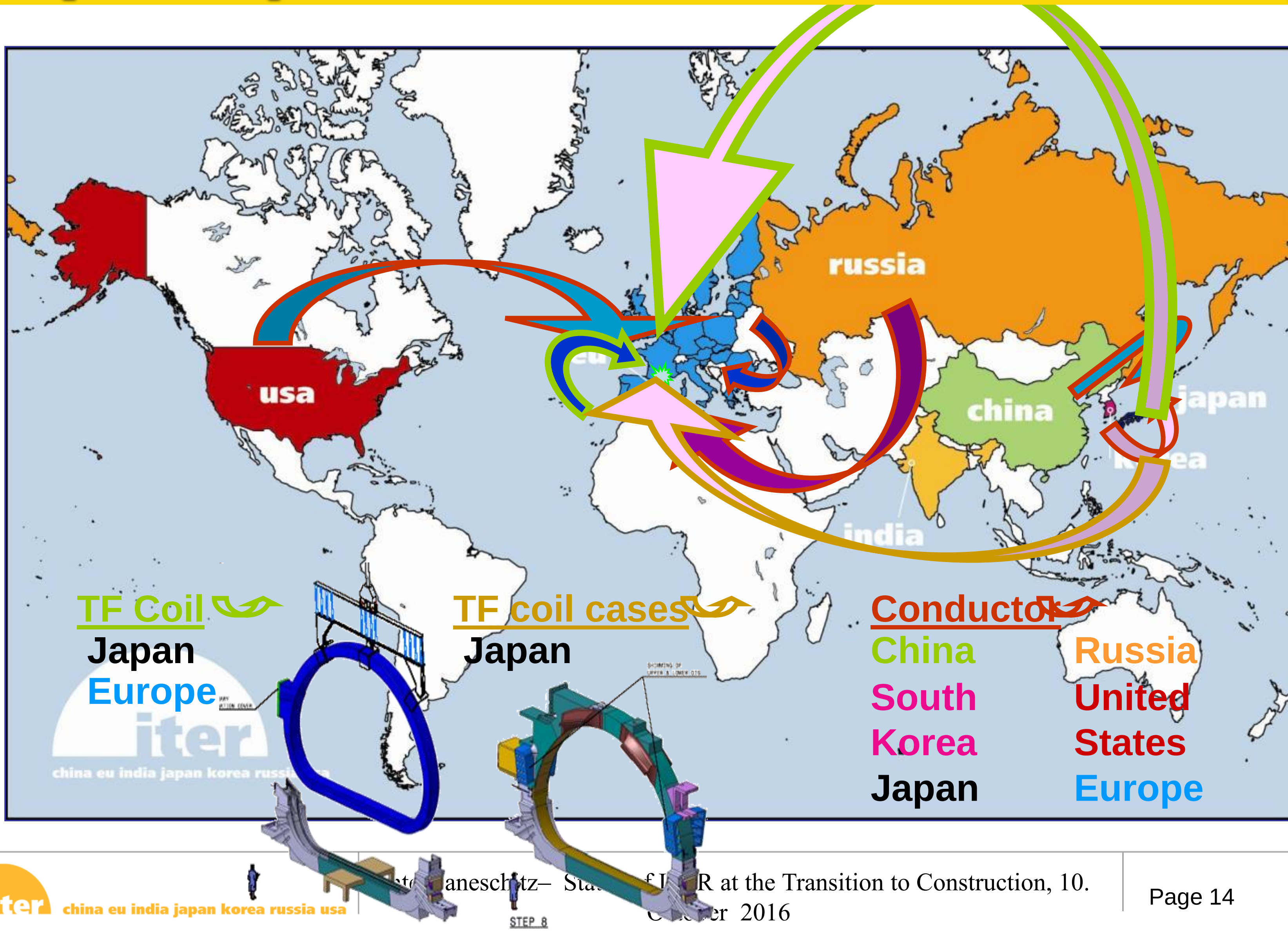


ITER: an integrated project: Central Team & Seven Domestic Agencies

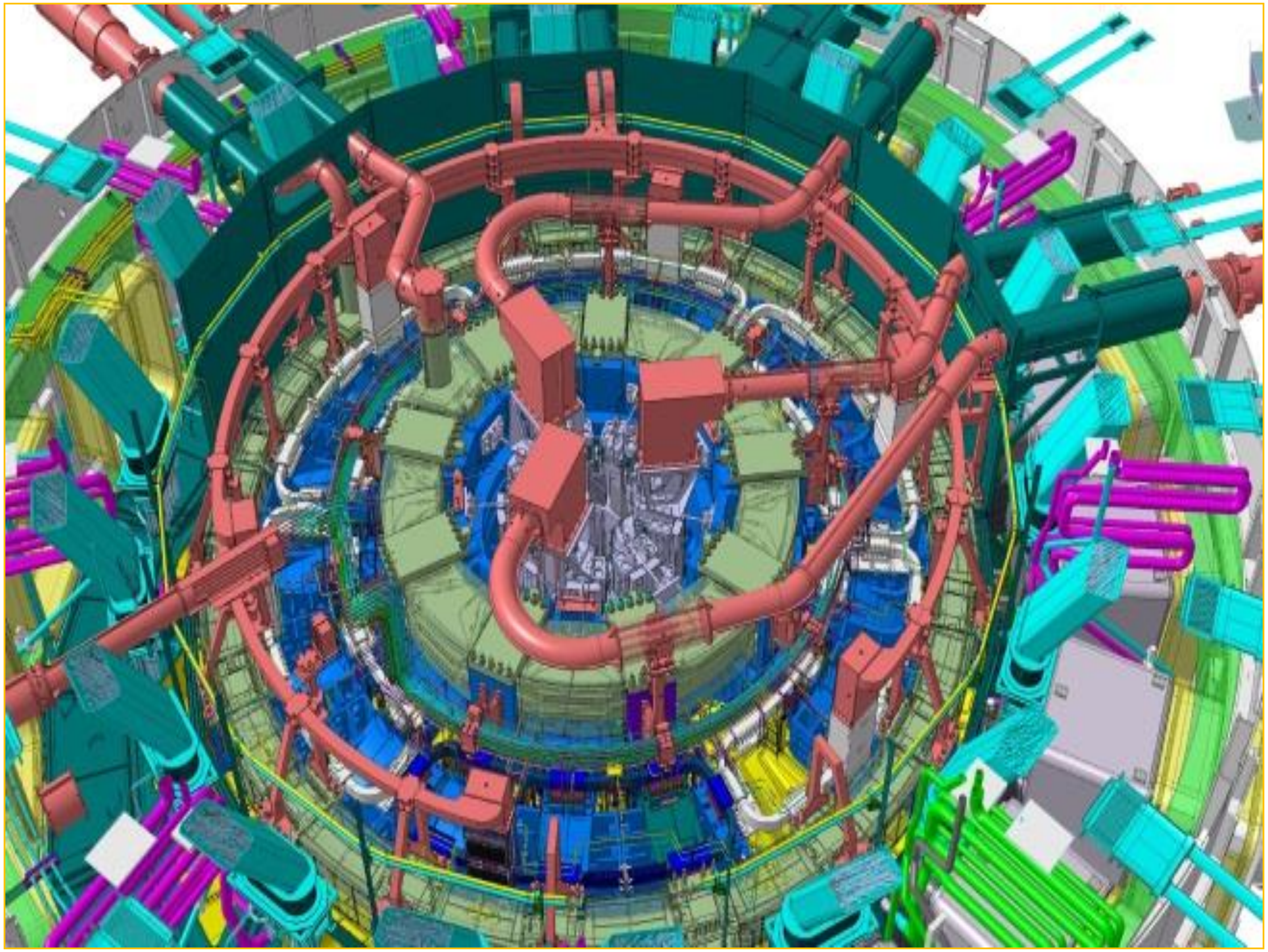
- **The 7 ITER Members make cash and in-kind contributions (90%) to the ITER Project.**
- **They have established Domestic Agencies to handle the contracts to industry.**
- **The ITER Organization Central Team manages the ITER Project in close collaboration with the 7 Domestic Agencies.**
- **The DAs employ their own staff, have their own budget, and place their own contracts with suppliers based on Procurement Arrangements (PAs) with the IO**



The management challenge
(Example shown: Toroidal Field Coils)

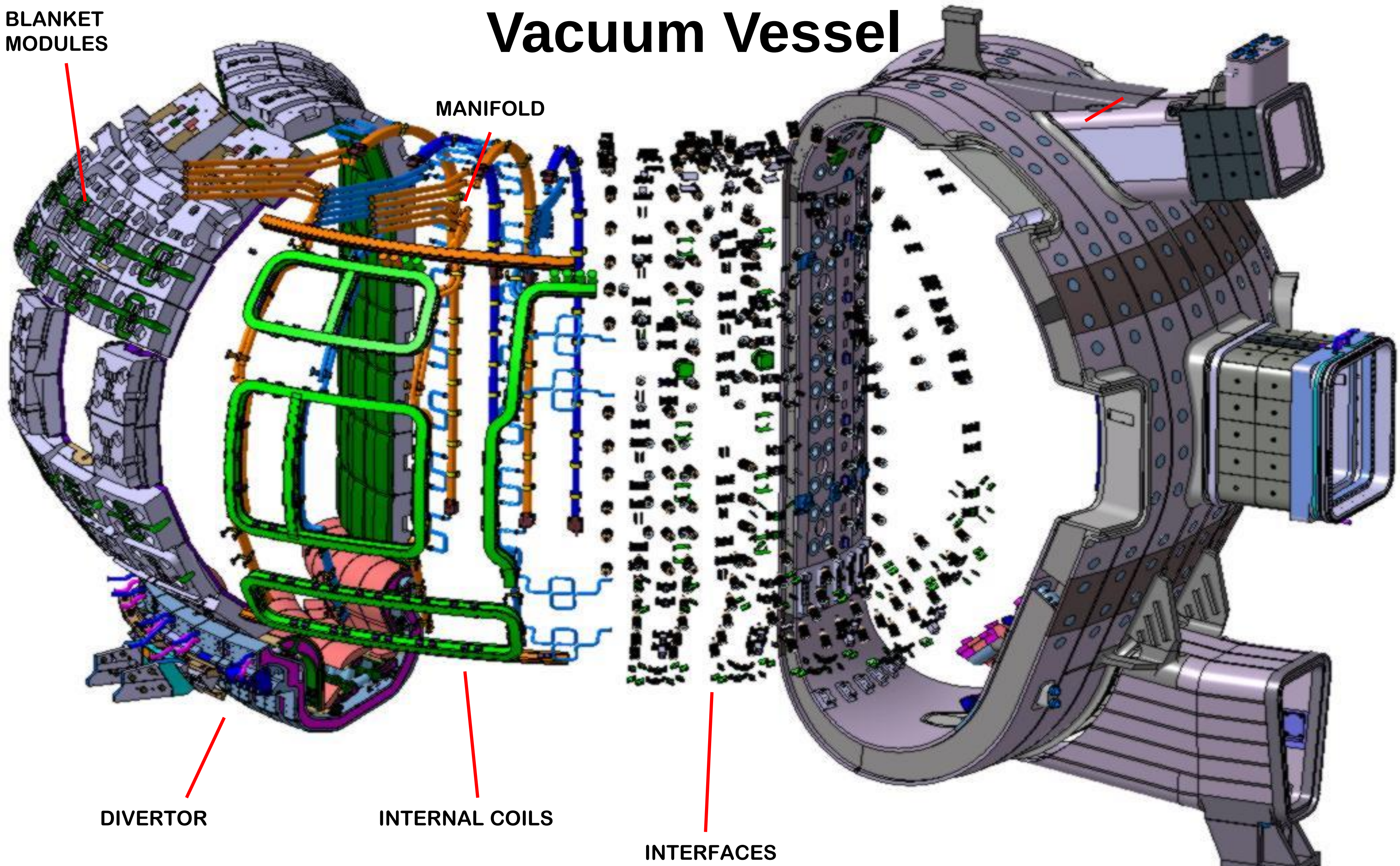


The integration challenge (1)

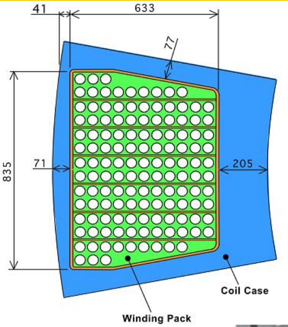


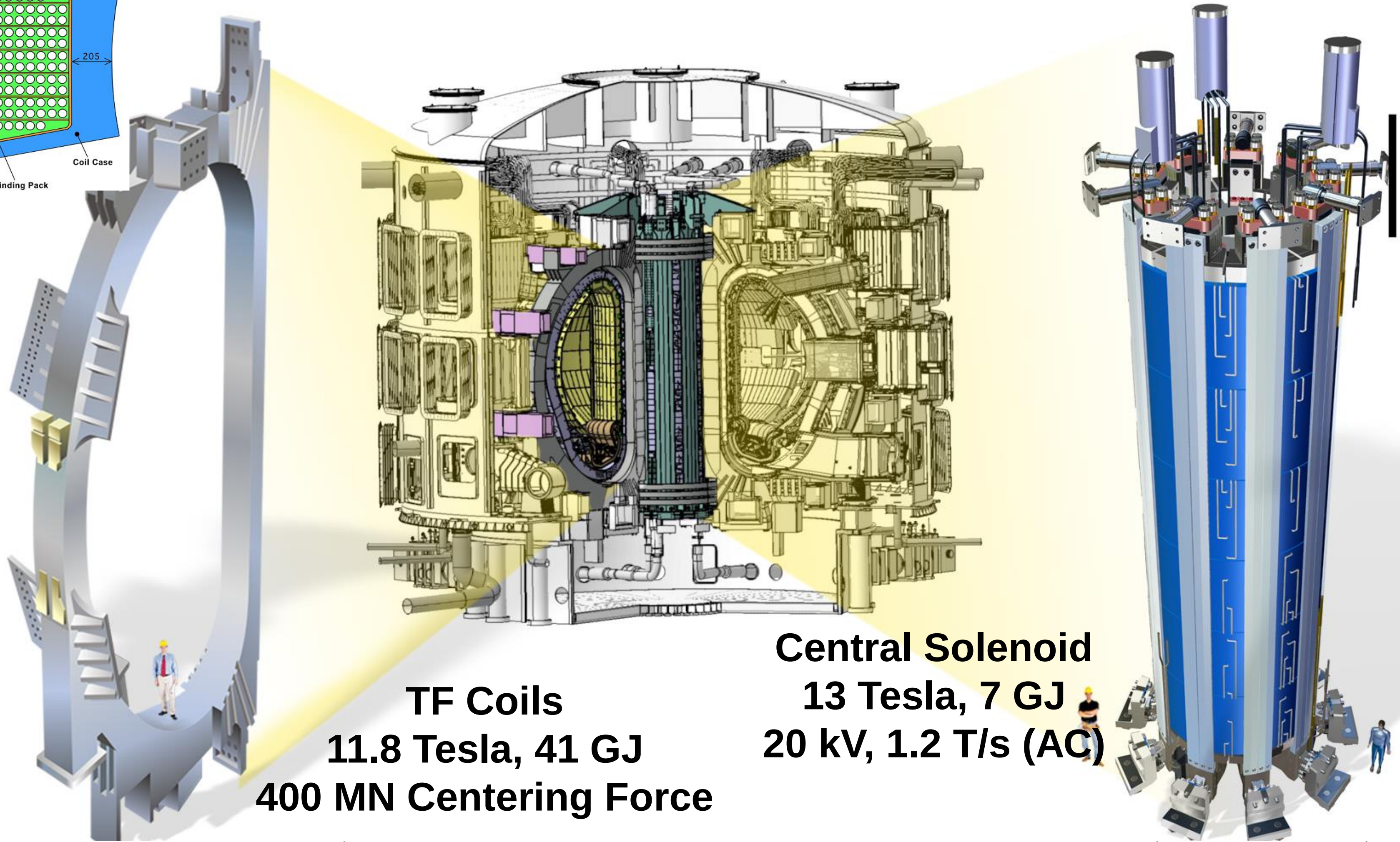
A top view of the cryostat illustrates the high density of sensitive equipment to be installed (e.g., magnet feeders shown in brown, blanket water pipes shown in light blue). A clash free design as well as the access to install and if needed maintain the systems must be ensured by the integration team.

The integration challenge (2)



The size and performance parameters challenge

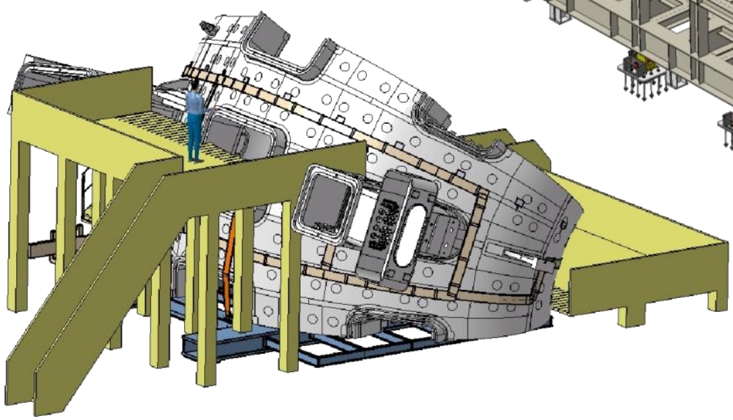


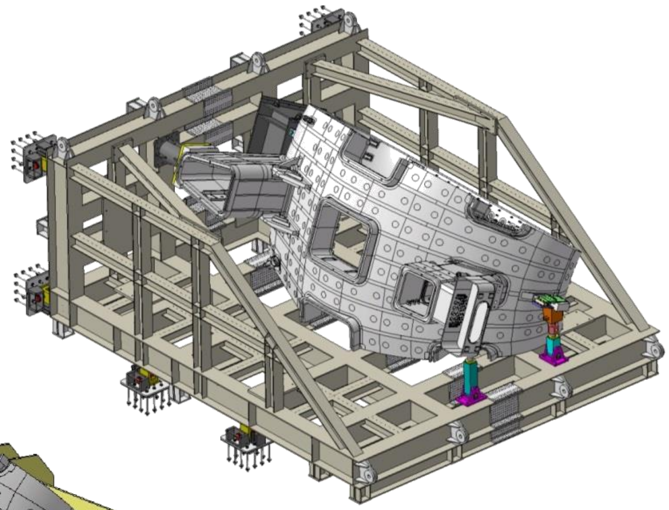


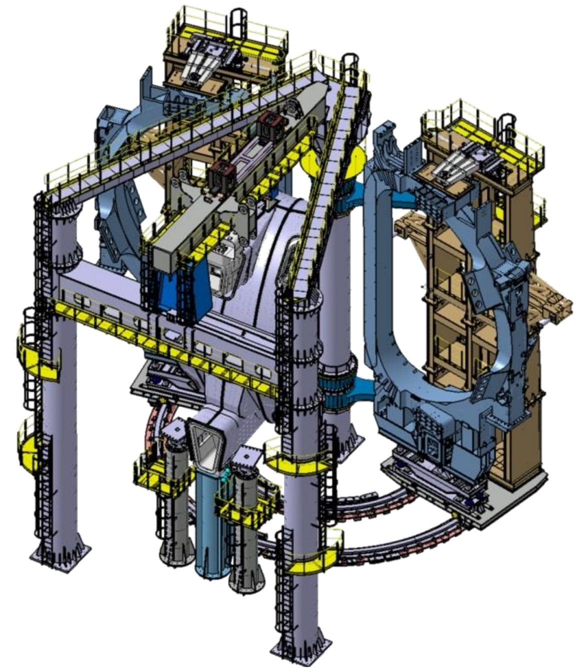
TF Coils
11.8 Tesla, 41 GJ
400 MN Centering Force

Central Solenoid
13 Tesla, 7 GJ
20 kV, 1.2 T/s (AC)

The Assembly Challenge





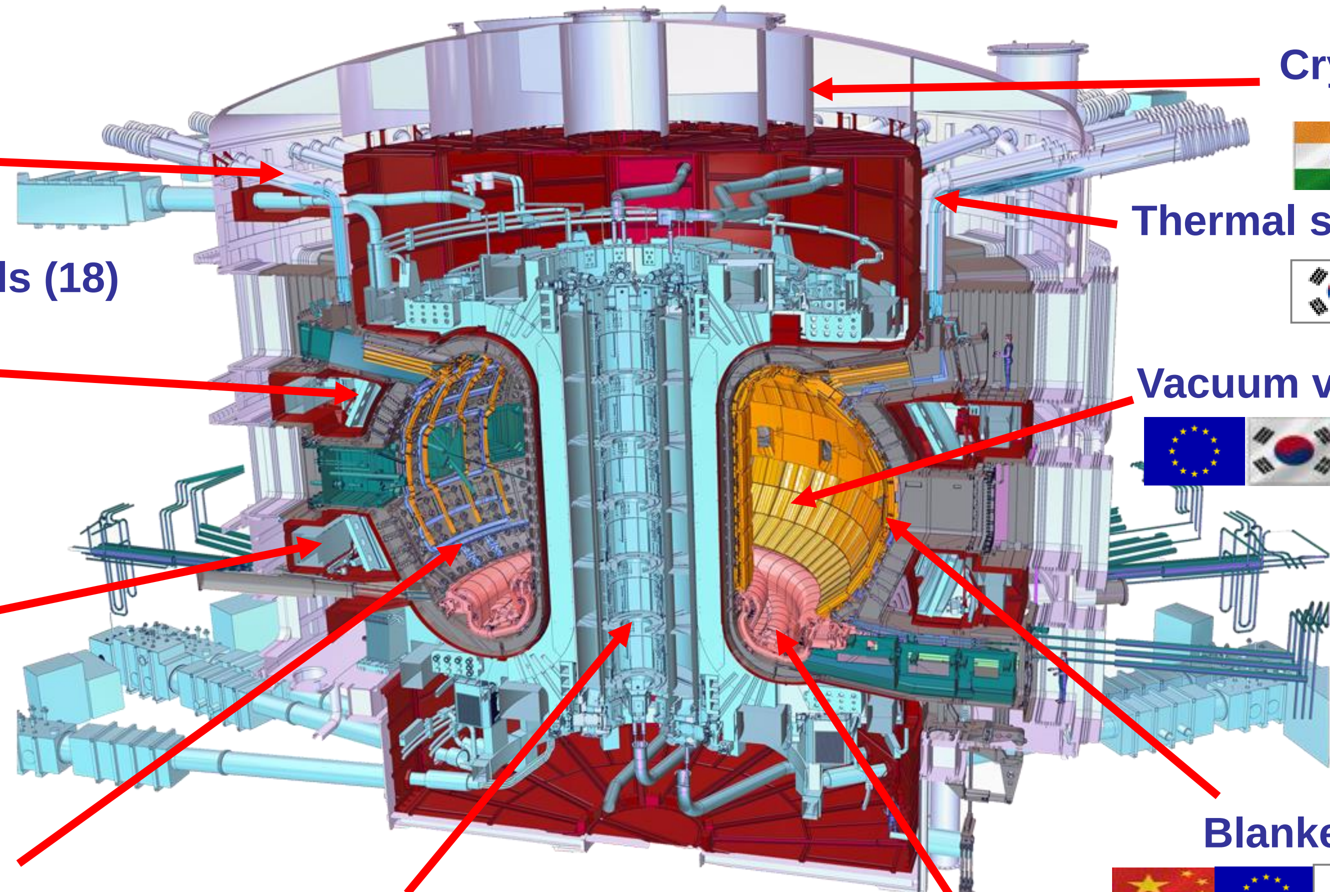


Installation on Transport Frame

Upending of VV Sector

Installation on Sector Sub-Assembly Tool

Who manufactures what?
The ITER Members share all intellectual property



Feeders (31)

Toroidal Field coils (18)

Poloidal field coils (6)

Correction coils (18)

Central solenoid (6)

Divertor

Blanket

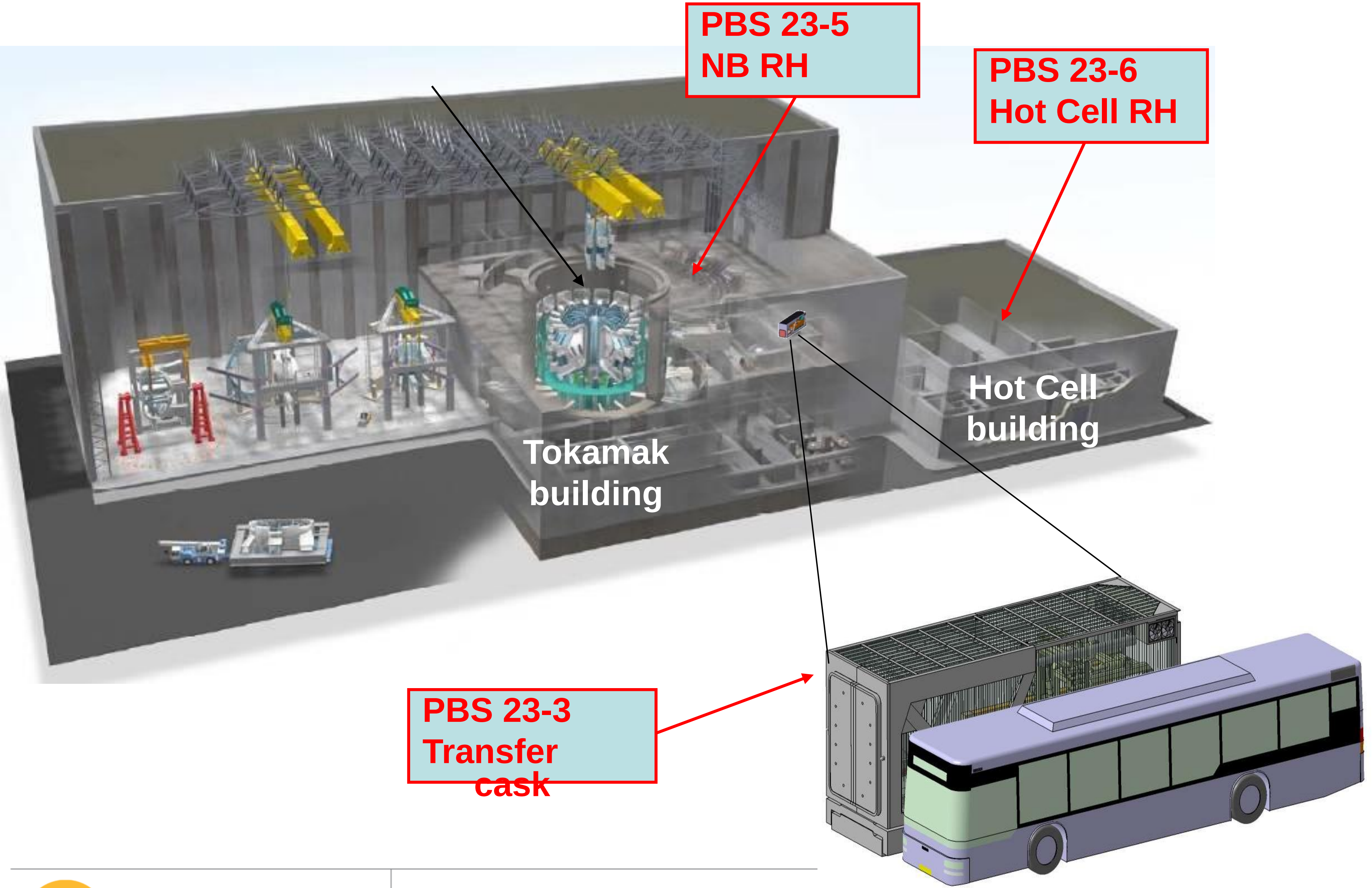
Vacuum vessel

Thermal shield

Cryostat

Worksite progress

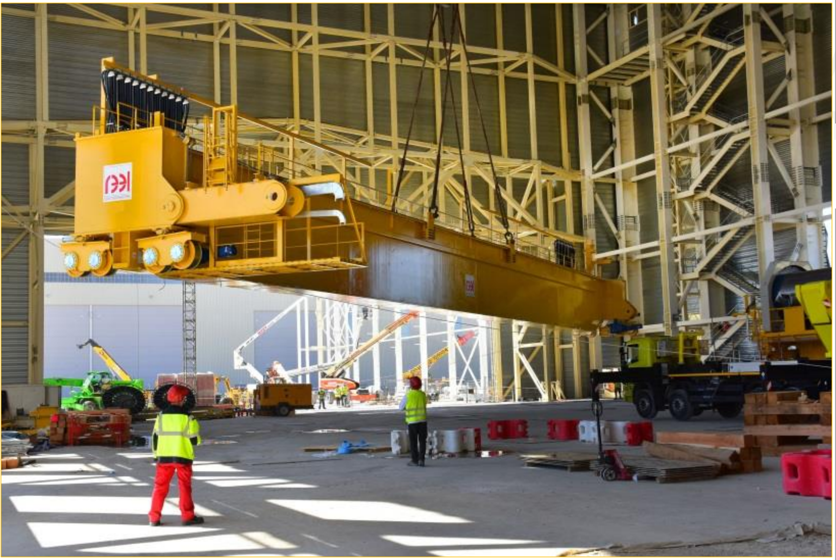
ITER Assembly / Remote Handling / Hot Cell



Tokamak Complex

Resting on 493 seismic pads, the reinforced concrete “B2” slab bears the 400 000-ton Tokamak Complex. Concrete casting of the B2 slab was finalized on August 27, 2014. Diagnostic Building (right): B1 level slab and walls/columns now complete; Tokamak Building (centre): completion of the BioShield wall B2 level. Start of the B1 slab on 26 April 2016, and construction of interior walls/columns is on-going. Tritium Building (left): steel reinforcement on B1 level.

Assembly Hall putting in Place 2x 750t Cranes



On 14 June lifting operations begin.

Complete with gear-motors, wheels, braces, electrical gear etc. , the beam now weighs 186 tons.

On
bea
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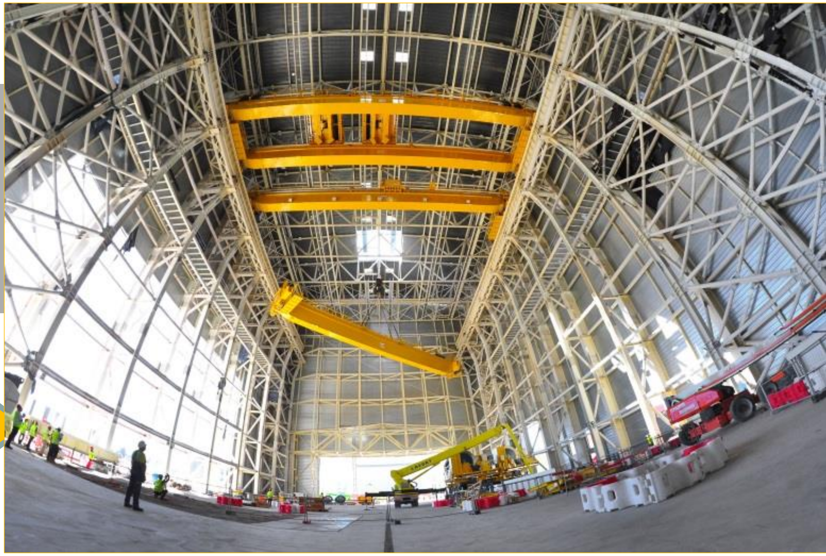
Each pair of cranes will have a lifting capacity of 750 tons.



1st TF Coil Winding Pack - Europe

European Domestic Agency contractors have made significant progress in the fabrication of the first toroidal field winding pack—the 110-ton inner core of ITER's D-shaped superconducting Toroidal Field Coils.
Following sophisticated, multi-stage winding operations, seven layers of coiled superconducting cable (double pancakes) have now been successfully stacked and electrically insulated.

PF Coil winding facility (Europe)

Too large to be transported by road, four of ITER's six ring-shaped magnets (the poloidal field coils) will be assembled by Europe in this 12,000 m² facility. "White rooms" are currently being equipped prior to the start of manufacturing operations (mockup) in the summer of 2016.

Manufacturing progress

USA

General Atomics is fabricating the 1000-ton Central Solenoid (CS). In April 2016, winding of the first CS module was completed.

Module tooling stations are in place and being commissioned, including the heat treatment furnace shown here.

Cooling Water System, Magnet Systems, Diagnostics, Heating & Current Drive Systems, Fuel Cycle, Tritium Plant, Power Systems

Manufacturing progress

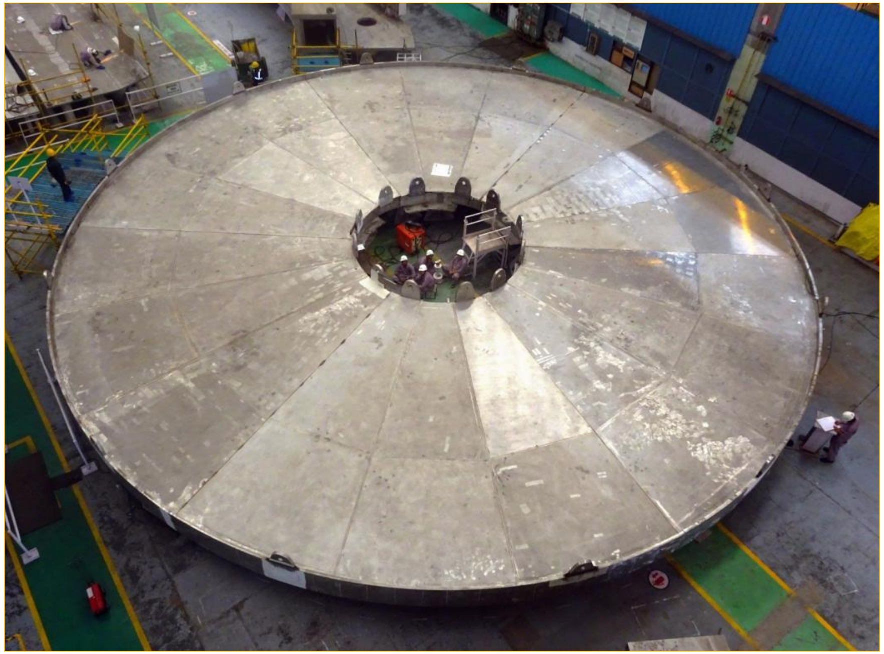
China

Internal components of a cryostat feeder prototype.

Correction coil at ASIPP in Hefei, China.

Magnet Systems, Power Systems, Blanket, Fuel Cycle, Diagnostics

Manufacturing progres India



India is responsible for fabrication and assembly of the 30x30 meter ITER cryostat. The base plates were delivered to ITER in December 2015.

The transportation frame/assembly and welding support for the cryostat has been assembled in the Cryostat Workshop where welding began in August.

Cryostat, Cryogenic Systems, Heating and Current Drive Systems, Cooling Water System, Vacuum Vessel, Diagnostics

Manufacturing progress

Japan

Connection of segments for the first inboard Toroidal Field Coil structure (completed in November 2015), a significant achievement for TF coil procurement.

Toroidal field coil heat treatment.

Magnet Systems, Heating & Current Drive Systems, Remote Handling, Divertor, Tritium Plant, Diagnostics

Manufacturing progress

Korea

At Hyundai Heavy Industries, where 2 of 9 vacuum vessel sectors are under construction, welding on the upper section of the inner shell for Sector #6.

Inner shell assembly of a lower port stub extension for the vacuum vessel.

Vacuum Vessel, Blanket, Power Systems, Magnet Systems, Thermal Shield, Assembly Tooling, Tritium Plant, Diagnostics

Manufacturing progress

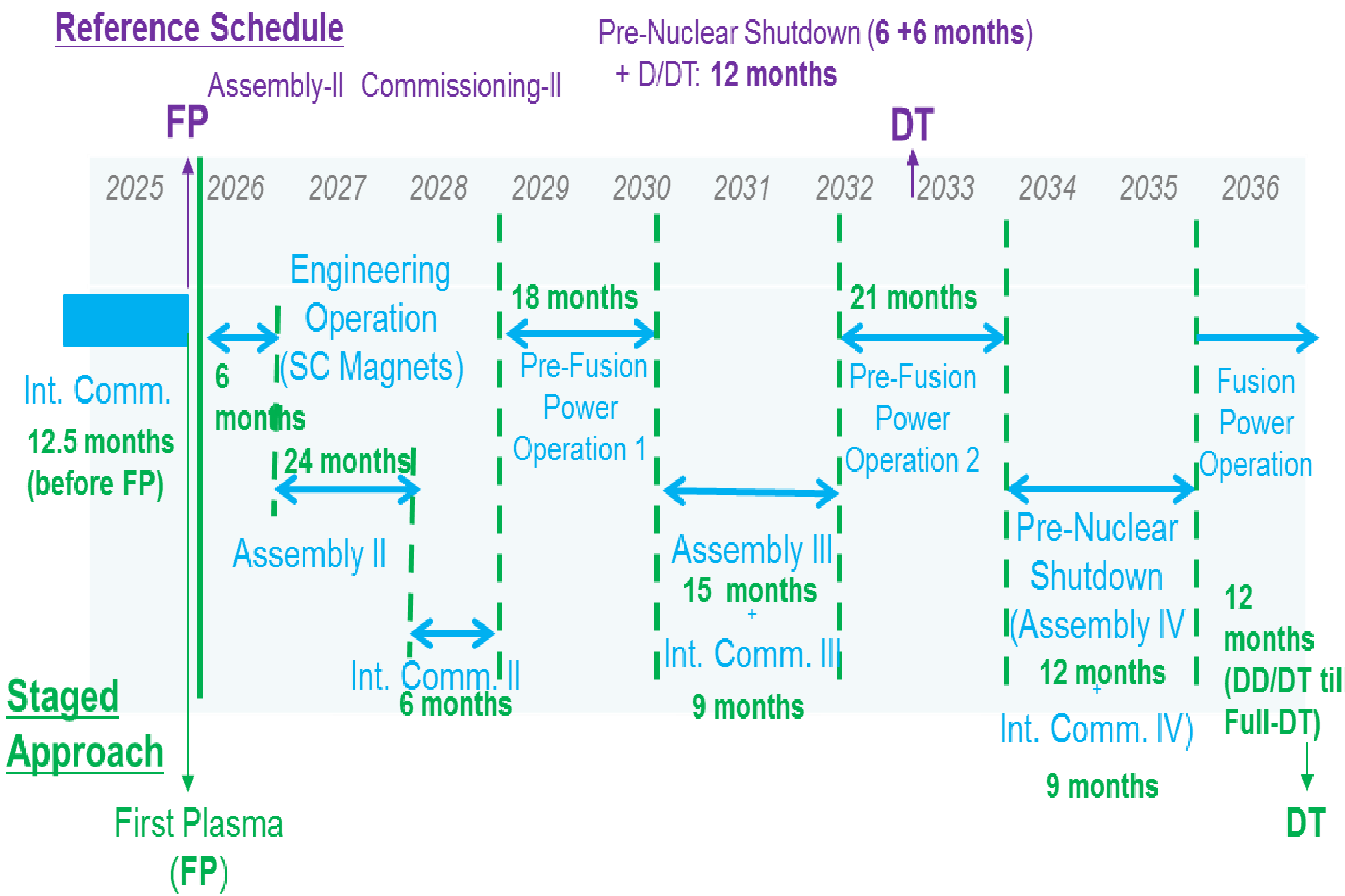
Russia

Fabrication and qualification tests of PF1 winding pack stack sample were successfully completed.

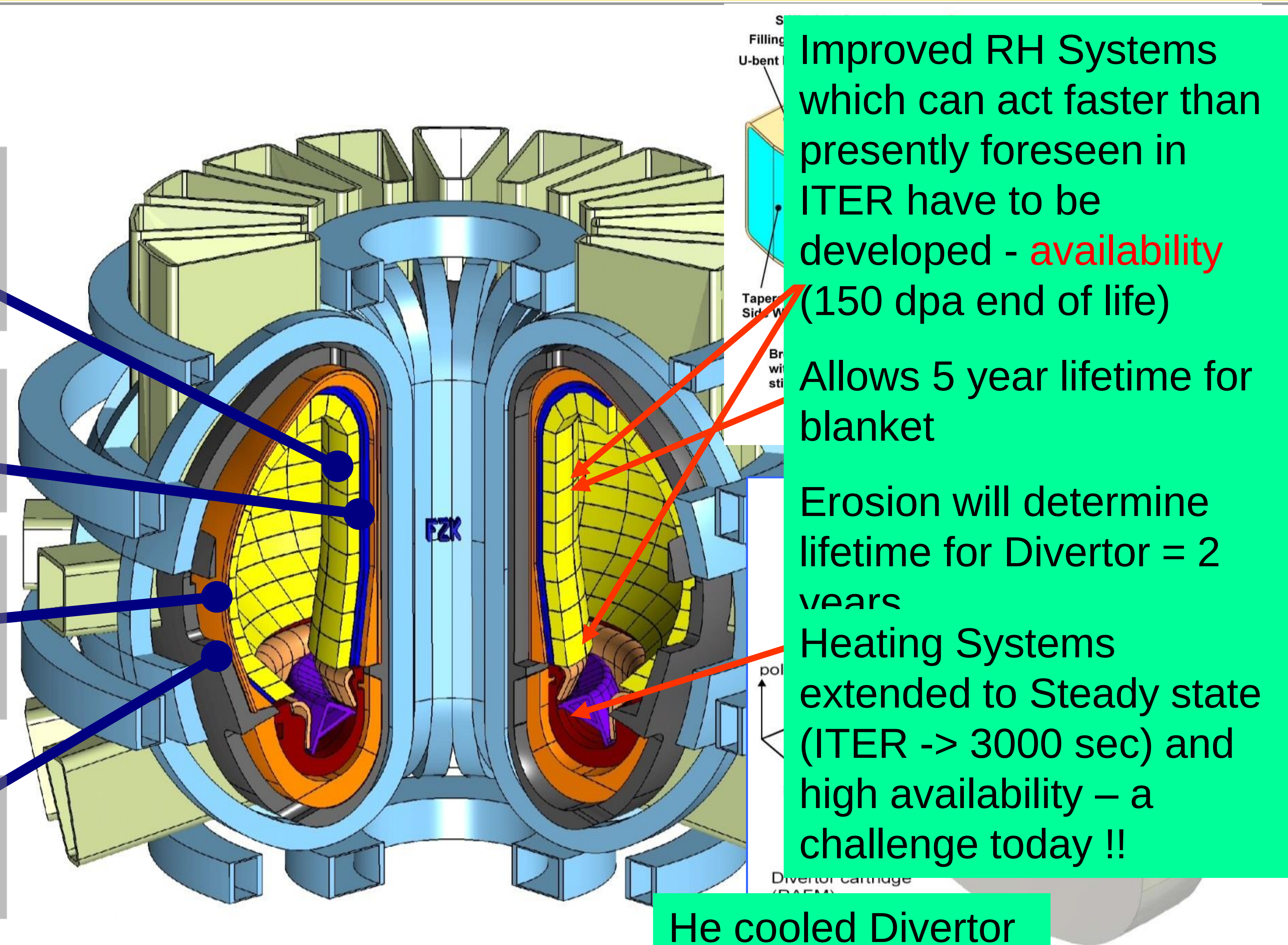
Winding of first double pancake for poloidal field coil #1 inside the clean room.

Power Systems, Magnet Systems, Blanket, Divertor, Vacuum Vessel, Diagnostics, Heating & Current Drive Systems

Outline Research Plan Structure (staged approach)



Main Technology Developments needed for DEMO



Improved RH Systems which can act faster than presently foreseen in ITER have to be developed - availability (150 dpa end of life)

Allows 5 year lifetime for blanket

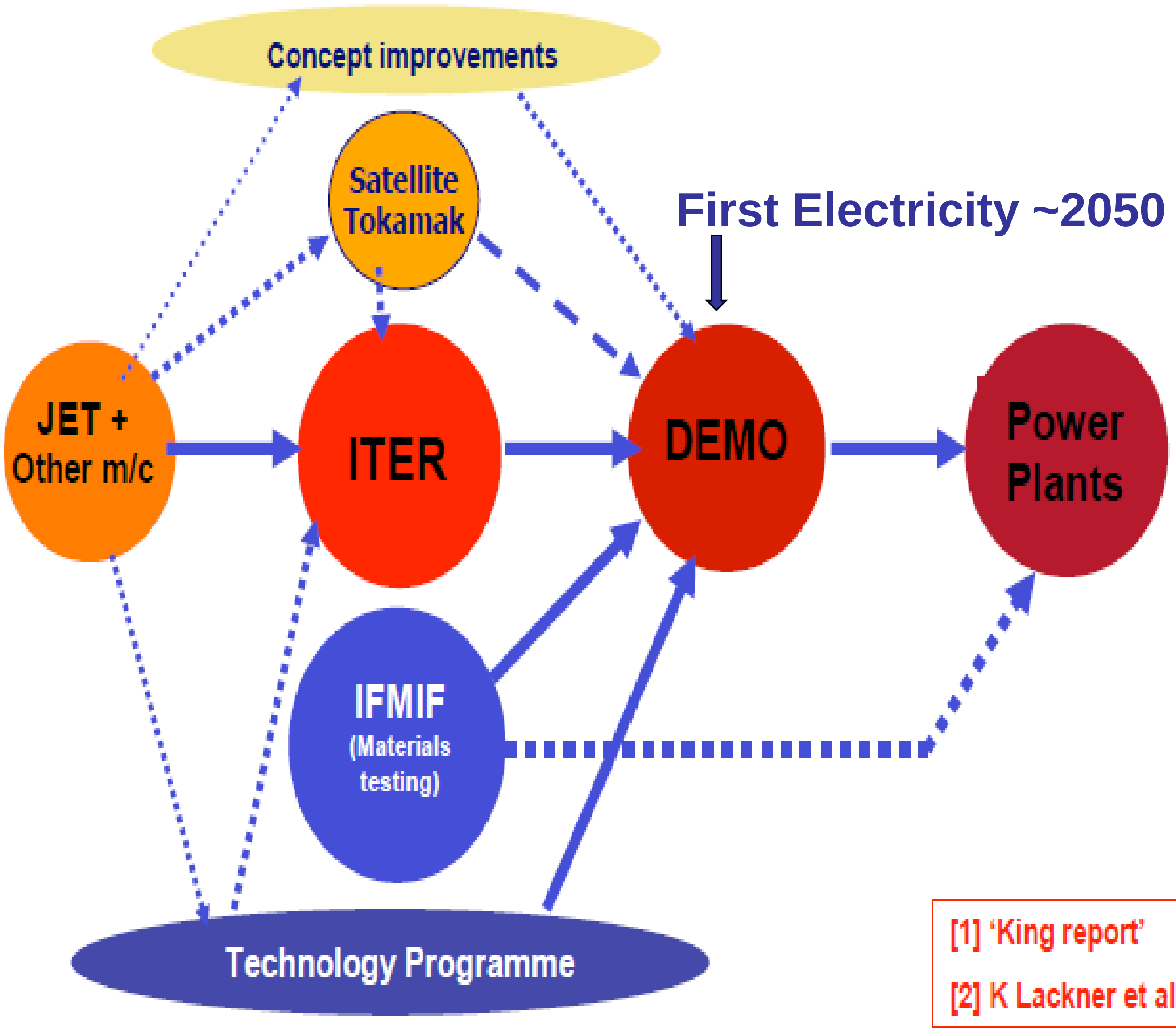
Erosion will determine lifetime for Divertor = 2 years

Heating Systems extended to Steady state (ITER -> 3000 sec) and high availability – a challenge today !!

He cooled Divertor

DEMO = Demonstration Fusion Reactor Plant

Roadmap to Fusion Power



[1] 'King report'
[2] K Lackner et al

Conclusions

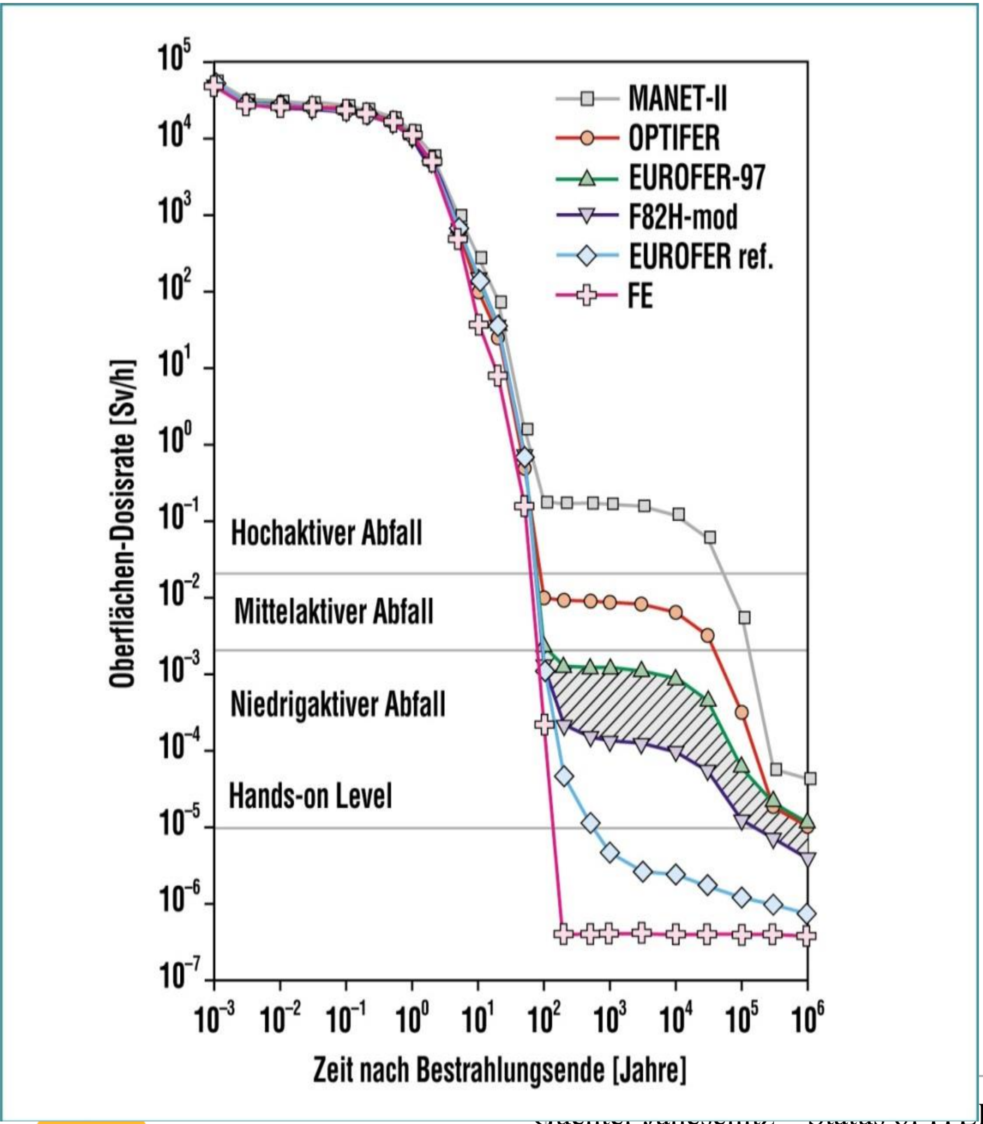
- ITER is the final Step before a Demonstration Power Plant and will demonstrate the viability of fusion energy from the technology and physics point of view

- The way ITER construction is organized ensures that all know how is developed in all ITER member countries

- This is not the cheapest and also not the easiest way to construct such a machine however, we have mastered it now after initial difficulties

- The project is progressing well now and will fulfill its mission

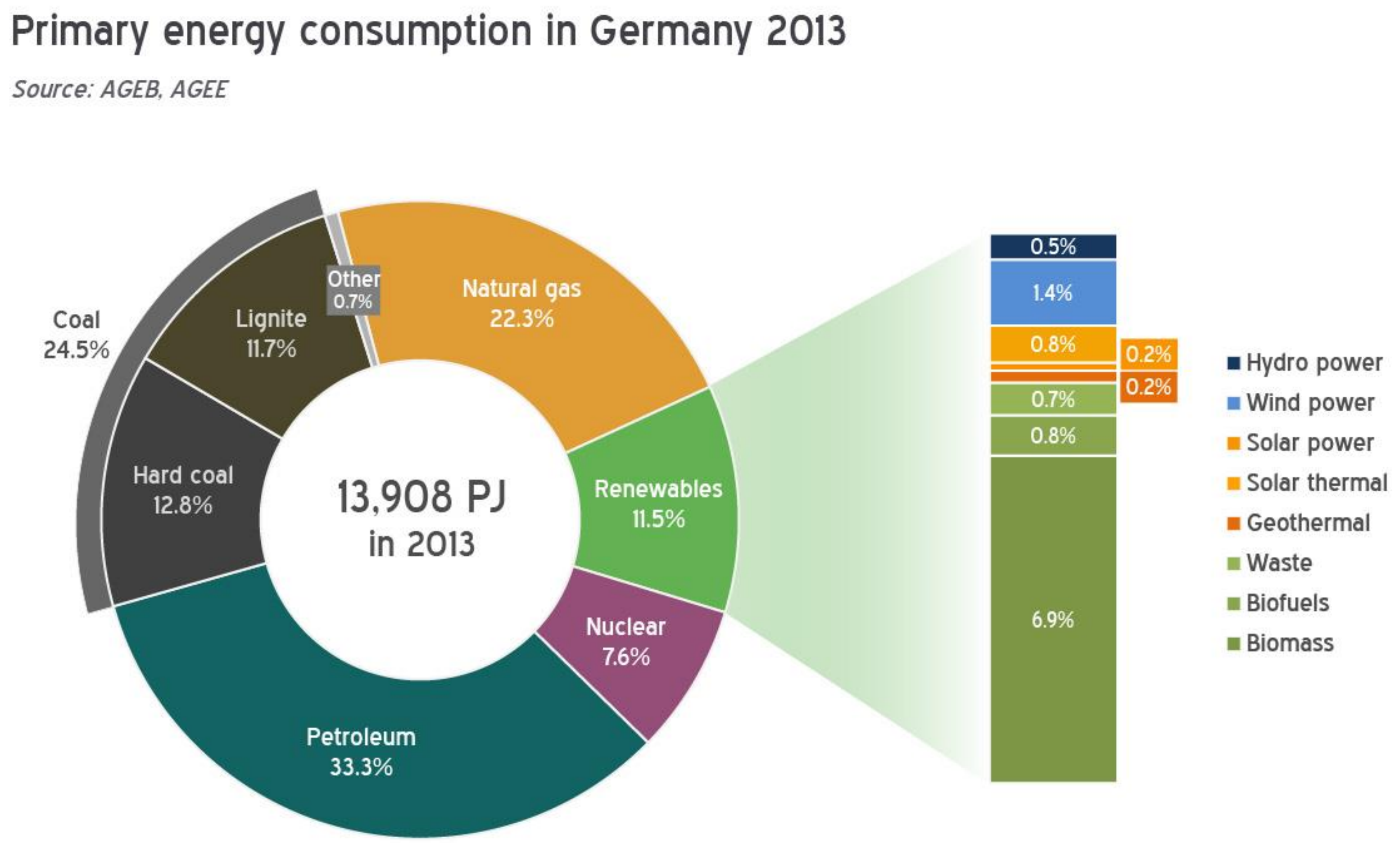
Low activation Structuiral Material Development



Low Activation Structural Materials

Behaviour of the γ-Dosisrate over time after neutron irradiation of up to 12.5 MWa/m^2

Primary Energy usage in Germany 2013



We have finite oil and gas resources and reserves

Depending on growth oil / gas could be very expensive within 2 decades

To replace only half of it means Terra W of energy from other sources (nuclear, coal, renewables, fusion)

Climate change prevents the increase of coal usage !!

What is the Economic Environment Fusion has to compete in ?

- **Looking 50 years into the future the time of cheap oil and gas will be over**
  - 2.5 billion people (IN, CN) having an increase of use of oil of 5% to 8%/a
  - Even with Fracking the present reserves are final => higher prices
  - We enter the electric century => traffic, heating, industry => electric !!
  - Significant increase of electricity production will be needed > factor 2
  - Air transport still needs fuel => Bio mass !!

- => **remaining options beside Fusion are:**
  - Renewables, Fission, Coal
  - Coal is problematic => climate change, pollution
  - Fission is a good solution but has acceptance issues in some countries
  - **=> Fusion needed in mid- to long term as base energy source !!**

What comes after ITER ? The Road Map to a Reactor

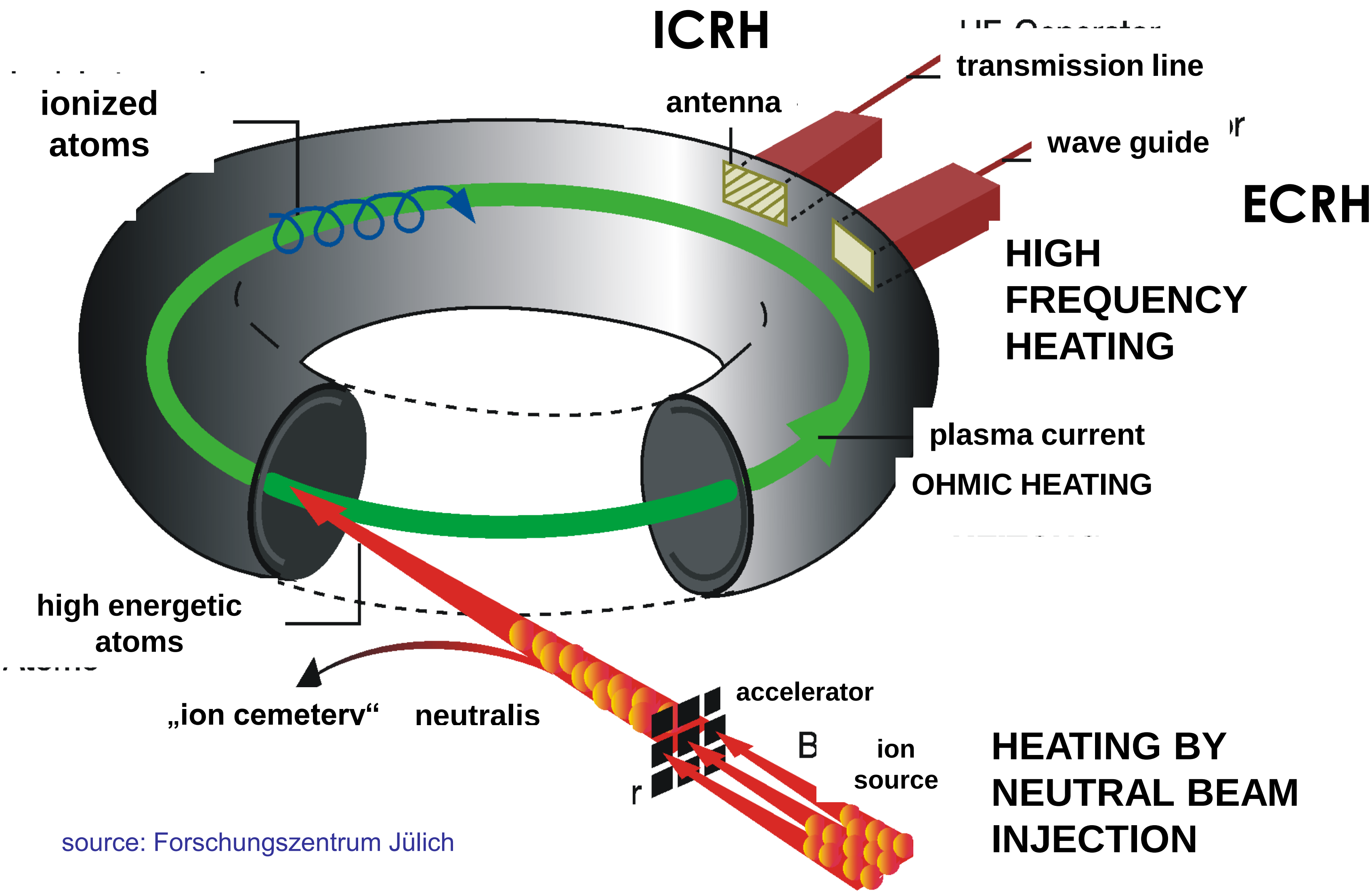
- The knowledge and the know-how gained during the ITER construction and the exploration of **ITER**'s hot plasmas will be used to conceive a prototype fusion reactor that will test the large-scale production of electrical power and tritium fuel self-sufficiency: **DEMO**

- ITER is the key facility in this strategy and the **DEMO** design/R&D will benefit largely from the experience gained with ITER construction.

- The term **DEMO** describes more of a phase than a single machine.

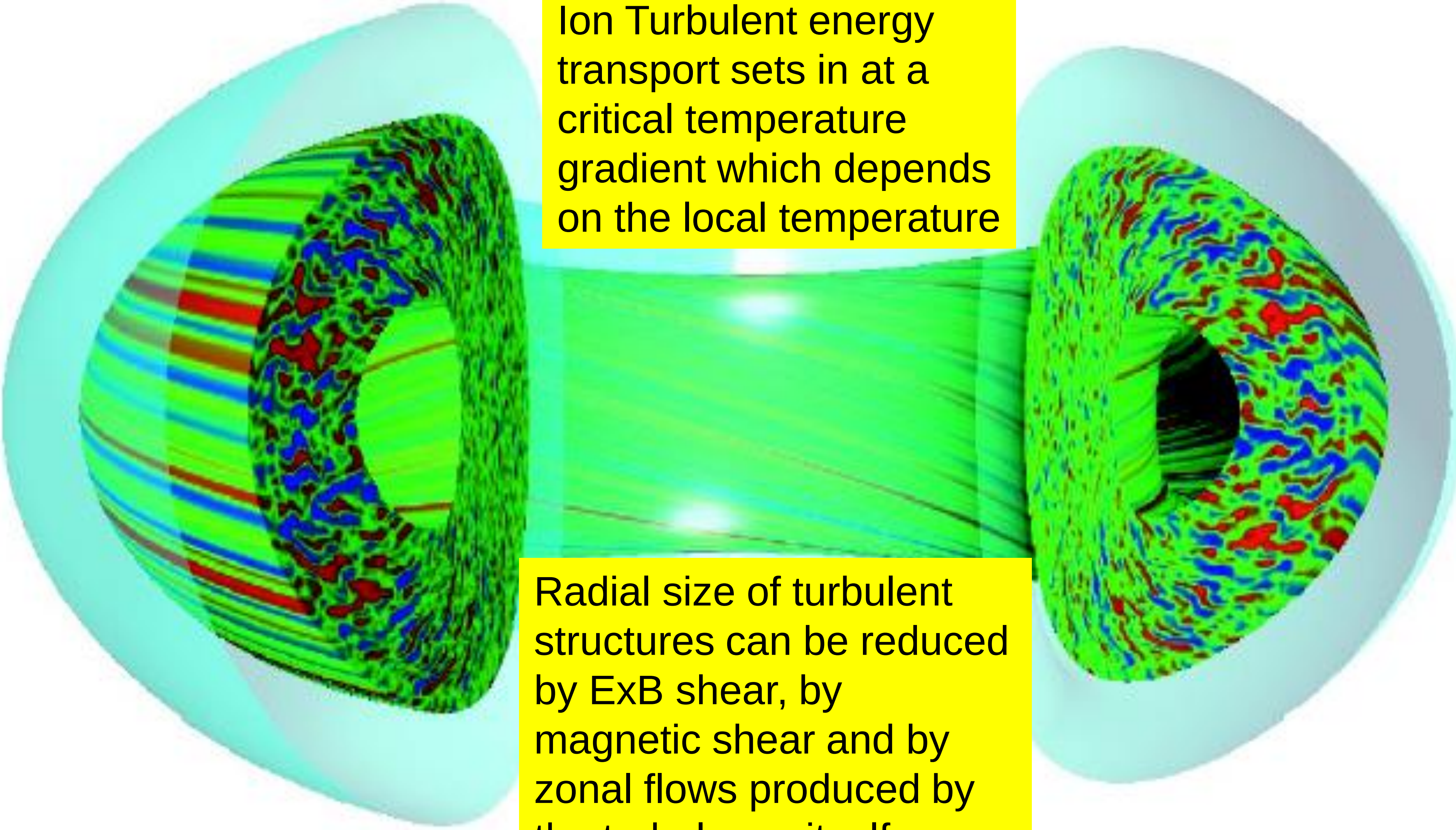
- For the moment, different conceptual **DEMO** projects are under consideration by all of the Member nations participating in ITER and it's too early to say whether DEMO will be an international collaboration like ITER, or a series of national projects.

Methods for the heating the 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

Goals of ITER – Design Specification

Physics Goals:

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