# ITER and the International Scientific Collaboration

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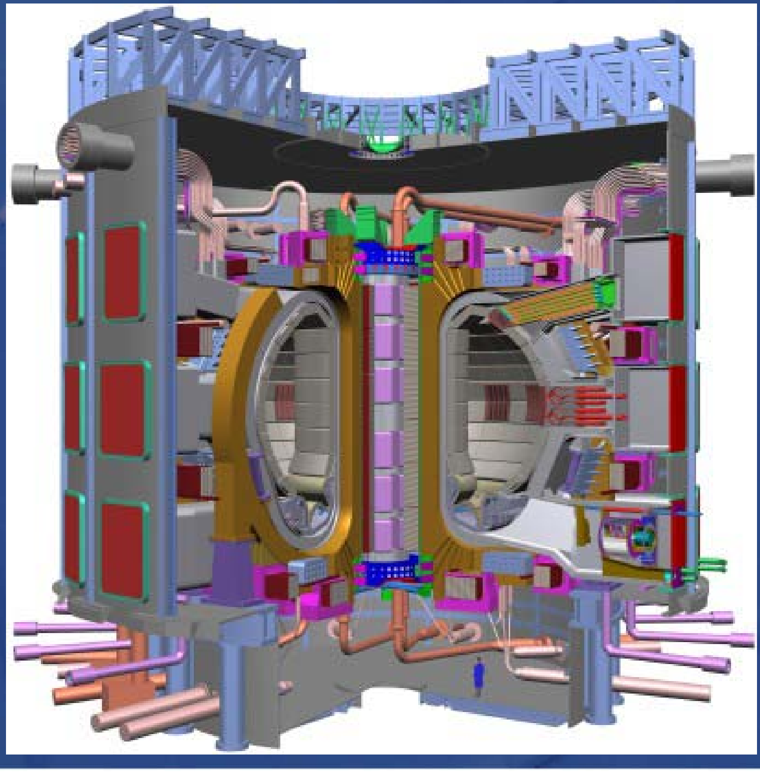
ITER JWS

## Synopsis

- Introduction
  - Nuclear Fusion
  - The Tokamak , ITER
- The status of the Design
- The ITER Organisation
- ITER and the international collaboration

# What is ITER?

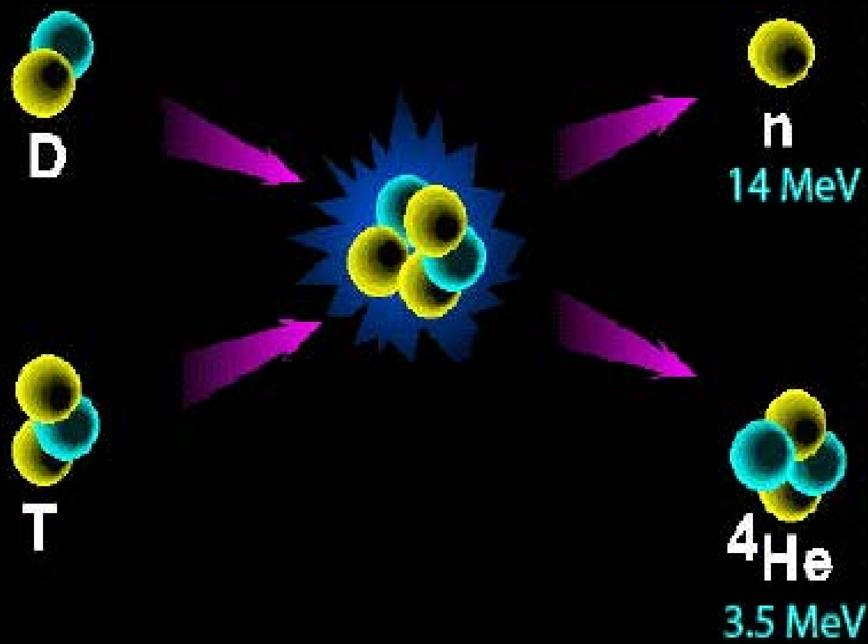
- ITER ("the way" in Latin) is the essential next step in the development of fusion.
- Objective - to demonstrate the scientific and technological feasibility of fusion power.
- The world's biggest fusion energy research project.
- An international collaboration.
- To be built in Europe, at Cadarache (France).



# What is fusion energy?

The process that generates the energy of the sun and stars.

Fusion occurs when the nuclei of two light atoms fuse to form a heavier element, releasing a large amount of energy.



# Why is Fusion important to us?

## Features

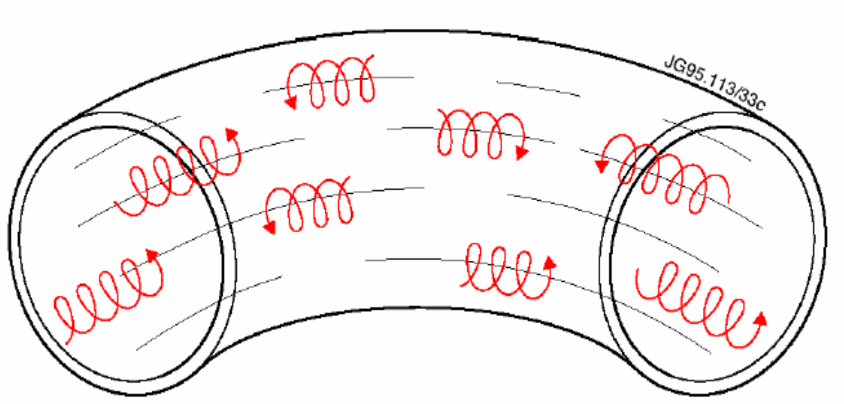
- Virtually inexhaustible
- No $CO_2$ emissions
- High energy density fuel
  - **1 gram of fully reacted Deuterium-Tritium = 26000 kW·hr of electricity (~10 Tonnes of Coal !!)**
- Inherently Safe Controllability
  - **low fuel inventory, ease of burn termination, self-limiting power level**
  - **No chain reaction to control**
  - **low power and energy densities, large heat transfer surfaces and heat sinks**

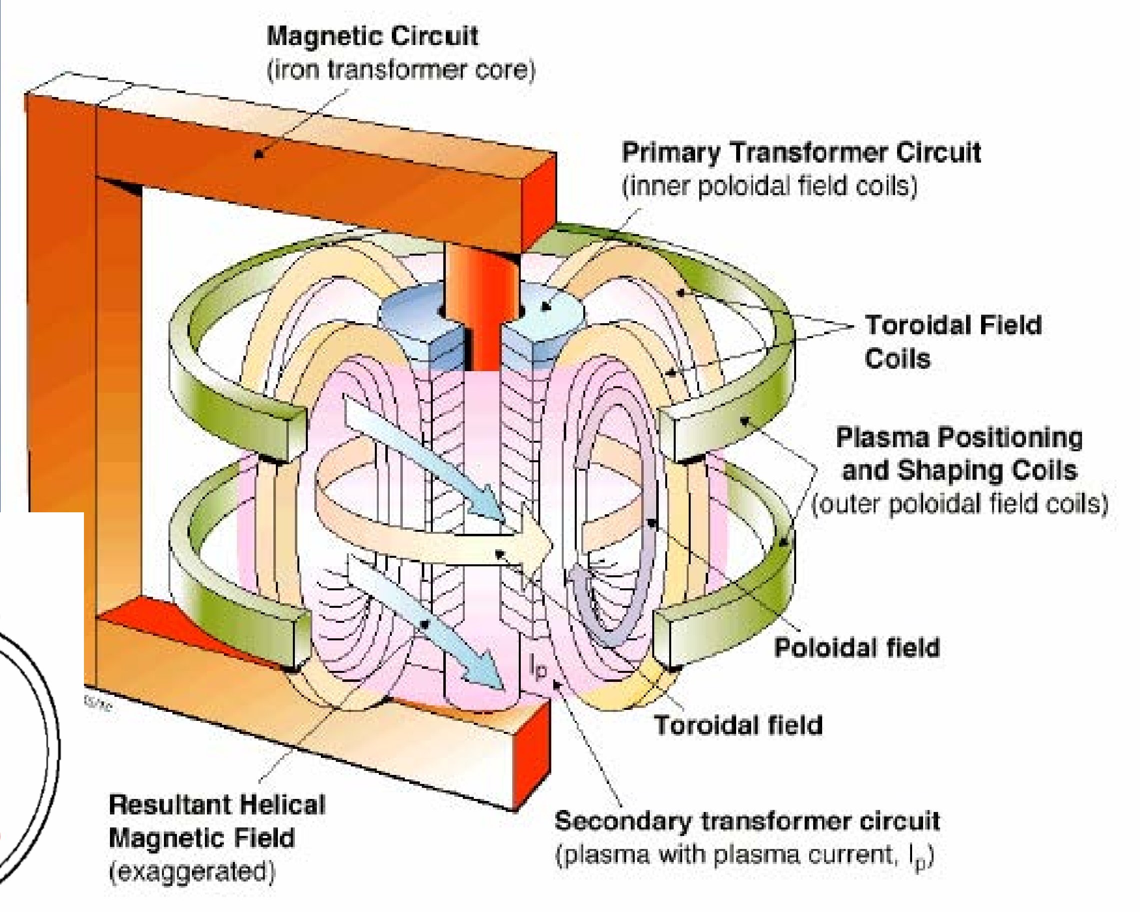
## Issues

- Fusion reaction is difficult to start and maintain
  - **High temperatures (Millions of degrees) in a pure environment are required**
  - Technically complex & LARGE **devices are required**

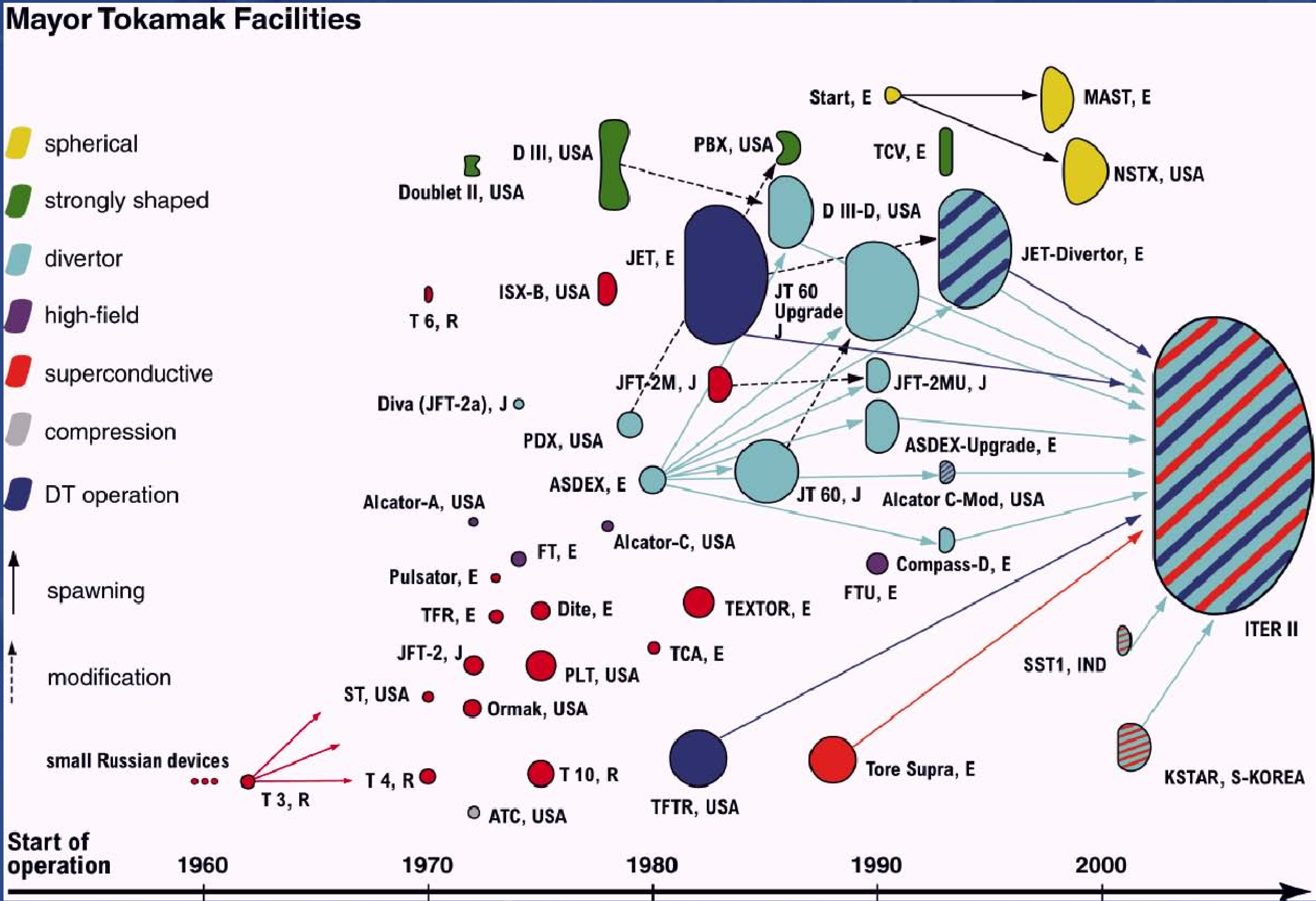
# The Tokamak

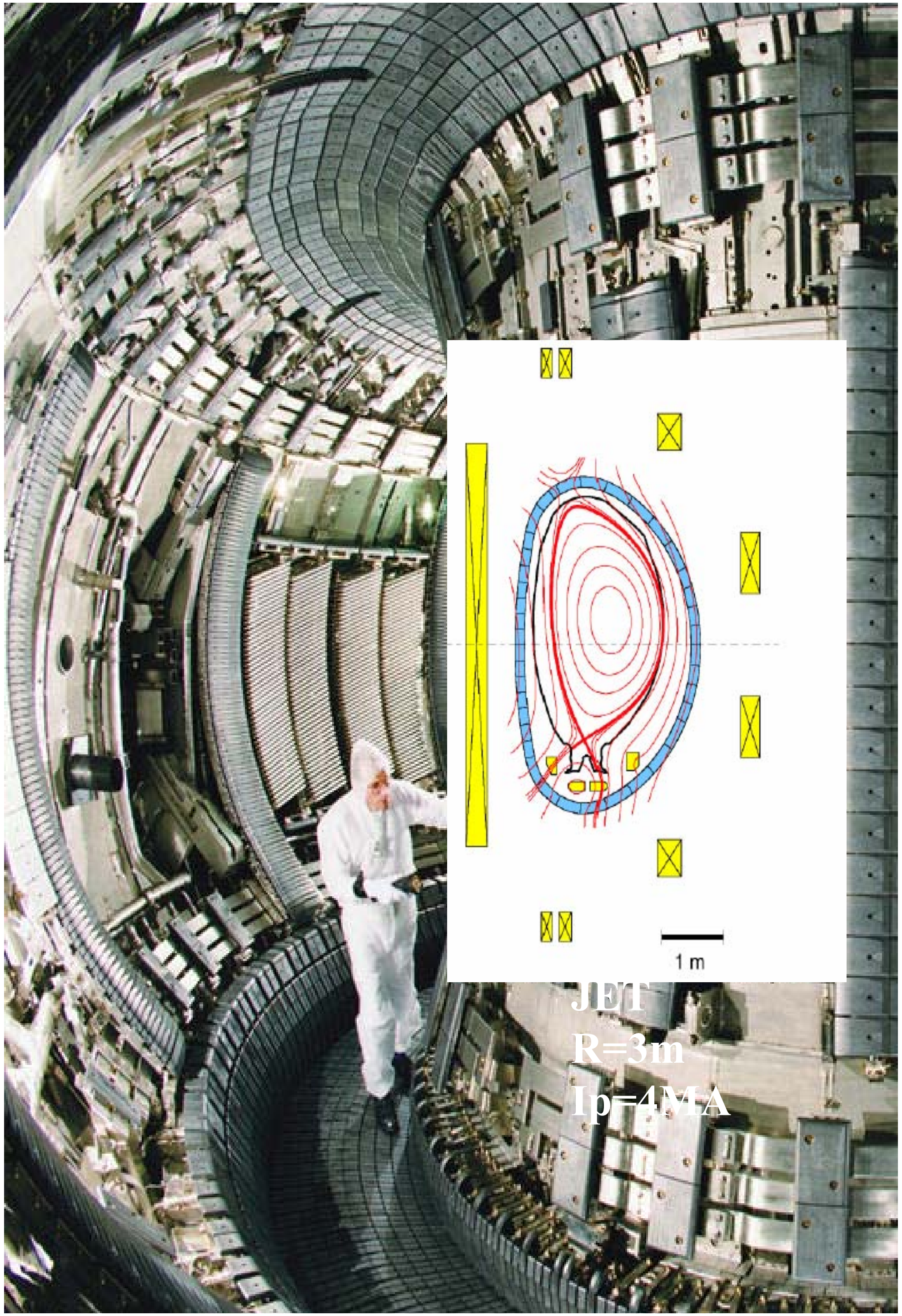
- Confinement: combination of an externally imposed toroidal field + poloidal field from plasma current.
- in a toroidal configuration plasma particles are lost to the vessel walls by relatively slow diffusion across the field lines.
- Magnetic forces = plasma pressure ($j \times \mathbf{B} = \nabla P$)

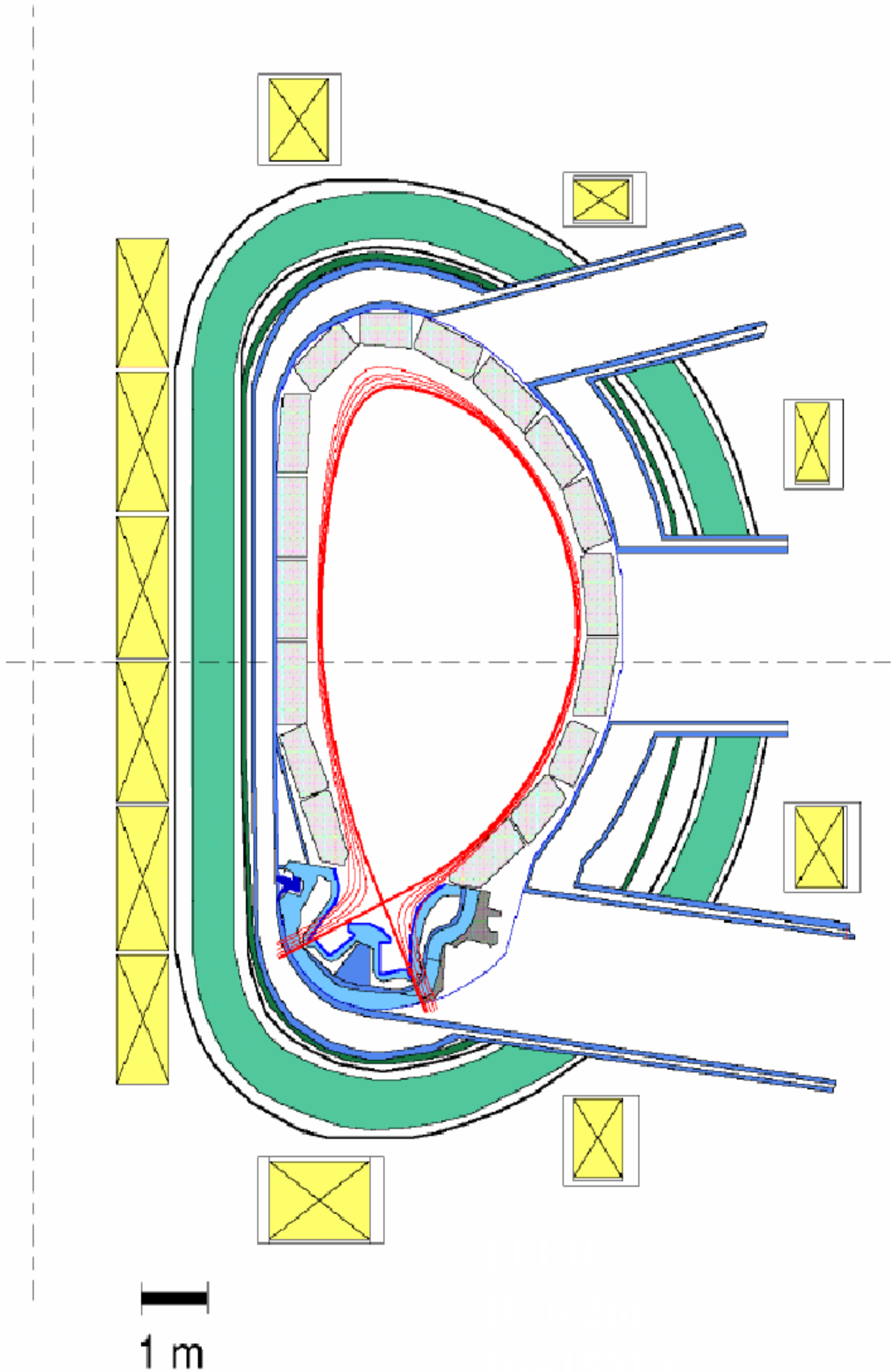


# The Genealogy of ITER



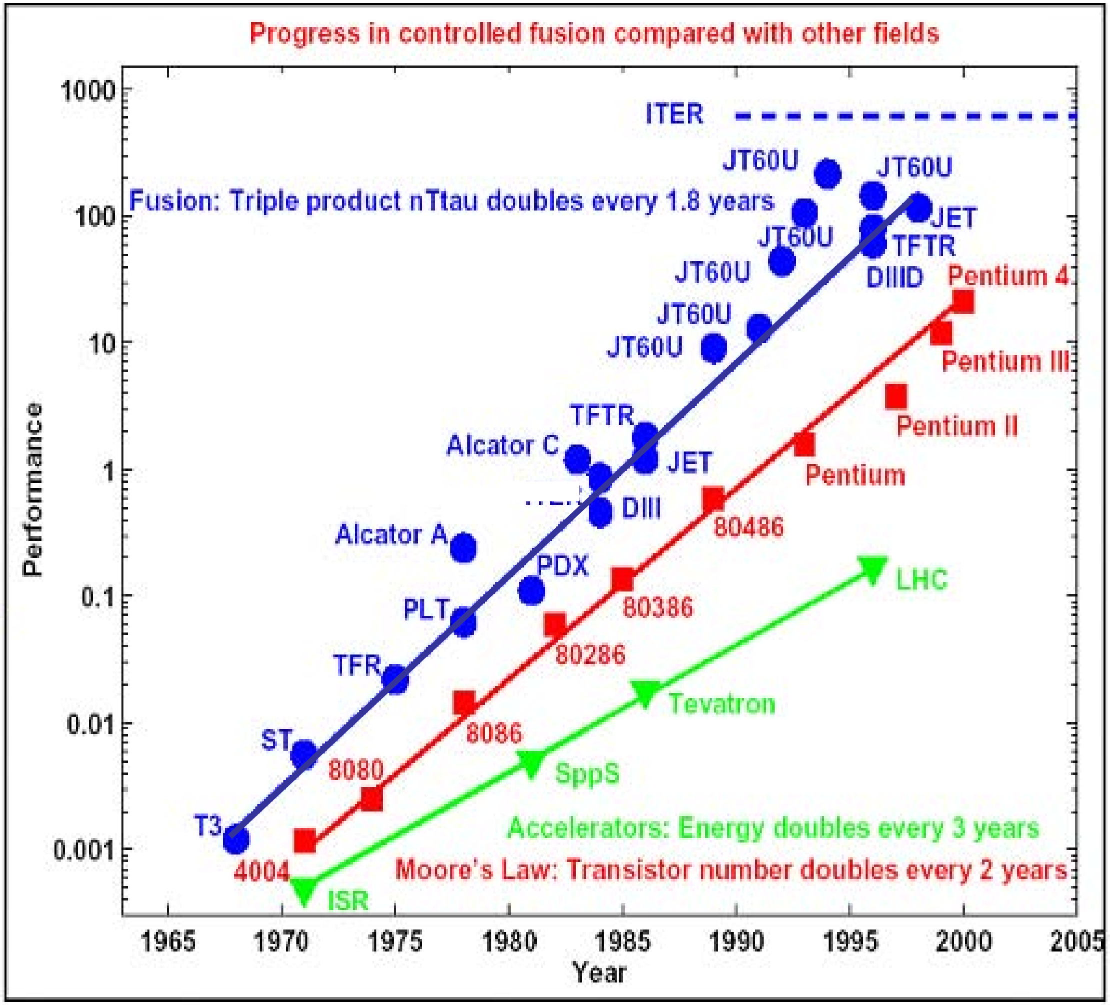

1 m
JET
R=3m
Ip=4MA


1 m

# Fusion Performance, nTτ

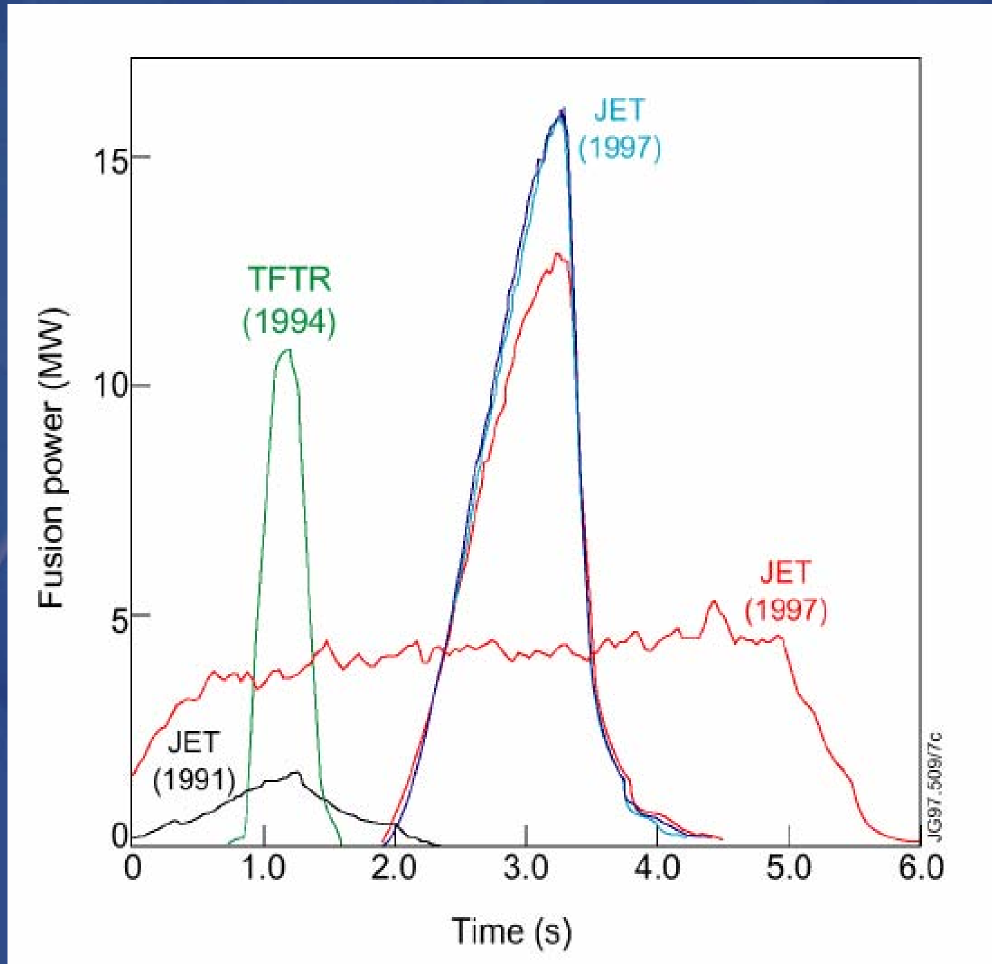
- Temperature ($T_i$): 10-20 keV (~10 × temperature of sun's core)
- Density ($n_i$): ~10 × $10^{19}$ $m^{-3}$ (~$10^{-6}$ of atmospheric particle density)
- Energy confinement time (τ): few seconds (plasma pulse duration ~500s)

Remarkable progress even when compared against other fast developing fields of research



# Fusion Power Production

**Experiments in JET and TFTR have initiated the study of DT plasmas with significant fusion power: best JET results correspond to a fusion power production of 16MW**




**Q, amount of power generated by the fusion energy divided by the power provided by external heating**

**In the JET shot α-particle heating amounted to ~15% of the input power to the plasma (Q~0.6)**

# ITER history

- 1988-1991 - (CDA) Conceptual Design Phase
  - Start of common activities among EU,RF, USA and JA
  - Selection of machine parameters and objectives
- 1992-1998 - (EDA) Engineering Design Phase
  - Developed design capable of ignition - large and expensive
  - The Parties (EU, JA, RF, US) endorsed design but could not afford to build it
- 1999 – 2001 – (EDA continues)
  - US withdraws from project
  - Remaining Parties searched for less ambitious goal
  - New design: moderate plasma power amplification at about half the cost.
- 2001 - now (CTA and ITA)
  - End of EDA and start of negotiations on construction and operation
  - 4 site offers, US re-joins, China & South Korea are accepted as full partners.
  - Cadarache selected as ITER site (28.06.2005), India joined in Dec 2005
  - Agreement initialised on May 24, 2006

# ITER Collaboration

- For its size and cost and the involvement of virtually all the most developed countries, involving countries representing over half of today world's population ITER will become a new reference term for big science projects.

- The ITER project will be one of the world's biggest scientific collaboration.


# What will ITER do?

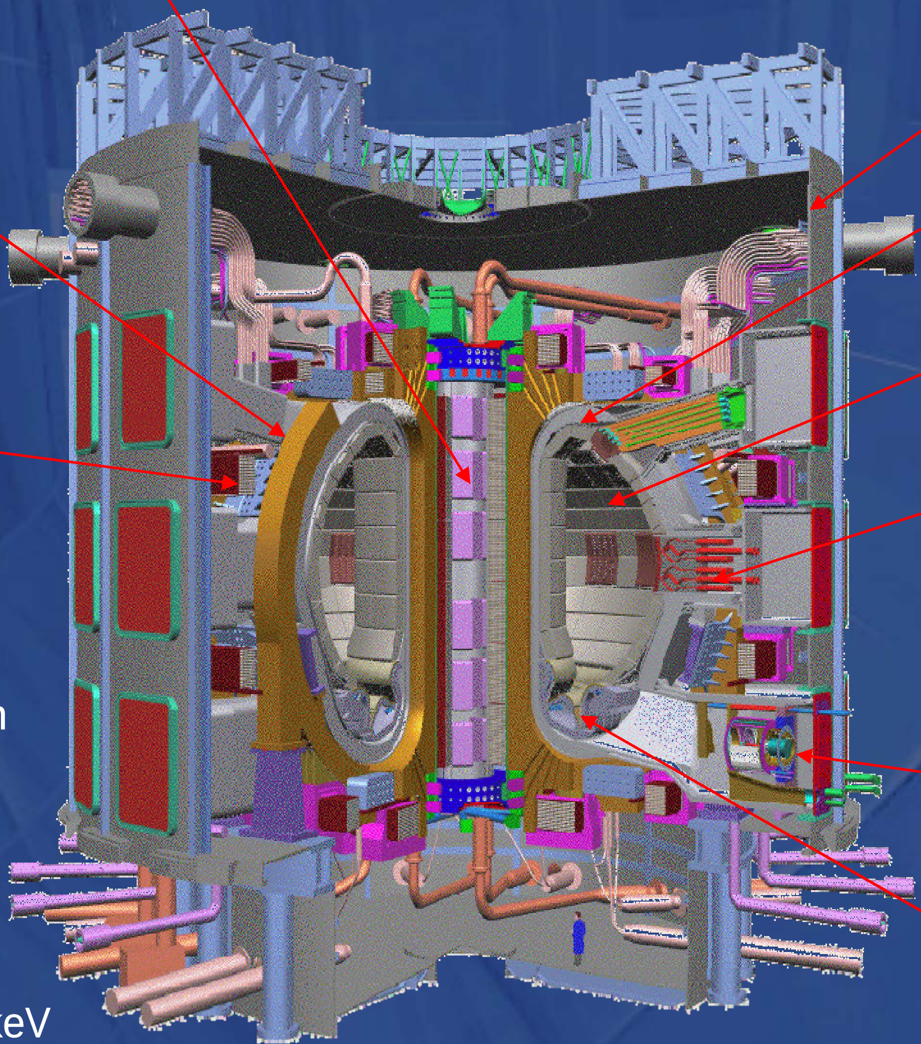
- Demonstrate up to steady state fusion power production.
- Plasma makes 10x more power than needed to run it.
- Study and optimise plasma behaviour.
- Have dimensions comparable to a power station.
- Produce about 500 MW of fusion power.
- Demonstrate or develop all the new technologies required for fusion power stations, except materials endurance.
- Require about 10 years for licensing and construction.
- Operate for about 20 years.
- Cost about €5bn to construct (over about 10 years) and €5bn to operate (about 20 years) and decommission.

# The core of ITER

**Central Solenoid**
$Nb_3Sn$, 6 modules

**Toroidal Field Coil**
$Nb_3Sn$, 18, wedged

**Poloidal Field Coil**
Nb-Ti, 6



**Cryostat**
24 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

**Divertor**
54 cassettes

Major plasma radius 6.2 m

Plasma Volume: 840 $m^3$

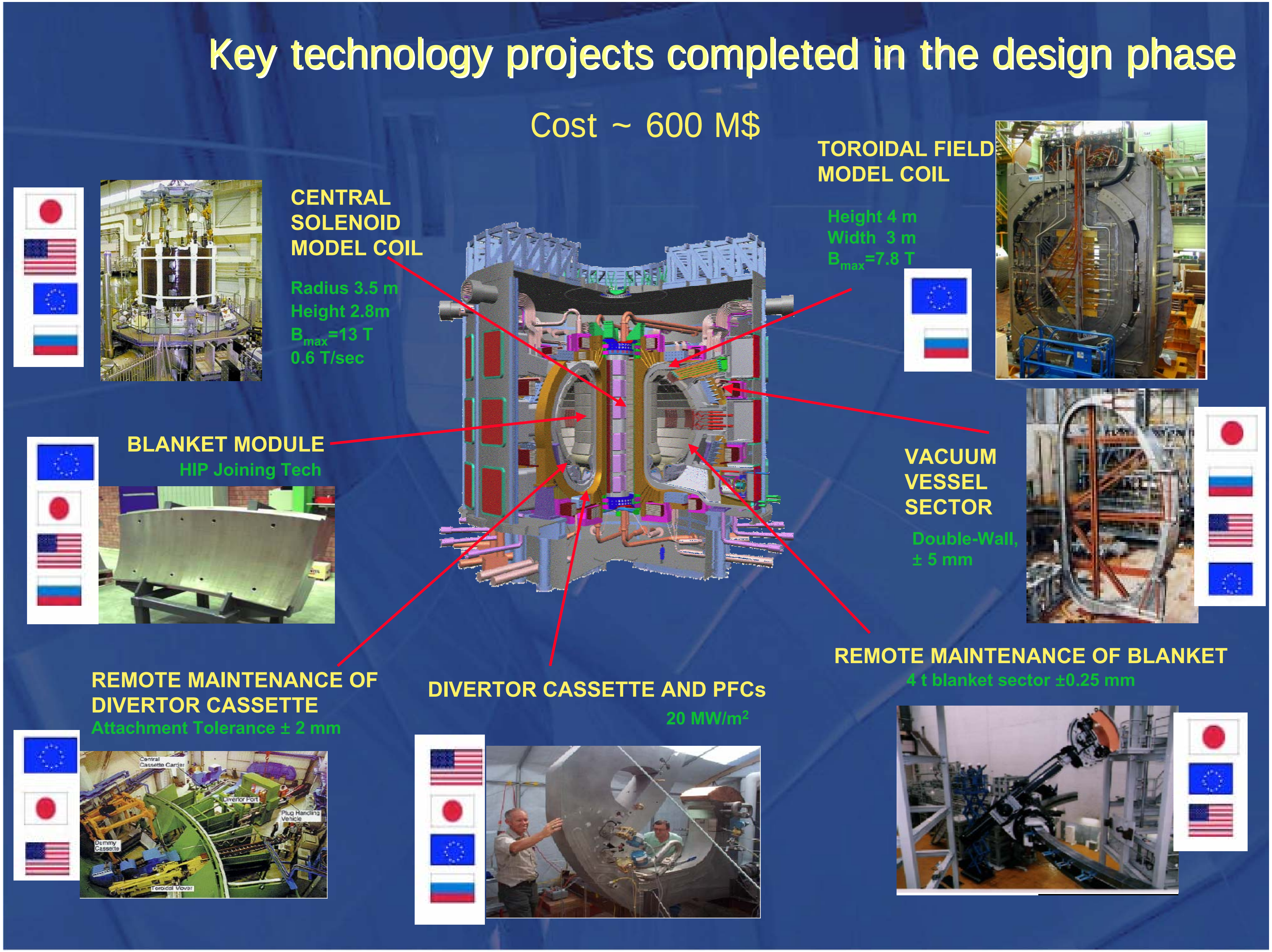
Plasma Current: 15 MA

Typical Density: $10^{20}$ $m^{-3}$

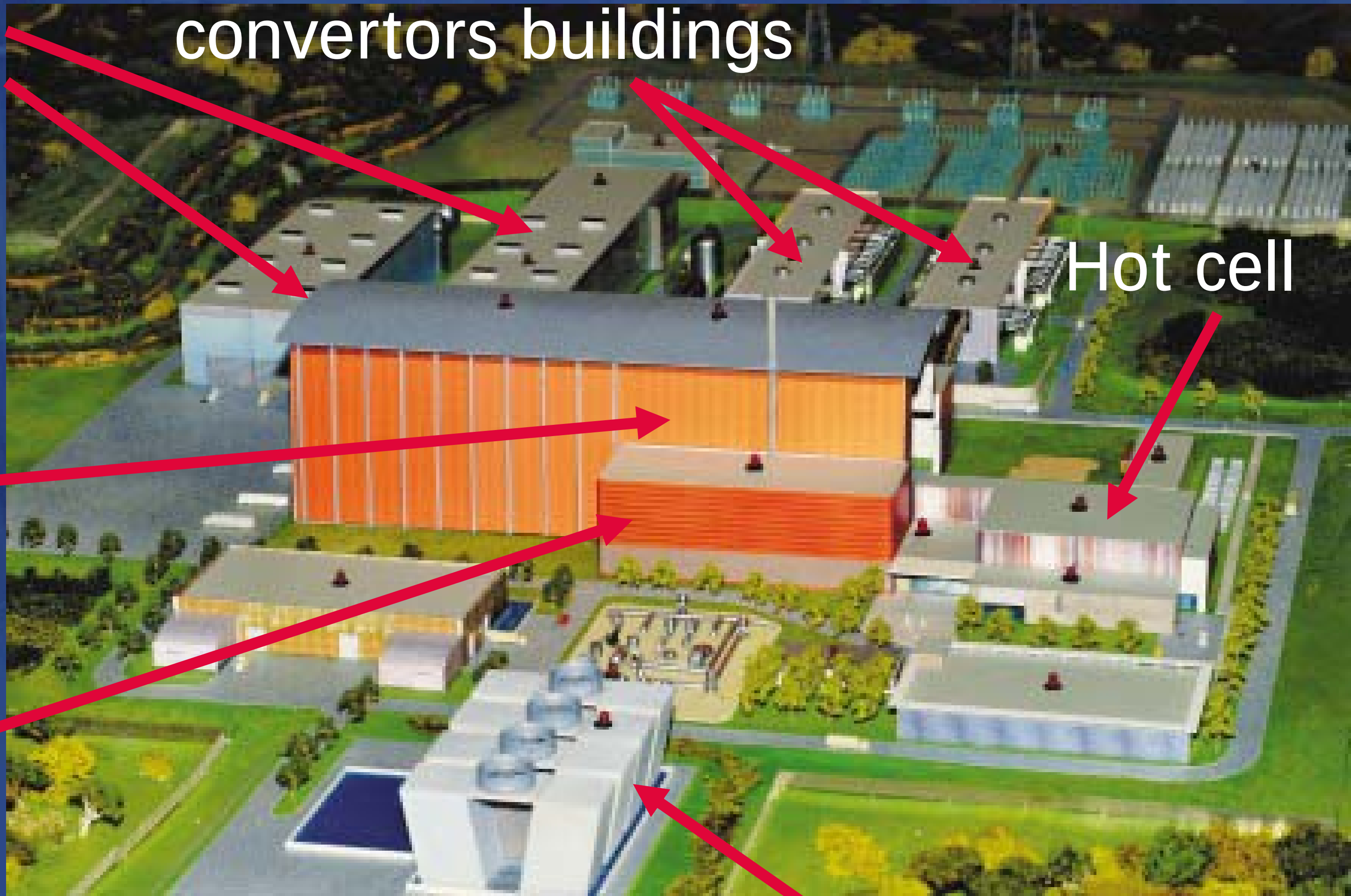
Typical Temperature: 20 keV

Fusion Power: 500 MW

**Machine mass: 23350 t (cryostat + VV + magnets)**
- shielding, divertor and manifolds: 7945 t + 1060 port plugs
- magnet systems: 10150 t; cryostat: 820 t


Key technology projects completed in the design phase
Cost ~ 600 M$
CENTRAL SOLENOID MODEL COIL
Radius 3.5 m
Height 2.8m
Bmax=13 T
0.6 T/sec
TOROIDAL FIELD MODEL COIL
Height 4 m
Width 3 m
Bmax=7.8 T
BLANKET MODULE
HIP Joining Tech
VACUUM VESSEL SECTOR
Double-Wall, ± 5 mm
REMOTE MAINTENANCE OF BLANKET
4 t blanket sector ±0.25 mm
REMOTE MAINTENANCE OF DIVERTOR CASSETTE
Attachment Tolerance ± 2 mm
DIVERTOR CASSETTE AND PFCs
20 MW/m2
Central Cassette Carrier
Divertor Port
Plug Handling Vehicle
Dummy Cassette
Toroidal Mover

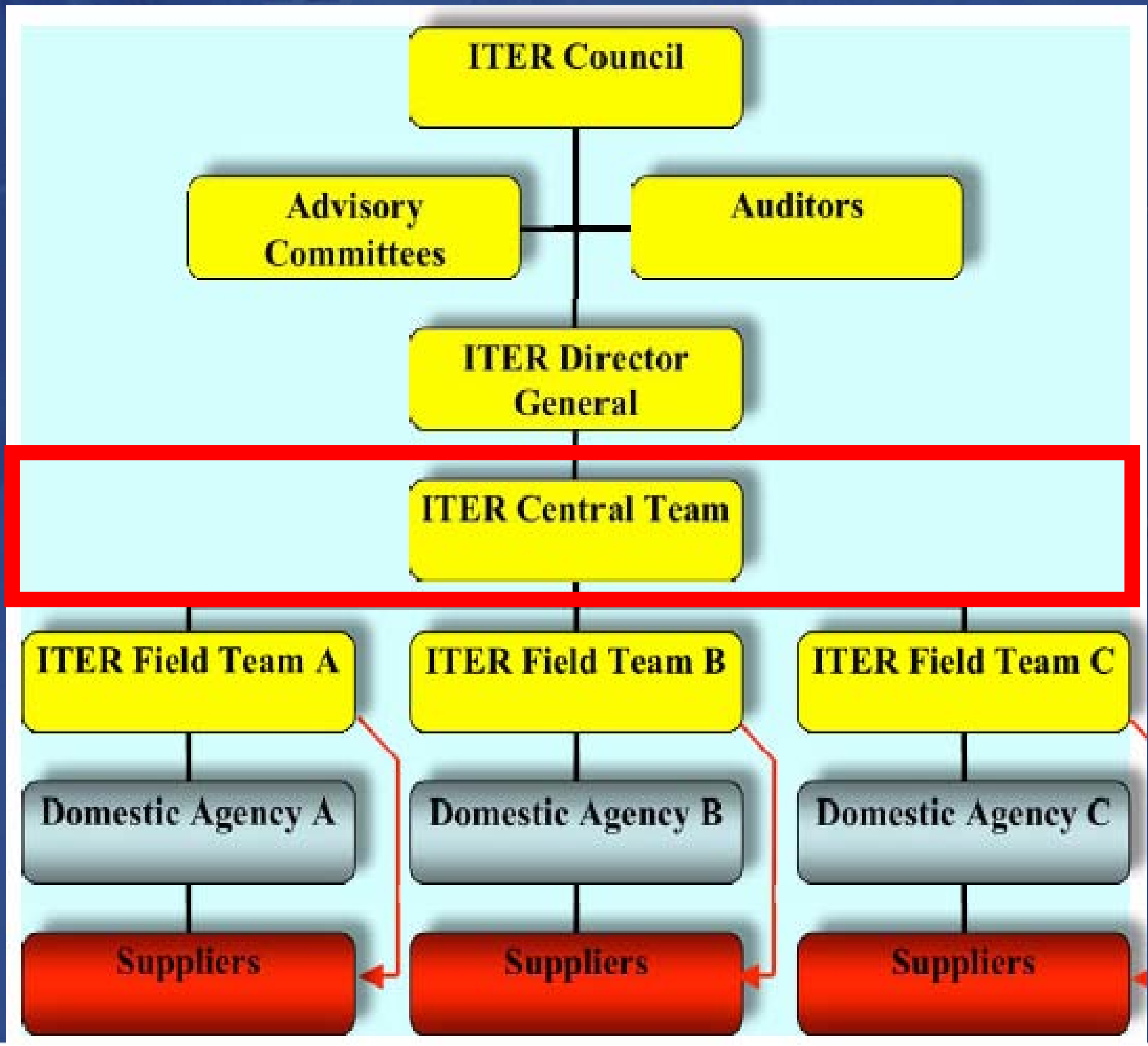
# The ITER site

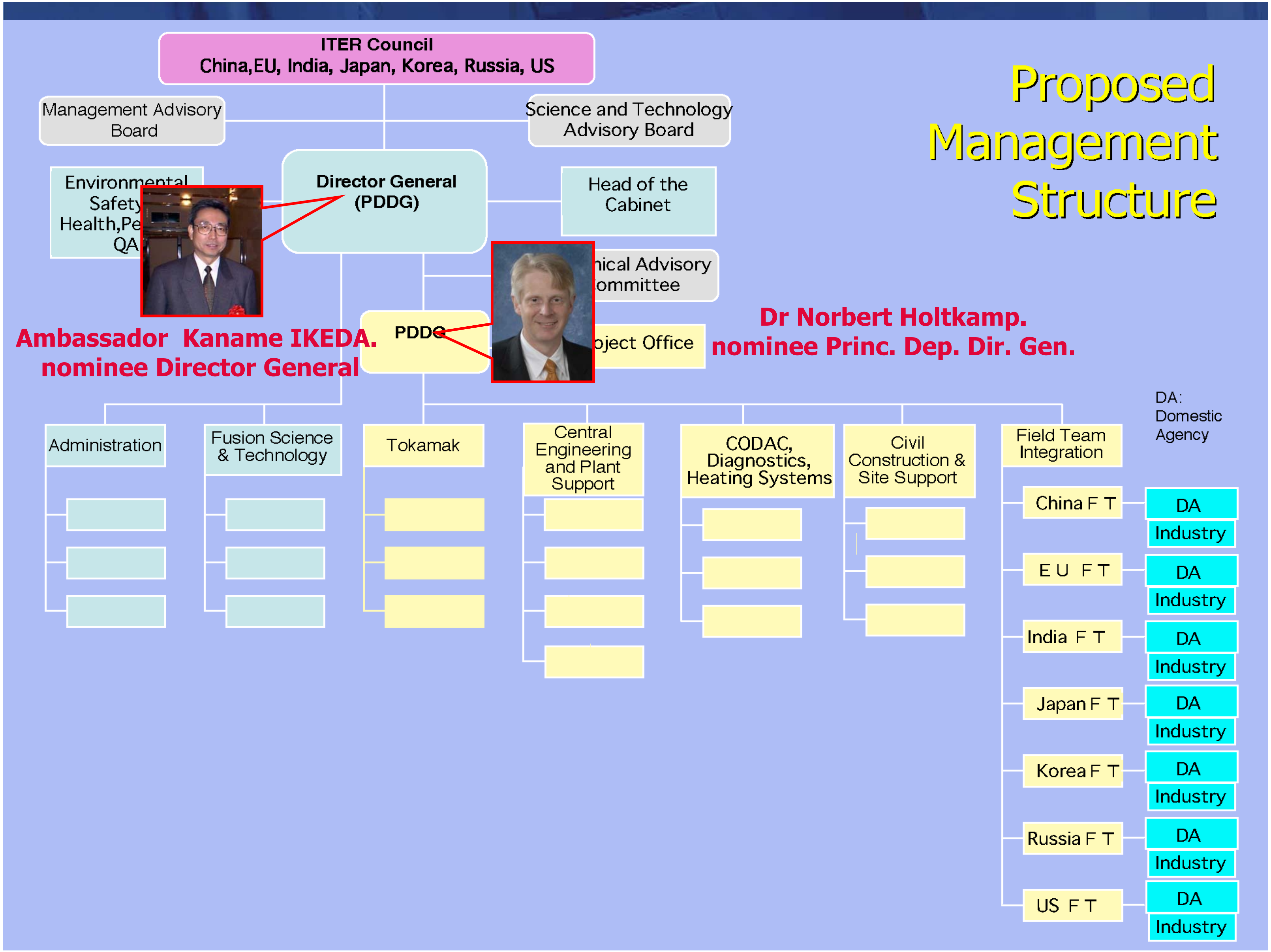



- **Will cover an area of about 60 ha**
- **Large buildings up to 170 m long**
- **Large number of systems**

# The ITER Organisation

Forging one coherent project team across multiple cultures (and time zones) with industrial support.




Proposed Management Structure
ITER Council
China,EU, India, Japan, Korea, Russia, US
Management Advisory Board
Science and Technology Advisory Board
Director General (PDDG)
Head of the Cabinet
Environmental Safety Health,Pe QA
ical Advisory ommittee
PDDG
oject Office
Ambassador Kaname IKEDA. nominee Director General
Dr Norbert Holtkamp. nominee Princ. Dep. Dir. Gen.
DA: Domestic Agency
Administration
Fusion Science & Technology
Tokamak
Central Engineering and Plant Support
CODAC, Diagnostics, Heating Systems
Civil Construction & Site Support
Field Team Integration
China F T
DA
Industry
E U F T
DA
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India F T
DA
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Japan F T
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Korea F T
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Russia F T
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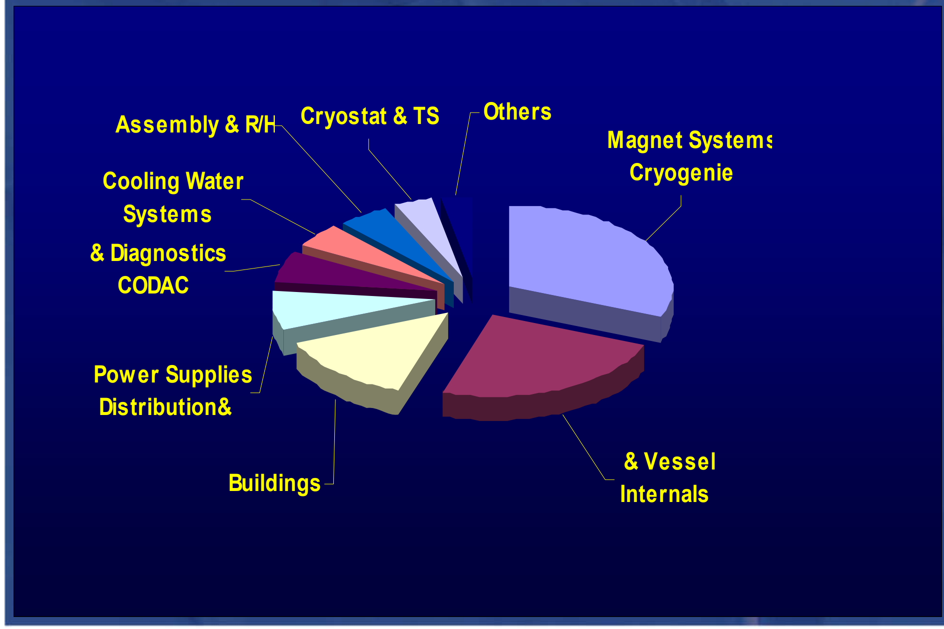
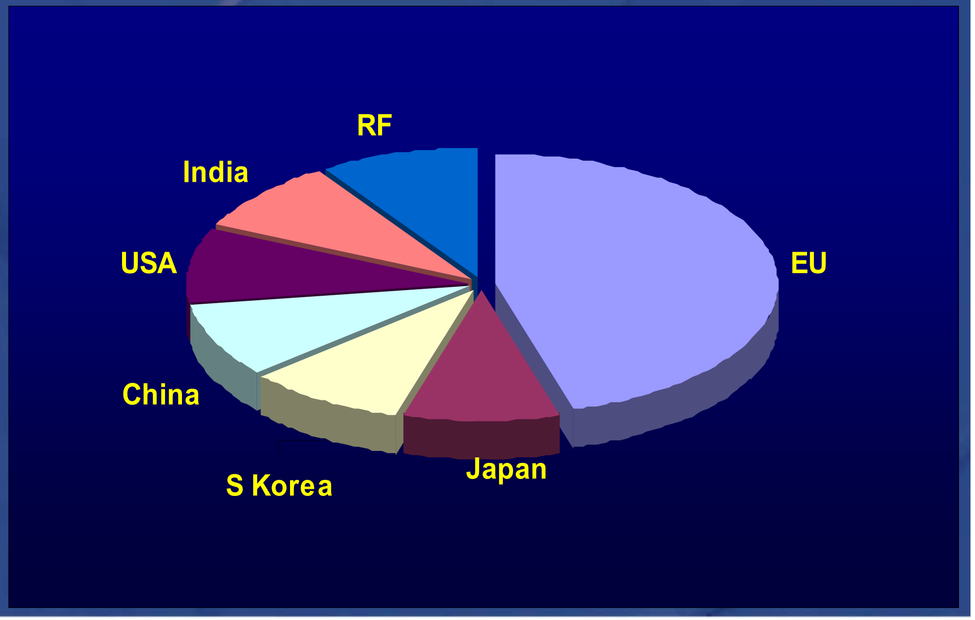
# The ITER Procurement

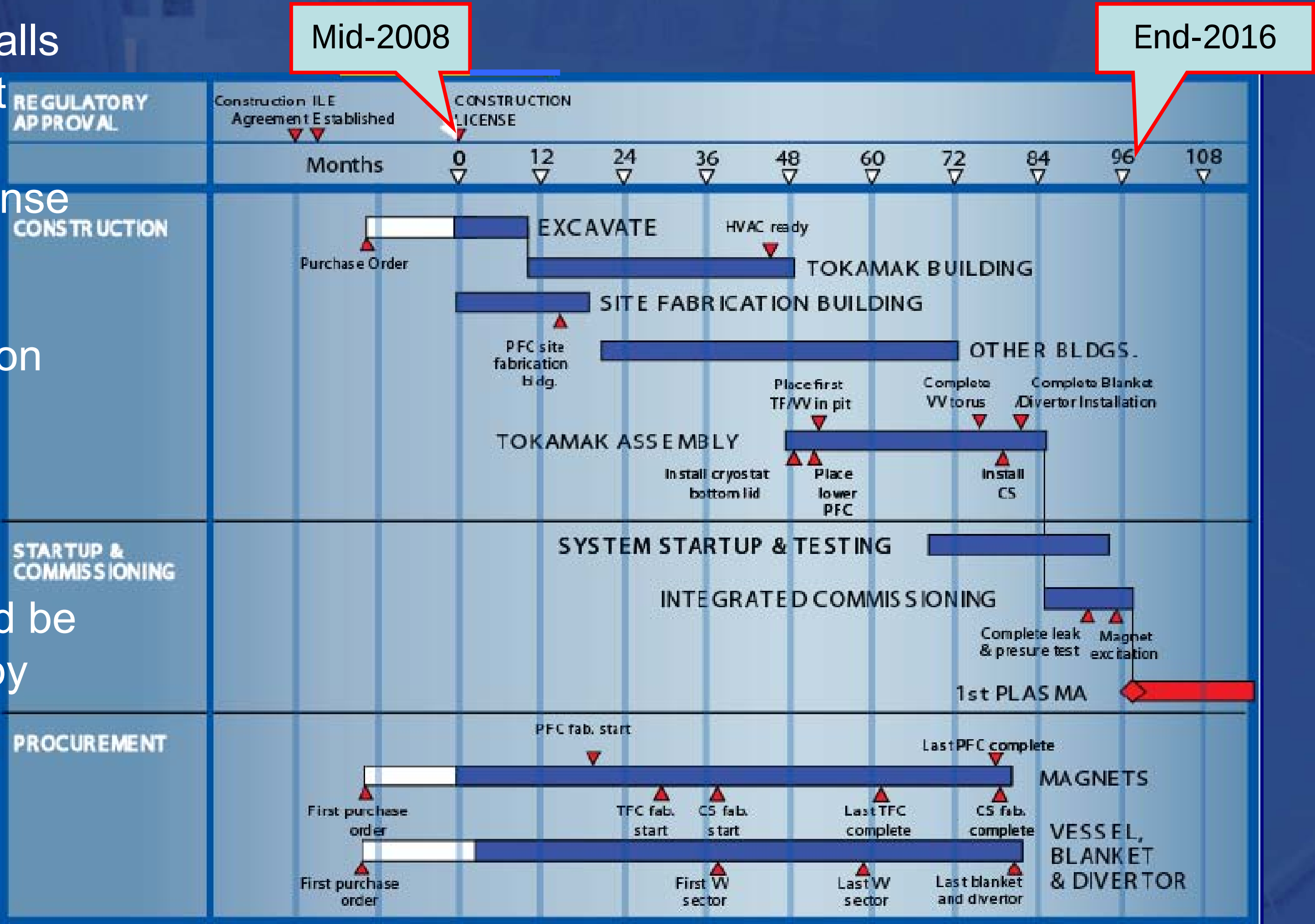
- In-Kind?
  - To ensure involvement of the Parties in key fusion technology areas.
  - To ensure a fair sharing of the cost of the device by ‘value’ and not by currency.
  - To automatically ensure fair return
- Sharing: 5/11 EU (1/11 procured in Japan), 1/11 Others. (of which 10% centrally funded and 90% in-kind)
- Total value 3020 KIUA  (equivalent to~ 4.3 MEuro)



# Construction schedule

- Construction license expected about 2 years after IO established (mid 2008).
- Long lead items calls for tender sent out and procurement started before license awarded.
- 7 years construction
- 1 year integrated commissioning
- first plasma should be possible in ITER by the end of 2016.



# Staff of the ITER Organisation

Construction phase

- Professional ~ 200 (direct employed or secondees)
- Technical and Support staff ~ 300

Operation phase

- Professional ~ 200 (direct employed or secondees)
- Technical and Support staff ~ 400

During the construction phase a considerable amount of work will be carried out by staff resident in fusion or high energy physics laboratories with the relevant expertises.

During operation Visiting Researchers will constitute substantial part of the ITER Research Team

# ITER and the scientific community

ITER can be built and operated only with a large support from the fusion and scientific community:

The technologies adopted by ITER in most cases have been used only in similarly large complex scientific projects.

- Large superconducting magnets
- Crygenic plant
- Vacuum chambers,
- Irradiation facilites
- Remote handling operations

Relevant Project Management practices exist in large scientific collaborations (International Space Station, CERN, SNS, Gen 3 and 4 nuclear projects, Inertial fusion devices).

# Involvement of the scientific community: fusion science

## MHD stability and plasma control:

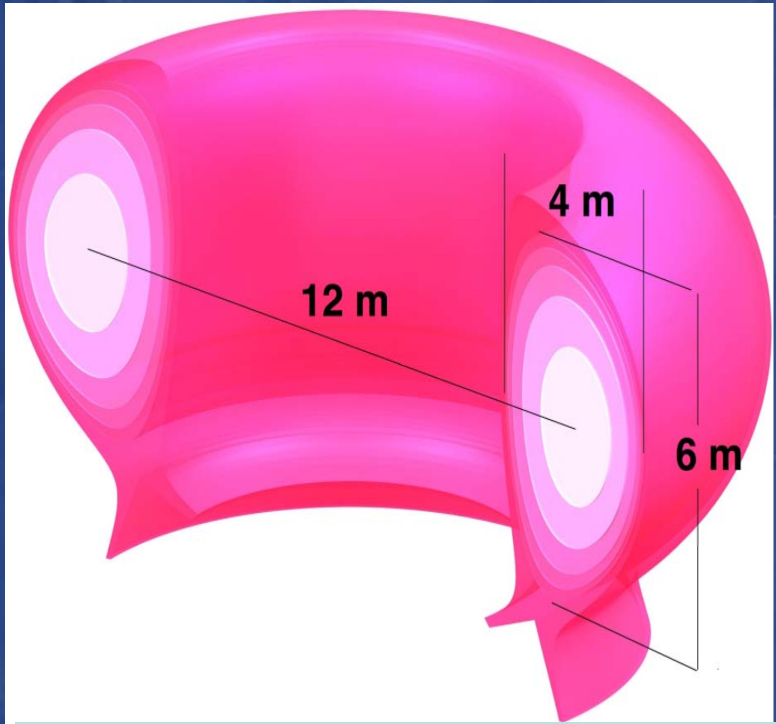
- extend the understanding of pressure limits to much larger size plasmas, e.g, NTM.
- Control of NTMs.
- Stabilization of RWMs.
- Disruptions control.

## Heat confinement:

- study strong heating by fusion products, in new regimes where multiple instabilities can overlap.

## Turbulences:

- Extend the study of turbulent plasma transport to much larger plasmas.




**Today:** 10 MW for 1 second, Q <1
**ITER :** 500 MW for ~10 minutes, Q ~10
**Power Plant:** 2500 MW, continuous, Q>25

## Plasma wall interactions:

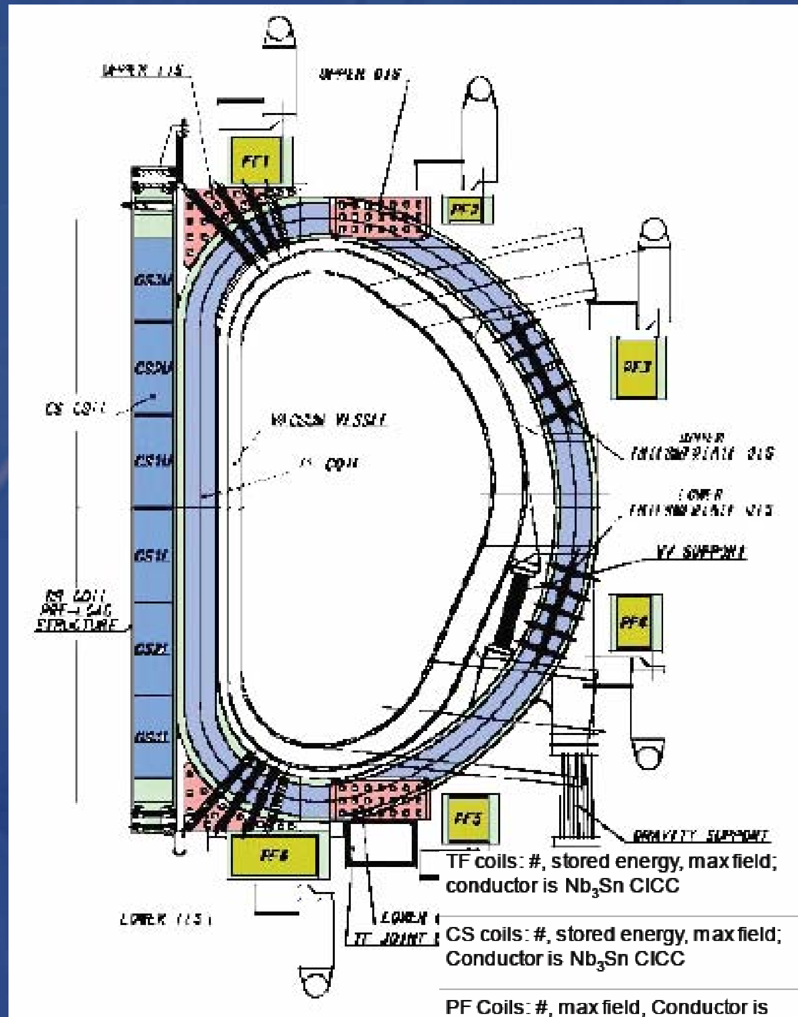
- Minimise/mitigate disruptions and ELMs,
- control build-up of tritium inventory.
- control plasma purity
- extend the study of PMIs to much higher power and much longer pulse duration.

## Steady-state operation:

- Expand operating space.

# Involvement of the scientific community: Engineering and technology

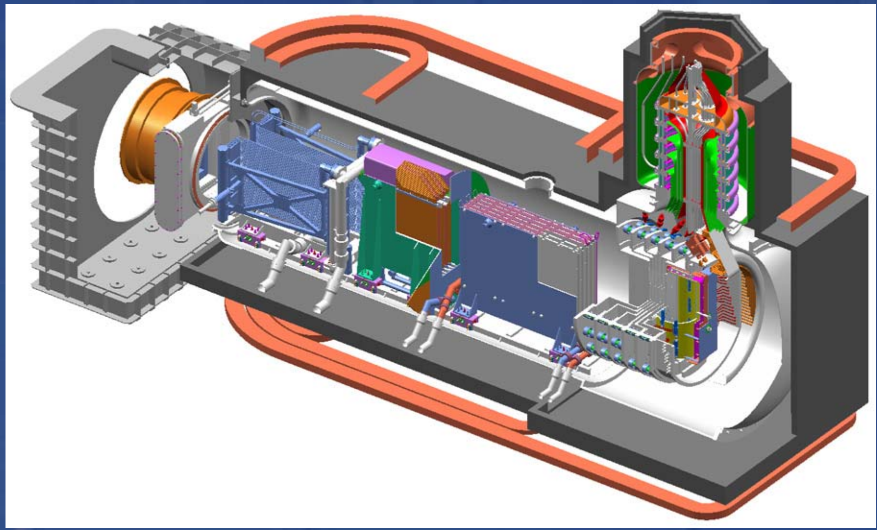
- **Superconducting magnets**
  - Unprecedented size of the super-conducting magnet and structures
  - High field performance ~12T
  - Power plant size
- **Plasma facing components**
  - >10 MW/m$^2$ steady heat flux
  - >10000 cycles/ severe damage
- **Remote maintenance**
- **Diagnostic systems**
  - 40 different diagnostic system
- **Vacuum and Tritium technology**
  - Active recycling of tritium
  - Test of lithium blankets
- **Cryogenic technology**
- **Heating and current drives**
  - ~ 100 MW continuous
  - Neutral particles accelerators up to 1 MeV
  - Ion cyclotron, electron cyclotron



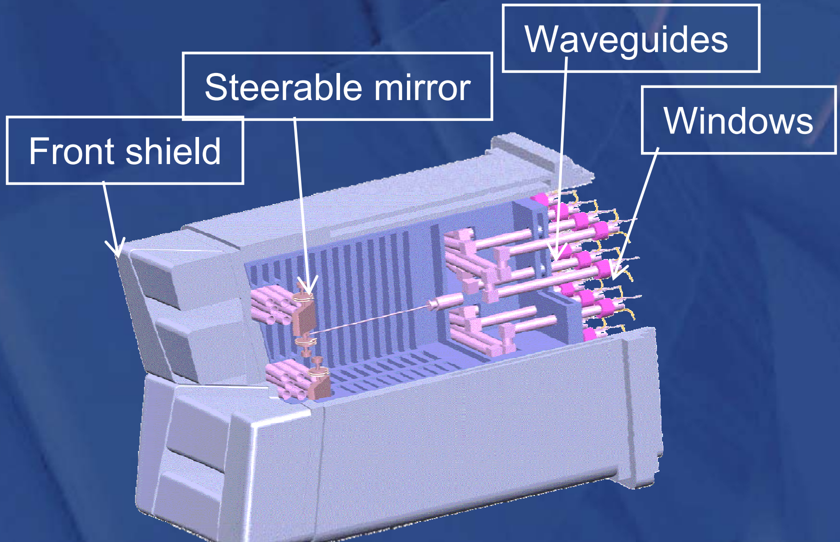
| | |
|---|---|
| TF coils: #, stored energy, max field; conductor is $Nb_3Sn$ CICC | 18, 41 GJ, 11.8T |
| CS coils: #, stored energy, max field; Conductor is $Nb_3Sn$ CICC | 6, 6.4 GJ, 13T |
| PF Coils: #, max field, Conductor is NbTi | 6, 6.4T |

# Heating and current drive

- Initial installation 73 MW with room for expansion to 130 MW.
- High energy (1 MeV $D^-$) ion beams + radio frequency heating tuned to key plasma frequencies (ion, electron cyclotron, lower hybrid);
- 2 main beam-lines, with room for third;
- RF systems modular and interchangeable in equatorial ports; EC used in upper ports;



**ITER requirements**
33 MW injected power (2 injectors, tangential)
• substantial current drive

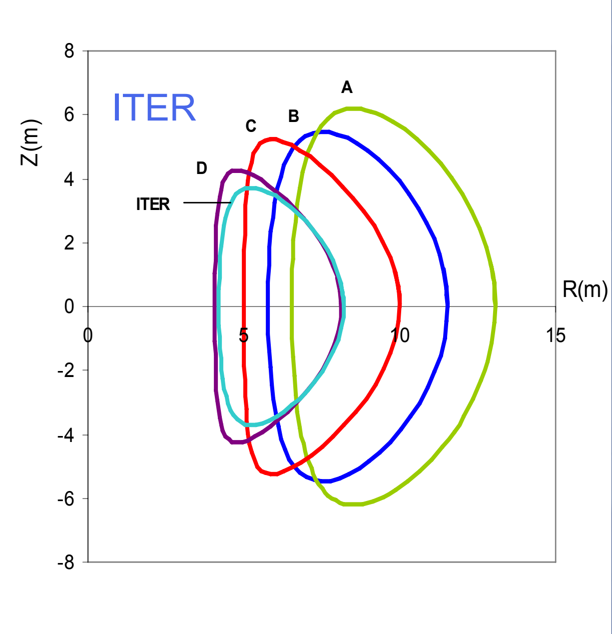



**Electron Cyclotron System Equatorial Port Plug**

# Involvement of the scientific community: beyond ITER

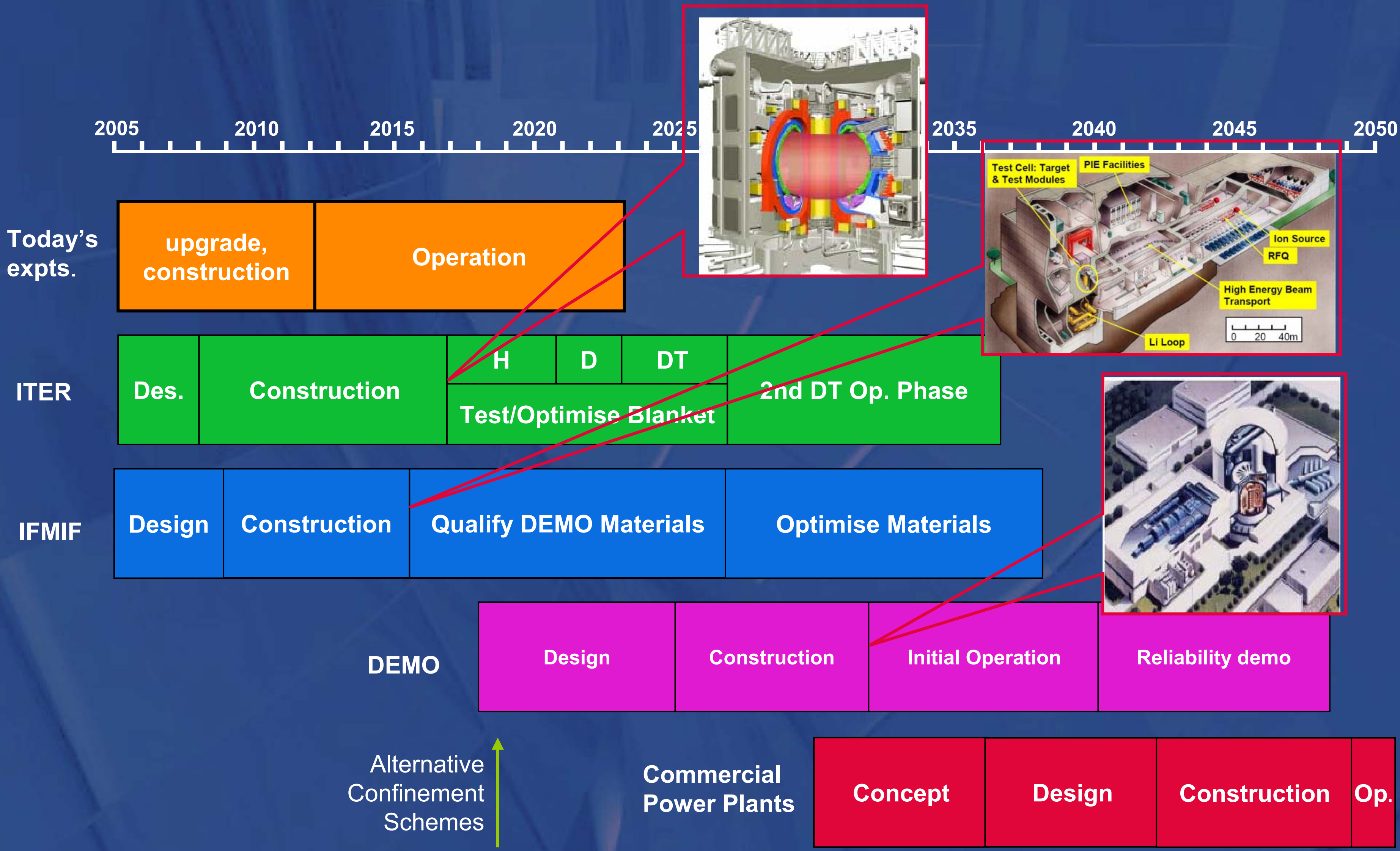
- Reliability - a fusion power station is a complex of many interacting systems:
  - high current high energy superconducting magnets;
  - high temperature and cryogenic components;
  - rapid remote replacement and refurbishment;
  - tritium cycle and breeding.
- Performance - after ITER, power plant needs 6x more power with only ~30% increase in machine size.
  - complementary physics program supporting ITER.
- Materials - key to fusion attractiveness is the possible ability to recycle all materials ~100 years after shutdown.
  - Materials exist but need to finish qualification - IFMIF

# from ITER to the reactor




| Parameter | ITER | A | B | C | D |
|---|---|---|---|---|---|
| | | limited extrapolation | | advanced | |
| Unit Size ($GW_e$) | - | 1.55 | 1.33 | 1.45 | 1.53 |
| Fusion Power (GW) | 0.5 | 5.00 | 3.60 | 3.41 | 2.53 |
| Major Radius (m) | 6.2 | 9.55 | 8.6 | 7.5 | 6.1 |
| Net efficiency | - | 0.31/ 0.33 | 0.36 | 0.42 | 0.60 |
| Plasma Current (MA) | 15 | 30.5 | 28.0 | 20.1 | 14.1 |
| Bootstrap Fraction | 0.15 | 0.45 | 0.43 | 0.63 | 0.76 |
| $P_{add}$ (MW) | 73 | 246 | 270 | 112 | 71 |
| Divertor Peak load ($MWm^{-2}$) | 15 | 15 | 10 | 10 | 5 |
| Av. neutron wall load ($MWm^{-2}$) | 0.8 | 2.0 | 1.8 | 2.2 | 2.4 |

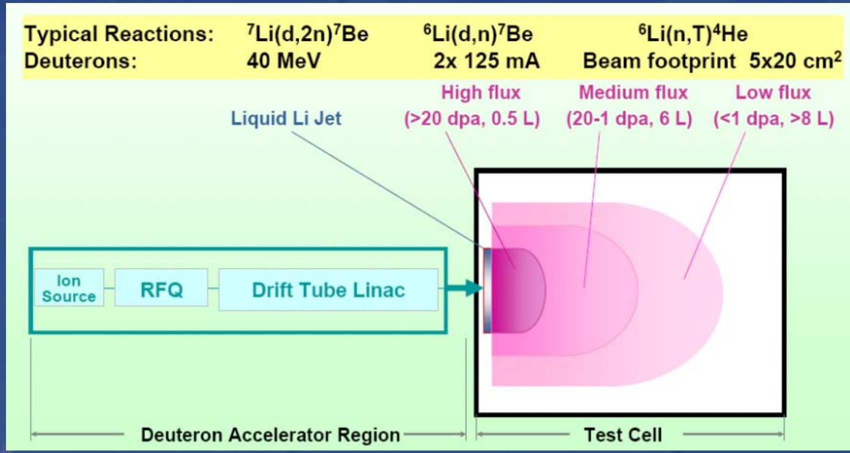
# The roadmap beyond ITER

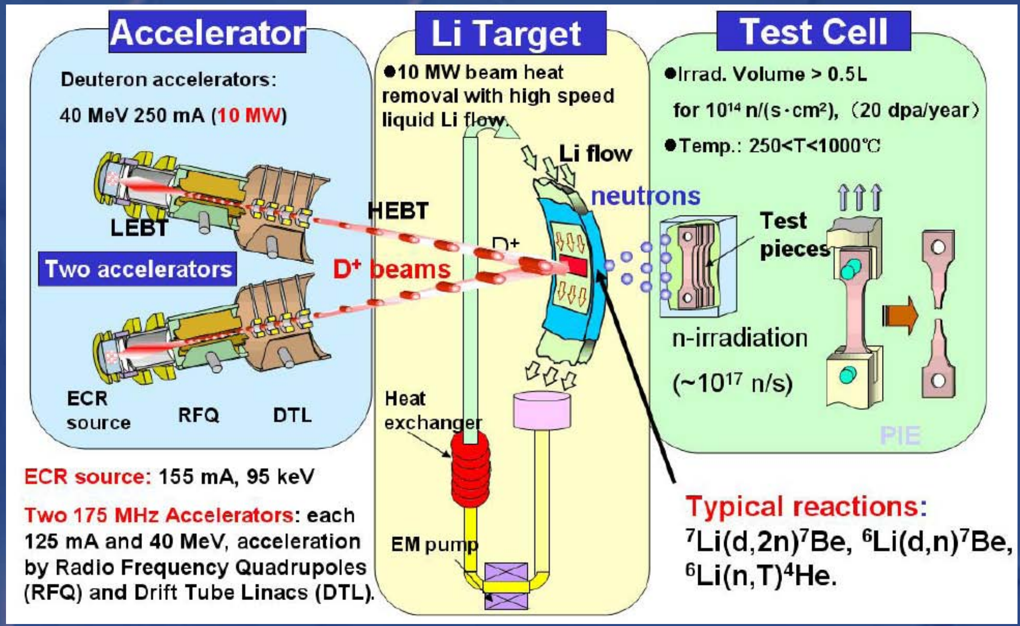


# Involvement of the scientific community: IFMIF

**High n-fluence testing of material for fusion reactors**

- Materials irradiation behaviour (design-relevant engineering data bases for a DEMO).
- Calibration and validation of data generated by fission reactor irradiations and other experiments with light or heavy ions. ( limited irradiation volume of IFMIF)
- Advanced material development for commercial reactors.
- Functional testing of small blanket component elements and blanket mock-ups.



# Summary

- International Agreement to establish ITER has been initalised on May 24 .
  Over half the world's population represented.
  New organisation under international law is being established.

- Design is well established.

- The site is chosen and team-building underway.

- ITER is the key step that will show whether magnetic confinement fusion can make a viable energy source.
  - will produce key data to optimise reactor performance;
  - will demonstrate all key technologies for power generation;
  - will show how to design demonstration/prototype.

- It is a challenge - multiparty, shared procurement, complex, technically challenging, and thus …

- To be a success it will need the support of the whole scientific community…

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