ITER Goals and Project

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Acknowledgements:

Many colleagues in the ITER IO and ITER Members

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

What is ITER?

ITER is a major international collaboration in fusion energy research involving China, the EU (plus Switzerland), India, Japan, the Russian Federation, South Korea and the United States

- **The overall programmatic objective:**
  - to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes

- **The principal goal:**
  - to design, construct and operate a tokamak experiment at a scale which satisfies this objective

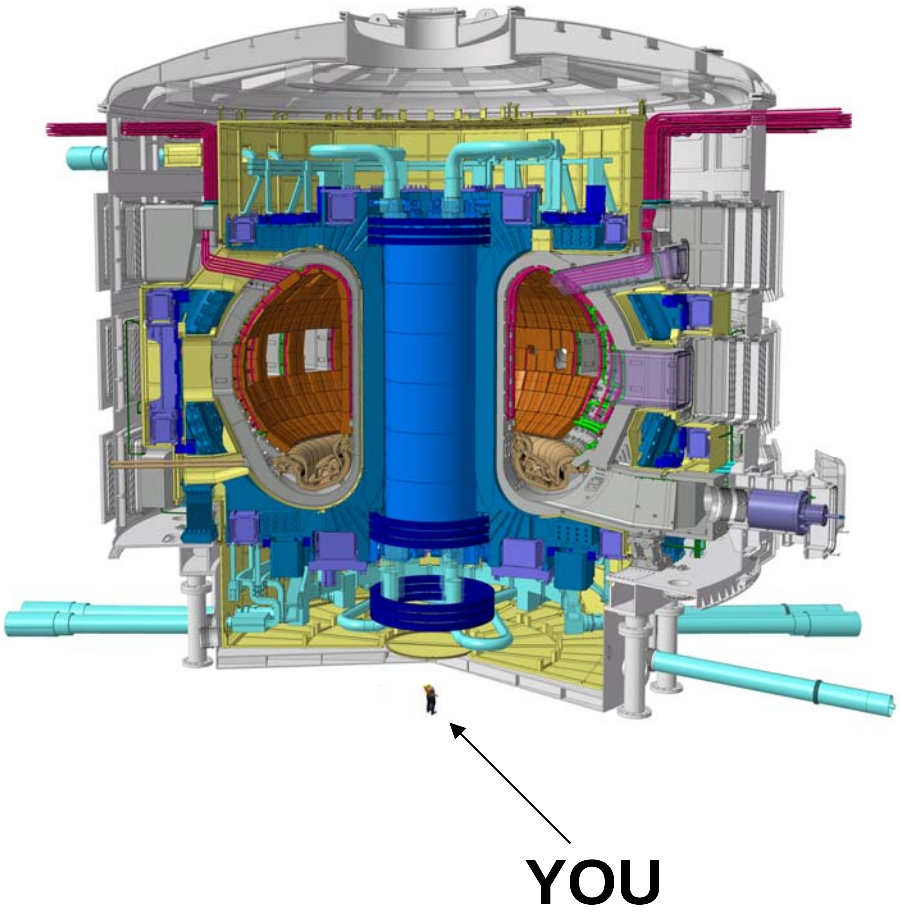
- **ITER is designed to confine a DT plasma in which α-particle heating dominates all other forms of plasma heating:**

$\Rightarrow$ a burning plasma experiment

ITER – An Introduction

- The ITER Team has been established at St Paul-lez-Durance for ~8 years
  - now ~550 team staff on site
- ITER Agreement signed in November 2006
- Project Baseline (scope, cost, schedule) approved by ITER Council in July 2010
- On-site construction started in July 2010 and IO team moved to new HQ on the ITER site in October 2012
- First components delivered to ITER site in September 2014

ITER tokamak



ITER – The Challenge of Scale

- Size: moving beyond the “human scale”
  - almost all components are “uncomfortably large”
  - can be a challenge for industry
- Cost: currently estimated to be 10-15 billion Euros
  - difficult for politicians, especially now
  - Project is doing all it can to streamline costs and stay within allowed budget cap
- Time: 10 years for construction, 20 years of operation
  - again, the long time scales can be difficult for politicians (and physicists/ engineers)
  - long timescales for manufacture
  - maintenance periods are difficult and lengthy
- Complexity: highly integrated components, built in different places
  - large effort to manage “interfaces” and establish and enforce quality assurance (QA) procedures

⇒ Benefit: realization of potential of fusion energy as a carbon-free energy source for which everyone has access to fuel

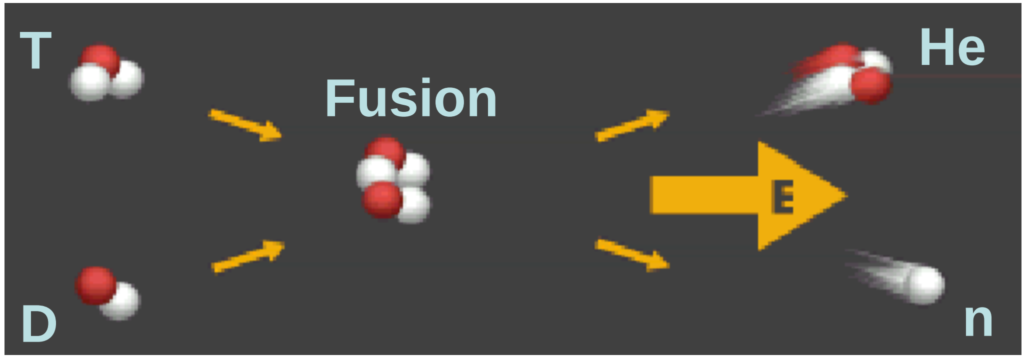
Synopsis

- **The rationale for ITER**
- **Framework of the ITER project**
- **Key elements of the ITER programme**
- **ITER construction status**

What are ITER’s primary goals?

⇒ The rationale for ITER

Essential fusion reactions



+ 20% of Energy (3.5 MeV)

+ 80% of Energy (14.1 MeV)

- **The D-T fusion reaction is the simplest to achieve under terrestrial conditions**

  $^{2}D + {}^{3}T \Rightarrow {}^{4}He\ (3.5\ MeV) + {}^{1}n\ (14.1\ MeV)$

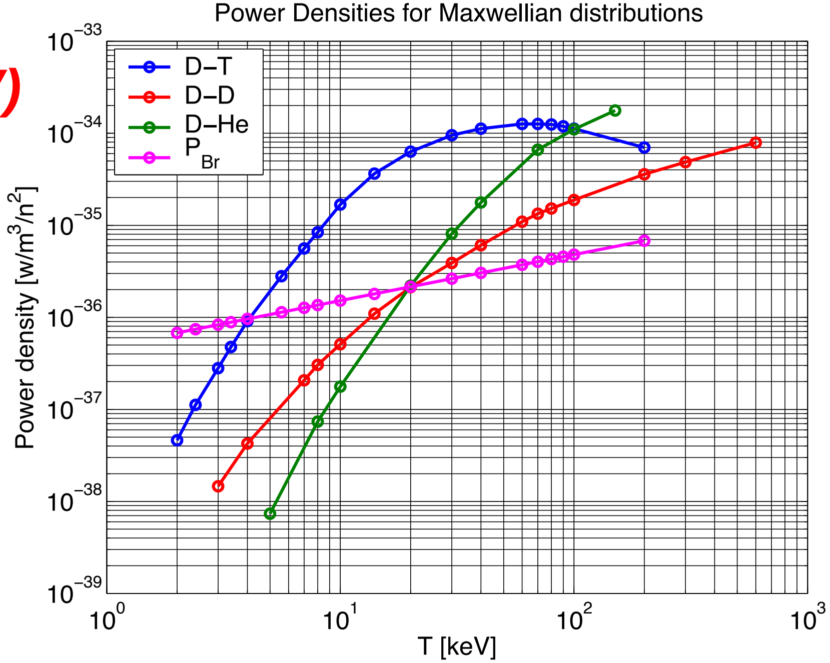
- **Two other important reactions for DT fusion:**

  $^{1}n + {}^{6}Li \Rightarrow {}^{4}He + {}^{3}T + 4.8\ MeV$

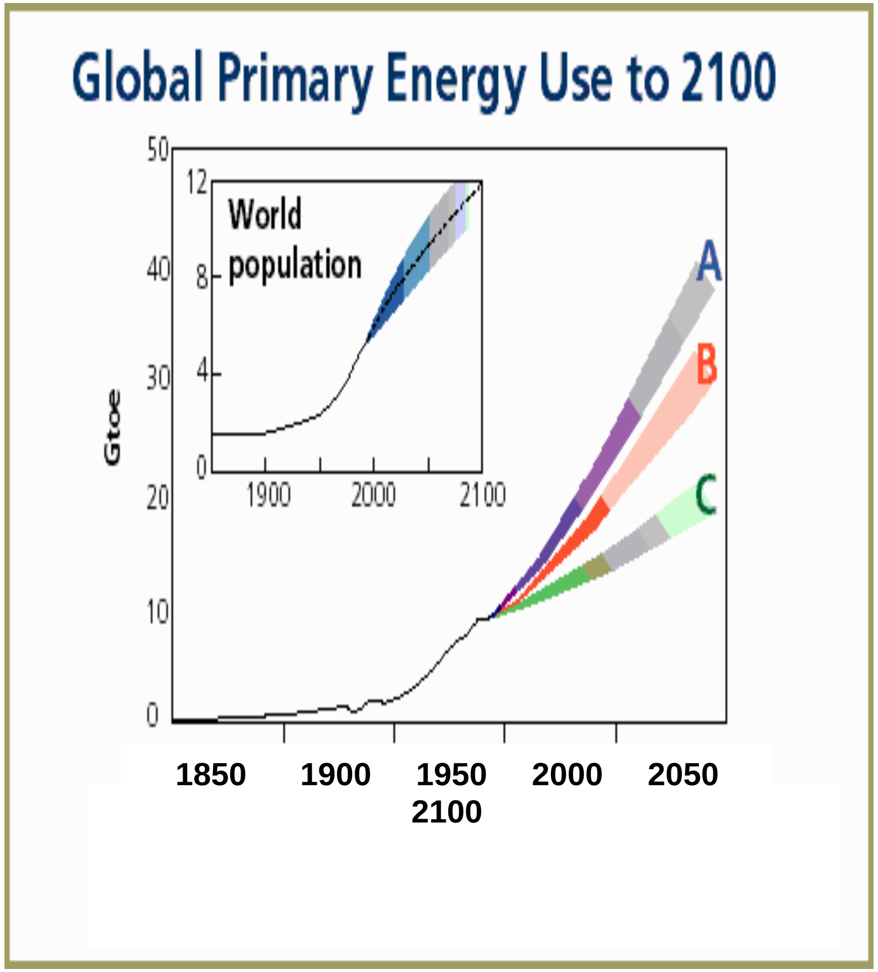
  $^{1}n + {}^{7}Li \Rightarrow {}^{3}He + {}^{3}T + {}^{1}n - 2.5\ MeV$

  - **these reactions will allow a fusion reactor to breed tritium**

1 keV = 1.16 × 10^7 K



Why Fusion ?

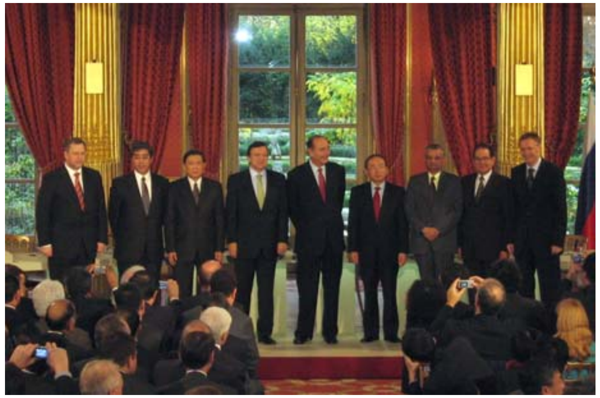


- **Fuel: abundant, world-wide distributed:**
  - sufficient deuterium in seawater for millions of years
  - tritium is produced from lithium - sufficient ore supplies for thousands of years (millions of years including seawater resources
- **Safety: no risk of major accidents:**
  - reactor contains fuel for only a few minutes burn
- **Waste: no long-term burden:**
  - low radio-toxicity after < 100 years
  - no CO_2

The ITER Project – Some History

- **1985-86: International summits, Gorbachev-Reagan-Mitterand-Tanaka developed proposal for international project to develop fusion energy: ITER (EU, JA, SU, US)**

- **1988-90: Conceptual Design Activity (CDA) - Garching**
- **1992-1998-2001: Engineering Design Activity (EDA)**
  Garching – Naka – San Diego
- **2001-2005: Negotiations and site selection - Cadarache**
- **2006: ITER team starts transition to joint work site at Cadarache**
- **November 2006: ITER Agreement signed**



- **October 2007: ITER Organization formally established**

Plasma fusion performance

Temperature - T_i: *1-2 × 10^8 K (10-20 keV)*
(~10 × temperature of sun's core)

Density - n_i: *1 × 10^{20} m^{-3}*
(~10^{-6} of atmospheric particle density)

Energy confinement time - τ_E: *few seconds (∝ current × radius^2)*
(plasma pulse duration ~1000s)

Fusion power amplification: $Q = \dfrac{\text{Fusion Power}}{\text{Input Power}} \sim n_i T_i \tau_E$

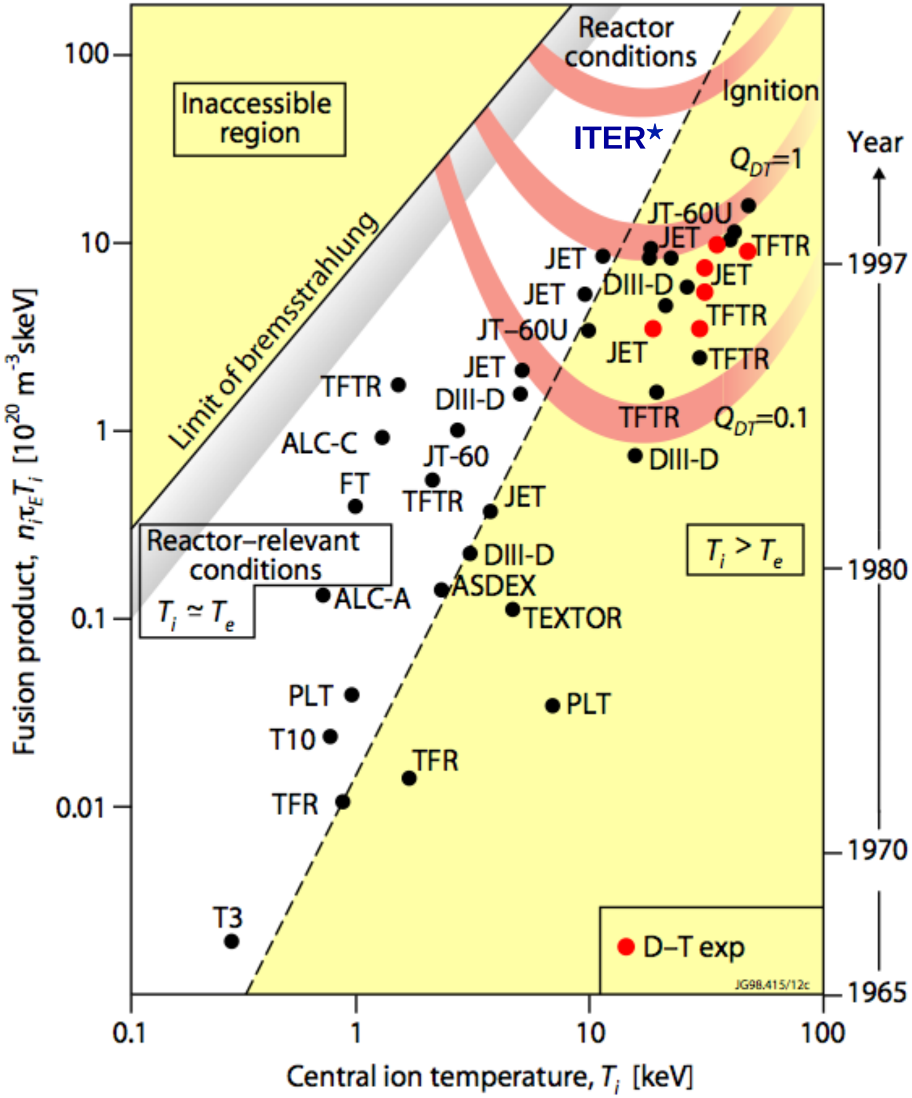
⇒ Present devices: Q ≤ 1

⇒ ITER: Q ≥ 10

⇒ 'Controlled ignition': Q ≥ 30

Fusion Triple Product

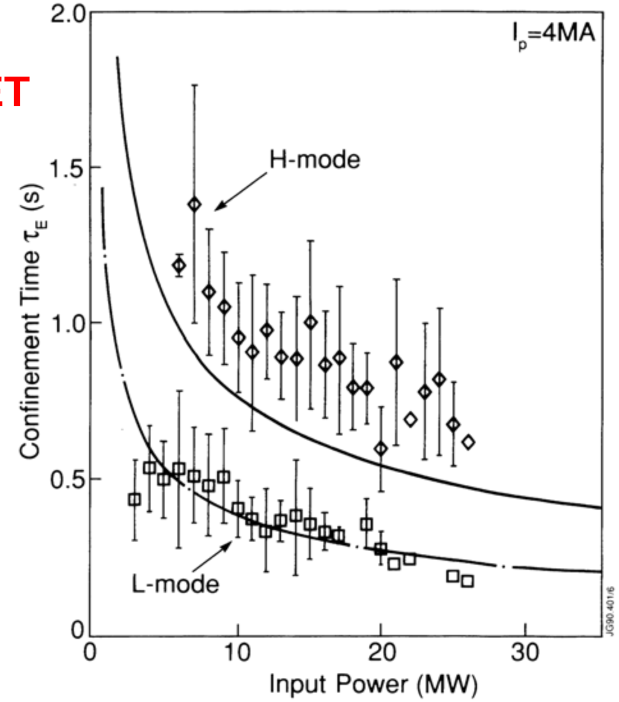
- Existing experiments have achieved nTτ values ~ 1×10^{21} m^{-3}skeV ~ $Q_{DT} = 1$
- JET and TFTR have produced DT fusion powers of >10MW for ~1s
- ITER is designed to a scale which should yield $Q_{DT} > 10$ at a fusion power of ~ 500MW for ~ 400s

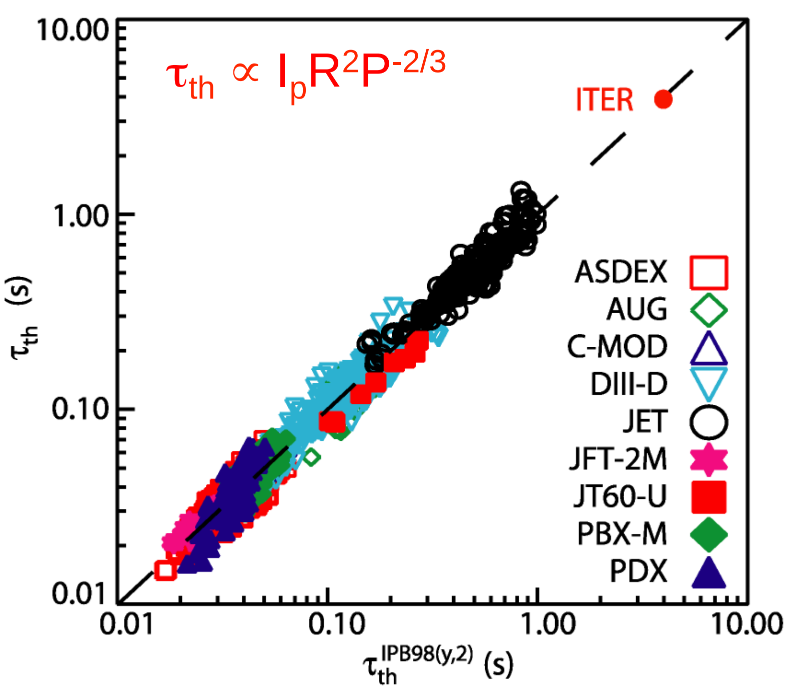


ITER Baseline Scenario - ELMy H-mode

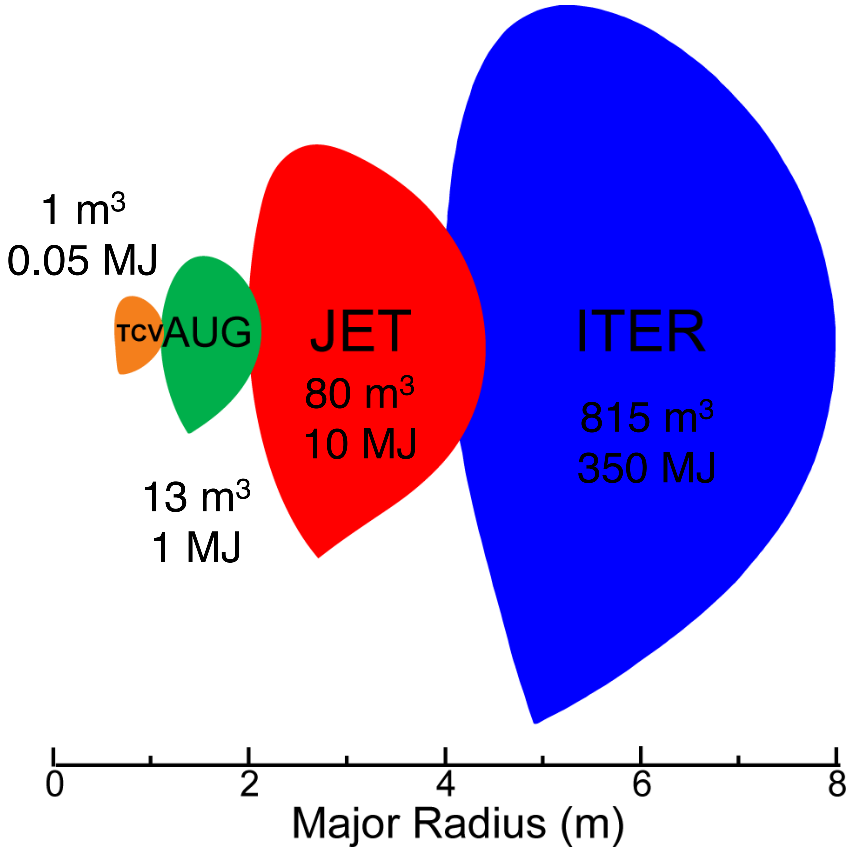
- **The ELMy H-mode is a robust mode of tokamak operation - ITER baseline scenario**
  - H-mode confinement time is approximately double that in L-mode
  - multi-machine database provides scaling prediction for ITER energy confinement time

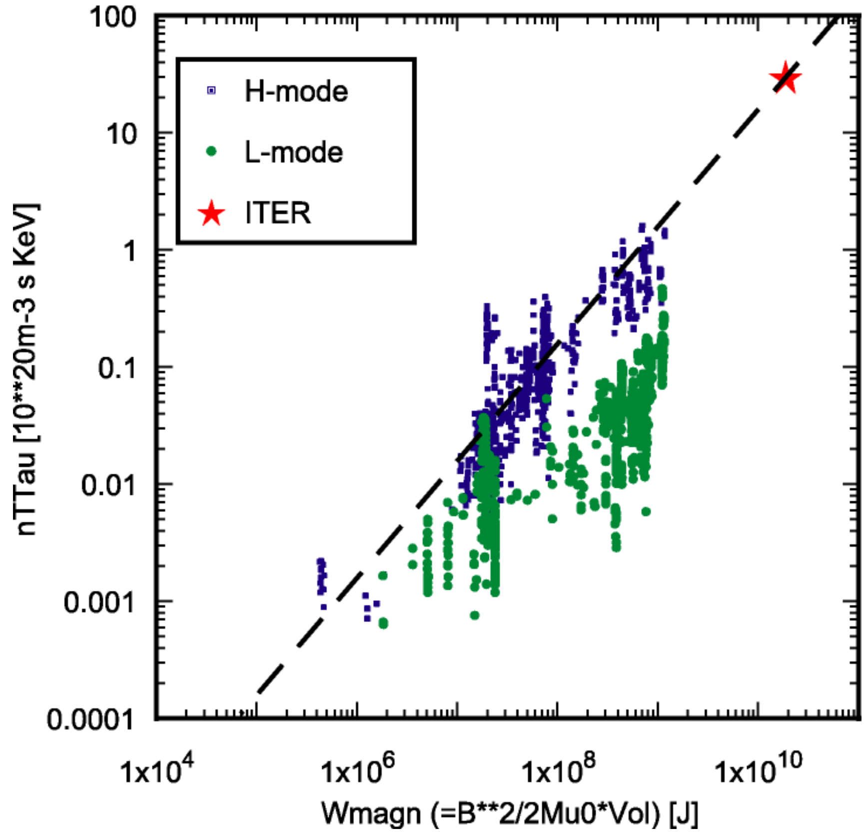
JET





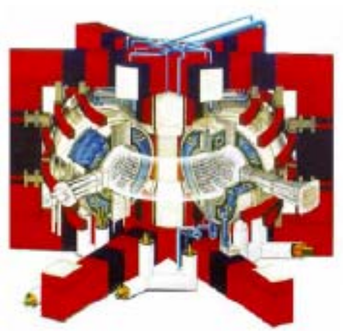
How big should ITER be?

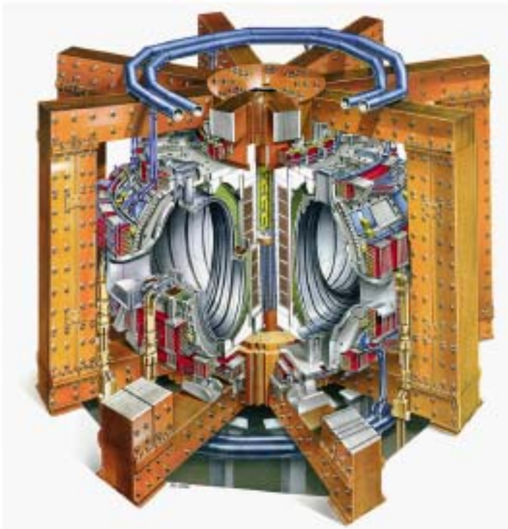


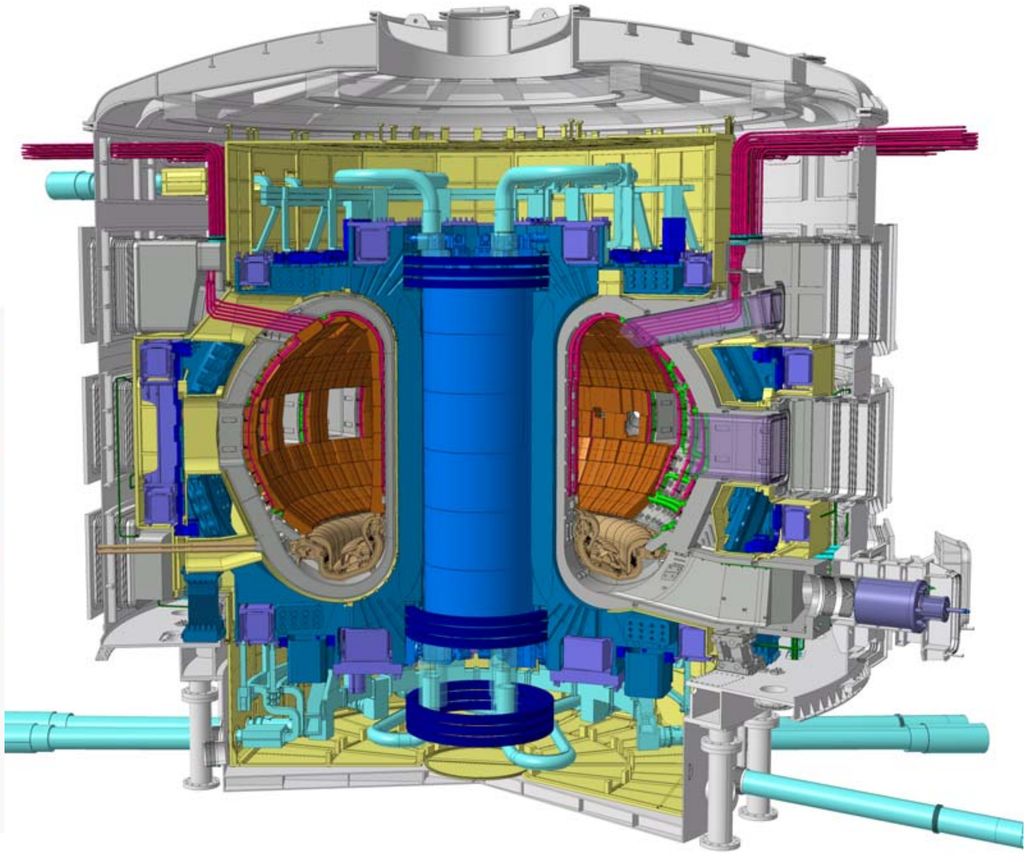


- **Confinement scaling studies provide the robust approach to determining ITER's size:**
  - detailed design relies on numerical codes combining engineering and physics constraints

ITER is twice as large as our largest existing experiments





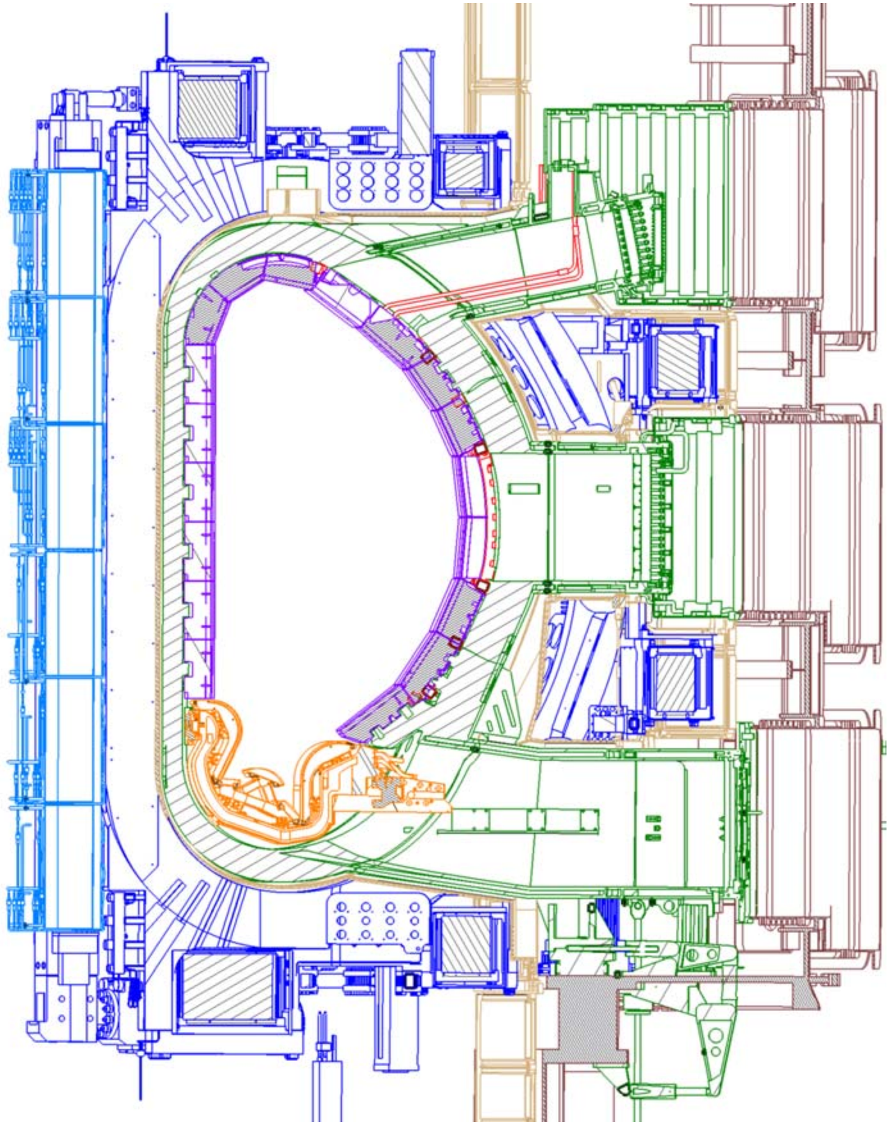


Tore Supra		*JET*		*ITER*	
V_{plasma}	$25\ m^3$	V_{plasma}	$80\ m^3$	V_{plasma}	$830\ m^3$
P_{fusion}	*~0*	P_{fusion}	*~16 MW, 2 s*	P_{fusion}	*~500 MW, ~400 s*
T_{plasma}	*~400 s*	T_{plasma}	*~30 s*	T_{plasma}	*~700 s*

ITER: Design Parameters

ITER Plasma:

R/a:	6.2 m /2 m
Volume:	830 m^3
Plasma Current:	15 MA
Toroidal field:	5.3 T
Density:	10^{20} m^{-3}
Peak Temperature:	2×10^8 K
Fusion Power:	500 MW
Plasma Burn	300 - 500 s
(“Steady-state”	~3000 s)



ITER Design Goals

Physics:

- 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' ($Q \geq 30$)

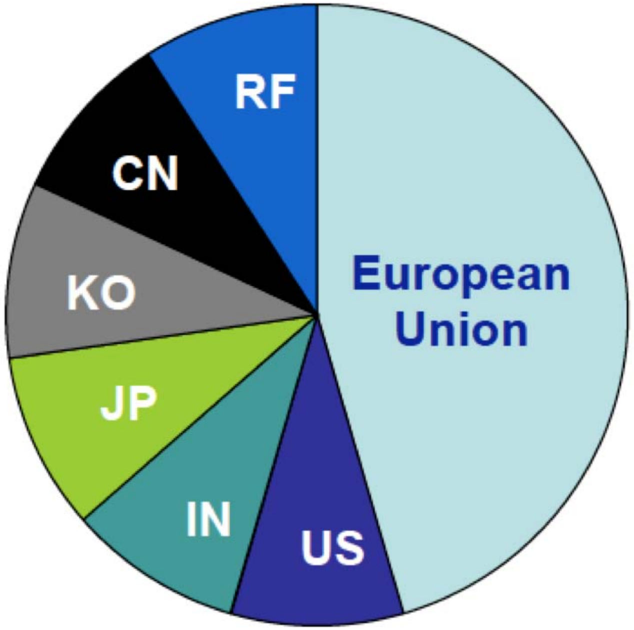
Technology:

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

How is ITER being constructed?

⇒ The framework for the ITER project

ITER Cost Sharing

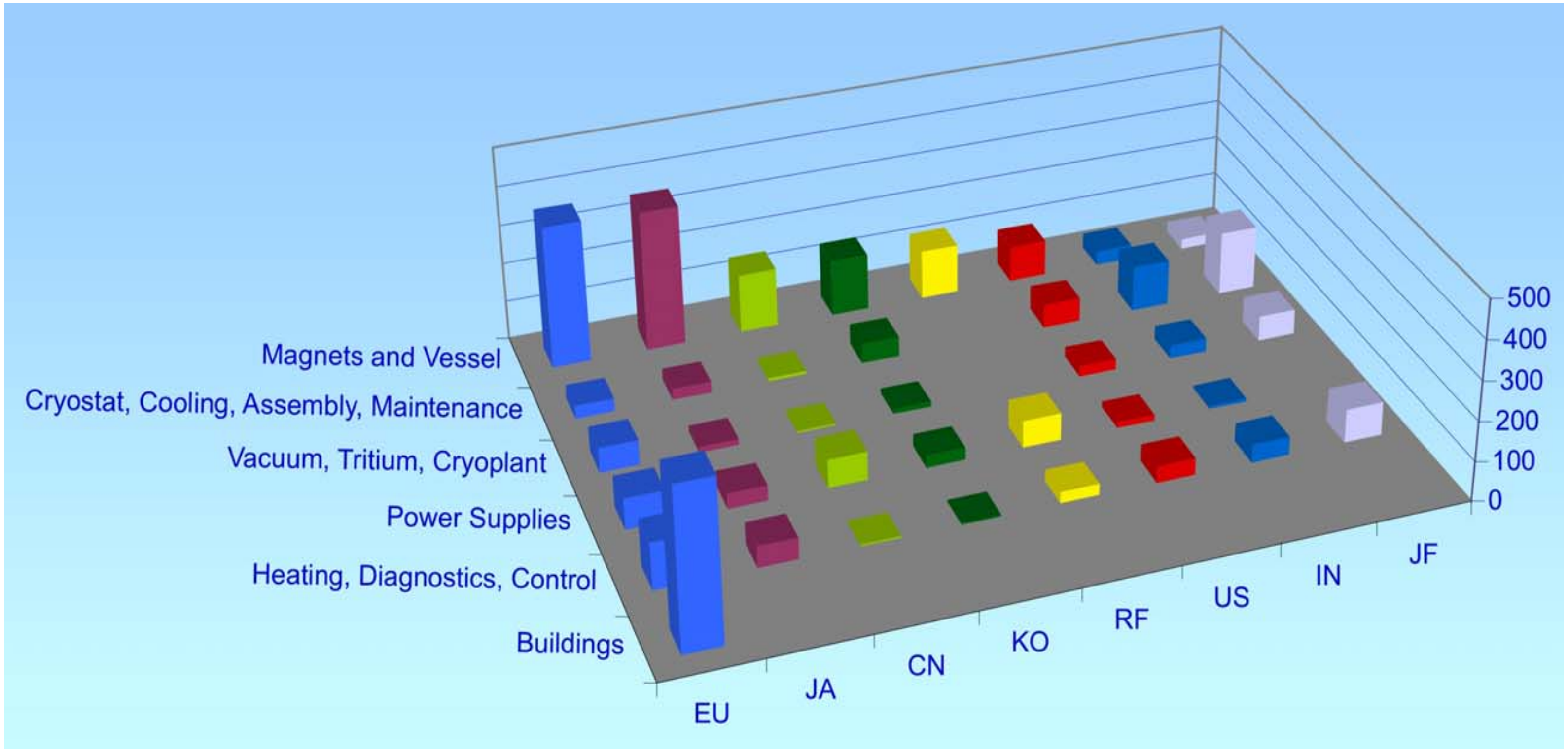


Total direct capital value:	3543.9
Management support:	944.8
R&D:	76.8
Additional Resources:	115.3
IO Management Reserve:	19.2
Total kIUA:	4700.0

- **The EU contributes 5/11 of the project cost and the other 6 Members each contribute 1/11**
  - as Host state, France contributes to EU contribution through 'local' arrangements such as preparation of site and transportation route, construction of international school etc

ITER Procurement Distribution

- **A unique feature of ITER is that almost all of the machine will be constructed through *in kind procurement* from the Members**



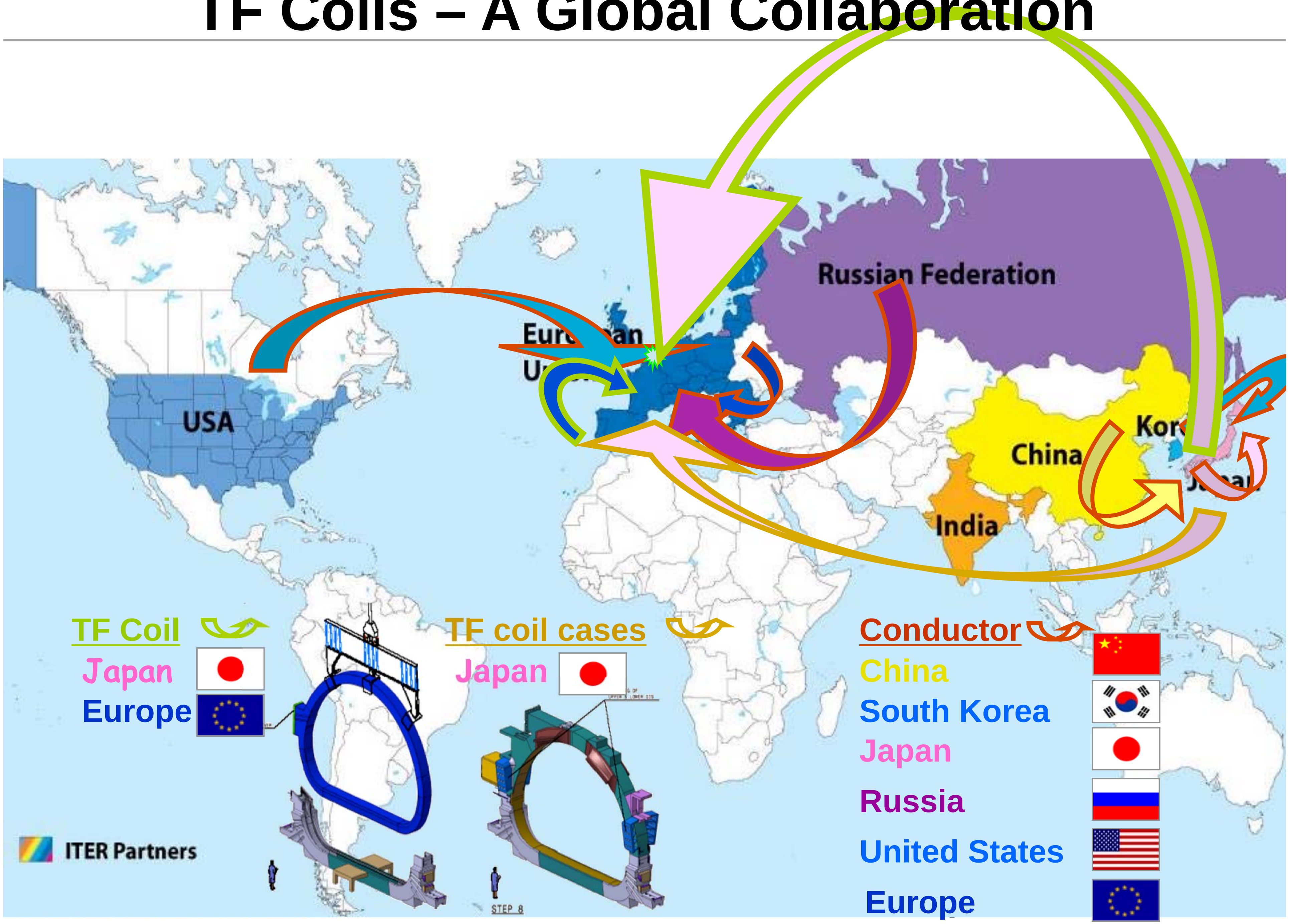
- **At the end of 2013, 98 Procurement Arrangements (out of 126) signed, with value of 2565 kIUA (88.4% of total in-kind procurement value)**

ITER – A Major International Collaboration

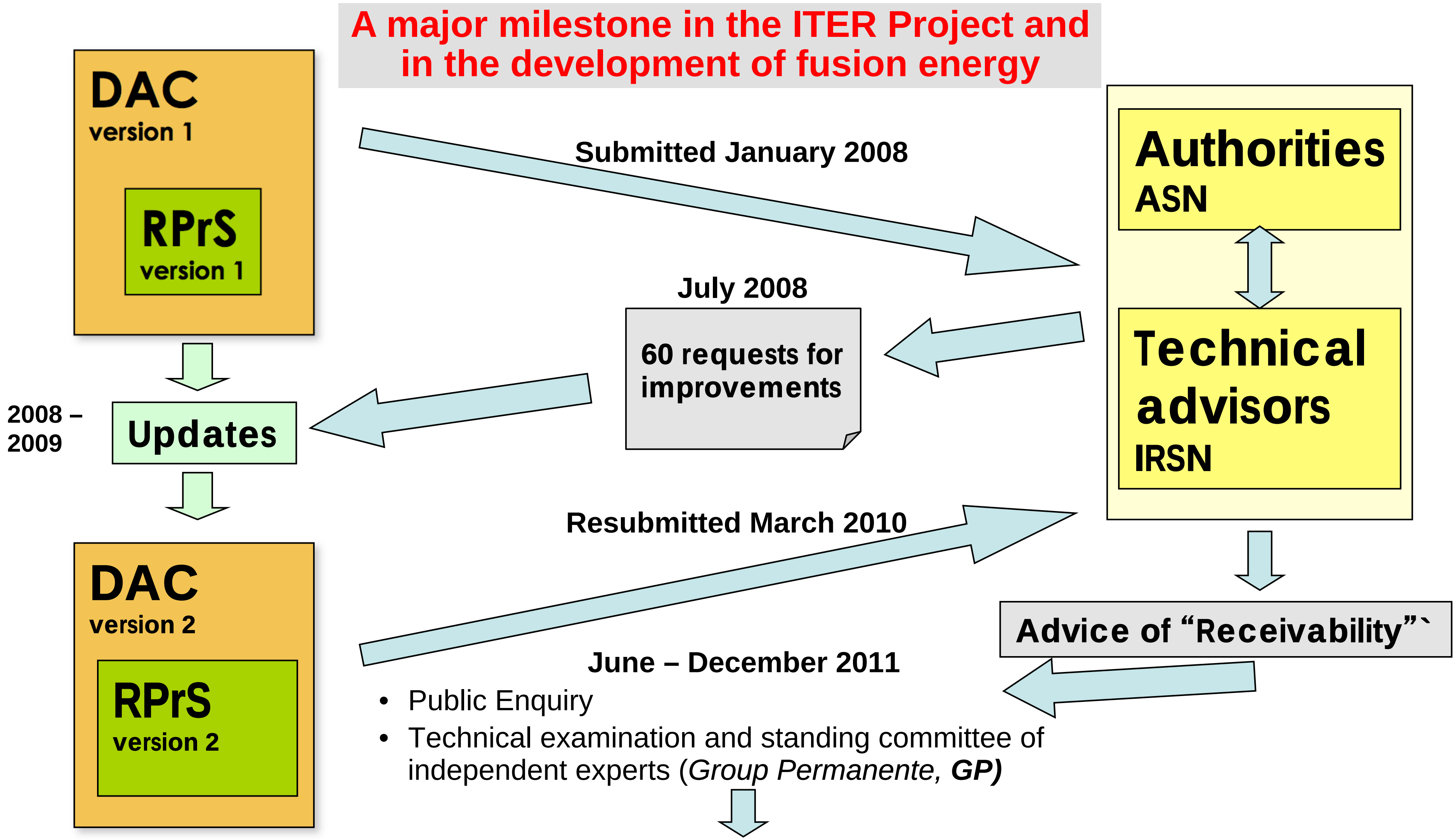
- **90% of ITER components will be supplied "in-kind" by the Members through their Domestic Agencies**

- **The Unique ITER Team integrates the ITER management, design and procurement activities across the globe**

TF Coils – A Global Collaboration



ITER Licensing



9 November 2012

- **Prime Minister Jean-Marc Ayrault signs decree authorizing creation of *installation nucléaire de base ITER***

Component Transport

For heaviest components: vacuum vessel sectors, toroidal field coils, poloidal field coil 1 and 6
Road upgrades from south coast to Cadarache complete and paid for by regional funding (115 M€)
ITER itinerary ~104 km by road + 32 km by barge

Component Transport

- **352 wheel test convoy carrying 800 ton load (33 m long, 9 m wide, 10 m high) trialled in September 2013 and March/ April 2014**
  - 2 power generators developing 730 horse power

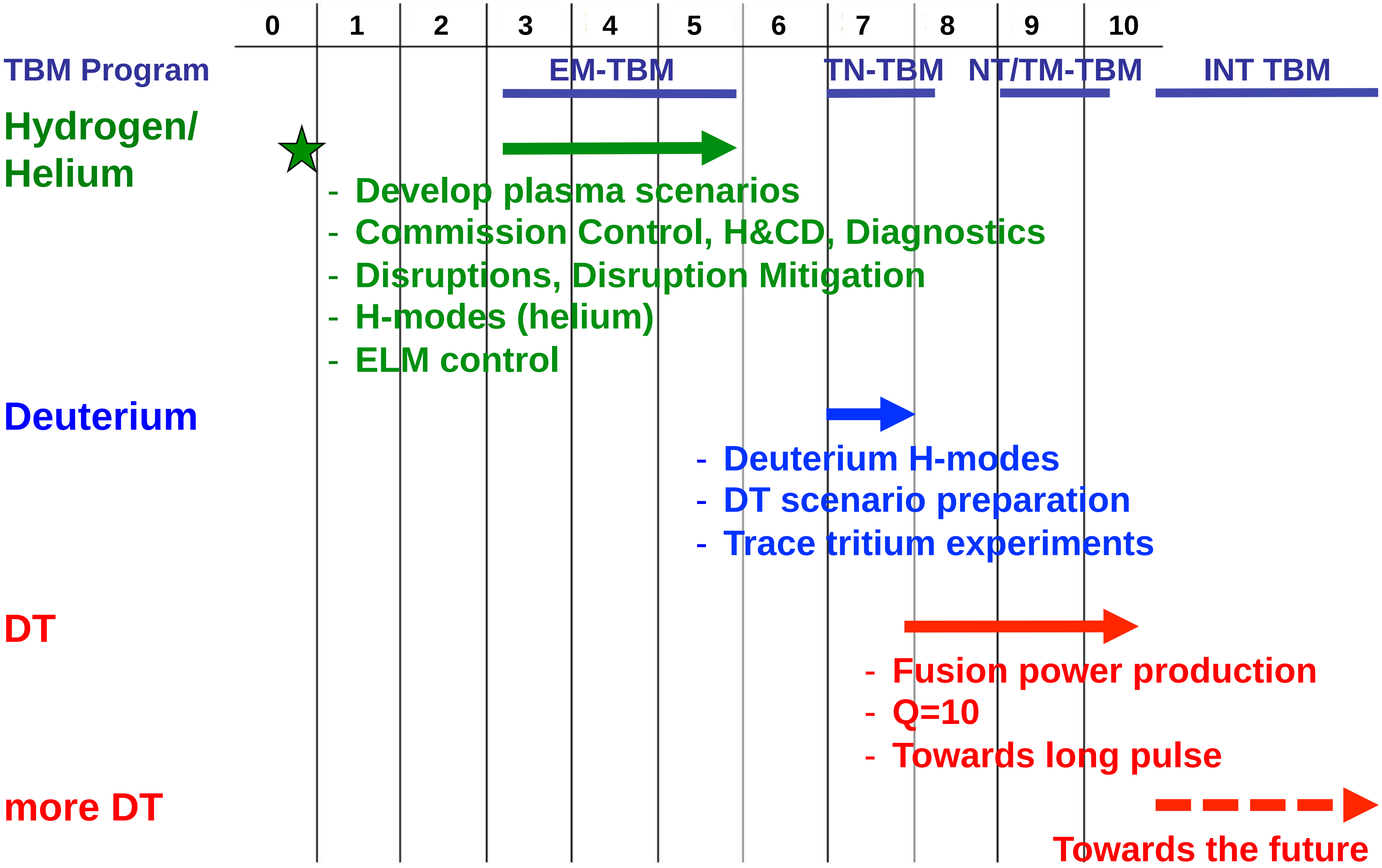

Crossing Etang de Berre (32 km)


Journey lasts 4 nights

What are ITER plasmas designed to do?

⇒ Key Elements of the ITER Programme

ITER Research Plan – Structure



ITER Baseline Reference Scenarios

- **The set of DT reference scenarios in ITER is specified via illustrative cases in the *Project Requirements*:**

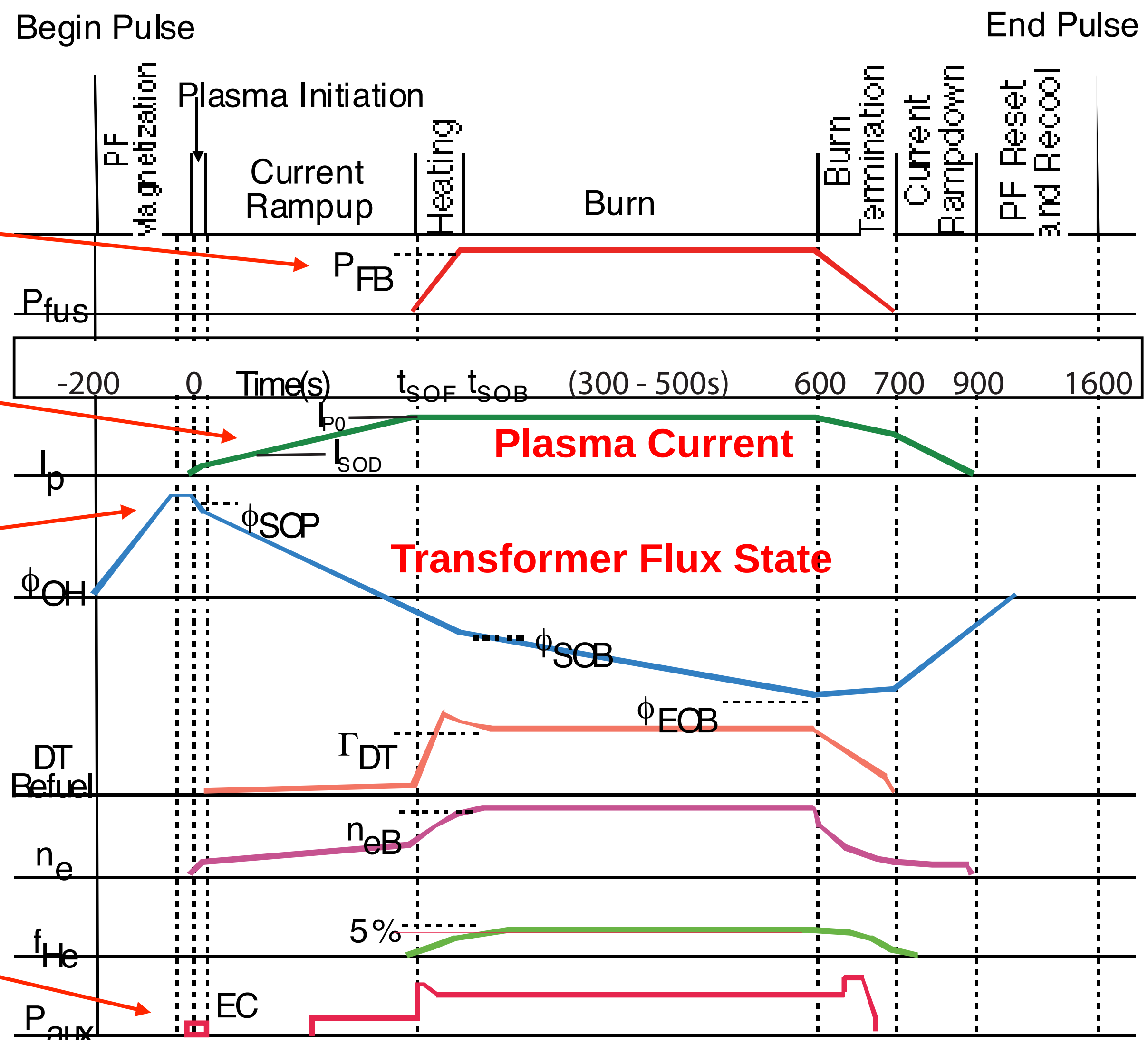
⇒ Design Basis scenarios

Parameter	**Inductive Operation**	**Hybrid Operation**	**Non-inductive Operation**
Plasma Current, I_p (MA) Safety Factor, q_{95}	15 3.0	13.8 3.3	9 5.3
Confinement Time, τ_E (s)	3.4	2.7	3.1
Fusion Power, P_{fus} (MW) Power Multiplication, Q	500 10	400 5.4	360 6
Burn time (s)	300 – 500	1000	3000

- **In addition, a range of non-active (H, He) and D plasma scenarios must be supported for commissioning purposes to support rapid transition to DT operation**

Overview of a Tokamak Plasma Pulse

Simulated ITER plasma pulse

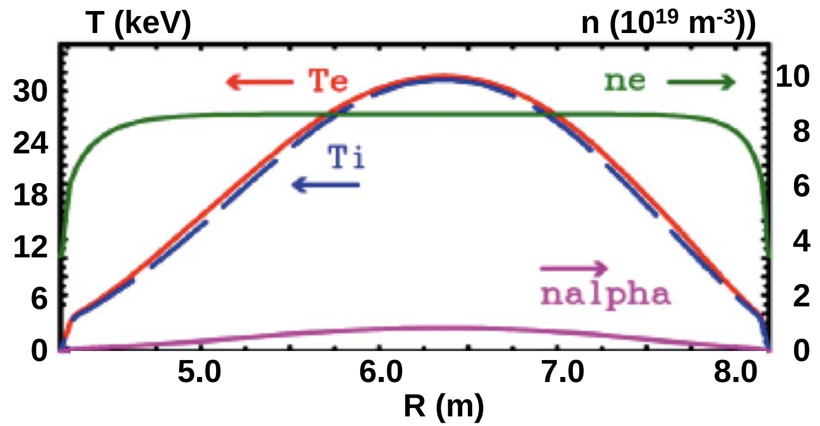


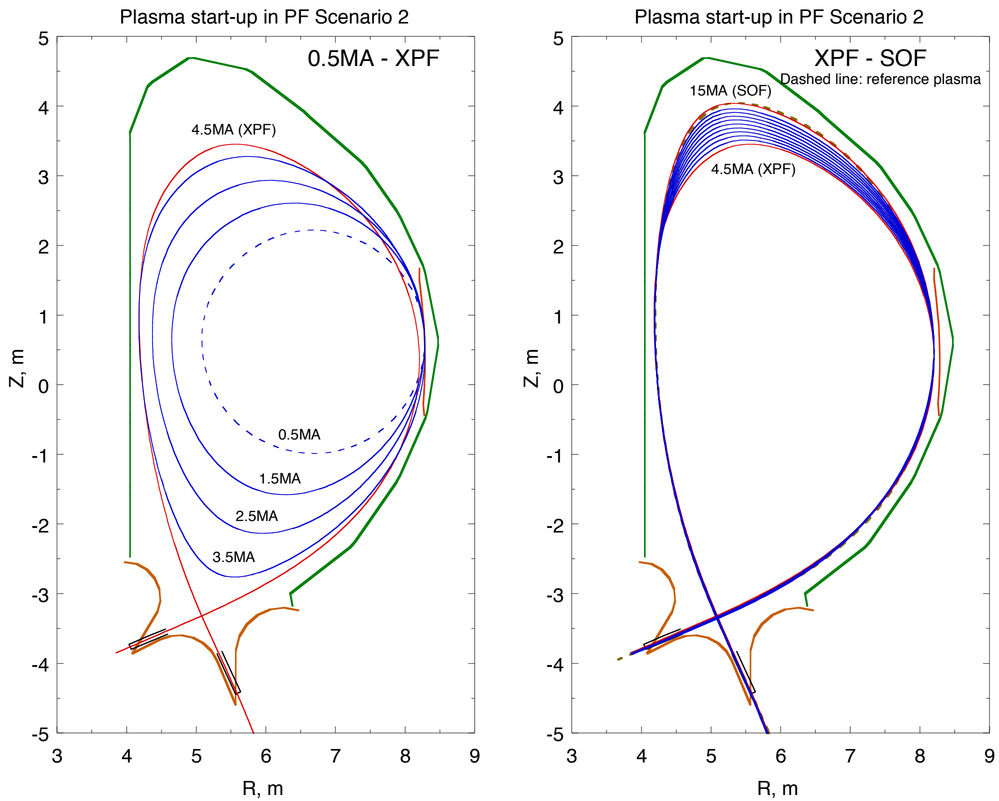
4. **Fusion burn** produced during the current flat-top
3. **Plasma current** ramps up in 60-100s and is held constant for ~400s
1. **Central solenoid** is initially charged and then discharged to initiate plasma and ramp current up
2. **External heating (EC)** is used to assist ionization and "burnthrough" of radiation barrier

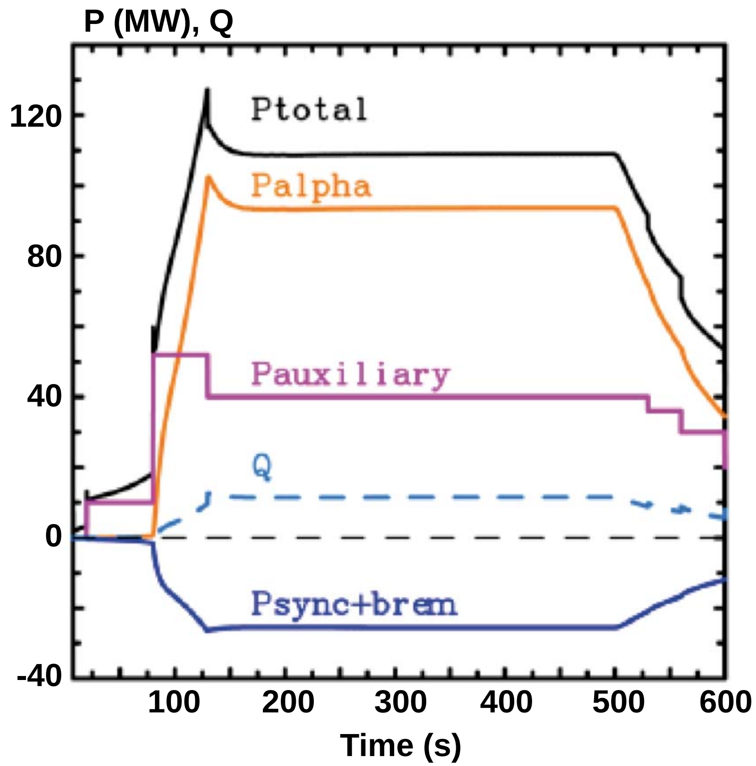
ITER Plasma Scenario - ELMy H-mode

A Q ≥ 10 scenario with:

I_p=15 MA, P_{aux}=40 MW, P_{fus}~500 MW



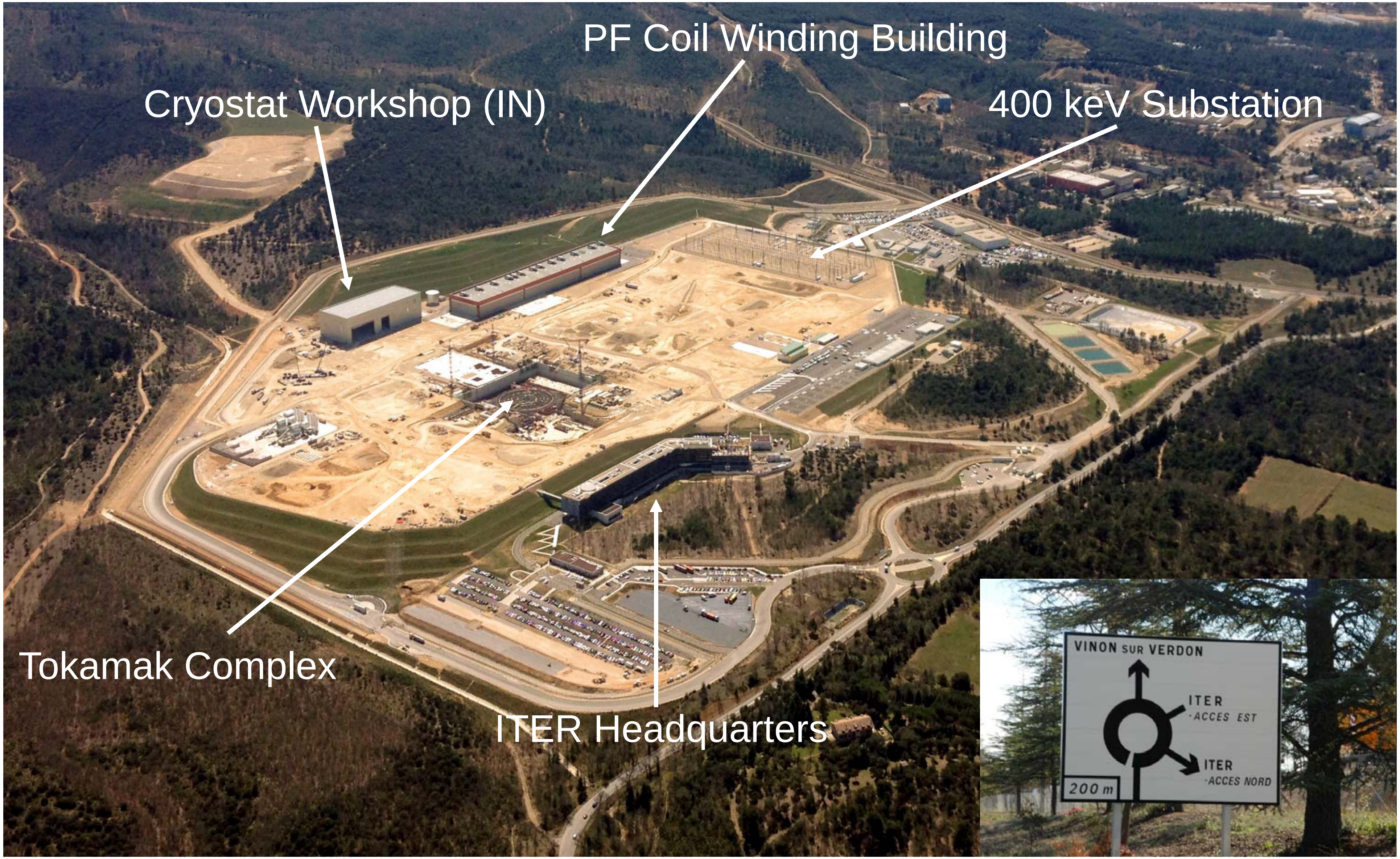




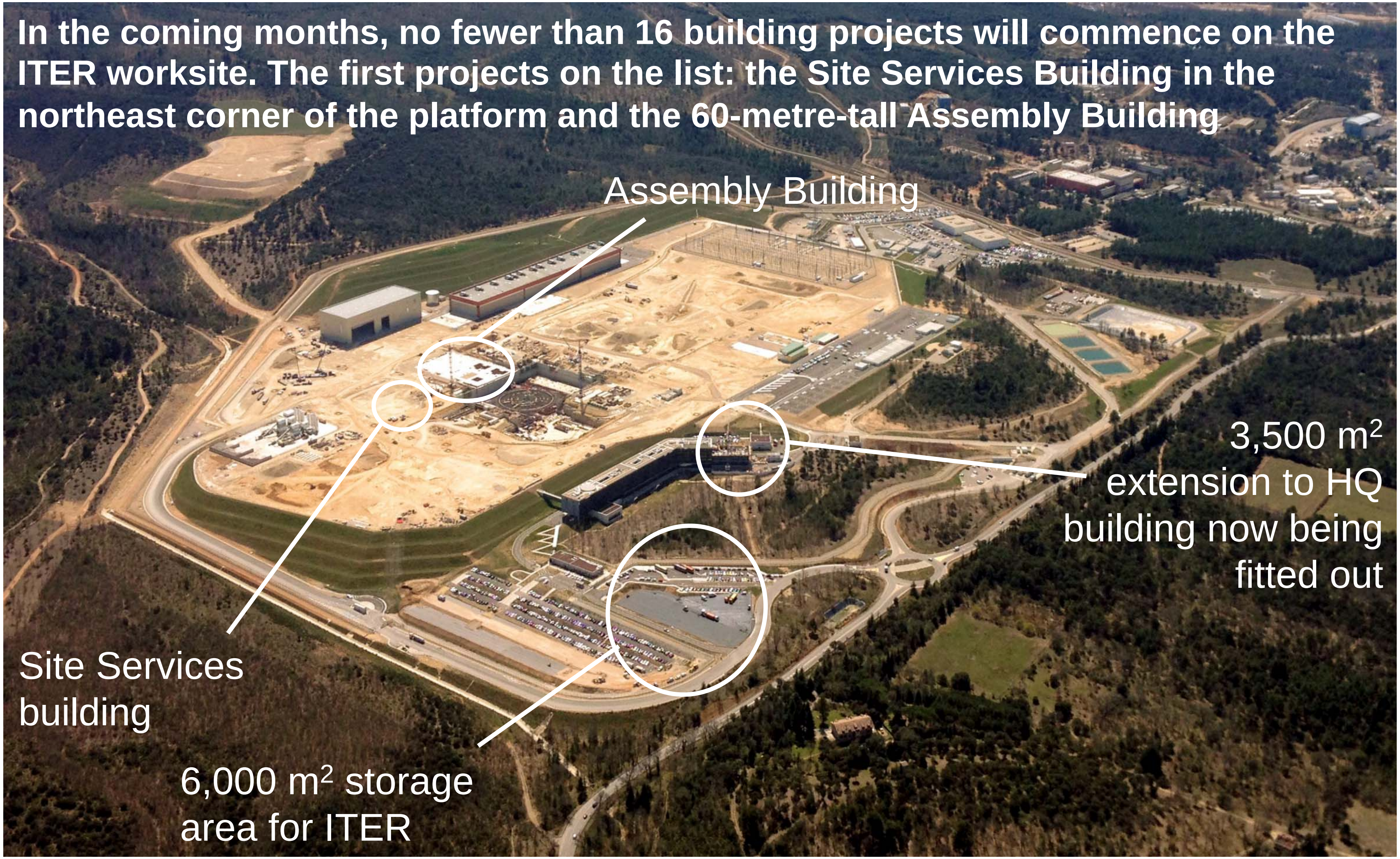
Current Ramp-up Phase

ITER Construction Status

ITER Construction at St Paul lez Durance



ITER Construction at St Paul lez Durance



Construction Status at Cadarache

Construction Status at Cadarache

PF Coil Winding Building

Tokamak Complex Concrete Pour

Tokamak Complex Construction with new ITER HQ Building

Tokamak Complex Propping/Forming

Construction Status at Cadarache

PF Coil Winding Building

Tokamak Complex Concrete Pour

Tokamak Complex Construction with new ITER HQ Building

Tokamak Complex Rebar

Construction Status at Cadarache

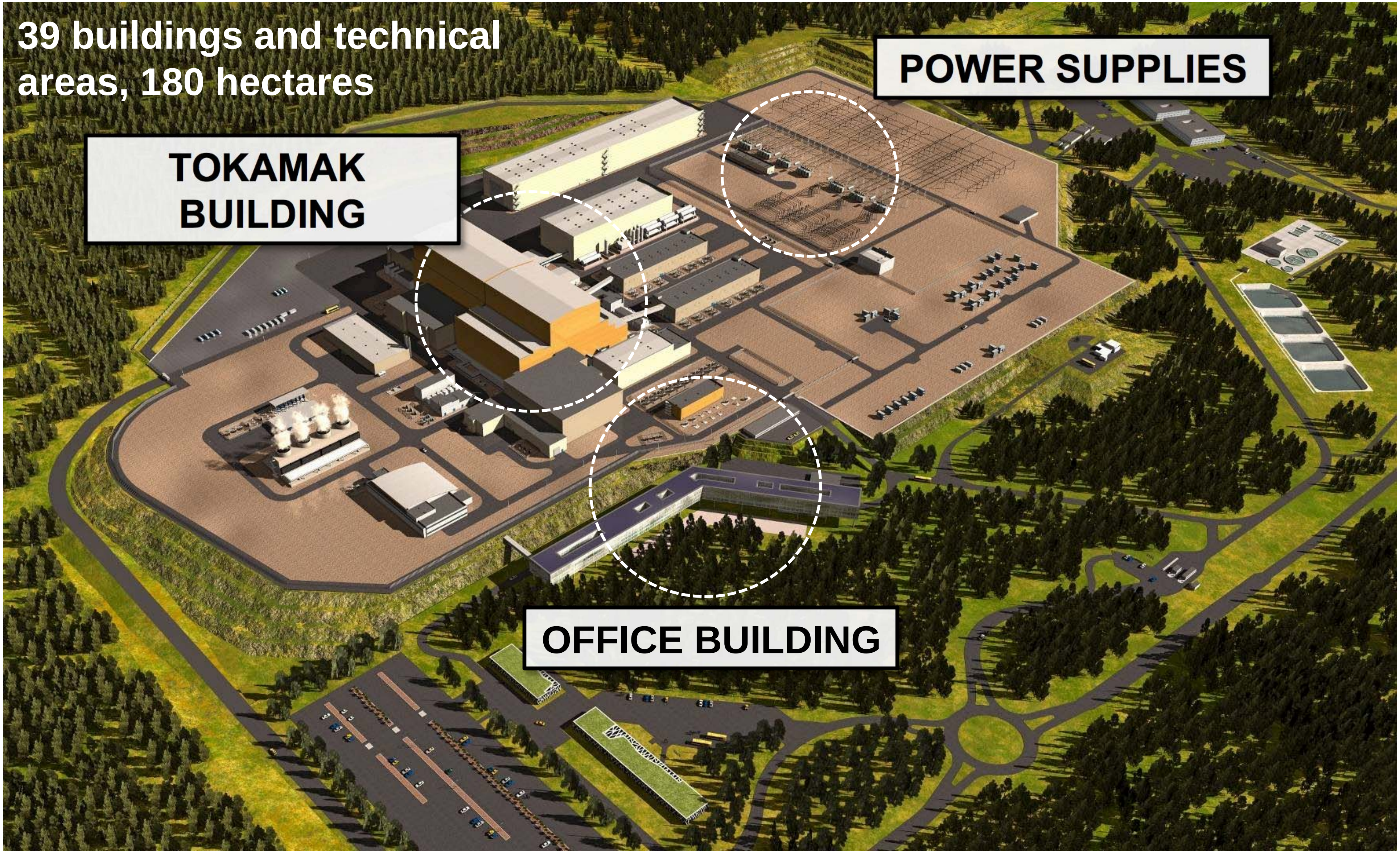

PF Coil Winding Building


Cryostat Workshop

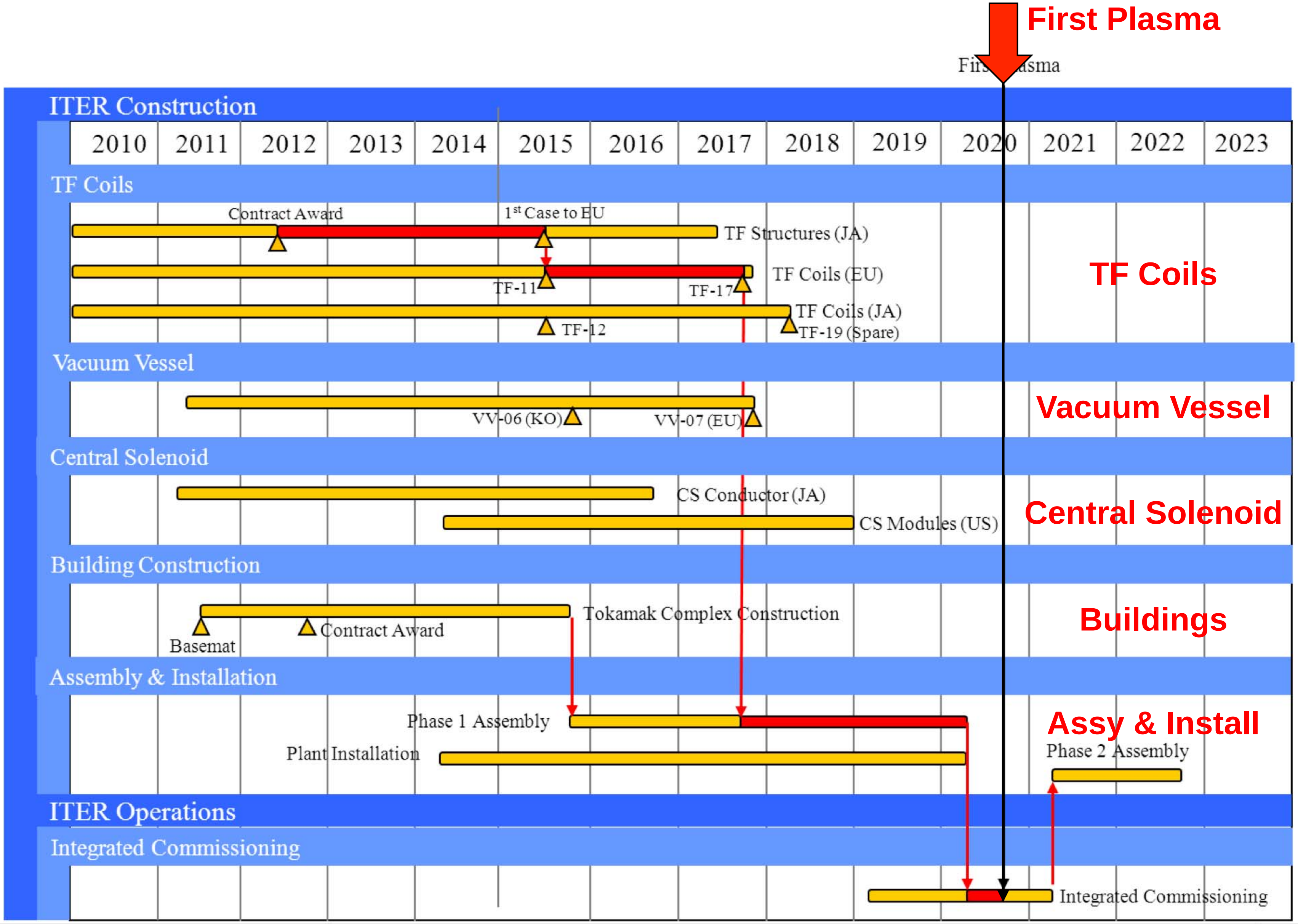

Tokamak Complex Construction with new ITER HQ Building


Tokamak Complex Rebar

ITER Site Overview (~2020)

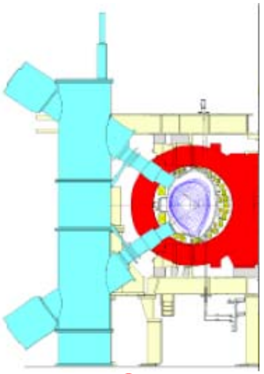


ITER Construction Schedule – SMP

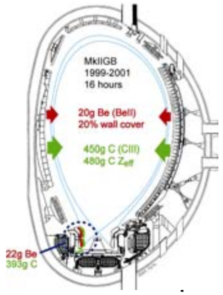


ITER and the Accompanying Programme

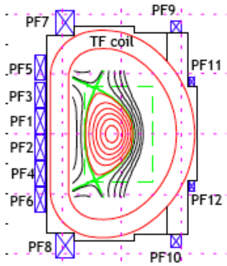
JT-60U

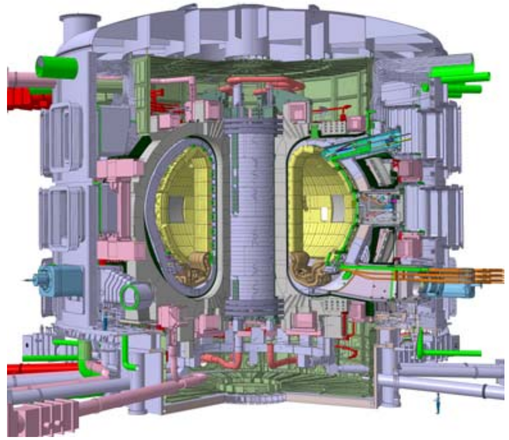


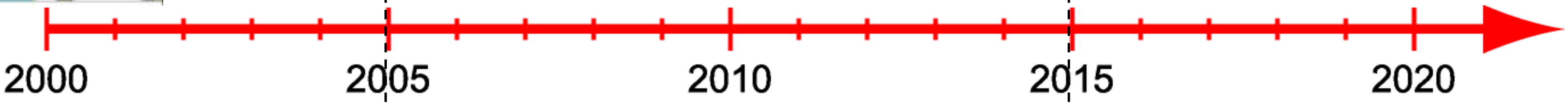
JET



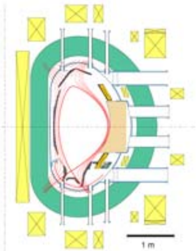
EAST



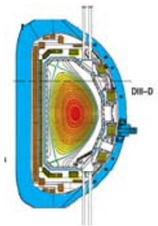




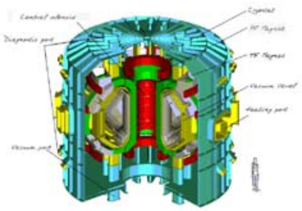
ASDEX-U



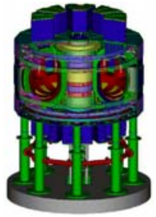
DIII-D



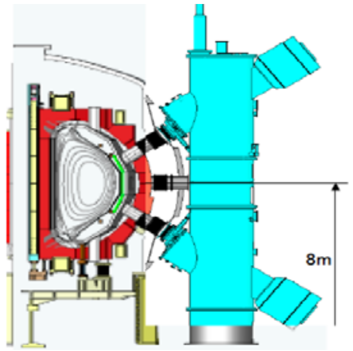
KSTAR

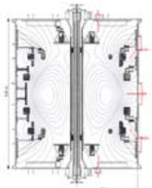


SST-1



JT-60SA





MAST

Tore Supra

Conclusions

ITER is a burning plasma experiment and the key step towards the realization of fusion energy

- **The main challenges are:**
  - first of a kind machine of large size and complexity
  - required (and still does) a very extensive, targeted R&D programme
  - decision-making in a distributed project requires excellent lines of communication
  - interfaces have multiplied due to procurement sharing within the ITER Agreement
- **What is the biggest challenge?**

  $\Rightarrow$ to keep cost and schedule within limits while maintaining performance

ITER construction is now well underway, with many procurements implemented and site construction in full swing!