FUSION FOR ENERGY

F4E STRATEGY TOWARDS FUSION ENERGY

by

Carlos Varandas

Chairman of the F4E Governing Board

CONTENT

I. **Introduction**

   What is the magnetic confinement strategy towards nuclear fusion energy (F4E)

II. **Fusion for Energy**

   What is Fusion for Energy (F4E)?

III. **Contributions to ITER**

   What are the main contributions from Euratom? What is the cost?

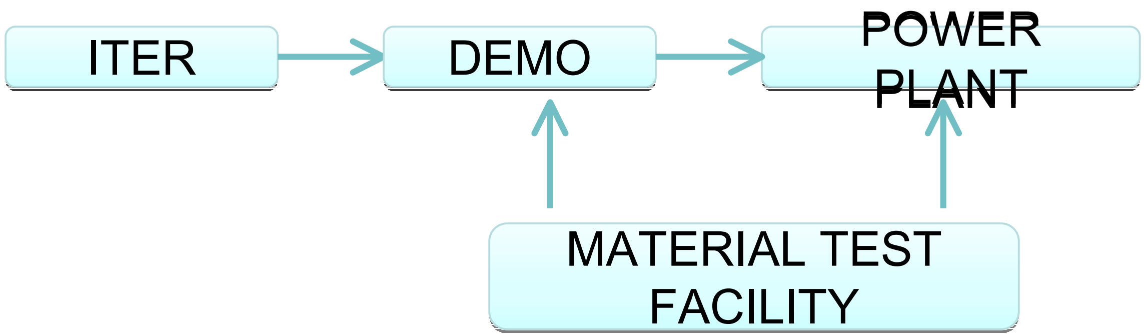
IV. **Contributions to the Broader Approach Agreement**

   What is the Broader Approach Agreement? Which are its main projects?

v. **Conclusions**

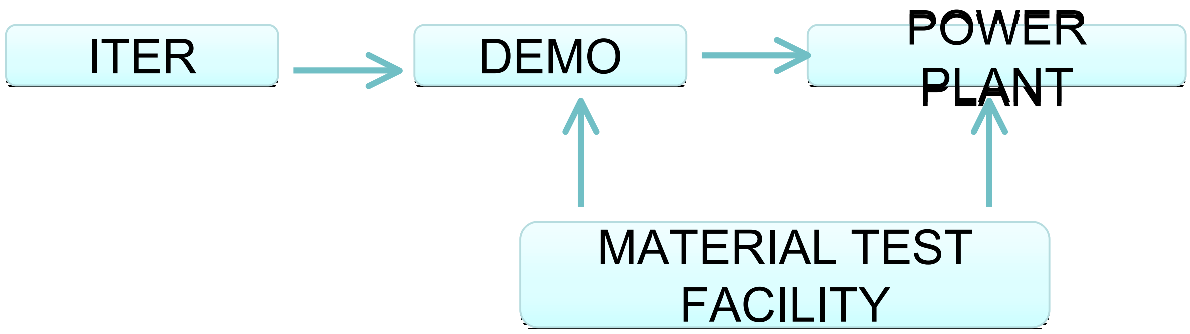
I. INTRODUCTION

• The classic magnetic confinement strategy towards fusion energy is based on three main steps:



• **ITER**

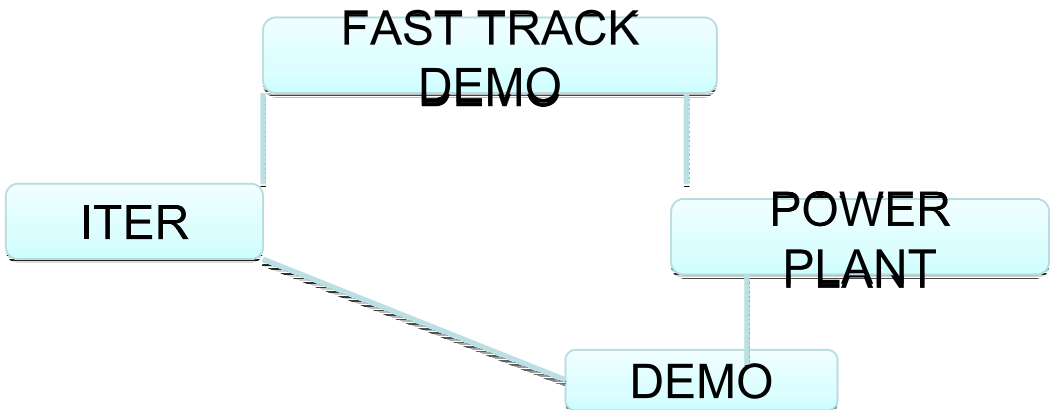
- To demonstrate the technical and scientific feasibility of fusion as an energy souce by producing 500 MW of fusion power, during 300 s, with Q
- To test the simultaneous operation of all the technologies needed for the operation of a fusion reactor



- **DEMO**
  - **To produce long-term electricity**

- **MATERIAL TEST FACILITY**
  - **To test the materials needed for DEMO and Fusion Power Plant**

- **Two important questions have been recently raised:**
  - **Which is the adequate facility to test and to qualify materials?**
    - **- IFMIF (European Union)   - CTF (USA)**
    - **- Tanden Mirror (Russian Federation)**
  - **What can we do to speed up the path towards Fusion Energy?**
    - **To start immediately the design of a small DEMO**



II. FUSION FOR ENERGY (F4E)
II.1. INTRODUCTION

- **Fusion for Energy (F4E)** is the **European Joint Undertaking for ITER and the Development of Fusion Energy** created in 2007 by the Council of Ministers in the frame of the Euratom Treaty.

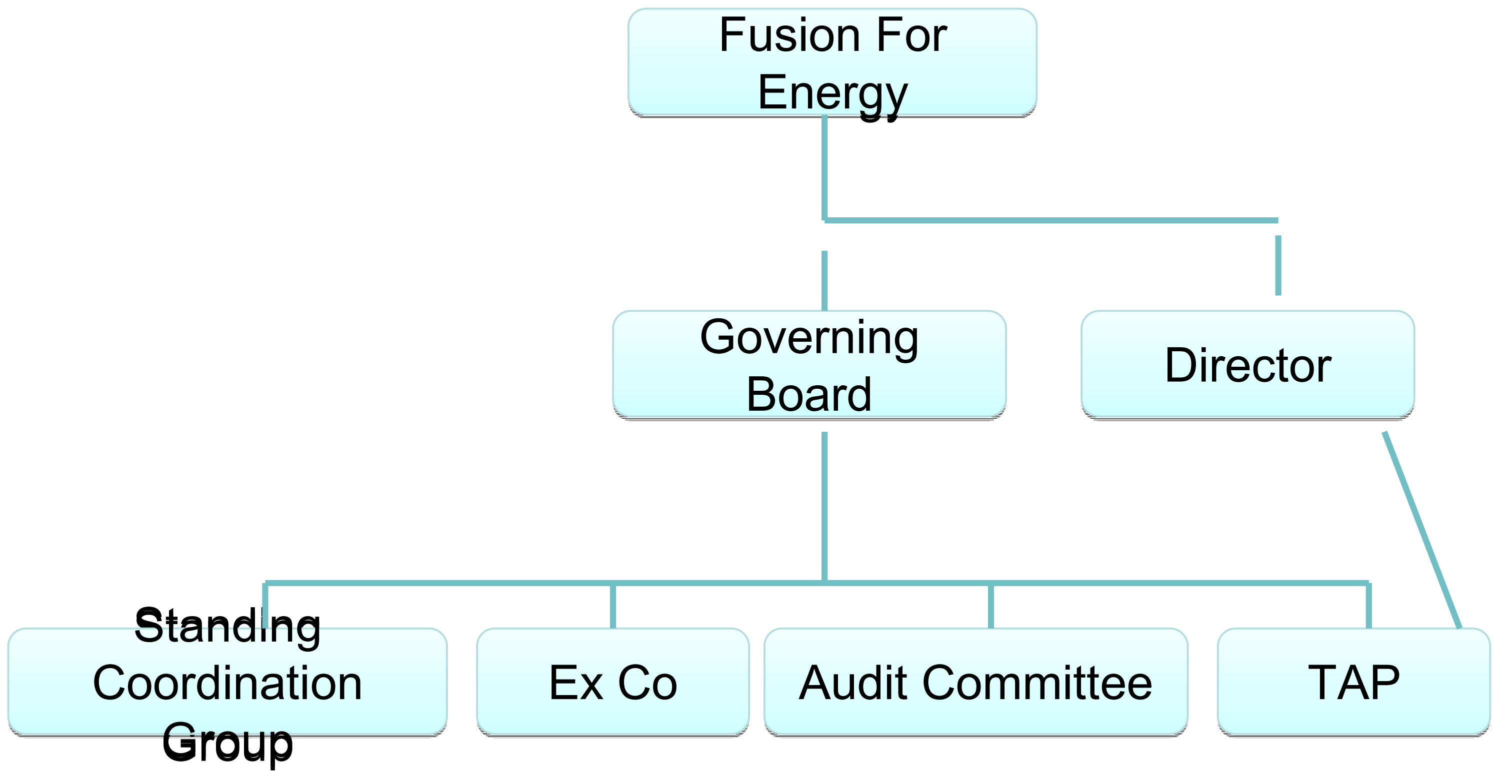
- **Fusion for Energy has the following Members**:
  - **Euratom**, represented by the European Commission;
  - **The Member States of Euratom**;
  - **Third countries which have concluded cooperation agreements with Euratom in fusion** that associate their respective research programmes with the Euratom programmes and **which have expressed their wish to become Members.**

II.2. OBJECTIVES

- **Fusion for Energy** has three main objectives:
  - **To provide Euratom's contribution to ITER.**
  - **To implement the Broader Approach Agreement between Euratom and Japan.**
  - **To prepare the construction of demonstration fusion reactors (DEMO).**

II.3. GOVERNANCE

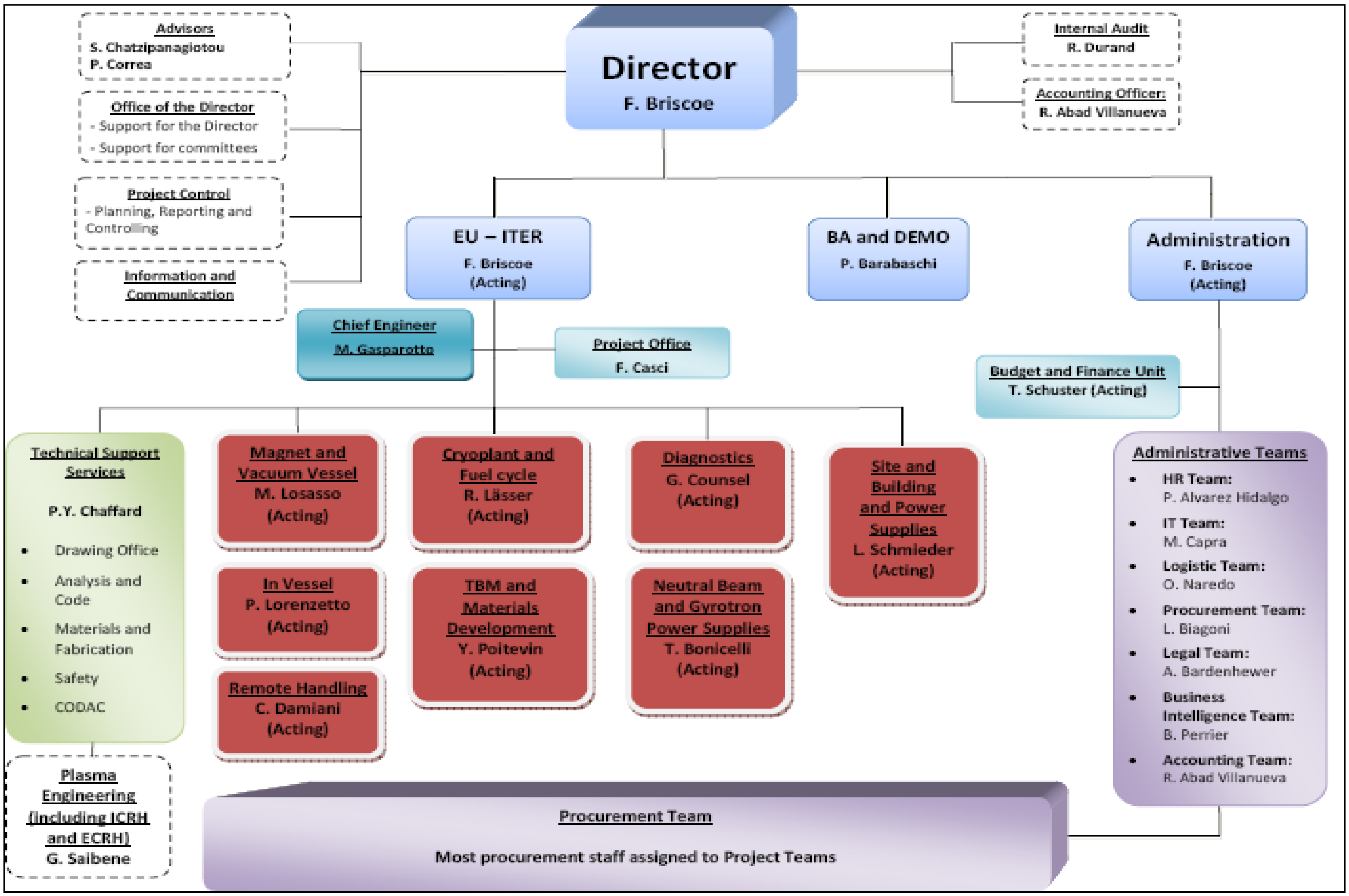
- **F4E has two management bodies:**
  - ❖ **The Governing Board**
  - ❖ **The Director**



- The **Governing Board is** composed by two Representatives of the F4E Members**. It meets usually three times per year**.

- **The GB is responsible for the supervision of 'Fusion for Energy' in the implementation of its activities.**

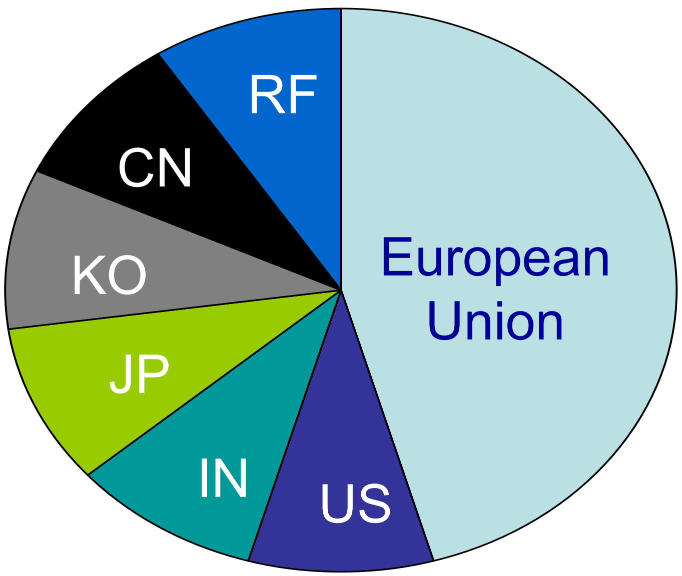
- The **Director** is the **Chief Executive Officer** responsible for day-to-day management of the organization.



Advisors
S. Chatzipanagiotou
P. Correa
Office of the Director
- Support for the Director
- Support for committees
Project Control
- Planning, Reporting and Controlling
Information and Communication
Director
F. Briscoe
Internal Audit
R. Durand
Accounting Officer:
R. Abad Villanueva
EU – ITER
F. Briscoe
(Acting)
BA and DEMO
P. Barabaschi
Administration
F. Briscoe
(Acting)
Chief Engineer
M. Gasparotto
Project Office
F. Casci
Budget and Finance Unit
T. Schuster (Acting)
Technical Support Services
P.Y. Chaffard
Drawing Office
Analysis and Code
Materials and Fabrication
Safety
CODAC
Magnet and Vacuum Vessel
M. Losasso
(Acting)
Cryoplant and Fuel cycle
R. Lässer
(Acting)
Diagnostics
G. Counsel
(Acting)
Site and Building and Power Supplies
L. Schmieder
(Acting)
In Vessel
P. Lorenzetto
(Acting)
TBM and Materials Development
Y. Poitevin
(Acting)
Neutral Beam and Gyrotron Power Supplies
T. Bonicelli
(Acting)
Remote Handling
C. Damiani
(Acting)
Administrative Teams
HR Team:
P. Alvarez Hidalgo
IT Team:
M. Capra
Logistic Team:
O. Naredo
Procurement Team:
L. Biagoni
Legal Team:
A. Bardenhewer
Business Intelligence Team:
B. Perrier
Accounting Team:
R. Abad Villanueva
Plasma Engineering (including ICRH and ECRH)
G. Saibene
Procurement Team
Most procurement staff assigned to Project Teams

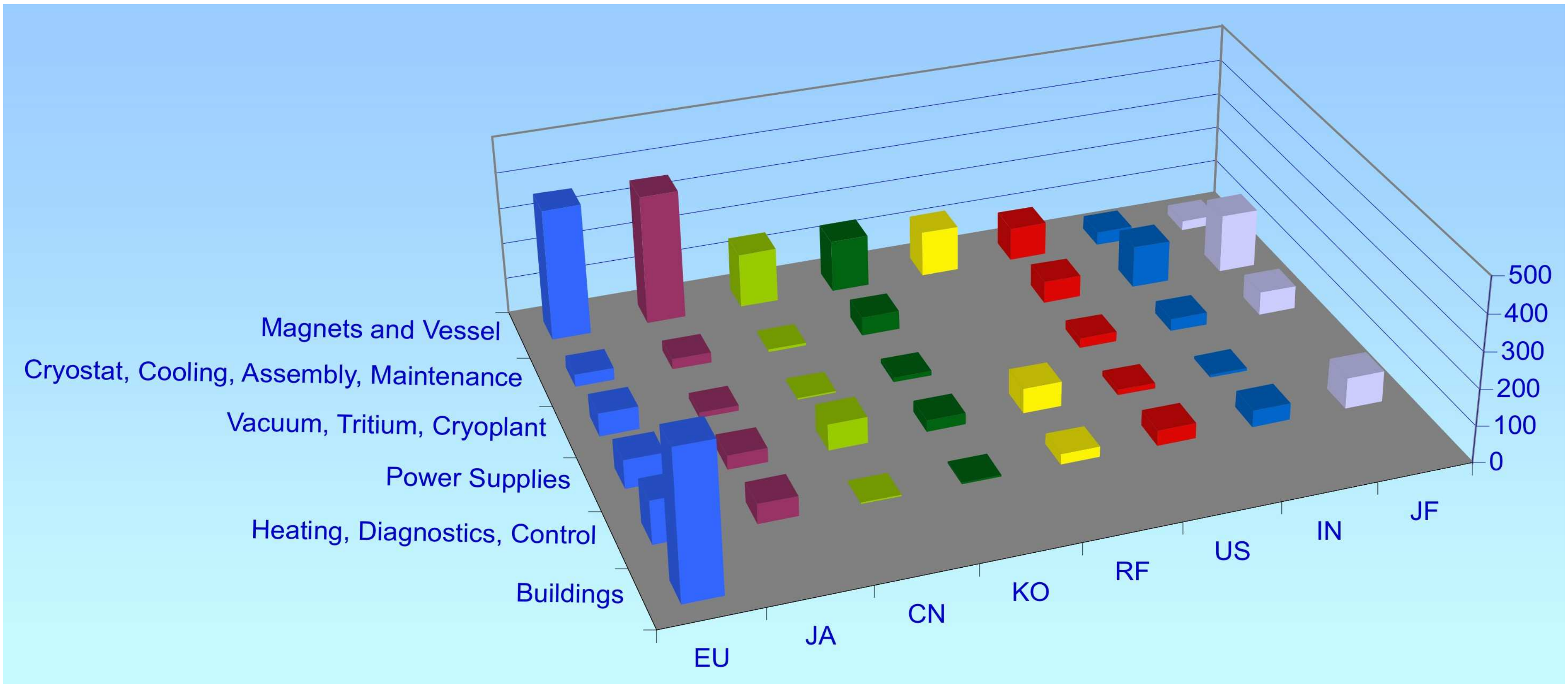
III. CONTRIBUTIONS TO ITER
III.1. INTRODUCTION

- **The Euratom contributions to the ITER project include:**
  - **Contributions in-kind (components and staff)**
  - **Contribution in cash**
  - **Research in support to the manufacturing of components**
  - **Research in preparation for the operation**



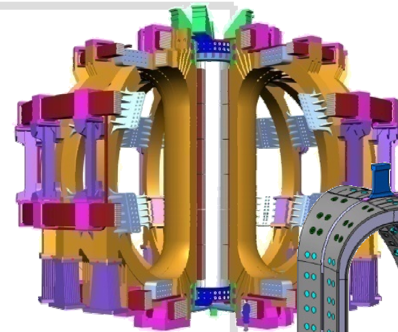
Overall sharing: EU 5/11,
Other six parties 1/11 each.
Total amount: 3577 kIUA
(5079 MEuro-2007)

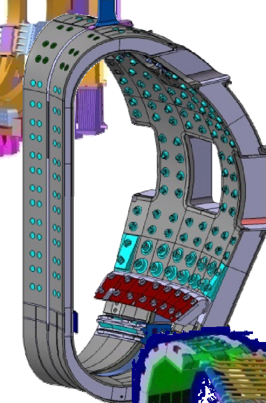
- **Being the HOST, Euratom is the only Party that contributes to all components of the ITER Project.**



III.2. EU PROCUREMENT PACKAGE - 1

EU In-kind
In Fund
Other Parties





MAGNET SYSTEM

11P1 (A&B) - Toroidal Field (TF) Coils Windings
11P2 (A&B) -TF Structures
11P2 C - Magnets Supports
11P3 (A&B) - Poloidal Field Coils
11P3 C - Correction Coils
11P4 - Central Solenoid (CS)
11P5 - Feeders
11P6 (A-TF, B-CS & C-PF) – Conductors

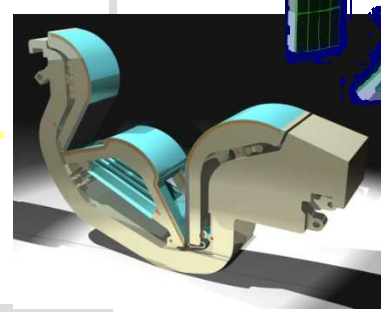
VACUUM VESSEL

15P1 (A,B & C)- Vacuum Vessel main vessel and blanket manifolds
15P2 (A,B &C)- Vacuum Vessel port structures

BLANKET SYSTEM & DIVERTOR

16P1 (A,B&C) - Blanket FW/Shield modules & port plugs
16P2 Port Limiters
16P3 Blanket Module Connections

17P1 Divertor cassette integration
17P2 (A,B,C&D) Divertor plasma facing components



III.3. COST

- **The F4E GB has welcomed a paper of the F4E Director estimating the total F4E budget until the end of 2020 in the amount of 7200 MEuros (in 2008 values).**

- **This budget covers:**
  - **ITER procurement and in cash contributions (5911 MEuros).**
  - **Broader Approach including in cash transfer to Japan 63 MEuros).**
  - **F4E Administration (209 MEuros)**
  - **Test Blanket Module Programme (403 MEuros)**
  - **Contingencies (662 MEuros)**

- **Justifications for the cost increase of ITER construction:**
  - Increase of 30% of the ITER IO cost mainly due to:
    - ❖ Increase of staff
    - ❖ Missing items
    - ❖ Spare componentts
    - ❖ New direct investiments
    - ❖ Increase of the number of Parties
  - Use of 2008 values
  - The increase of the commodities cost was much higher than the inflaction rate;
  - Cost based on industrial estimates instead of research calculations;

- **The EU Council of Ministers approved committments until the end of 2020 in the amount of 6600 MEuros.**
  600 MEuros are missing. Cost containement is needed

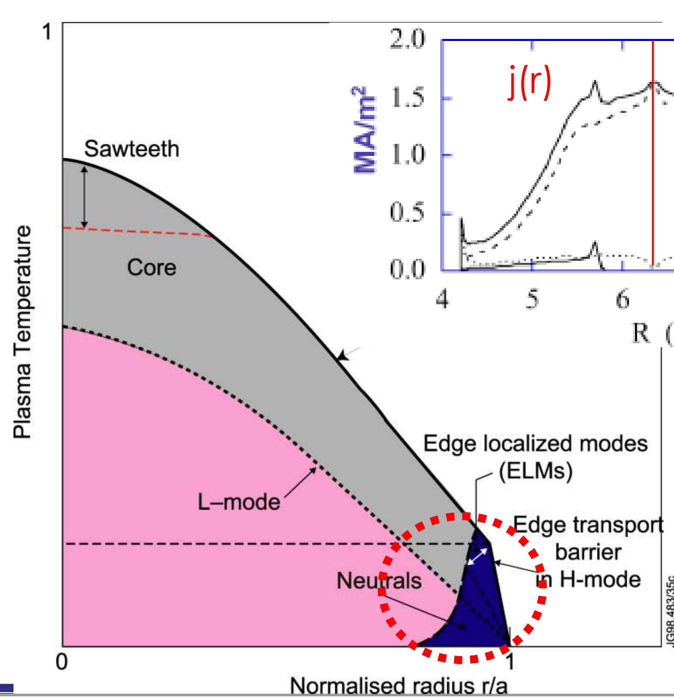
III.4 RESEARCH CONTRIBUTIONS

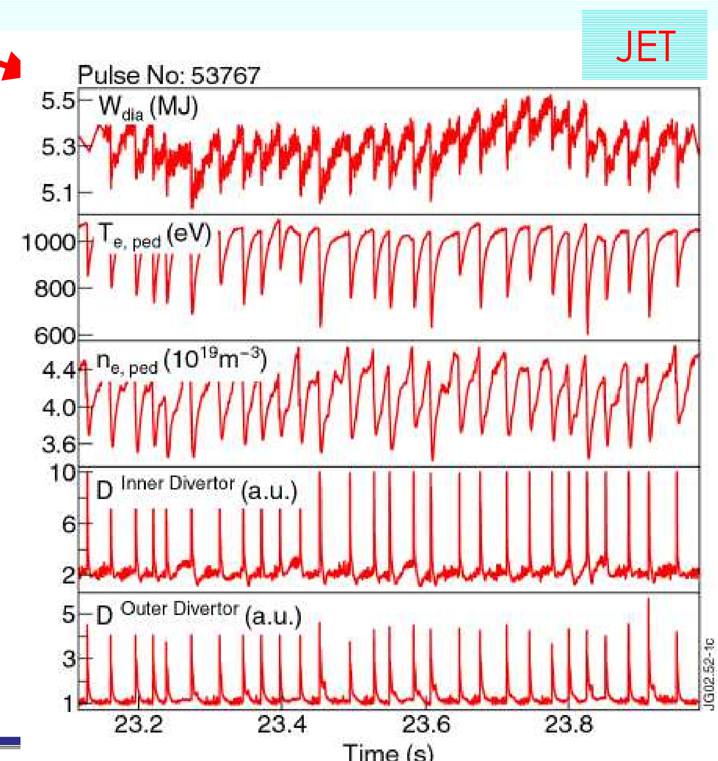
- The ITER research programme will develop along 3 major lines:
  - Provision of the necessary technical support to the ITER construction - next few years
  - Preparation for ITER plasma commissioning and exploitation phases- accompanying construction $\Rightarrow$ scientific framework and programme for ITER exploitation
  - Implementation of an extensive science and technology research programme to exploit the ITER device - exploitation phase
- The EURATOM Fusion Programme is strongly collaborating through F4E, EFDA and the Associates

- **Main R&D areas are:**
  - **Control and mitigation of MHD instabilities**
  - **Alpha-particles physics**
  - **Tritium retention and removal, and dust characterization and diagnosis**
  - **Selection of plasma facing components**
  - **Heating and Current Drive technology**
  - **Diagnostic systems**
  - **Tritium, Fuelling and Vacuum technology**
  - **Remote Handling**
  - **Real-Time Control**
  - **Control and Data Acquisition, Storage and Processing**

ITER Plasma Scenario - ELMy H-mode

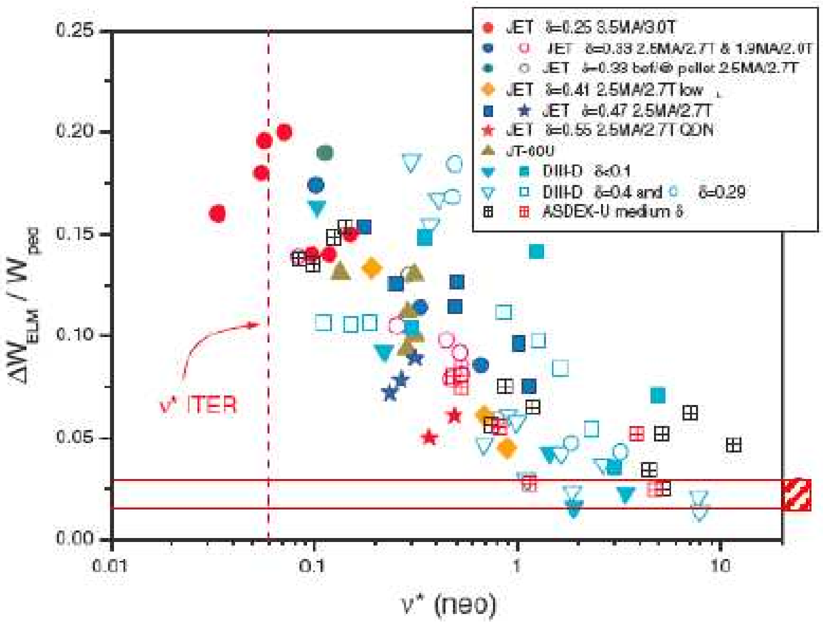
- **Conventionally, plasma confinement regimes denoted L-mode and H-mode**
  - **The difference between these modes is caused by the formation of an edge pedestal in which transport is significantly reduced - edge transport barrier**
  - **Edge Localized Modes (ELMs) maintain plasma in quasi-stationary state**



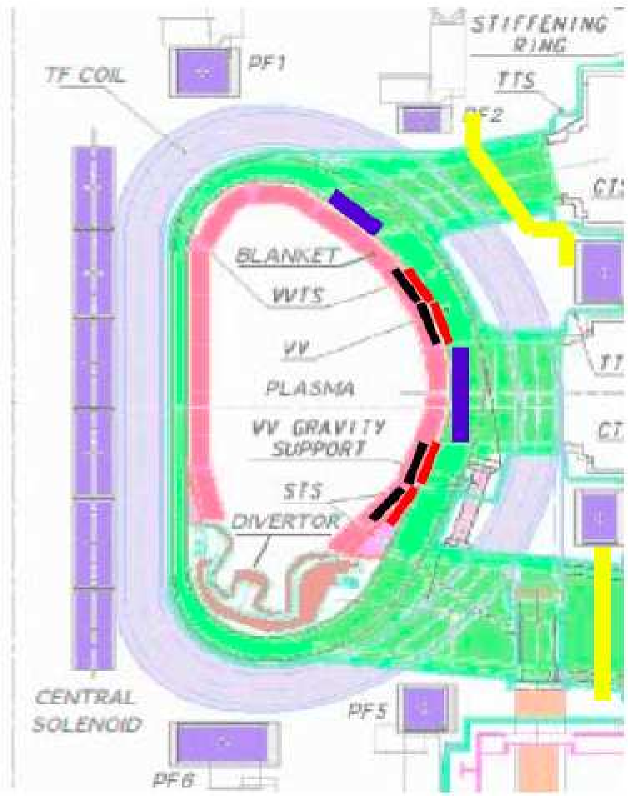


ELM Control/ Mitigation

Uncontrolled ELM heat pulses in ITER will lead to rapid erosion of divertor PFCs, implying that control/ mitigation methods are required



Minimum Acceptable Value (?)

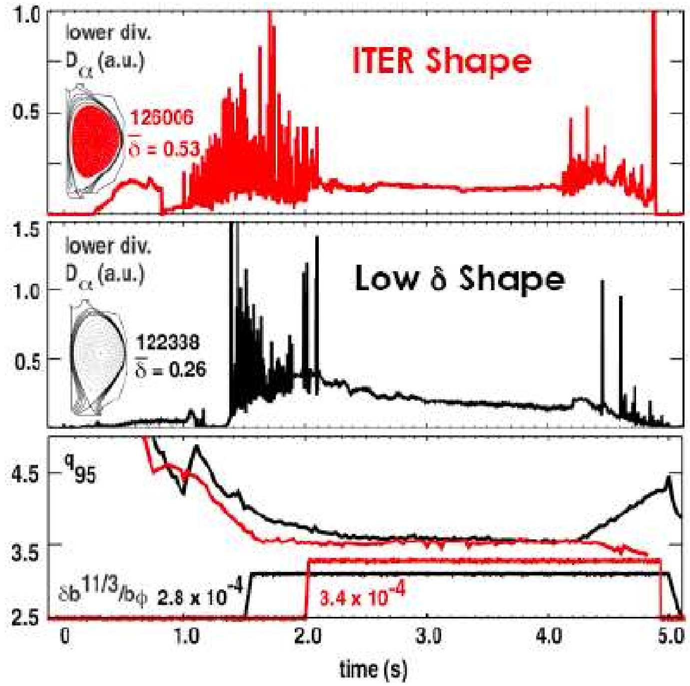


- **ITER requires a quantitative basis for applying ELM mitigation techniques:**
  - **RMP coils**
  - **Pellet pacemaking**

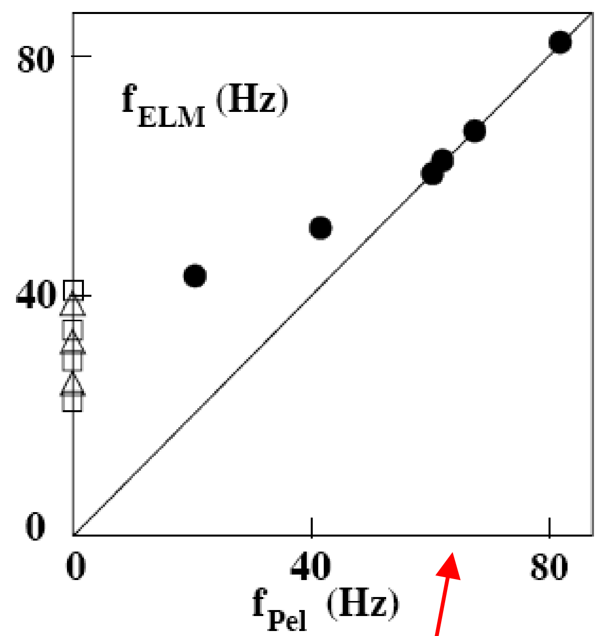
RMP Coil Options

ELM Control/ Mitigation

DIII-D Magnetic Control



AUG Pellet Pacemaking



- **Results with magnetic control look promising:**
  need to evaluate extrapolation to ITER and implications of stray fields on plasma

"ELM pacemaking" using pellet injection also effective:
quantitative basis for application in ITER requires further study

Disruption Mitigation and Control

- **Several issues need to be addressed:**
  - **Electromagnetic forces**
  - **Thermal loads**
  - **Runaway electrons**

- **The development of high pressure gas injection looks promising for disruption mitigation**

- **Need to understand:**

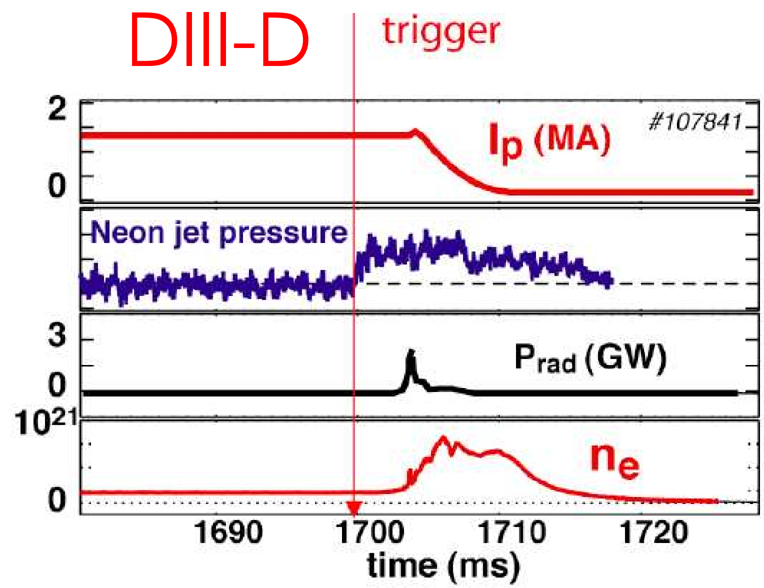
- Quantitative extrapolation to ITER

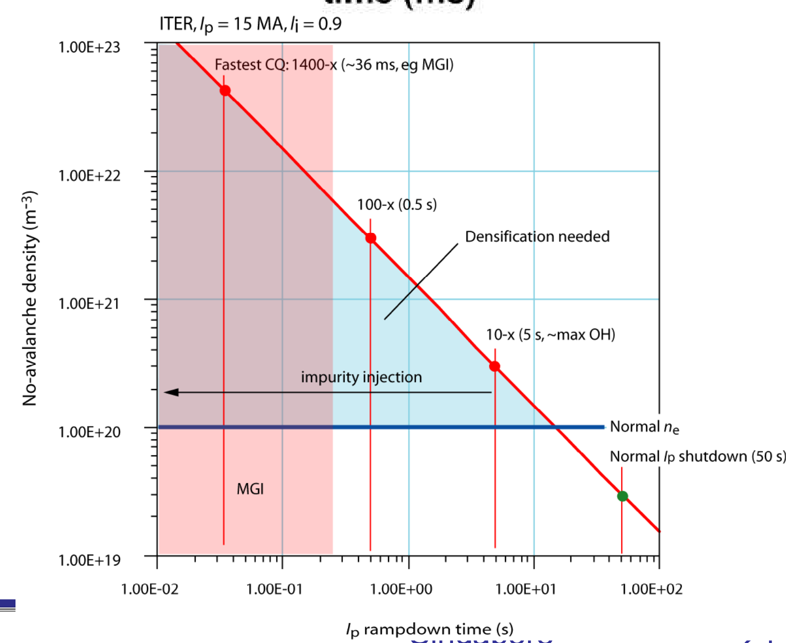
- Reliability of routine use

- Implications for use in ITER

- First wall heat loads

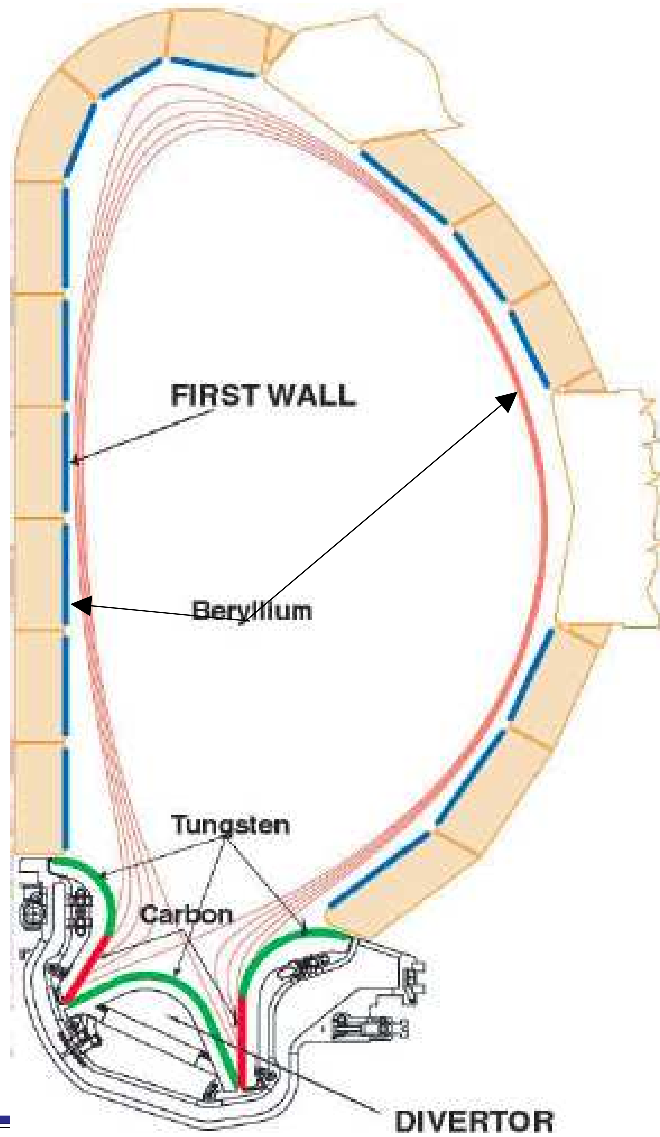
- Runaway electron generation



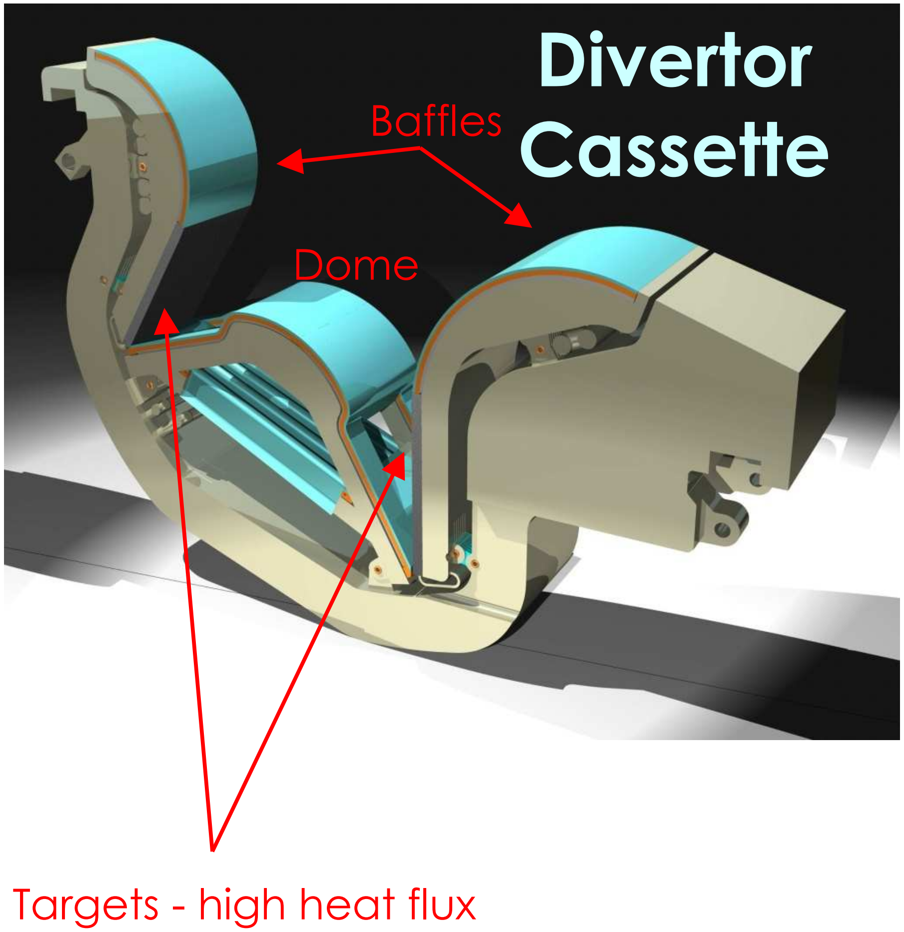


Plasma Facing Components - Challenges

- **CFC divertor targets (~50m²):**
  - erosion lifetime (ELMs!) and tritium codeposition
  - dust production
- **Be first wall (~700m²):**
  - dust production and hydrogen production in off-normal events
  - melting during VDEs
- **W-clad divertor elements (~100m²):**
  - melt layer loss at ELMs and disruptions
  - W dust production - radiological hazard in by-pass event



Plasma Facing Components - Strategy



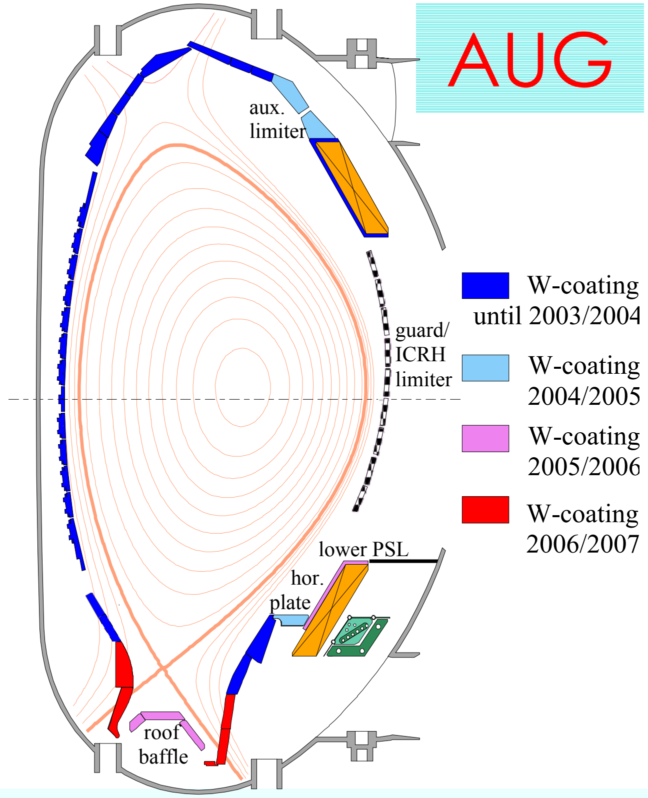
- **Strategy for the use of plasma facing materials in ITER has been revised:**
  - CFC will be used for high heat flux regions of divertor in advance of DT phase
  - Tungsten targets will be installed before DT operation

  Substantially reduces potential limitations in operation due to tritium co-deposition with carbon
- **R&D required:**
  - To complete qualification of tungsten high heat flux components
  - To develop relevant plasma scenarios
  - To quantify tritium retention in W/ Be environment

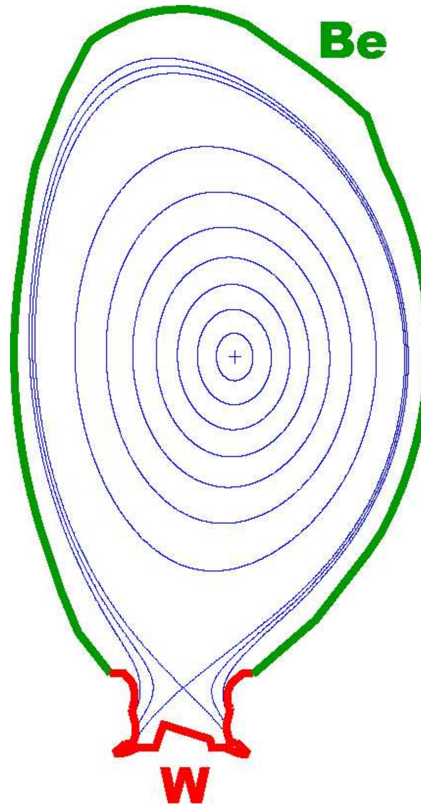
Plasma Facing Components - R&D

TORE SUPRA

AUG



JET

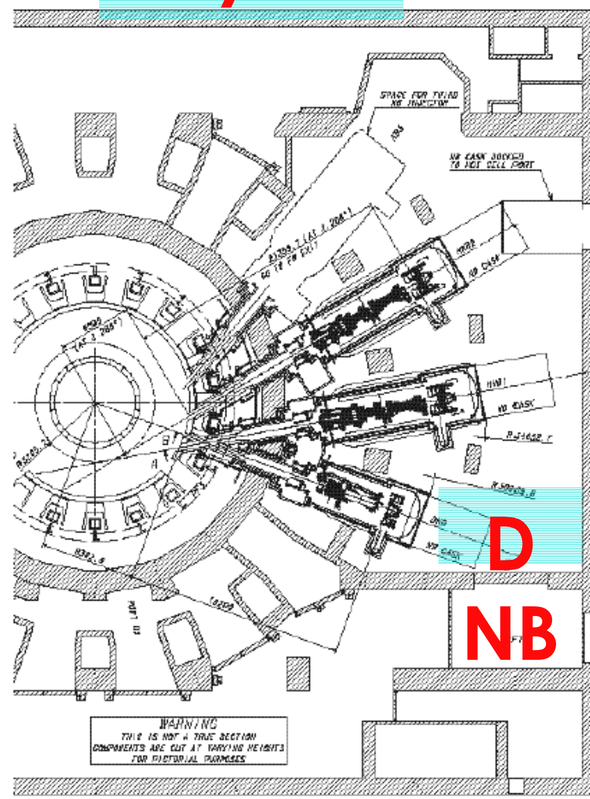


- **EU is uniquely equipped to address this key issue for ITER:**
  - **Tore Supra: long pulse operation with CIEL CFC pumped limiter**
  - **ASDEX Upgrade: conversion to all tungsten PFCs complete**
  - **JET: installation of beryllium wall and tungsten divertor in 2009**

ITER Heating and Current Drive

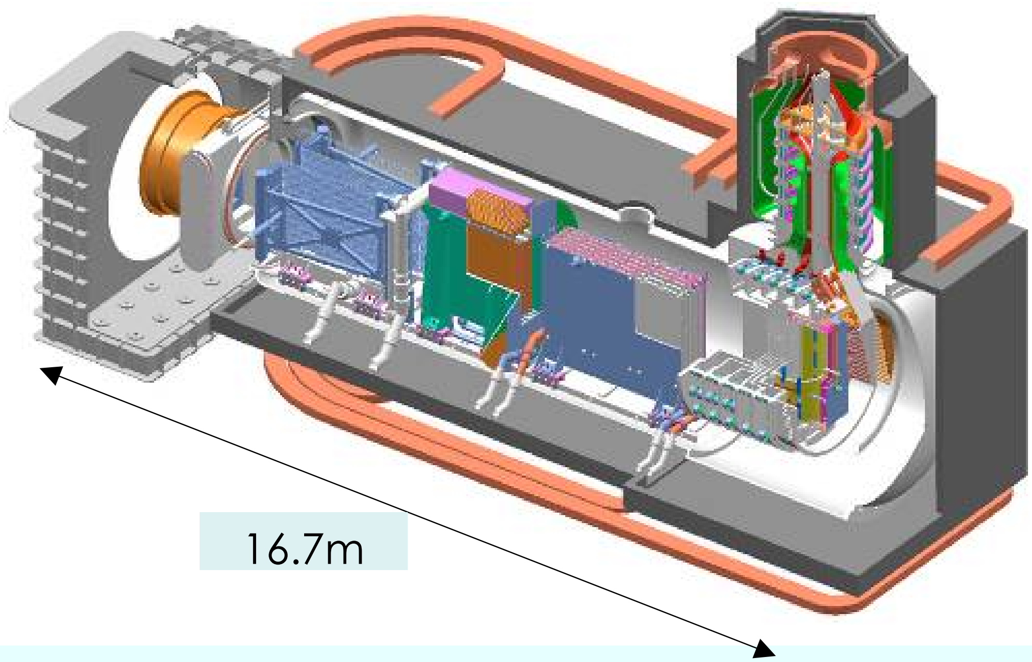
Heating System	Stage 1	Possible Upgrade	Remarks
NBI (1MeV Ğve ion)	33	16.5	Vertically steerable (z at Rtan -0.42m to +0.16m)
ECH&CD (170GHz)	20	20	Equatorial and upper port launchers steerable
ICH&CD (40-55MHz)	20		$2\Omega_T$ (50% power to ions Ω_{He3} (70% power to ions, FWCD)
LHH&CD (5GHz)		20	$1.8<n_{par}<2.2$
Total	73	130 (110 simultan)	Upgrade in different RF combinations possible
ECRH Startup	2		120GHz
Diagnostic Beam (100keV, H^-)	>2		

NBI Layout



All systems require continuing R&D - technology and physics

Negative Ion NB R&D

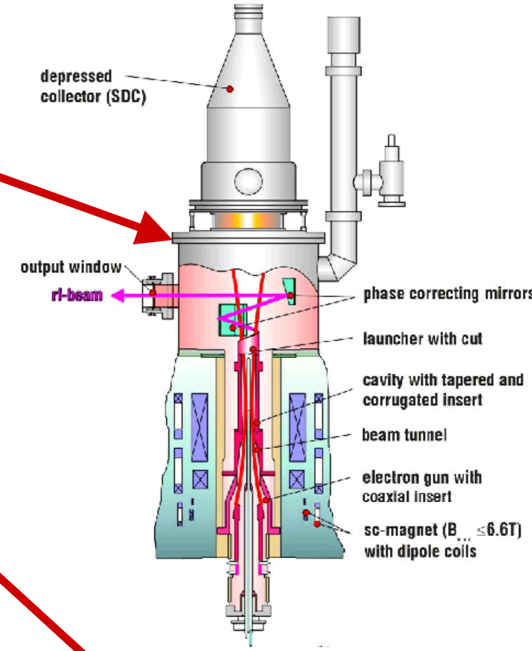


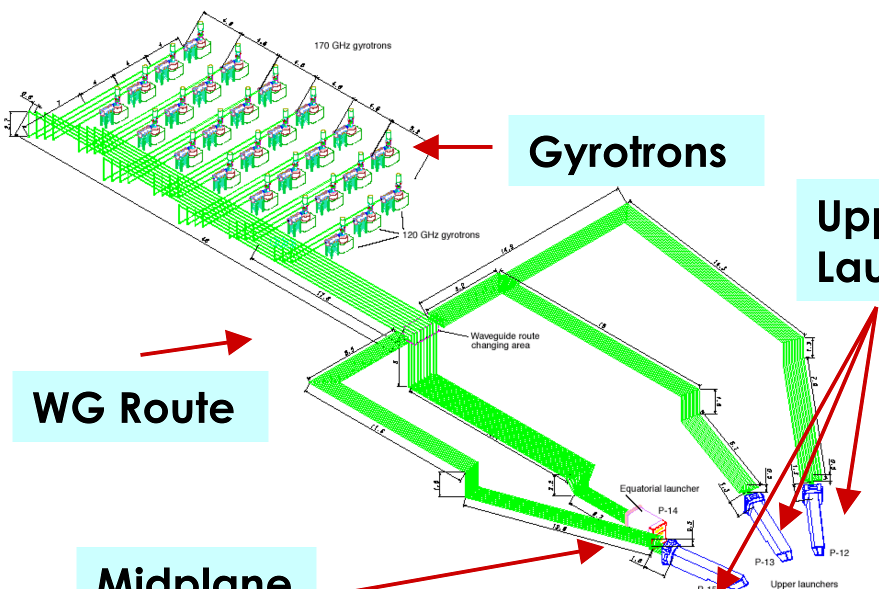
- Major elements of 1MeV ITER heating beam require further R&D:
  - 1 MV Power Supply
  - Negative ion (deuterium) source to provide 40 A accelerated current
  - 1 MeV accelerator
  - Neutralizer cell, residual ion dumps, vacuum containment, 1 MV insulators, magnetic correction and shielding

A Negative Ion Beam Test Facility is under construction in Padova.

Electron Cyclotron H&CD R&D

- **20 MW 170 GHz millimetre wave system:**
  - 170 GHz CW gyrotron and magnet
  - microwave transmission line/ load
  - CVD-diamond window
  - steerable antennas (upper launcher)



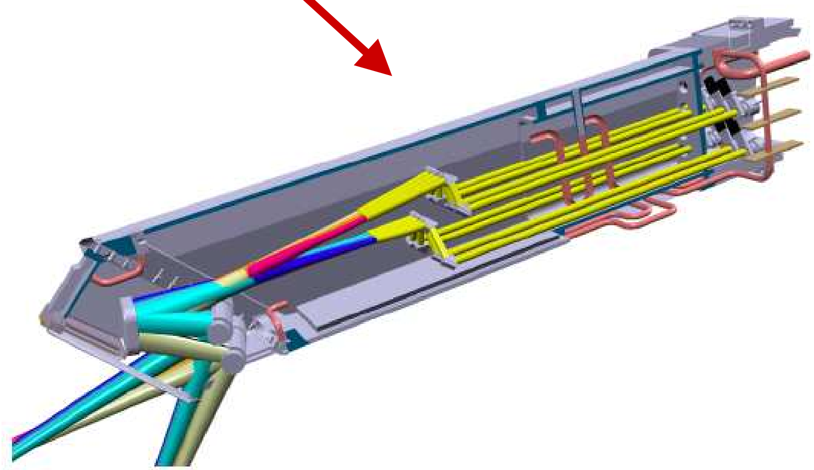


Gyrotrons

Upper Launcher

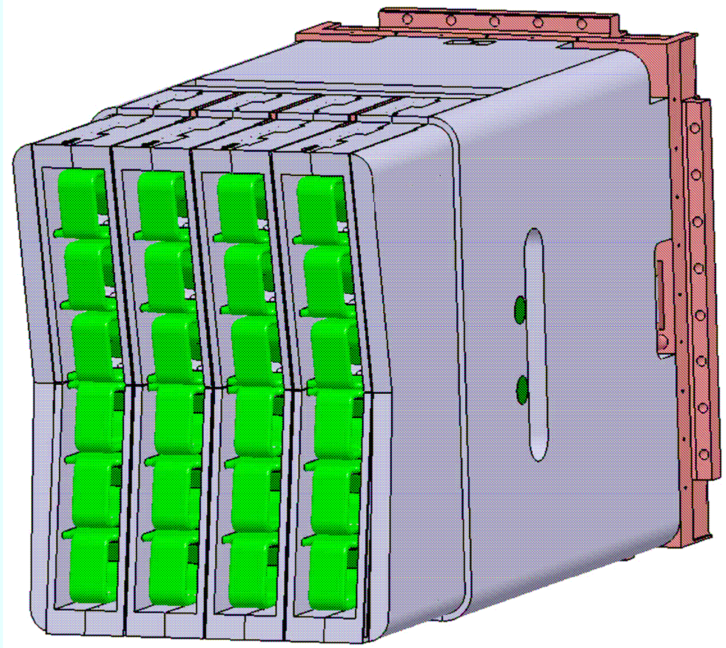
WG Route

Midplane Launcher



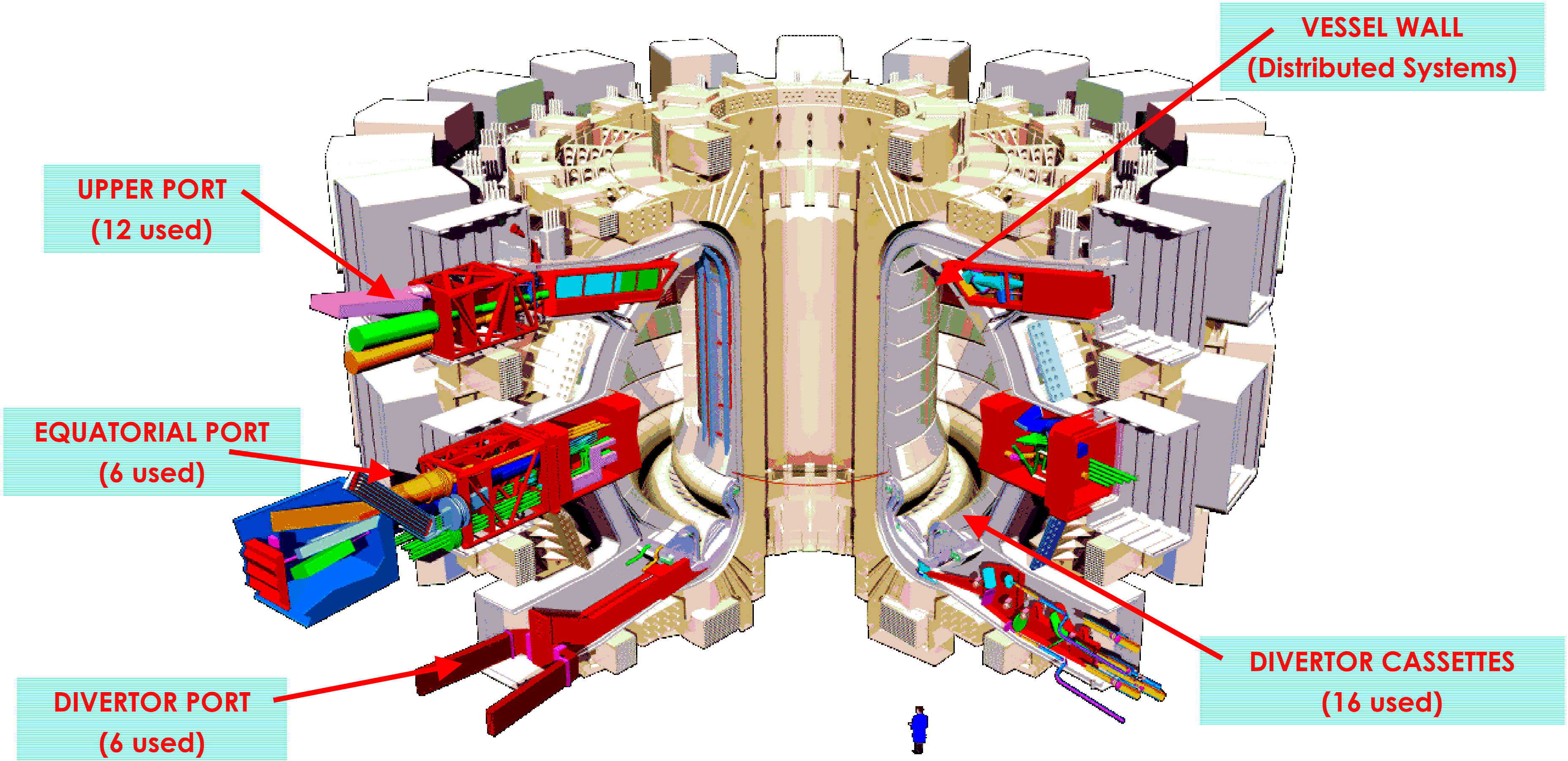
Ion Cyclotron H&CD R&D

- **Development of 24-strap antenna is major R&D activity:**
  - High power density, high coupling efficiency over 40-55 MHz frequency range is essential
  - Efficient coupling at high plasma-antenna gap is required
  - Resilience to ELMs is a necessary feature
  - Development of matching algorithm for reliable coupling is a key activity



Demonstration of high power density (~9 MWm^{-2}) operation insensitive to rapid changes in coupling conditions is critical

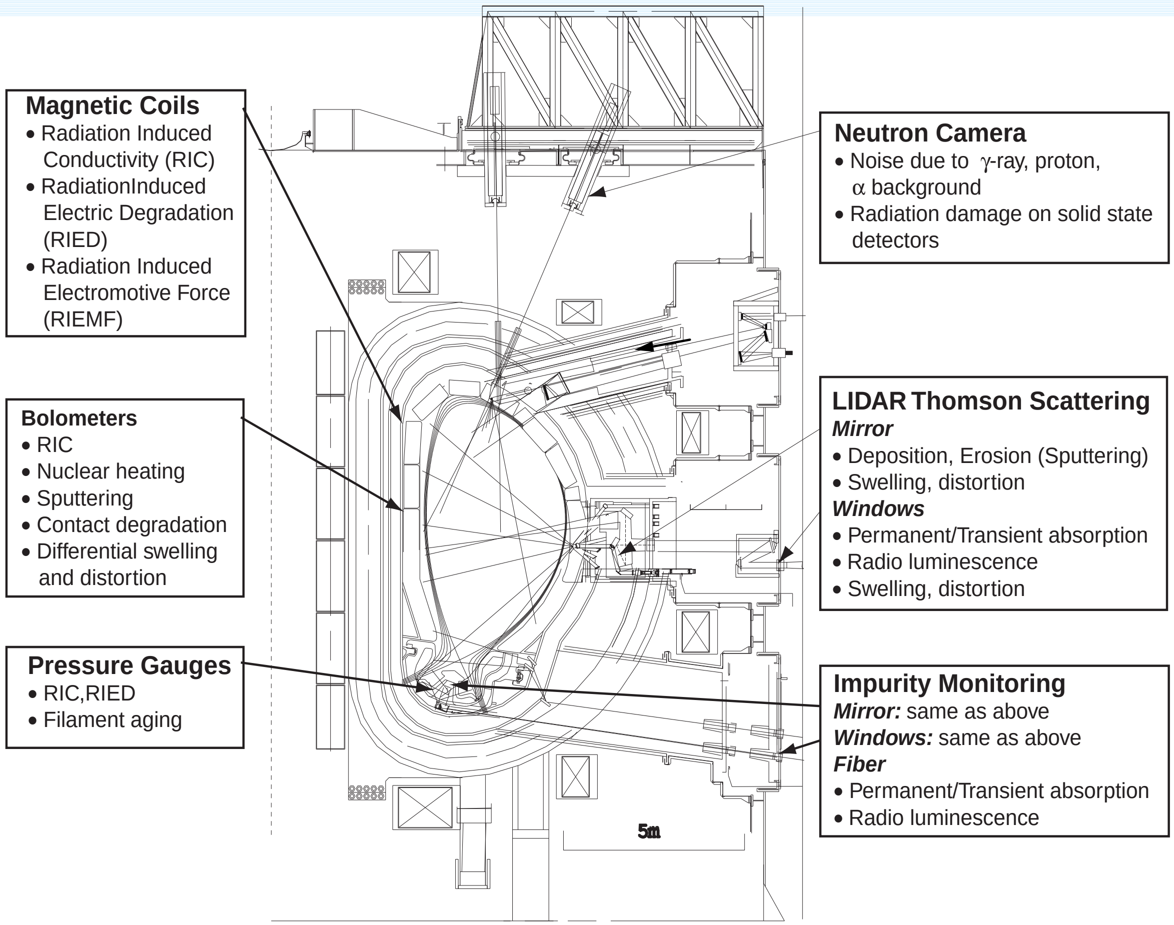
ITER Diagnostics



- 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 ….)

ITER Diagnostics R&D Needs

- **Key Issue**: lifetime of in-vessel ceramics, mirrors, windows, sensors and cabling
- **Extensive R&D necessary to ensure reliable operation in ITER**

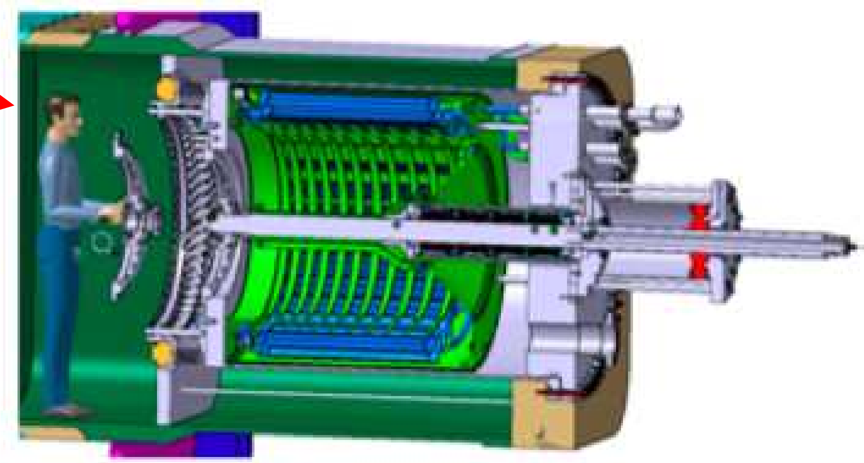


Tritium Handling R&D

- **In DT operation, ITER will rely on a large scale Tritium Plant for fuel supply, fuel reprocessing and exhaust processing.**
  - **Experience in tritium handling and specific know how is concentrated on very few places around the world**
- **Significant R&D is required to establish key processes in the ITER tritium fuel cycle:**
  - **Testing of tritium shipping/delivery in relevant containers**
  - **Testing of metal hydride storage beds under full tritium load**
  - **Demonstration of the accuracy of the Tritium accountancy, which is mainly based on the in-bed calorimetry features of the metal hydride beds in the Storage and Delivery System**
  - **Development of technology for processing of highly tritiated water to allow recovery of tritium**
  - **R&D on tritium removal techniques from high heat flux components to allow treatment of tritiated materials in Hot Cell**

Vacuum System R&D

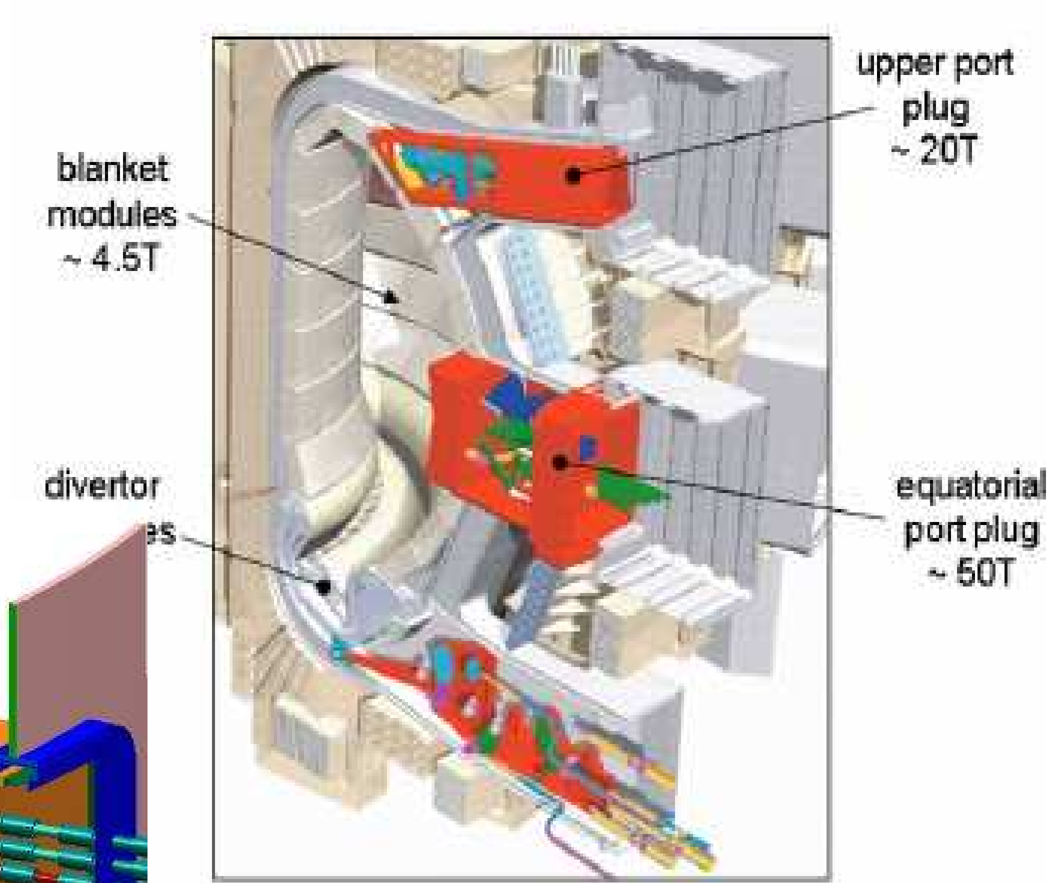
- **Key Vacuum R&D:**
  - **Operational characterization of the full size torus cryopump**
  - **Concepts for leak detection and localization**
  - **Validation of transition flow models for gas conductance calculations in ITER regime**
  - **Optimization of ITER divertor recycling gas paths**

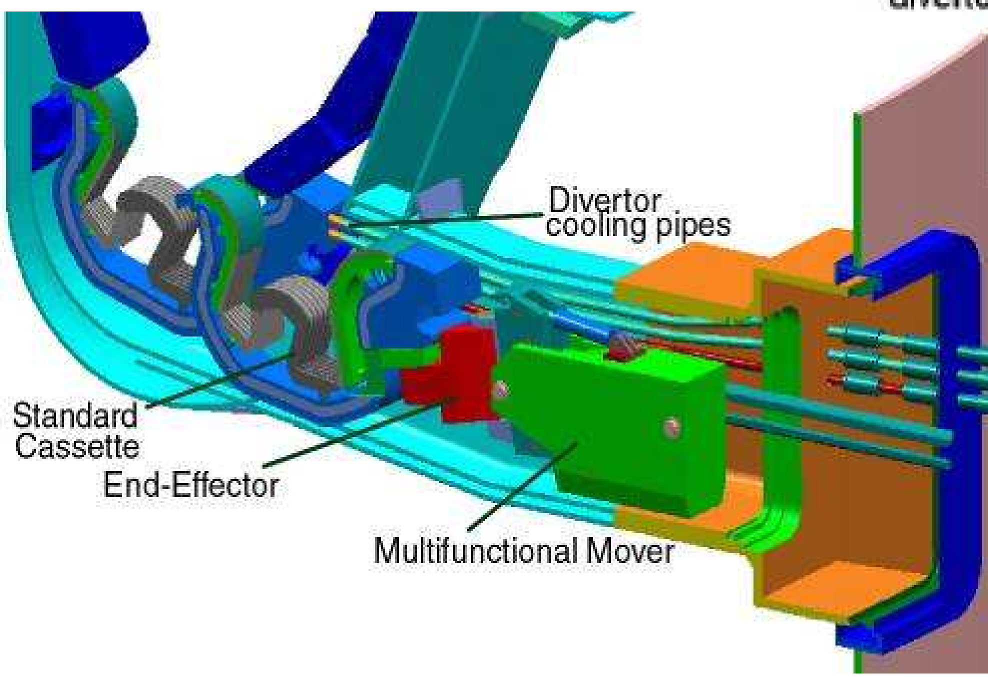


- **Development of tritium compatible vacuum pumping and tokamak scale process elements**
- **Development of critical vacuum process control and instrumentations components for ITER radiation and magnetic environments**

Remote Handling R&D

- **RH of Large Complex Systems:**
  - **Blanket modules**
  - **Divertor modules**
  - **Port plugs**





EU is working on the Divertor RH Tools and on the Air Cushion Casks Transfer System

IV. CONTRIBUTIONS TO THE BROADER APPROACH

- **Broader Approch (BA) is a bilateral agreement between Euratom and Japan, agreed in the frame of the very complex negotiations regarding the ITER site.**

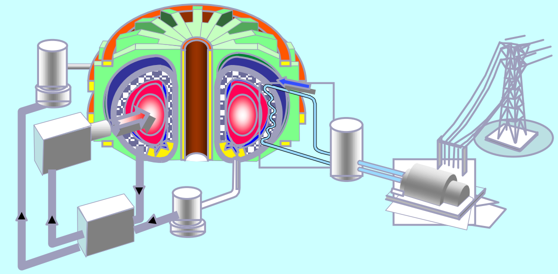
- **The EU contributions are provided by the donnor countries: France, Spain, Italy, Germany and Belgium.**

Broader Approach for Realization of Fusion

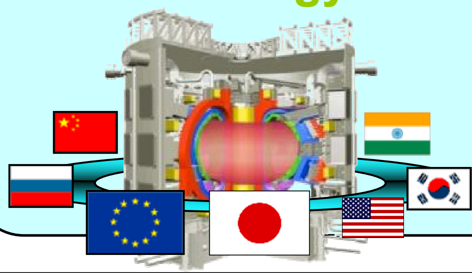
(1) Taking Initiative of Fusion Research
(2) Development of Fundamental Fusion Technology
(3) Human Resource Development

DEMO

Demonstration of Fusion Power Plant

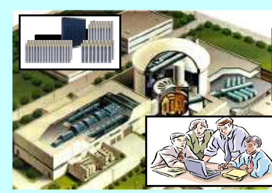


ITER : Demonstration of Scientific and Technological Feasibility of Fusion Energy



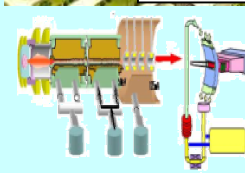
Q =10
DT Burning 300-500s

Broader Approach Activities



Rokkasho, Aomori

IFERC



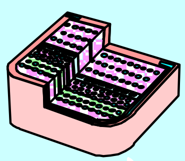
IFMIF/EVEDA

Naka, Ibaraki

Satellite Tokamak

JT-60

Q = 1.25
Ti(0) = 45keV

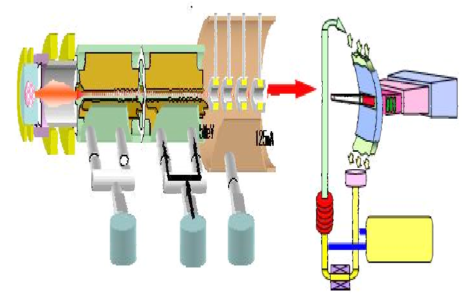


Fusion Technology

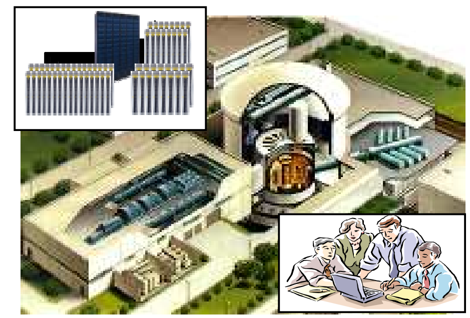
Material
Blanket
R&D (Coils, VV, Heating)

Broader Approach Activities (2007-2017) comprise three Projects

1) **Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA)**

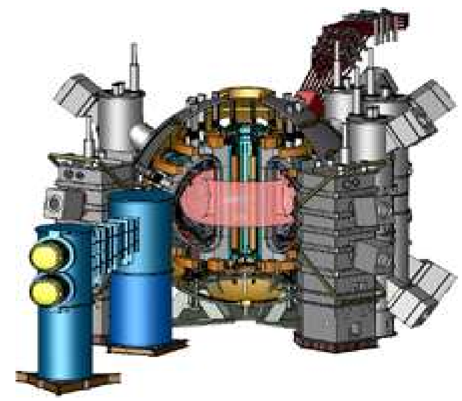


2) **International Fusion Energy Research Centre (IFERC),**
   - a) **DEMO Design and R&D coordination Centre**
   - b) **Computational Simulation Centre**
   - c) **ITER Remote Experimentation Centre**



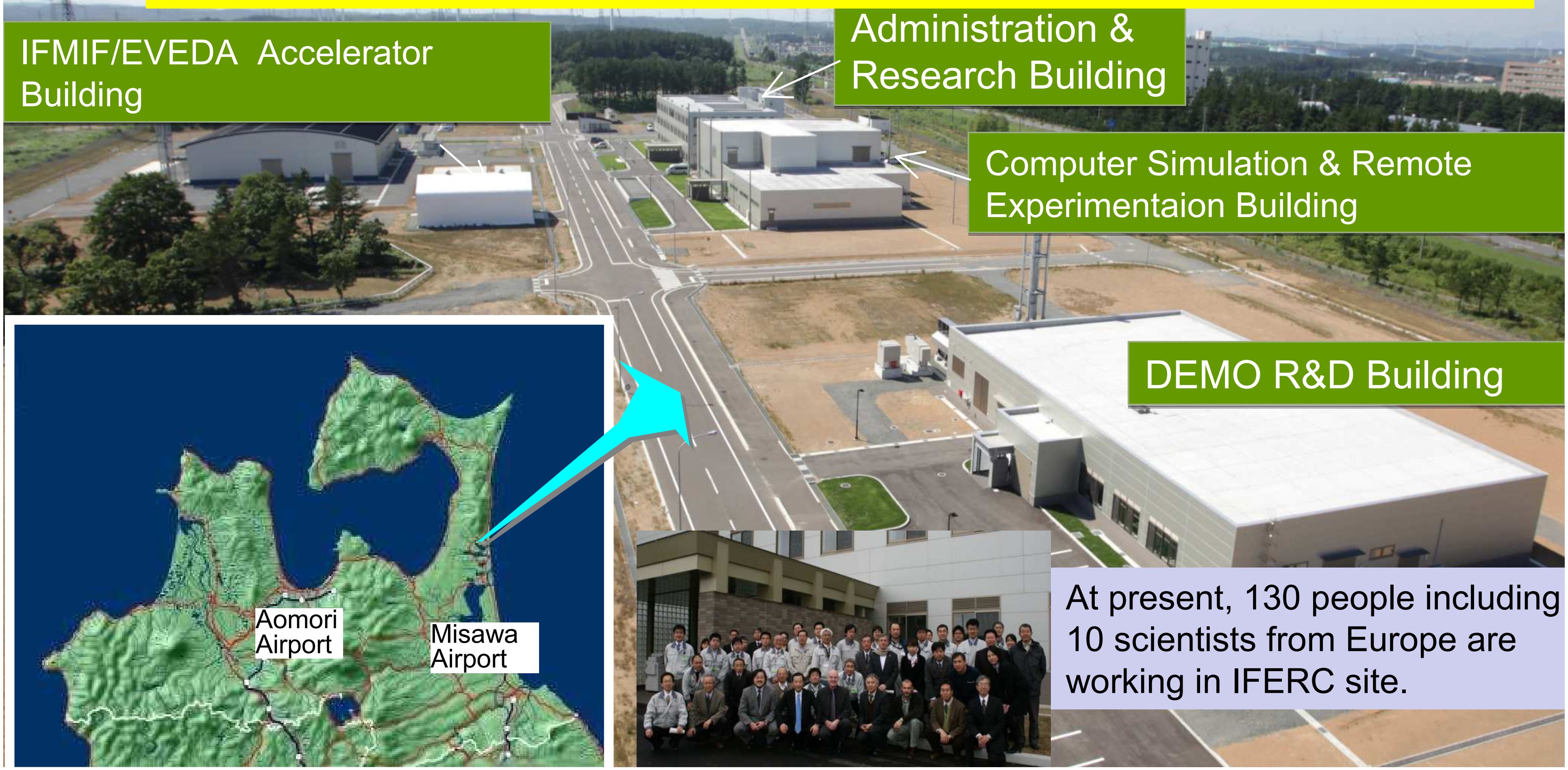
3) **Satellite Tokamak Programme**

Participation to upgrade of JT-60 tokamak toJT-60SA and its exploitation.



International Fusion Energy Research Centre (Rokkasho village, Aomori prefecture)

- All the research buildings have been completed in March 2010.
- Technological R&D on key issues for DEMO reactor is being conducted.
- Supercomputer of 1 Peta flops class will be operational in January 2012.
- Accelerator prototype for IFMIF will be tested from 2012.



Present Status of IFMIF/EVEDA Accelerator

- **Injector (Saclay, France):** The first hydrogen plasma and proton beam will be produced in March 2011.

- **RFQ (INFN, Italy):** The RFQ modules are under construction. The modules necessary for high power tests will be ready in autumn 2011.

- **Superconducting Linac (Saclay, France):** The final design of the HWR for series will be completed in beginning of 2011.

- **RF power system(CIEMAT, Spain):** The engineering design of the RF power chains will be completed in April 2011. The proto chain will be tested and available for Superconducting Linac couplers conditioning in December 2011.

Injector (ECR ion source)

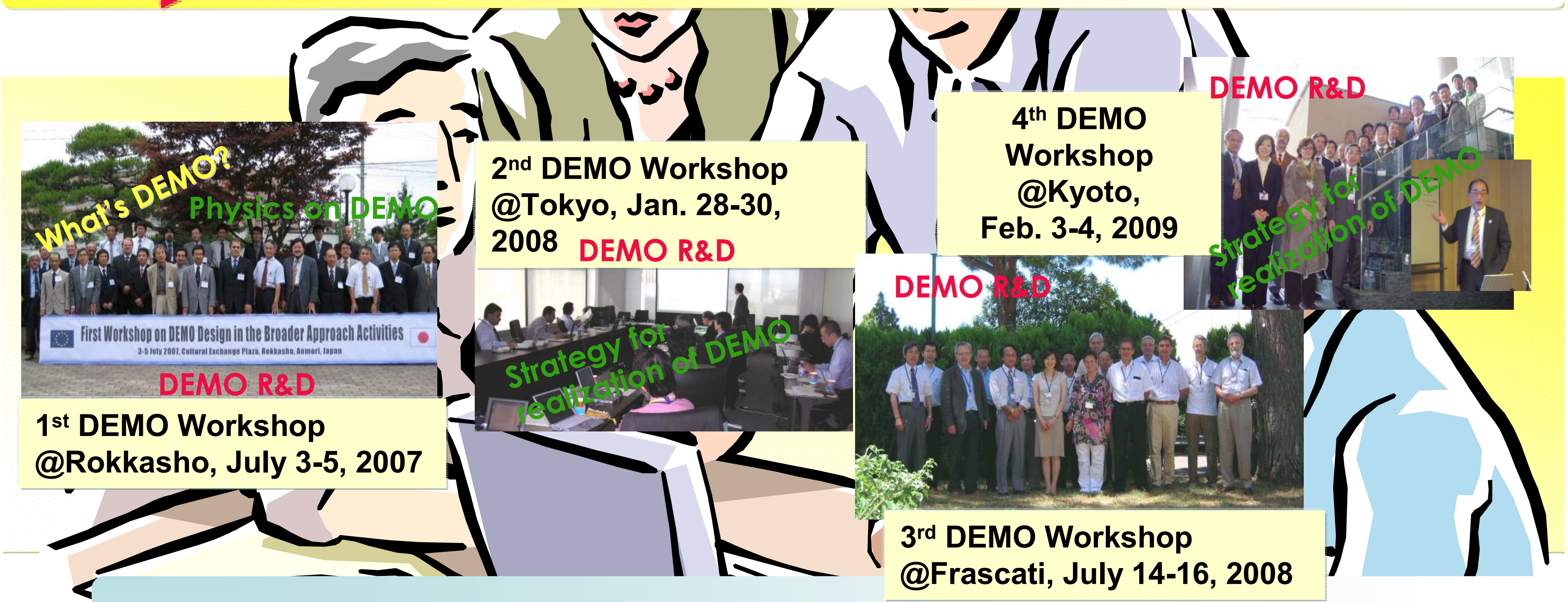
RFQ (1 section)

DEMO Design R&D Coordination

< Mission and Scope >

The DEMO Design R&D Coordination Centre shall play an important role in coordinating scientific and technological activities necessary to DEMO design including design activities and technology R&Ds on key issues of common interest. The expected products will include conceptual designs of DEMO, in which the outcome of R&D activities are reflected.

Active technological R&Ds have been carried out through workshops

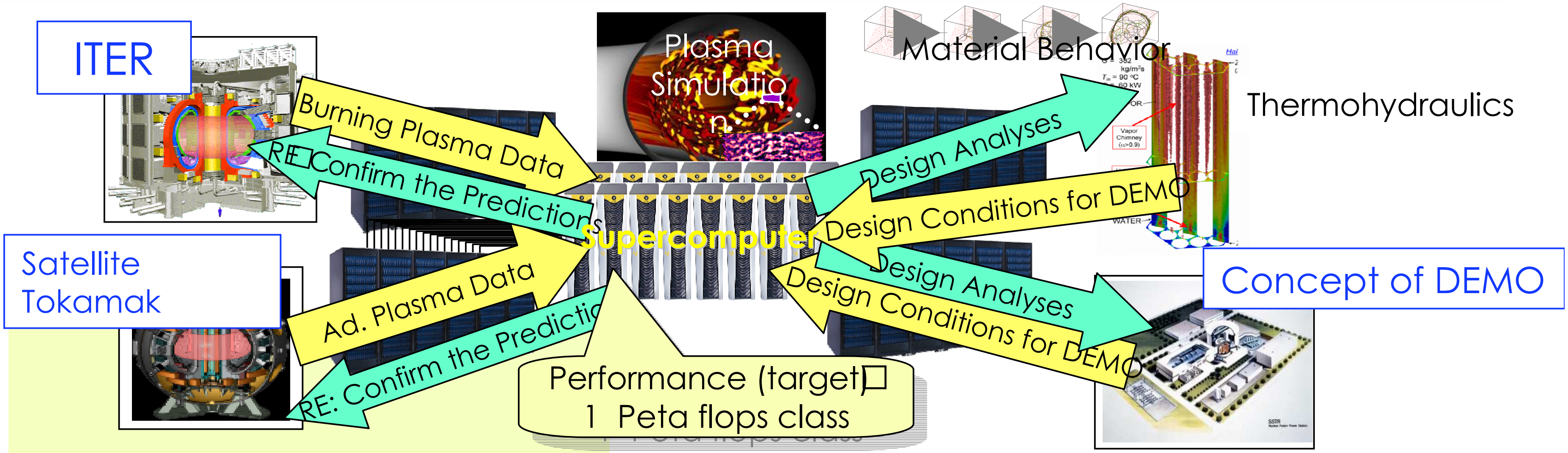


IFERC□Project	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
DEMO Design R&D Coordination		PHASE ONE				PHASE TWO				

Fusion Computational Simulation Centre

< Mission and Scope

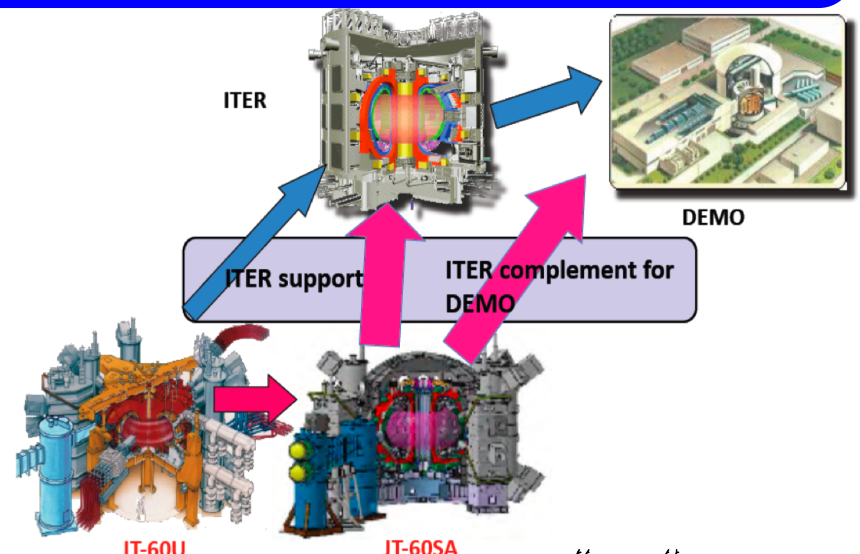
➢ To establish a Centre of Excellence (COE) for the simulation and modelling of ITER and the Advanced Superconducting Tokamak and other fusion experiments, and for the design of future fusion power plants, in particular DEMO. The computer resources shall be externally accessible, with a sufficient transmission rate to Europe including the ITER site, to allow an efficient remote use of the facilities.

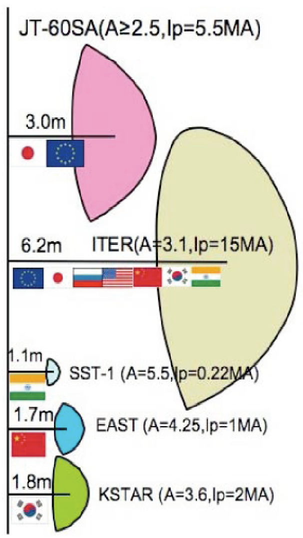


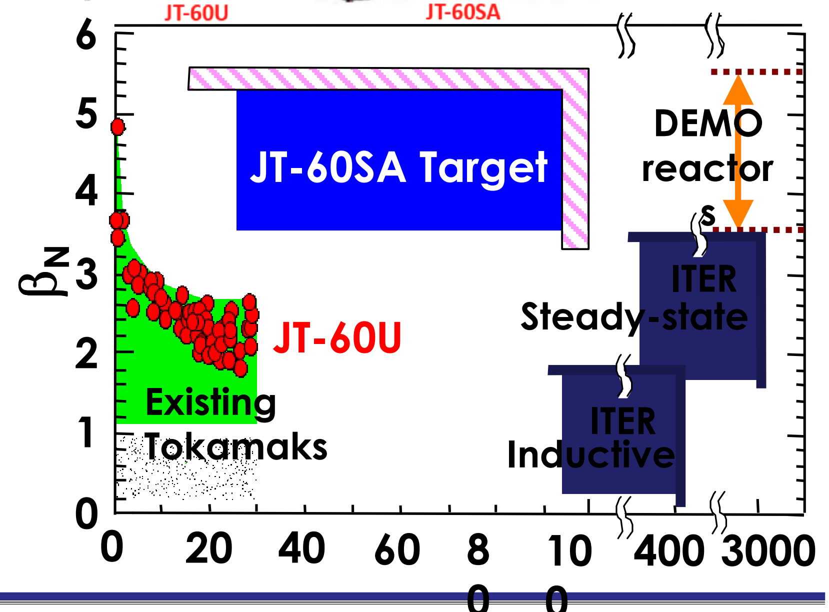
The JT-60SA Project
(Naka city, Ibaraki prefecture)

JT-60SA will have Ip-max=5.5 MA discharges lasting for a duration of typically 100 s, with high heating power 41 MW.

N-NB 500keV 10MW (Co)
P-NB 85keV 24MW (Co,Ctr, Bal)
ECH 110 GHz 7MW

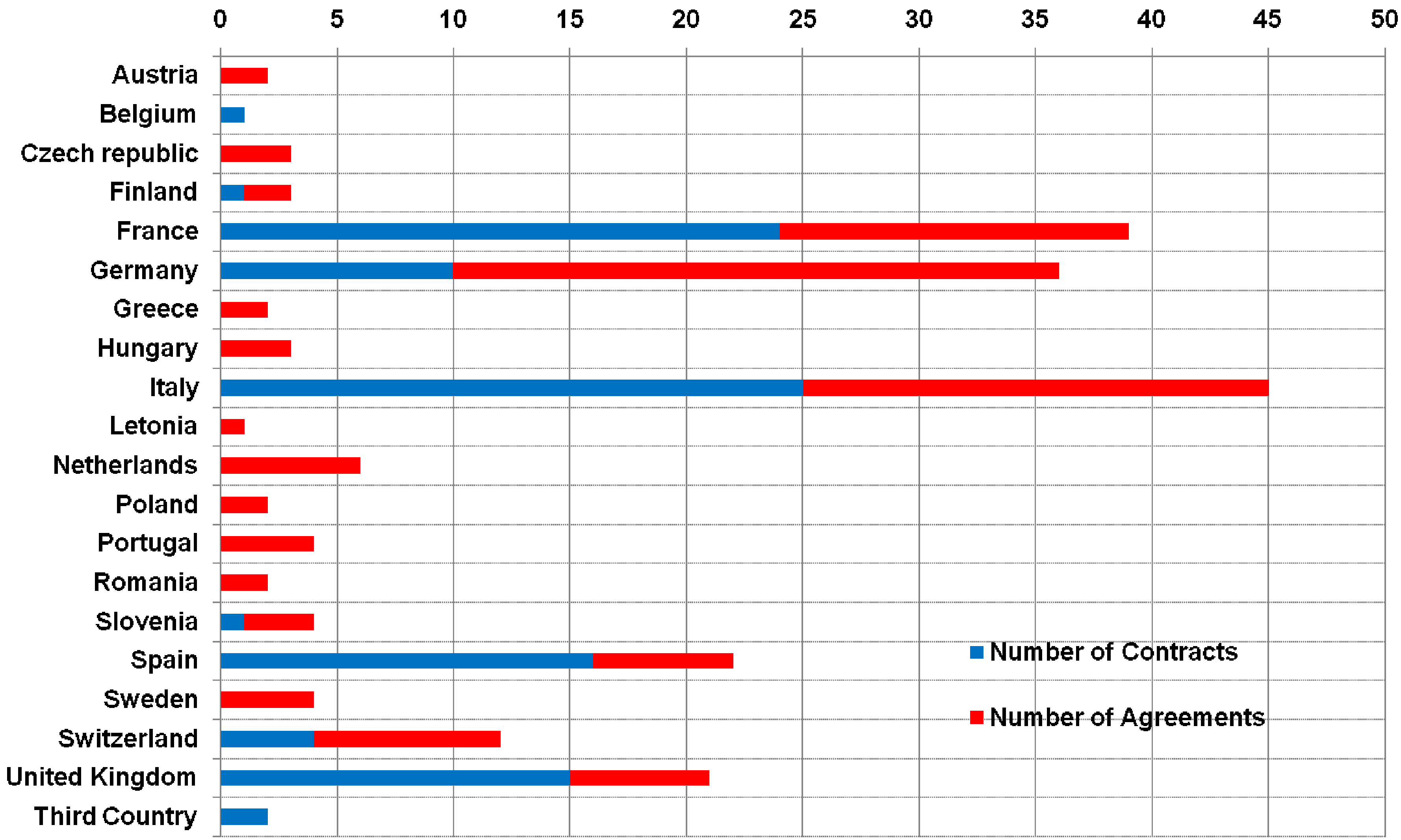


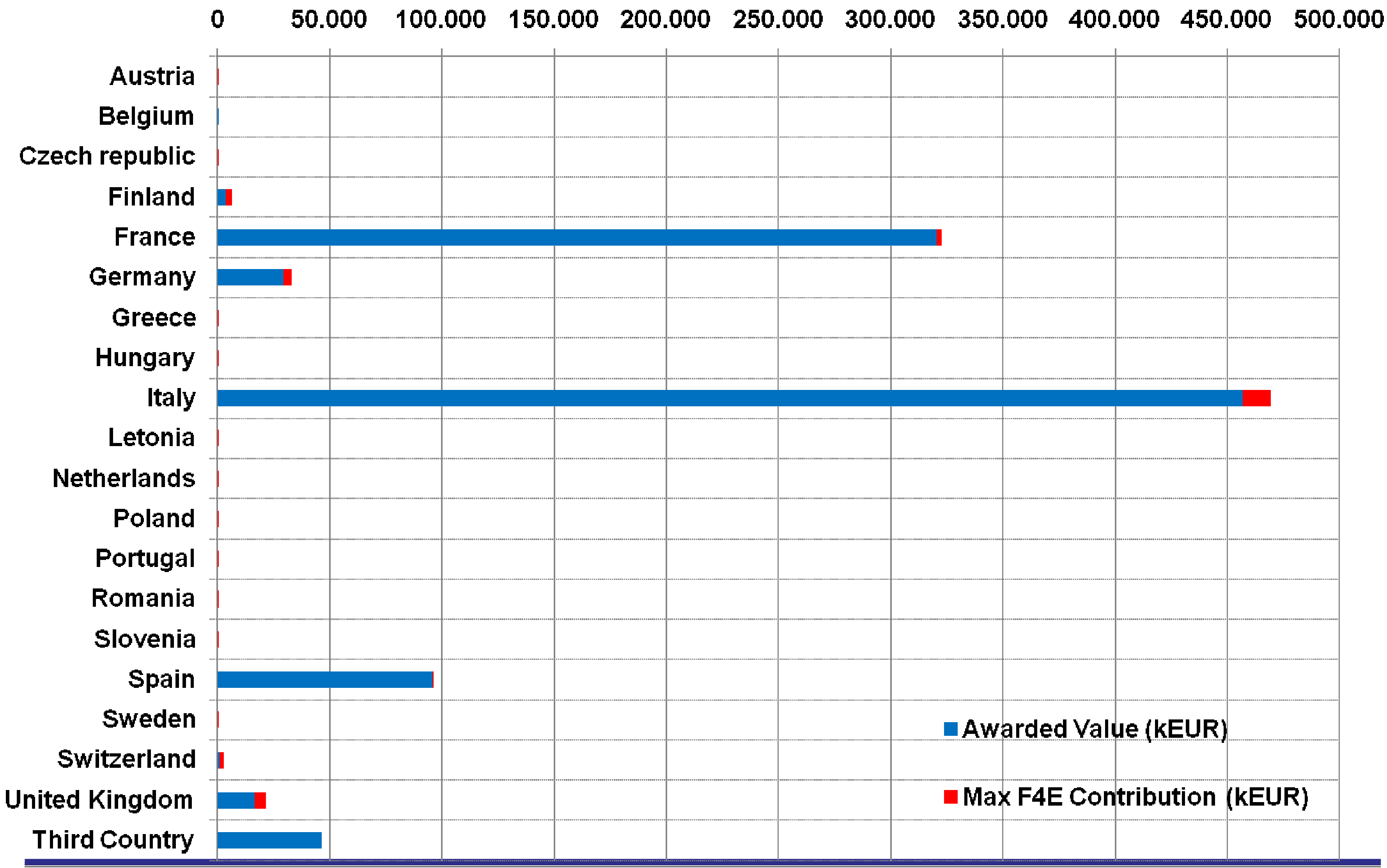




V. CONCLUSIONS





0
5
10
15
20
25
30
35
40
45
50
Austria
Belgium
Czech republic
Finland
France
Germany
Greece
Hungary
Italy
Letonia
Netherlands
Poland
Portugal
Romania
Slovenia
Spain
Sweden
Switzerland
United Kingdom
Third Country
Number of Contracts
Number of Agreements


0
50.000
100.000
150.000
200.000
250.000
300.000
350.000
400.000
450.000
500.000
Austria
Belgium
Czech republic
Finland
France
Germany
Greece
Hungary
Italy
Letonia
Netherlands
Poland
Portugal
Romania
Slovenia
Spain
Sweden
Switzerland
United Kingdom
Third Country
Awarded Value (kEUR)
Max F4E Contribution (kEUR)

THANK YOU VERY MUCH FOR YOUR ATTENTION

cvarandas@ipfn.ist.utl.pt

fusionforenergy.europa.eu