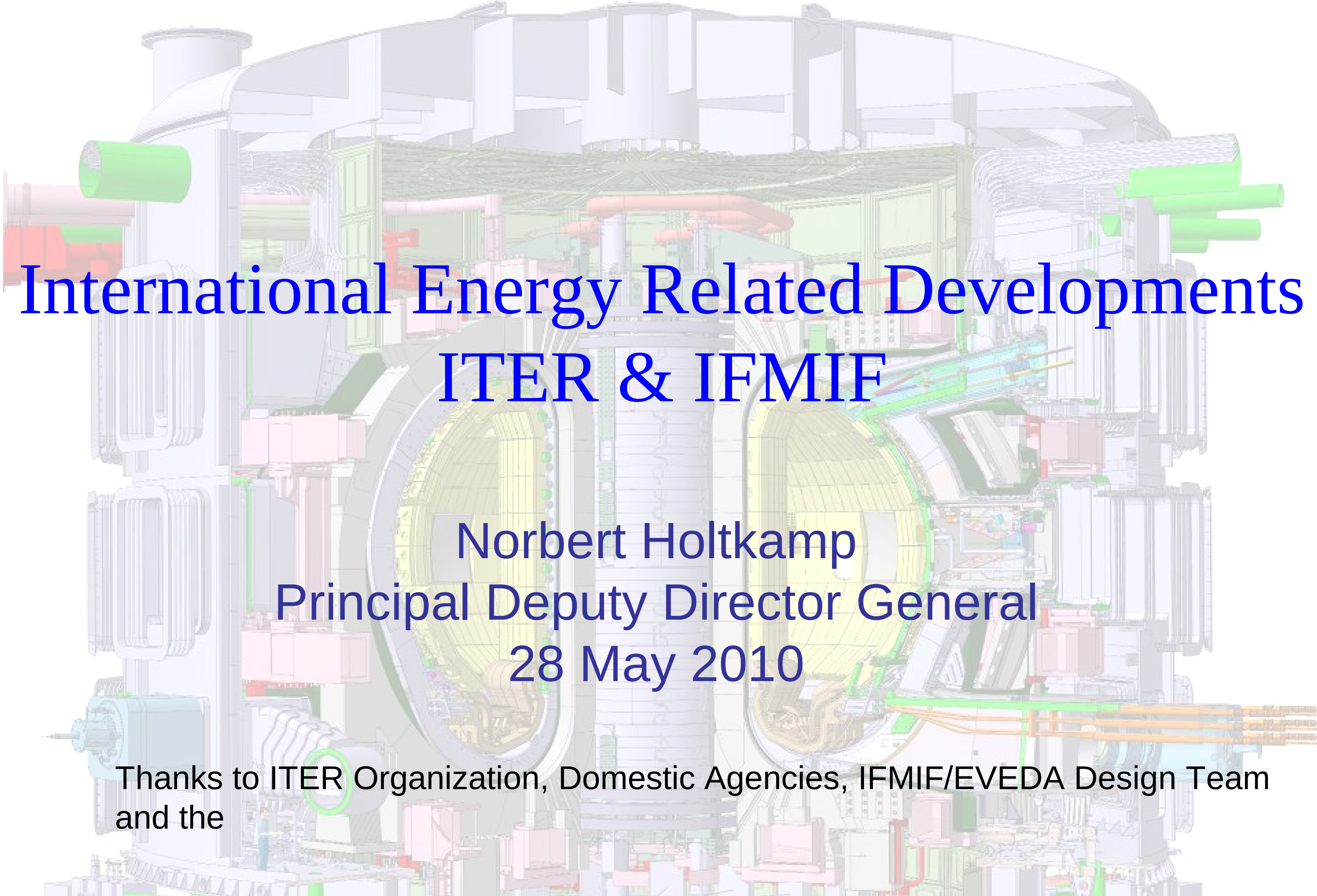


# International Energy Related Developments
# ITER & IFMIF


Norbert Holtkamp
Principal Deputy Director General

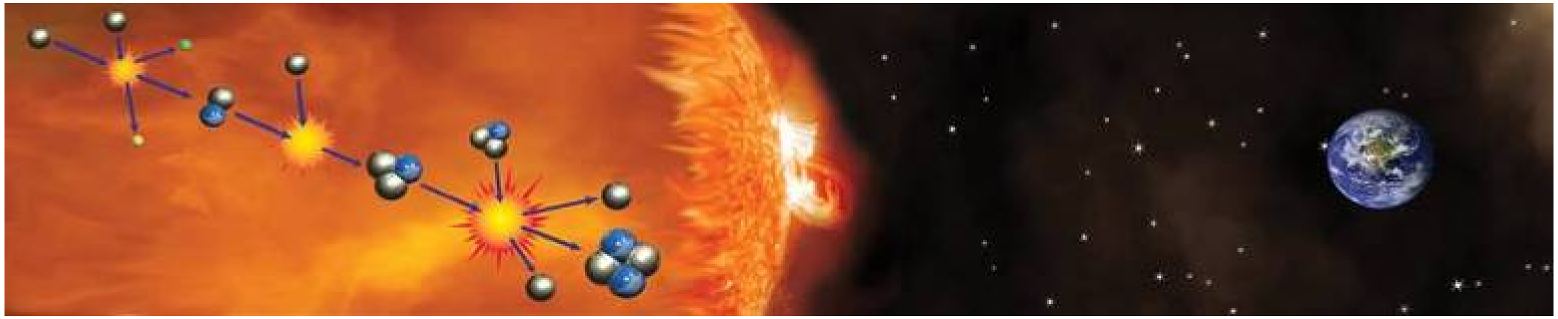

28 May 2010

Thanks to ITER Organization, Domestic Agencies, IFMIF/EVEDA Design Team and the

# Contributions to this Conference


- [1] N. Holtkamp, “International Energy Related Developments, ITER and IFMIF”, these proceedings.
- [2] C. Vermare et al. “Commissionning of the IFMIF/EVEDA Accelerator Prototype Objectives, Organization and Plans”, these proceedings.
- [3] R. Gobin et al. “General design of the IFMIF deuteron injector: source and beam line”, Proc. of ICIS’09, Gatlinburg Tennessee, USA.
- [4] M. Comunian, A. Pisent, E. Fagotti, “The IFMIF-EVEDA RFQ: Beam Dynamics Design”, proc. of LINAC’08, Vancouver, Sept. 2008.
- [5] A. Pepato et al, “Engineering Design and First Prototype Tests of the IFMIF-EVEDA RFQ”, these proceedings.
- [6] S. Maebara, “Design of an RF Input coupler for the IFMIF/EVEDA RFQ”, these proceedings.
- [7] F. Orsini et al, “Study and Realization of the First Superconducting Half Wave Resonator Prototype for the SRF Linac of the IFMIF Project”, these proceedings.
- [8] H. Jenhani et al, “Status of the CW RF Power Couplers for the SRF Linac of the IFMIF Project”, these proceedings.
- [9] F. Toral et al, “Calculation and Design of the Magnet Package in the Superconducting SRF Linac of IFMIF”, these proceedings.
- [10] N. Grouas et al, “Mechanical and Cryogenic System Design of the 1st Cryomodule for the IFMIF Project”, these proceedings.
- [11] D. Regidor et al, “IFMIF/EVEDA RF Power System”, these proceedings.
- [12] C. Oliver et al, “Magnet Design for the Medium and High Energy Beam Transport Lines of the IFMIF-EVEDA Accelerator”, these proceedings.
- [13] C. Oliver et al, “Alignment and Magnet Error Tolerances for the HEBT Line for the IFMIF-EVEDA Accelerator”, these proceedings.
- [14] H. Takahashi et al, “Present Status of the Development of MPS and TS for IFMIF/EVEDA Accelerator Prototype Control System”, these proceedings.

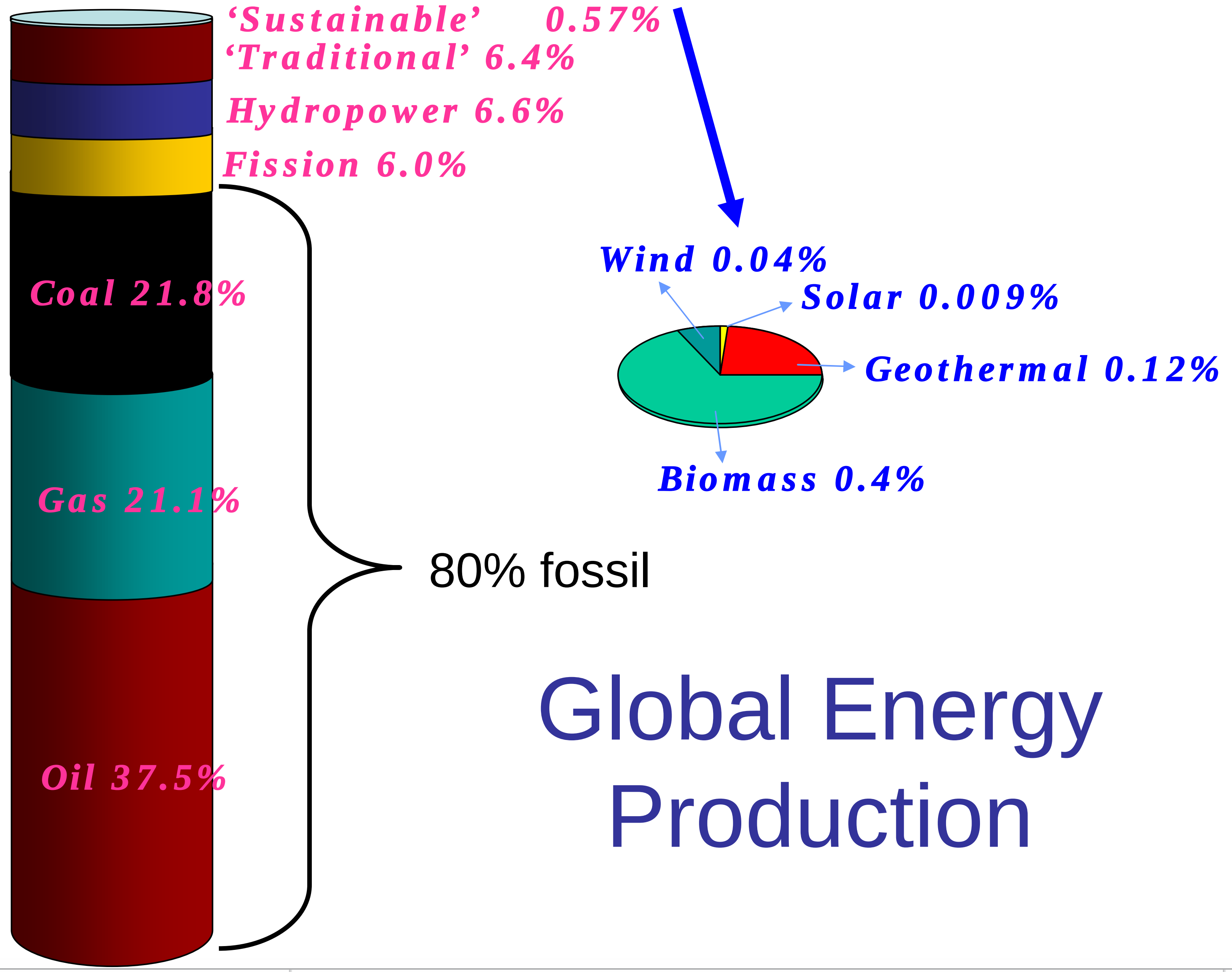
# Fusion powers the sun and the stars
## *"…Prometheus stole the fire from the heaven"*



**On Earth,**

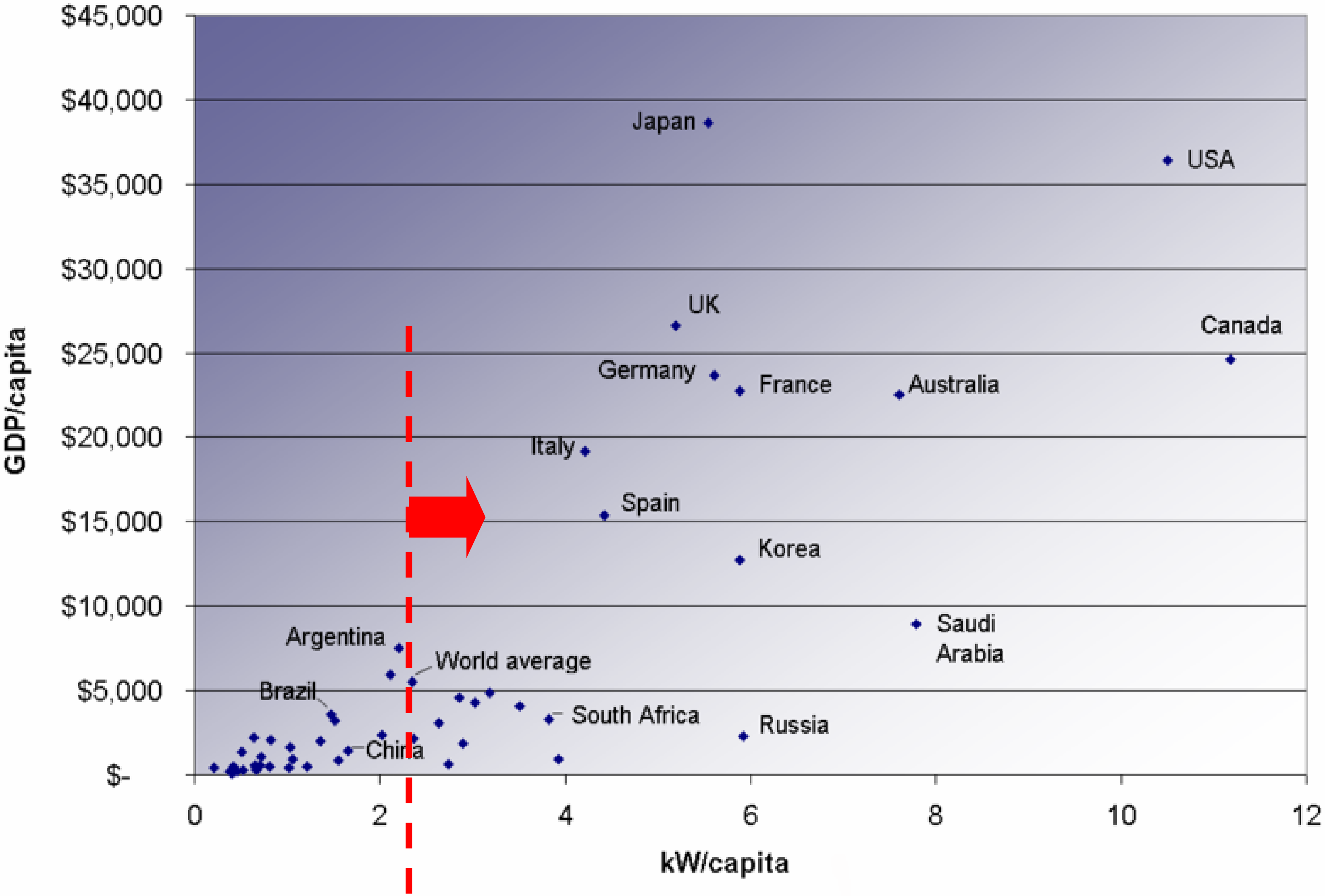
**fusion could provide:**

- Essentially limitless fuel, available all over the world
- No greenhouse gases
- Intrinsic safety
- No long-lived radioactive waste
- Large-scale energy production

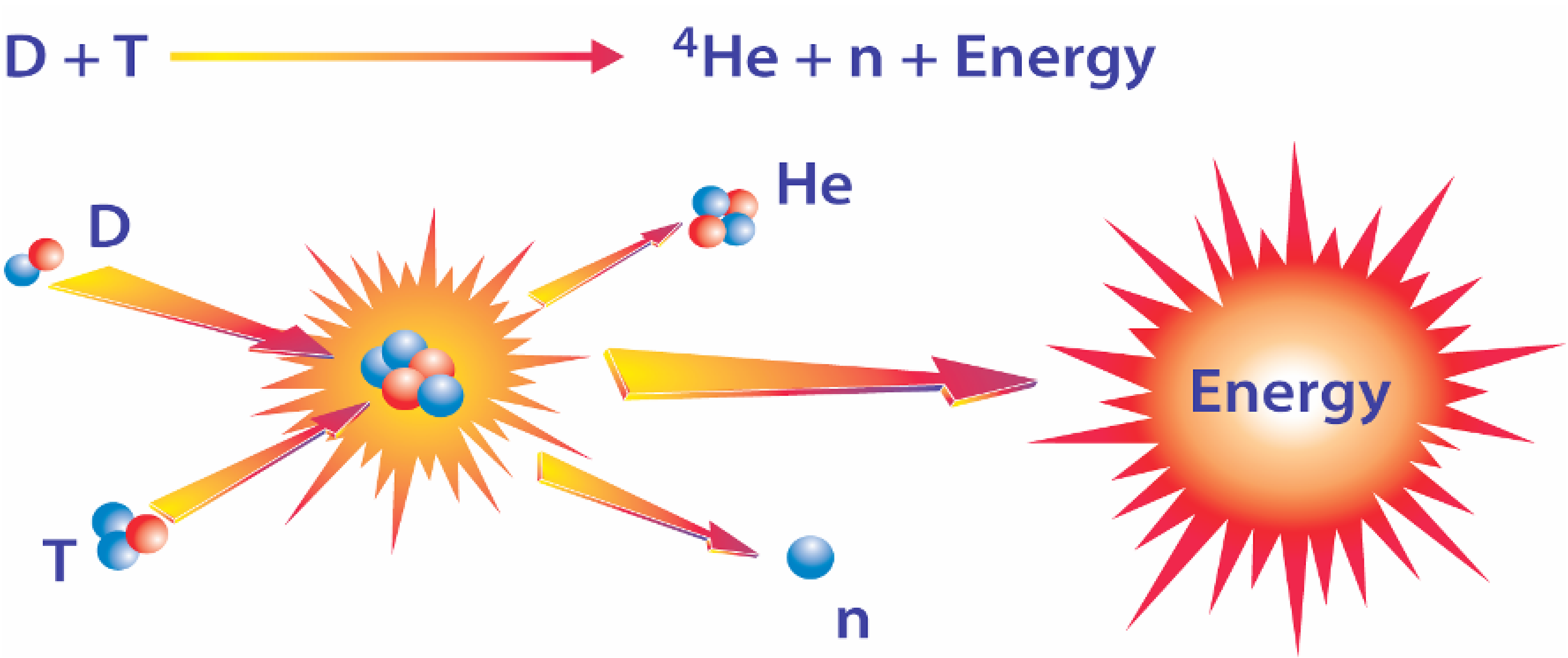



# Global Energy Production

# The Energy Dilemma



# The Fusion Reaction on Earth
## *"... is not the same as in the Sun"*



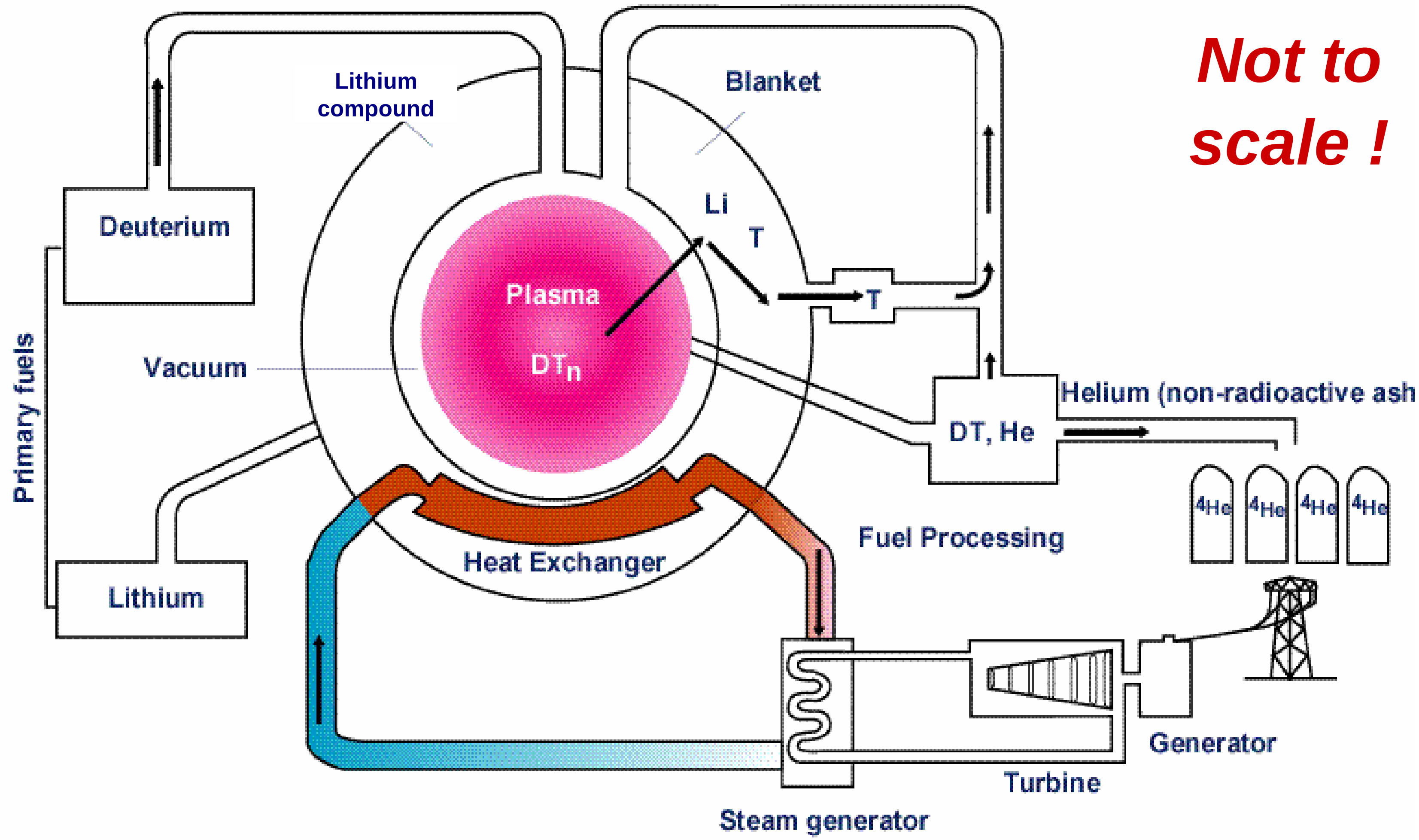

$$ {}_1D^2 + {}_1T^3 \rightarrow {}_2He^4 + {}_0n^1 $$

**3.5MeV + 14.1 MeV**

# The Goal: A Fusion Power Plant

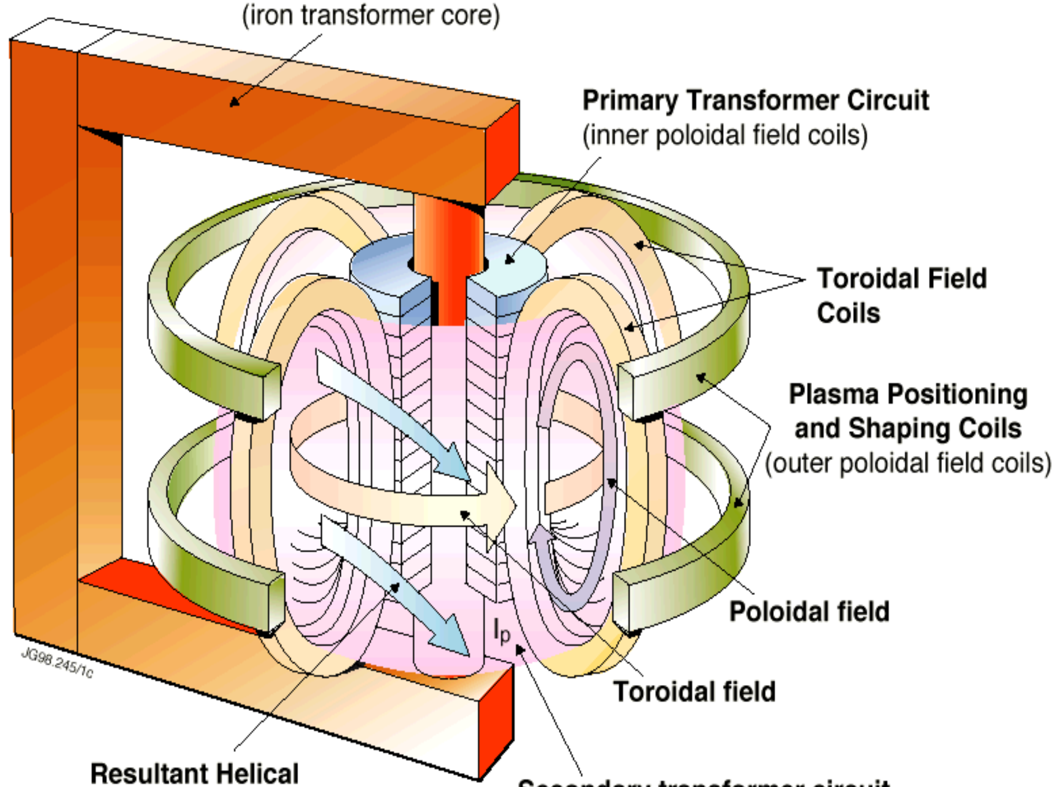
- Technology → ITER
- Materials → IFMIF
- Fuel (Tritium Production) → Test Blankets
- Reactor Concept Development → DEMO

# The Goal: A Fusion Power Plant

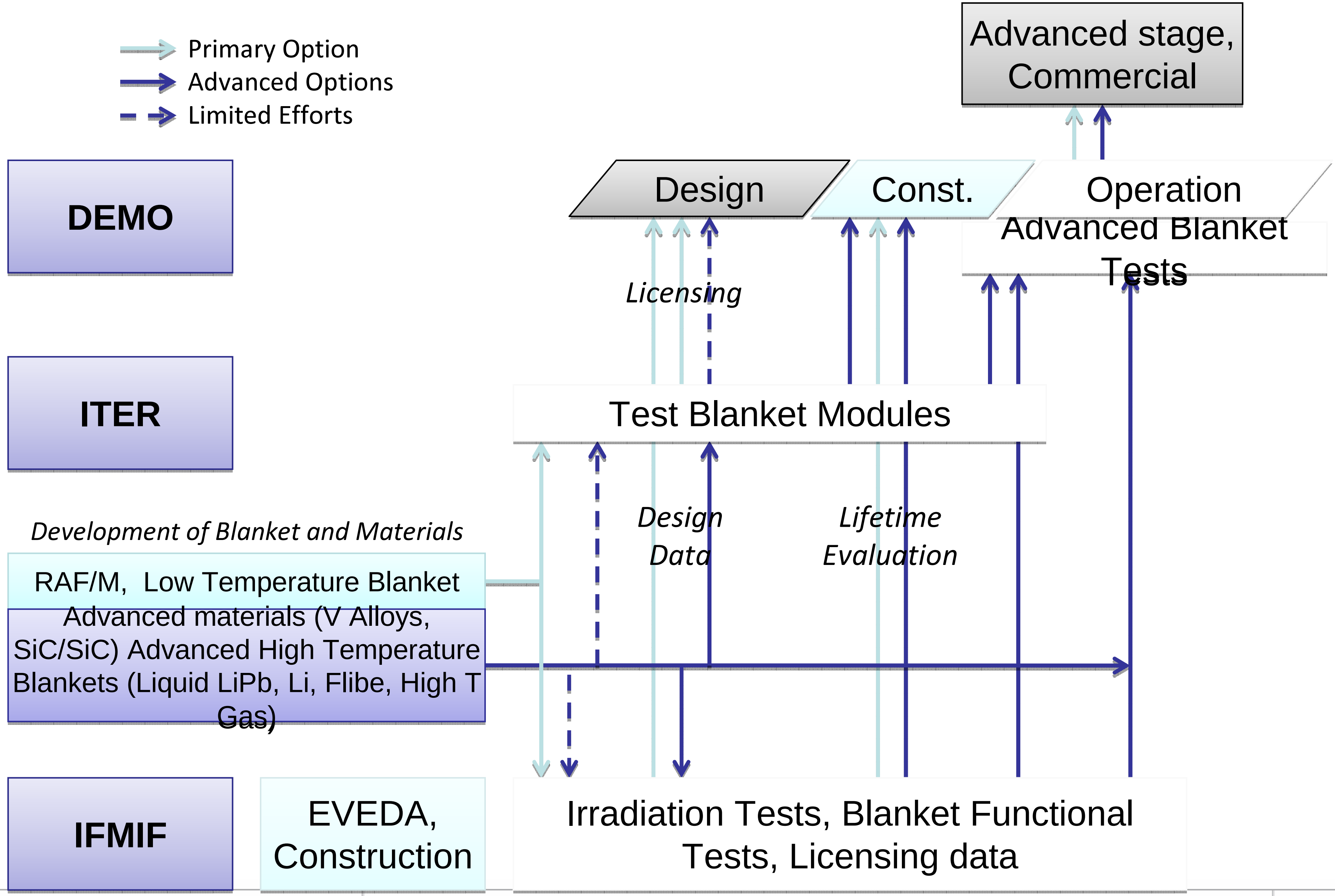


# The Tokamak concept

- operationally, it is essentially an electrical transformer
- toroidal magnetic field is produced by external magnetic field coils
- plasma current produces poloidal magnetic field
- result is a set of nested helical surfaces
  $\Rightarrow$ plasma confinement



# Fusion Power to the Grid: ITER – IFMIF - DEMO



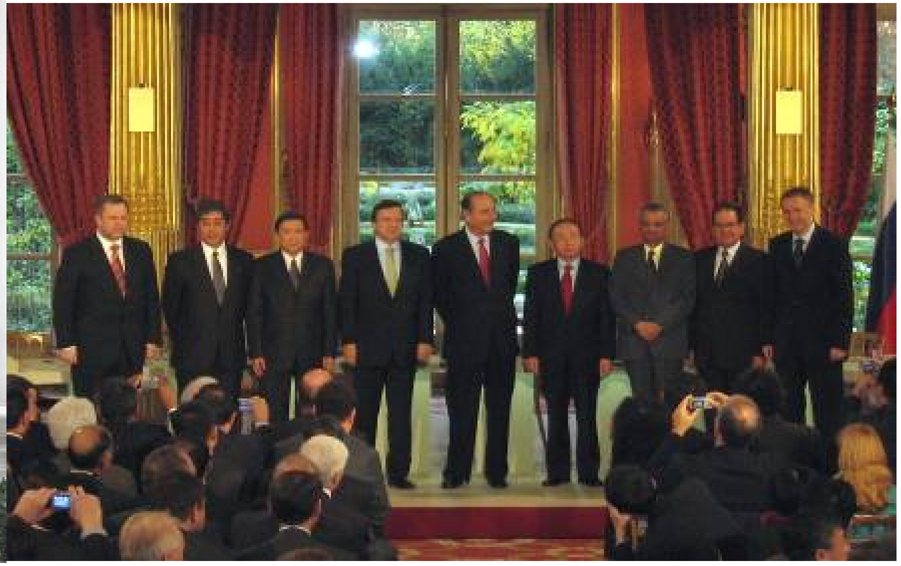
# ITER -the way to fusion energy

# The Way to Fusion Power – The ITER (Hi-)story

"***For the benefit of mankind*** "

The idea for ITER originated from the Geneva Superpower Summit in 1985 where Gorbachev and Reagan proposed international effort to develop fusion energy…

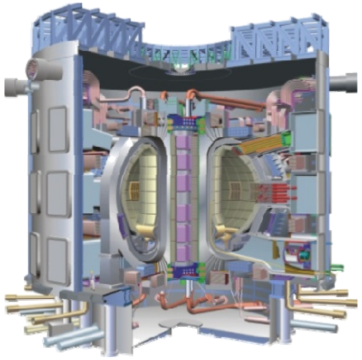
…"*as an inexhaustible source of energy for the benefit of mankind*".

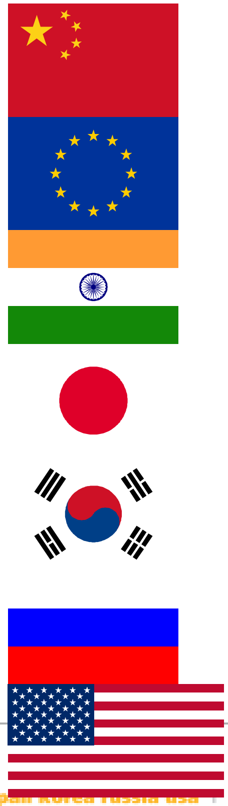


November 21, 2006: China, Europe, India, Japan, Korea, Russian Federation and the United States of America sign the ITER Agreement

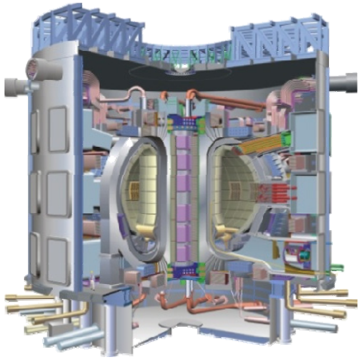

Monaco
Nice
Cadarache
Cannes
Aix-en-Provence
Marseille
Saint-Tropez

# Broader Approach agreement

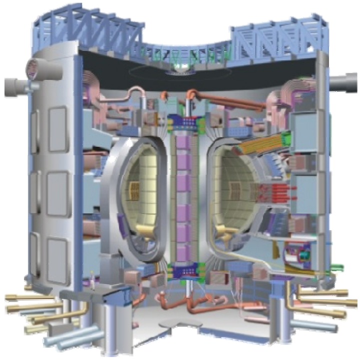


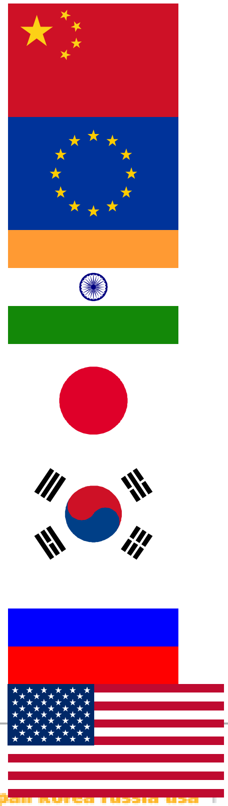


# Broader Approach agreement

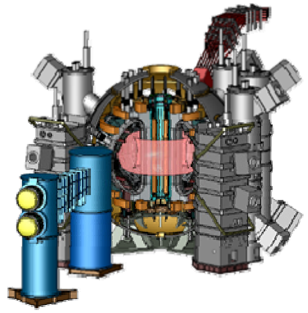


# Broader Approach agreement



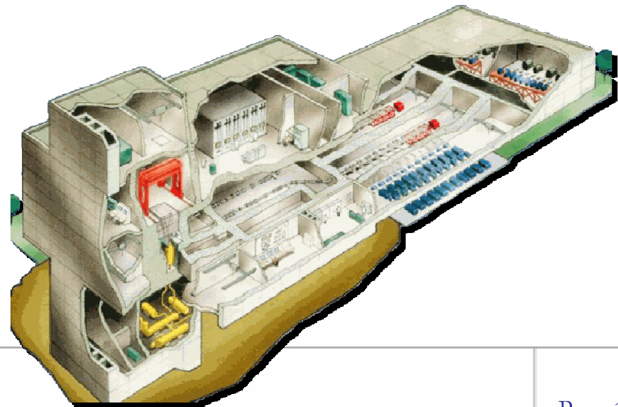


JT60-SA

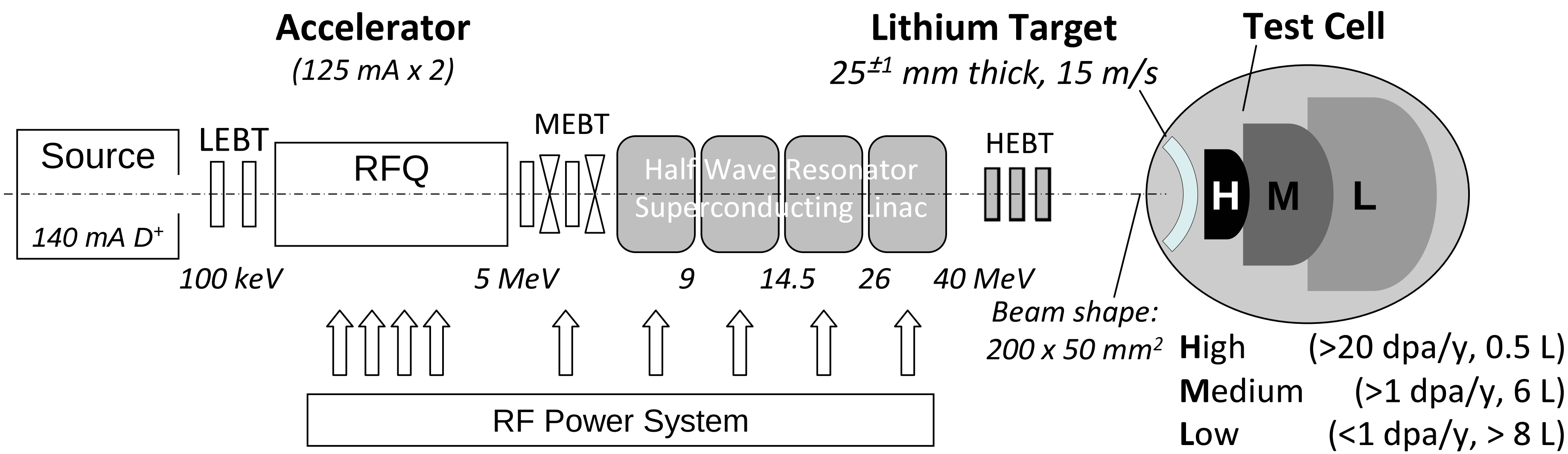


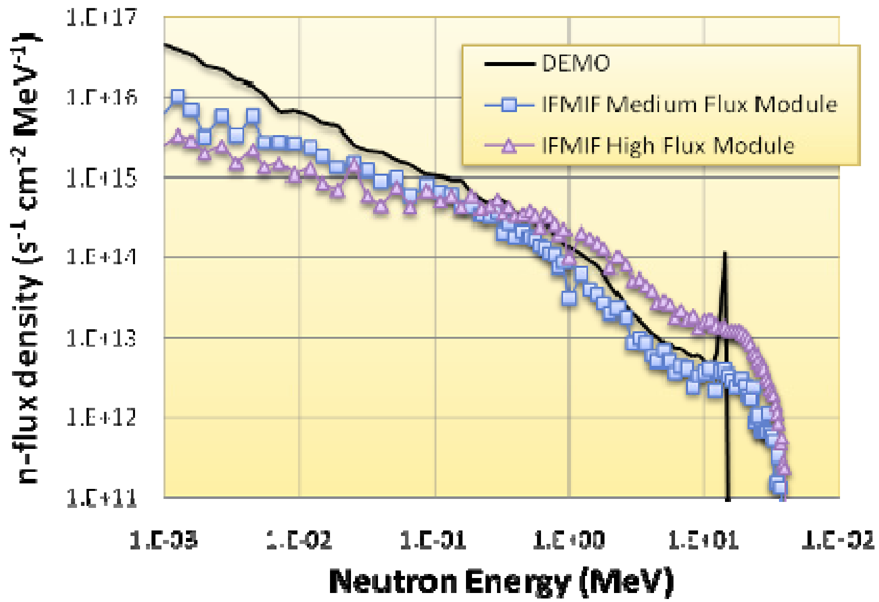
IFERC

IFMIF/EVEDA



# Principle of IFMIF



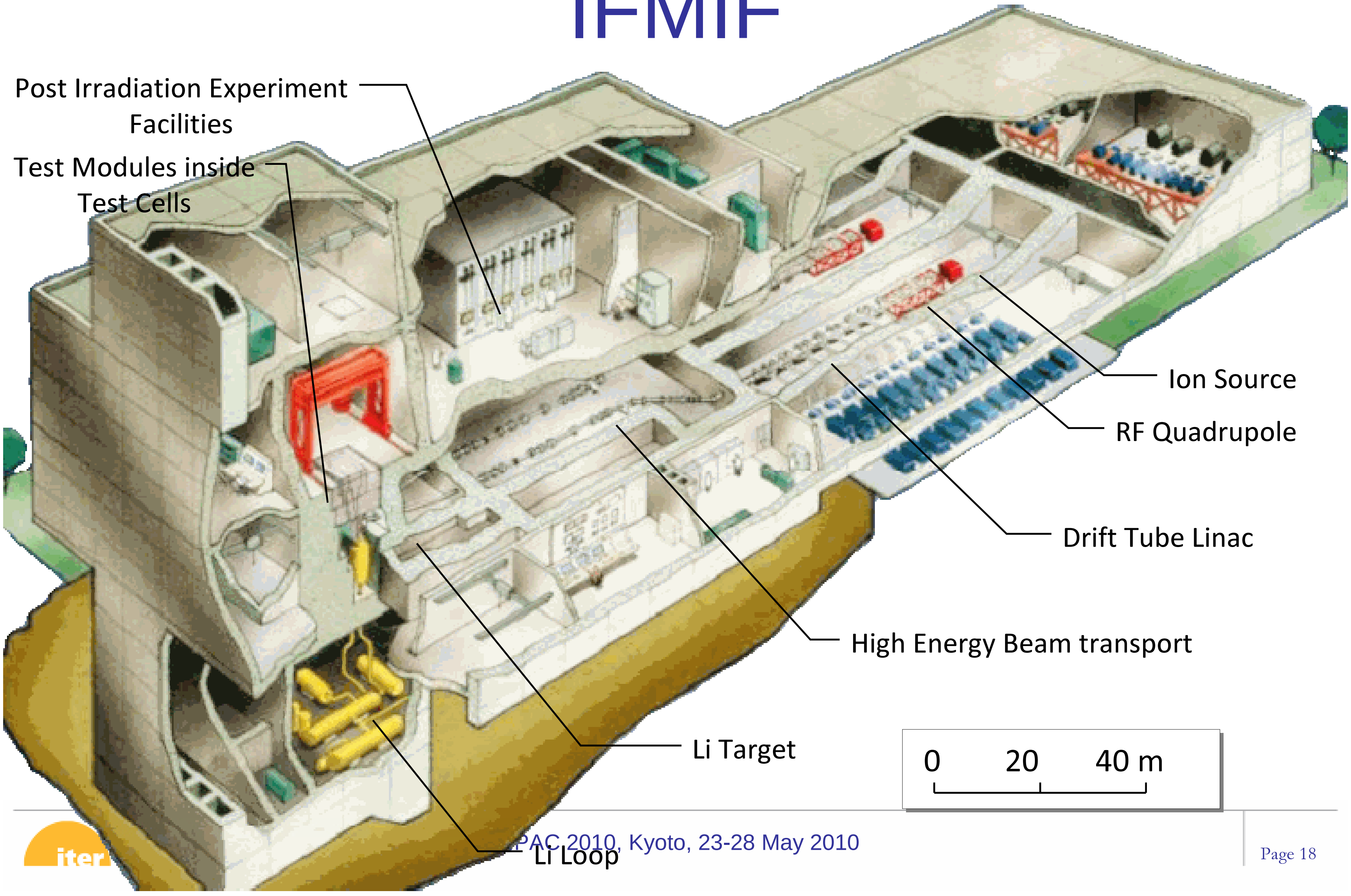

Typical reactions

$^{7}Li(d,2n)^{7}Be$

$^{6}Li(d,n)^{7}Be$

$^{6}Li(n,T)^{4}He$

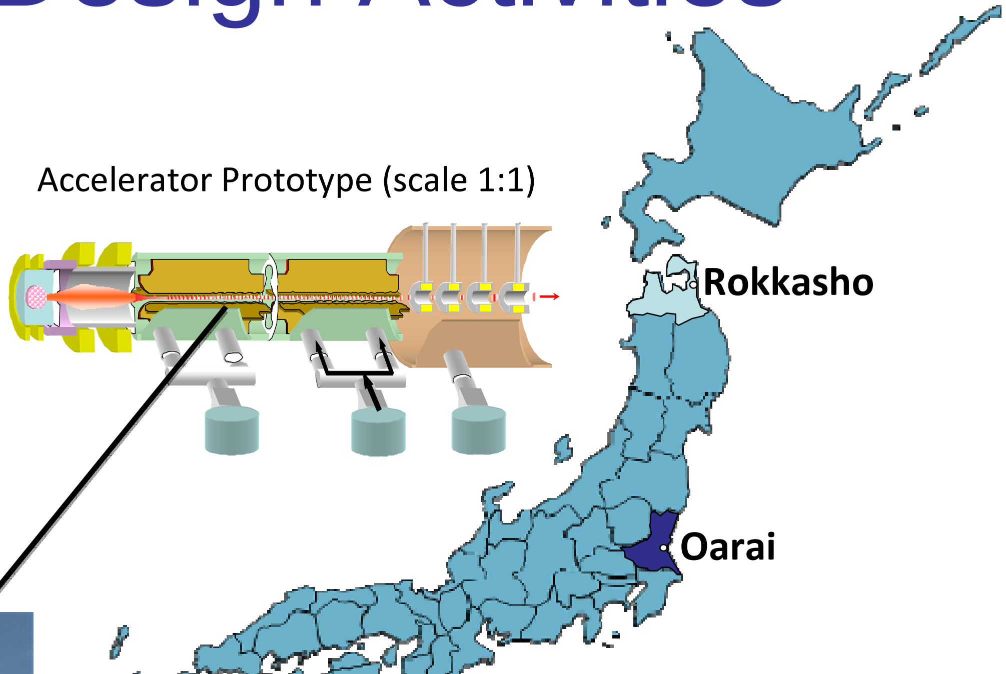
# IFMIF


Post Irradiation Experiment Facilities
Test Modules inside Test Cells
Ion Source
RF Quadrupole
Drift Tube Linac
High Energy Beam transport
Li Target
Li Loop
0 20 40 m

# Engineering Validation & Engineering Design Activities

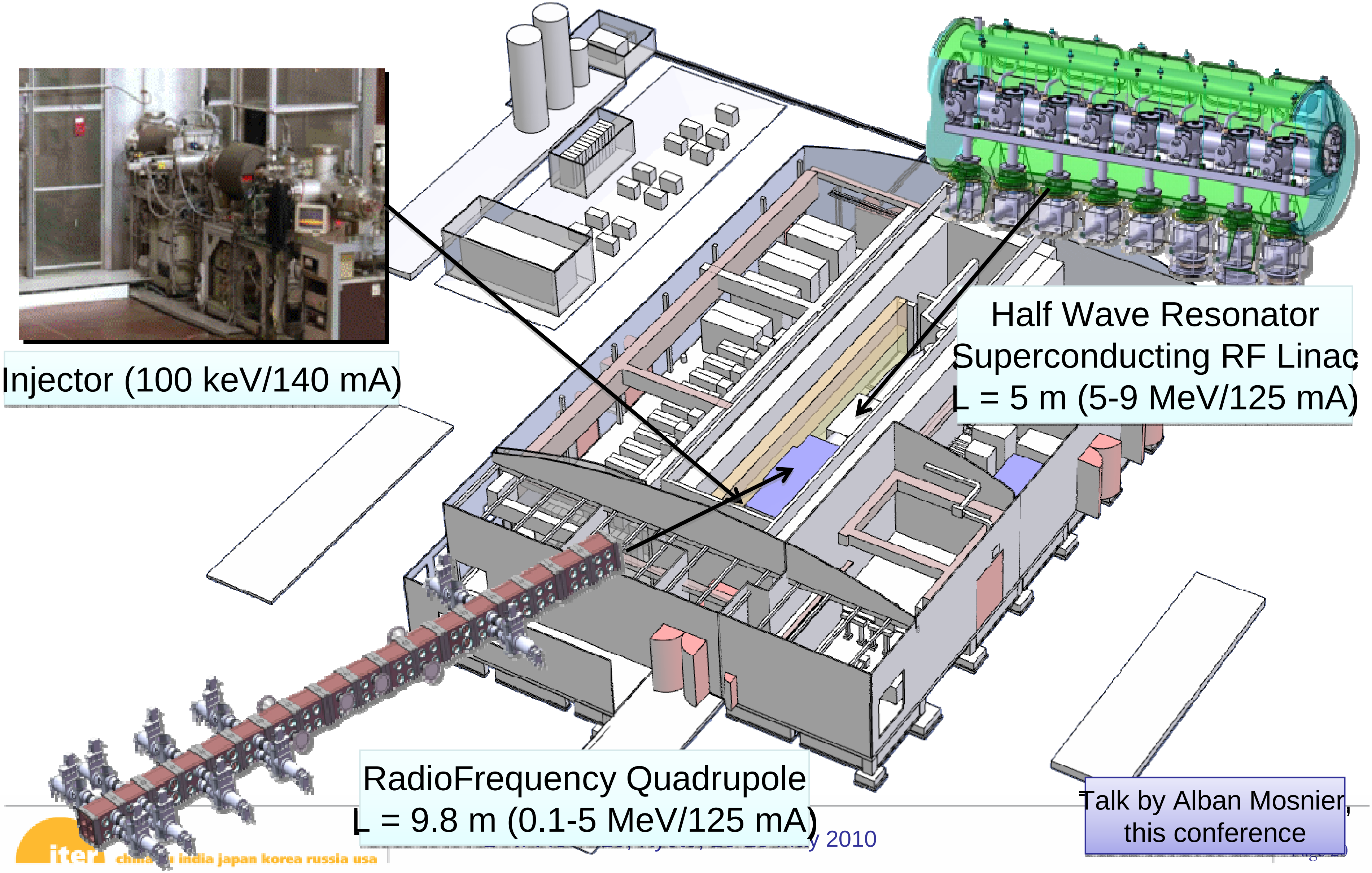
- Engineering Validation
  - The Accelerator Prototype
  - The Lithium Test Loop
  - High Flux Test Modules
- Engineering Design
  - Of the whole IFMIF Plant

Accelerator Prototype (scale 1:1)





# IFMIF/EVEDA Project – Accelerator Development




- The ITER Organization and the ITER Domestic Agencies: 80% of the ITER construction is “In-Kind”

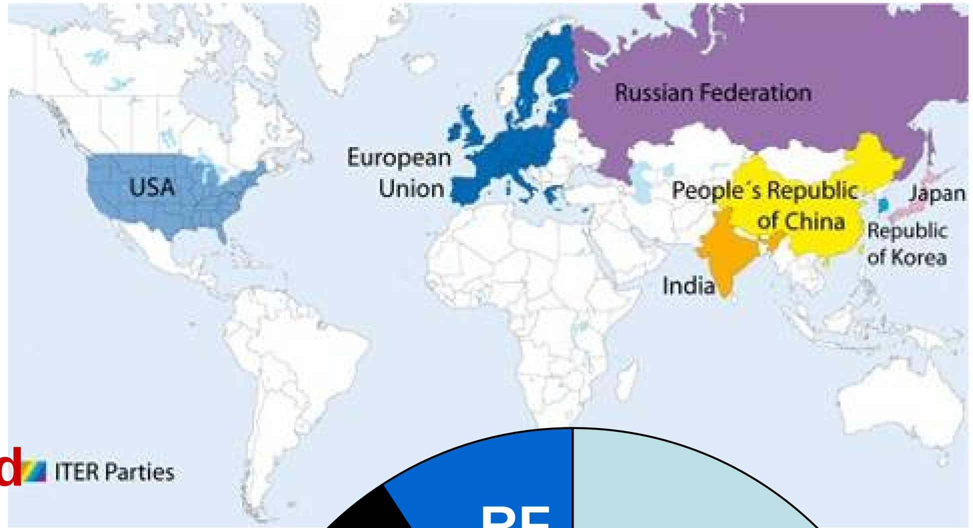
# ITER – Key Facts

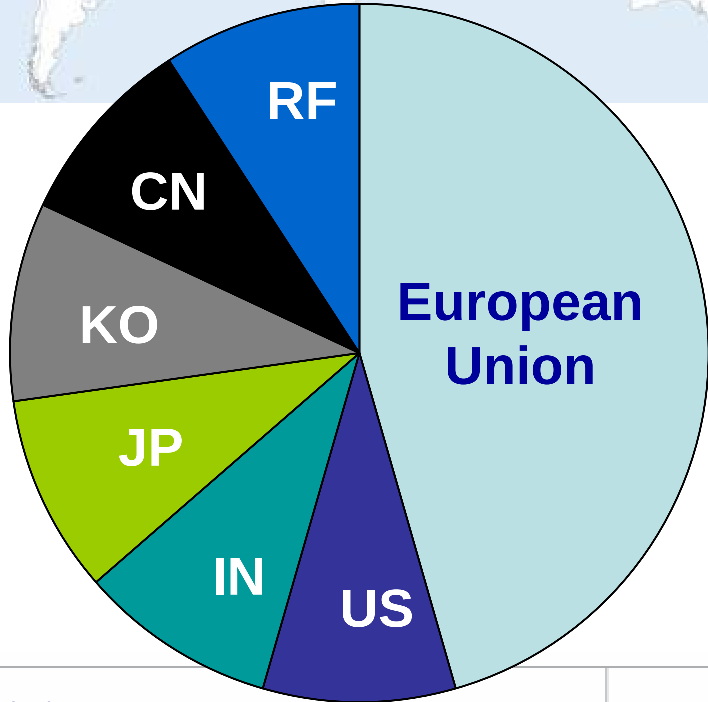
- **Mega-Science Project among 7 Members:**
  **China, EU, India, Japan, Korea, Russia & US**

- **10 years construction, 20 years operation**

- **Cost: ~5.6 billion Euros approved for construction, and ~5.5 billion for operation and decommissioning**

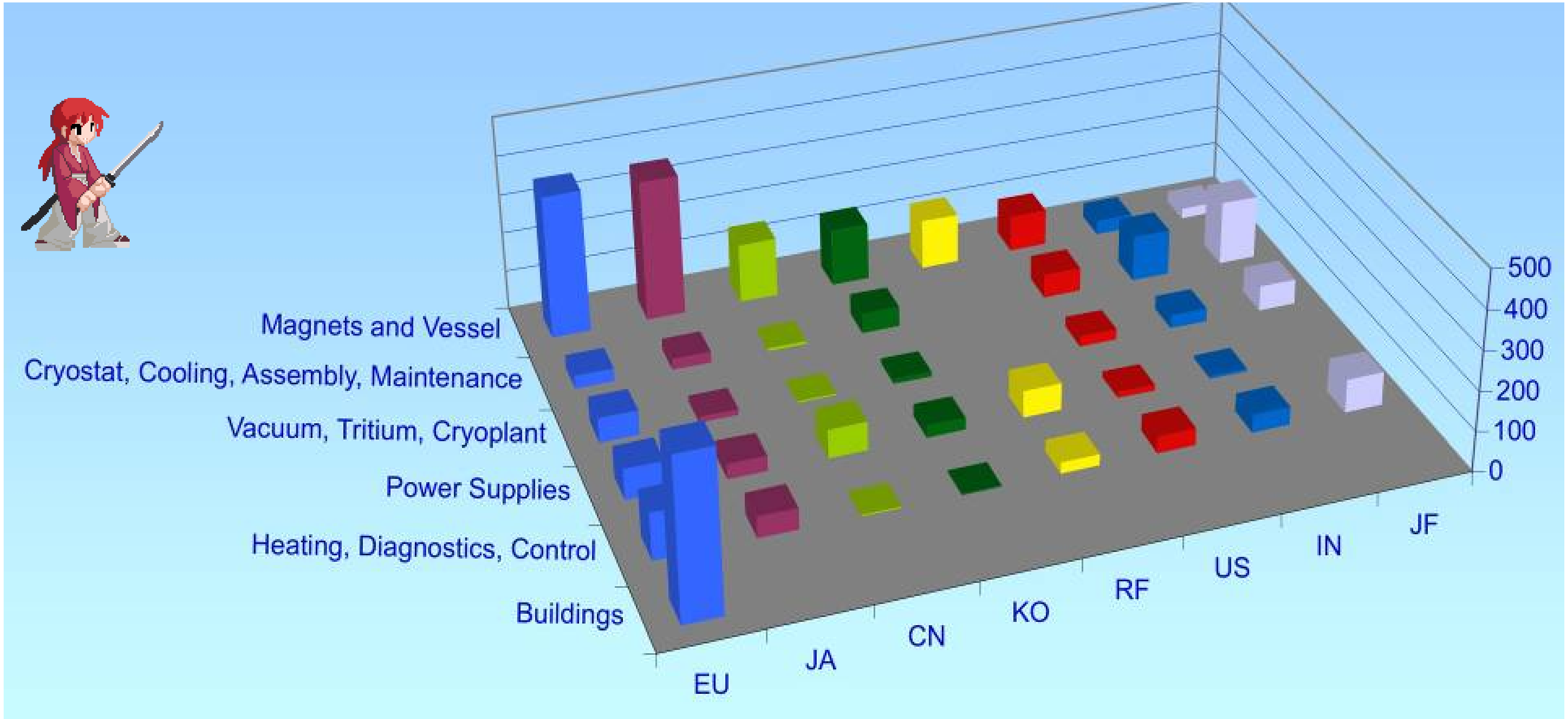
- **EU 5/11, other six parties 1/11 each. Overall reserve of 10% of total.**



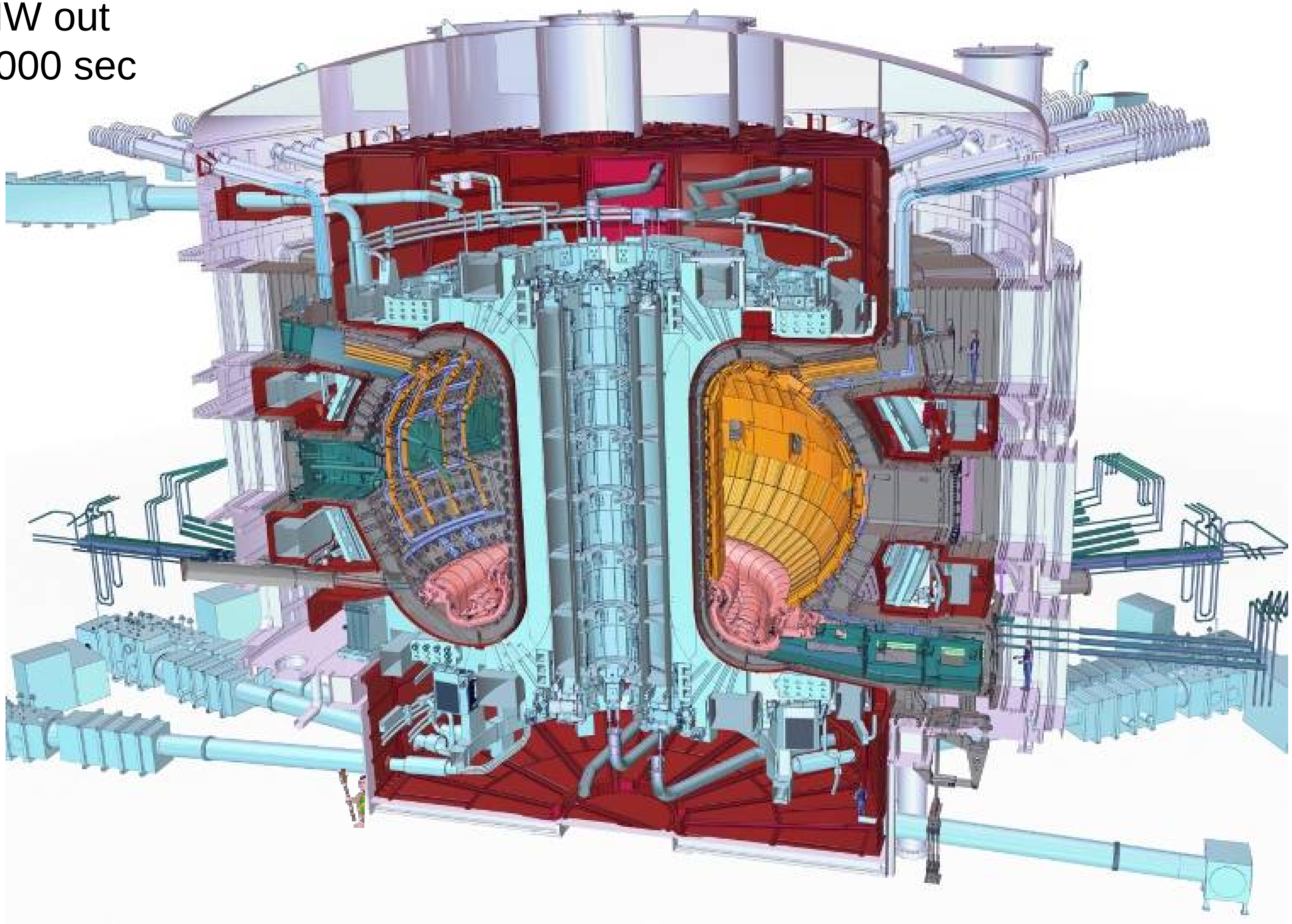
# Procurement Sharing

- A unique feature of ITER is that almost all of the machine will be constructed through *in kind* procurement from the Members with essentially every member involved in every component.
- As of today, there are a total of 44 signed Procurement Arrangements, amounting to 1729 kIUA (approximately EUR 2683.7 million), about 60% of the total in-kind PA value; Among them the major systems: buildings, vacuum vessel, magnets
- 16 PAs are scheduled to be signed byond 2010 for a total of 433 kIUA (an estimated EUR 671.9 million). At this point more than 75% of ITER will be under contract.



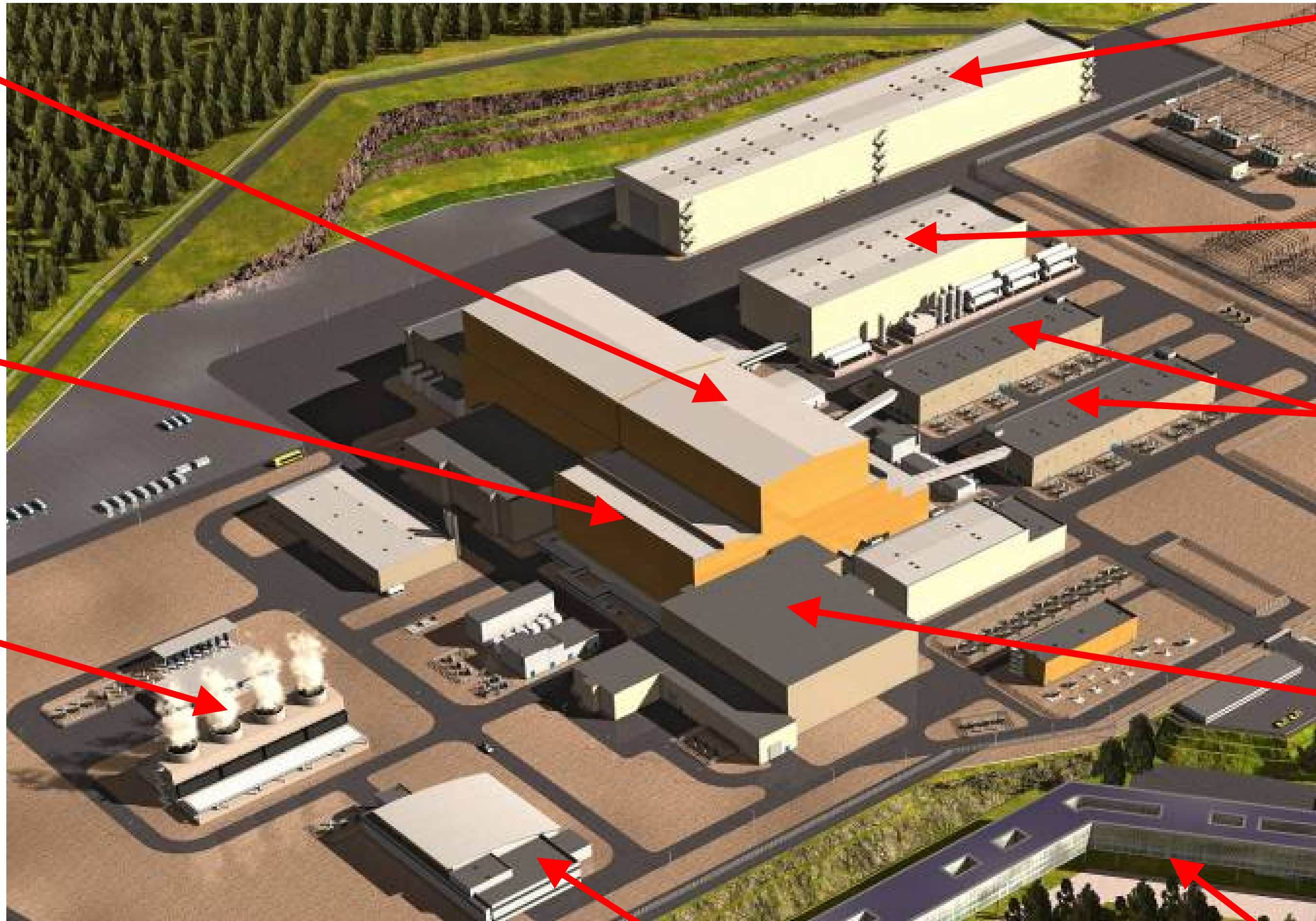
# Technical Baseline

Q > 10
500 MW out
300-3000 sec



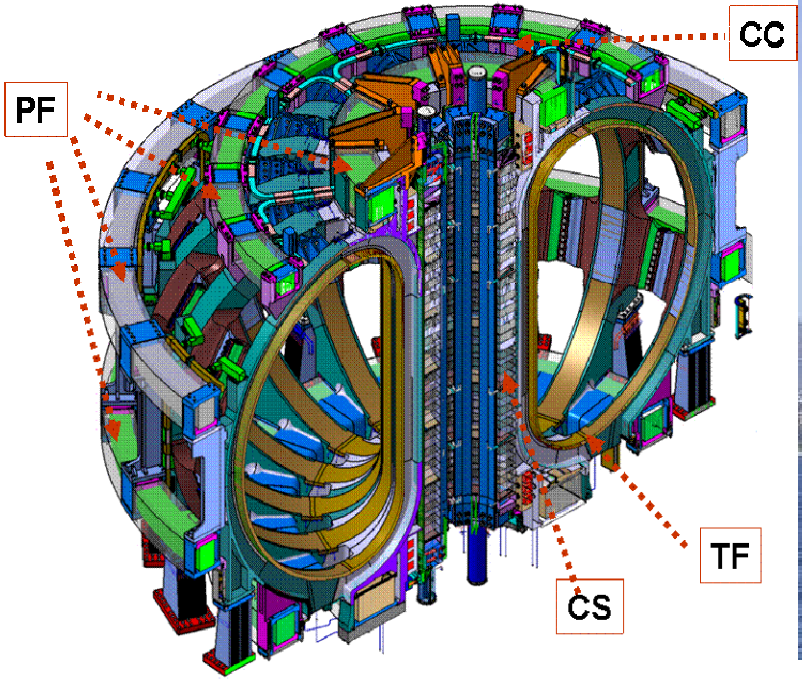
# Main Buildings on the ITER Site

**A facility licensed under the French Nuclear Regulatory Authority (ASN)**




- **Will cover an area of about 60 ha**
- **Large buildings up to 250m long**
- **Large number of systems**

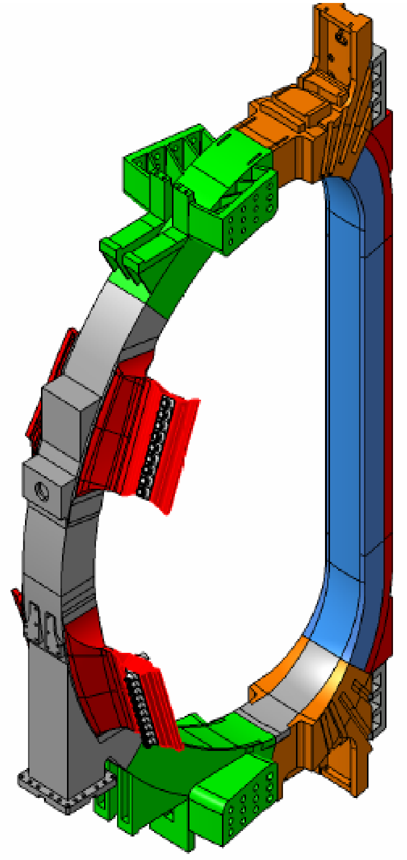
# Magnet Energy Comparison




**Superconducting Magnet Energy:**
**~51 GJ**

**Charles de Gaulle Energy:**
**~38000 t at ~150 km/hr**

# TF Coil – Mass Comparison




**Mass of (1) TF Coil:**
**~360 t**
**16 m Tall x 9 m Wide**

**Boeing 747-300**
**(Maximum Takeoff Weight)**
**~377 t**

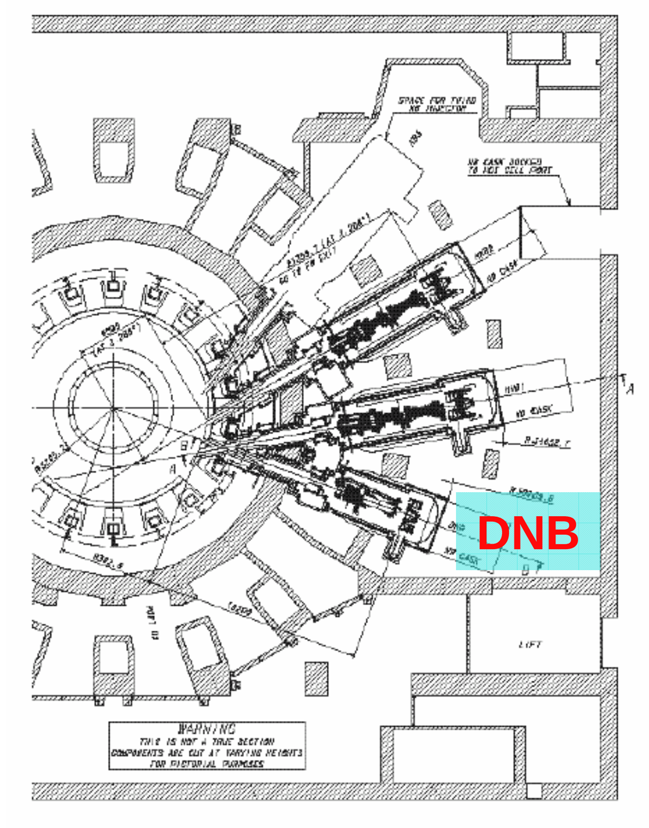
# TF and CS Jacketing in JA


TF & PF Jacketing Lines at ASIPP (March−June 09)

# ITER Heating and Current Drive

| Heating System | Stage 1 | Possible Upgrade | Remarks |
|---|---|---|---|
| **NBI** (1MeV Šive 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 $\Omega_{He3}$ (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 | | 126 or 170GHz |
| Diagnostic Beam (100keV, $H^-$) | >2 | | |

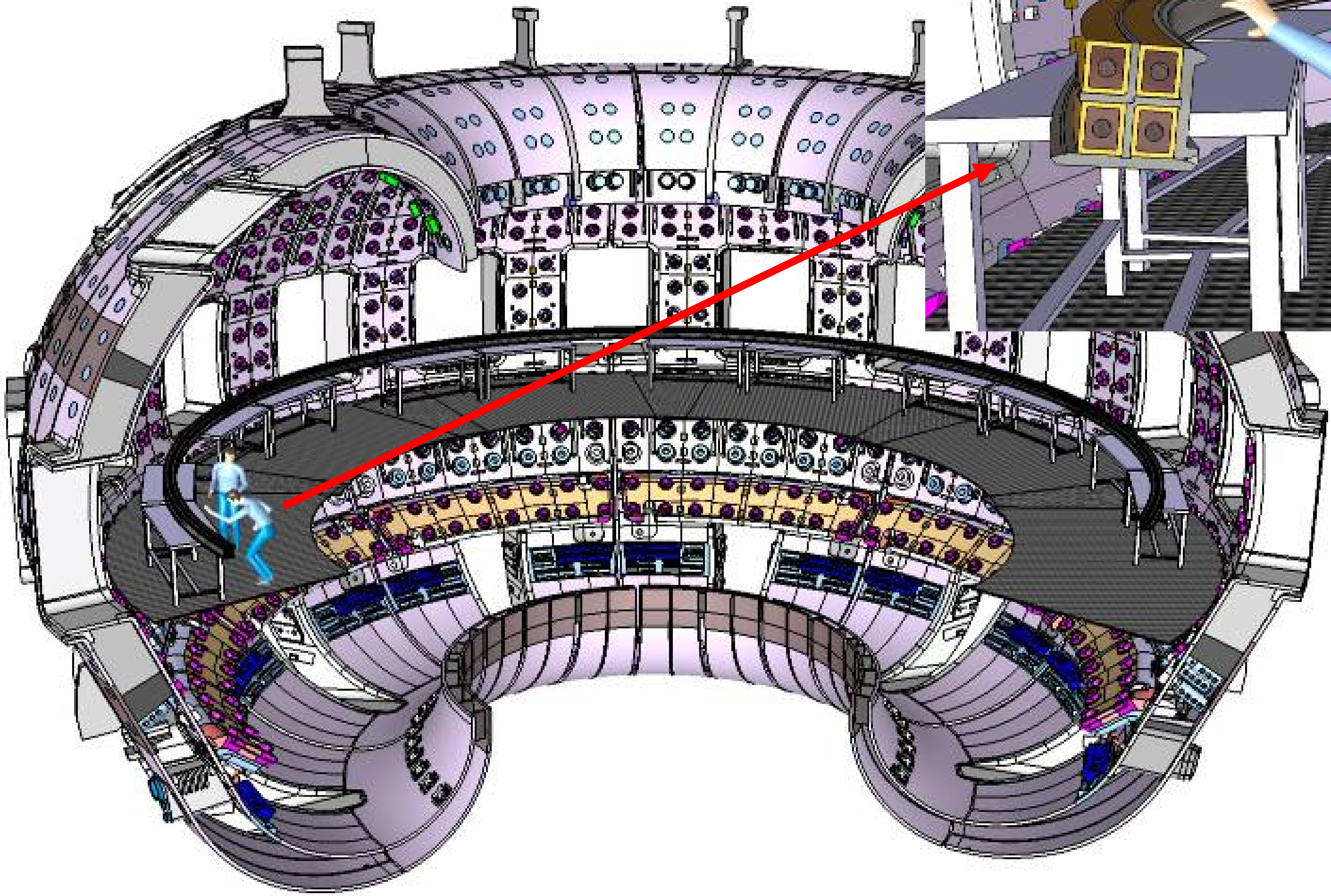
NBI Layout

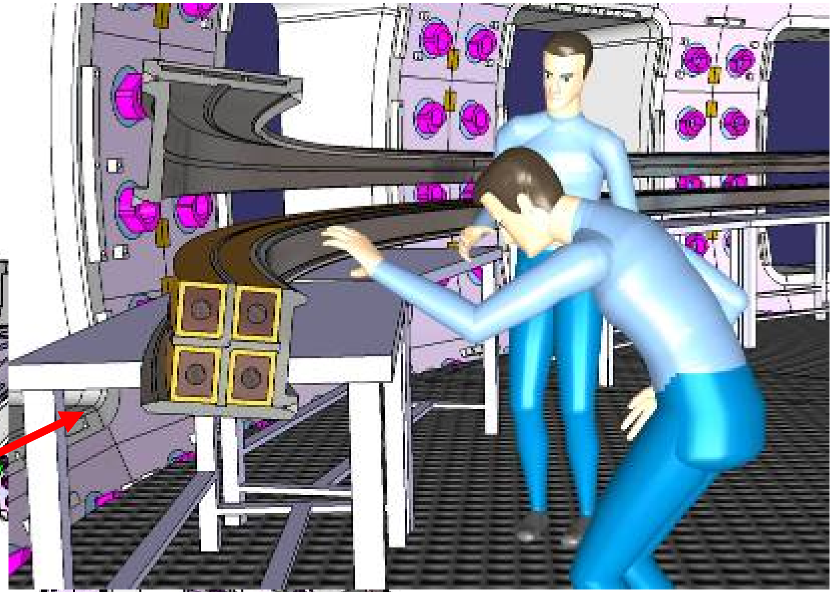



**$P_{aux}$ for Q=10 nominal scenario: 40-50MW**

# Internal Feedback Coil

In Vessel coils for Vertical Stability





Ongoing R&D for the project

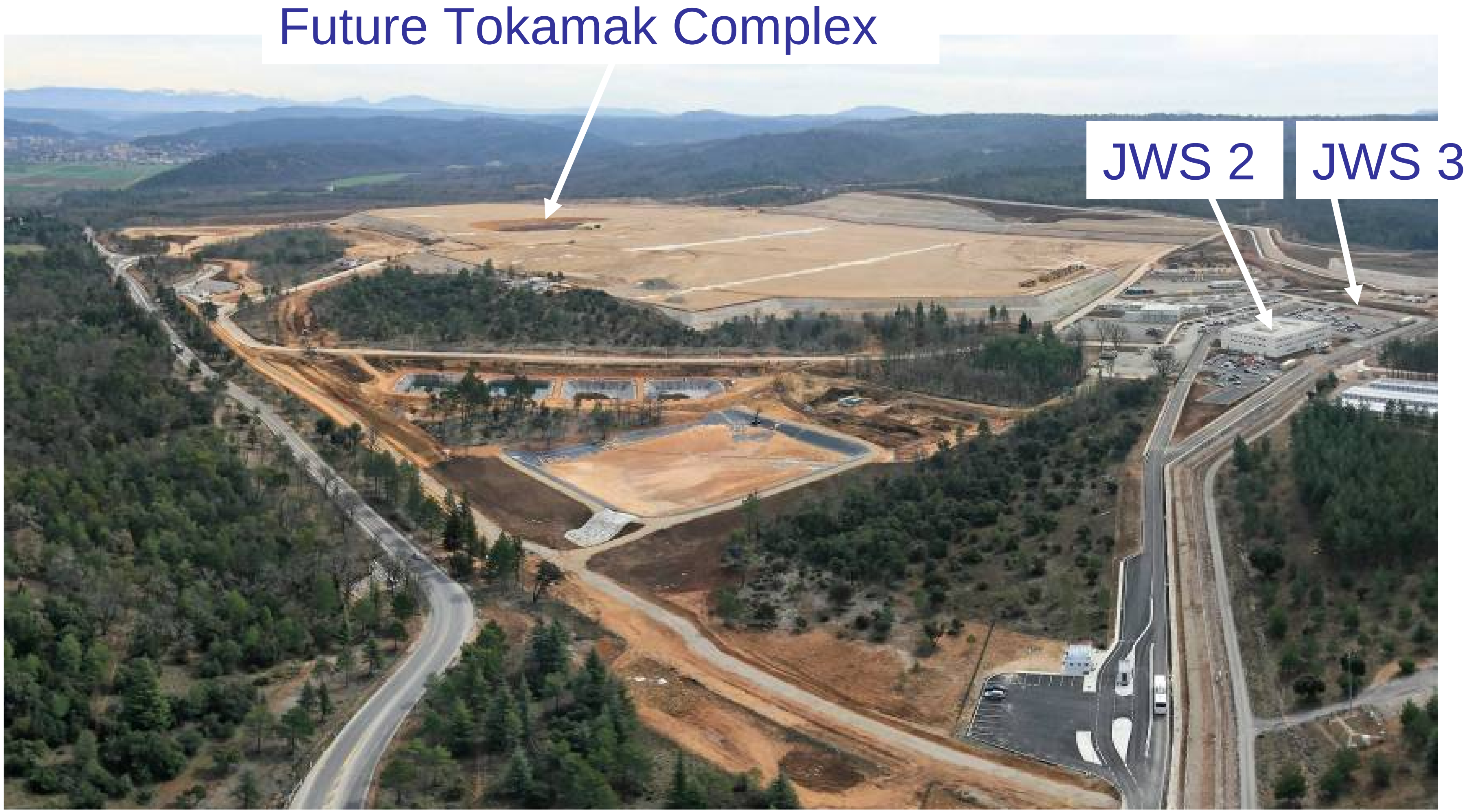
# Project Status: Scope – Schedule - Cost

- Following a design review that finished in 2007, the scope of ITER was fixed in June 2008. In parallel actual cost and an executable schedule was developed. [When this talk was given in 2006, First Plasma should happen approximately 8 years after construction begin (2016)]

- The "First Plasma" initiation is planned for Nov 2019. Deuterium - Tritium Operation for 2026. Between 2019 and 2026 a series of final construction steps and upgrades will lead to full performance operation.

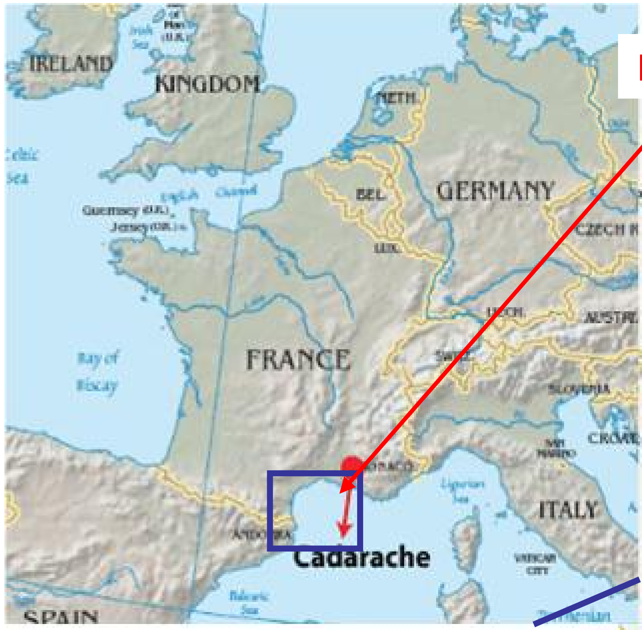
- The council will [should] approve in June 2010 the baseline together with the cost increase of ITER in its next meeting.

# Present ITER Construction Site




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

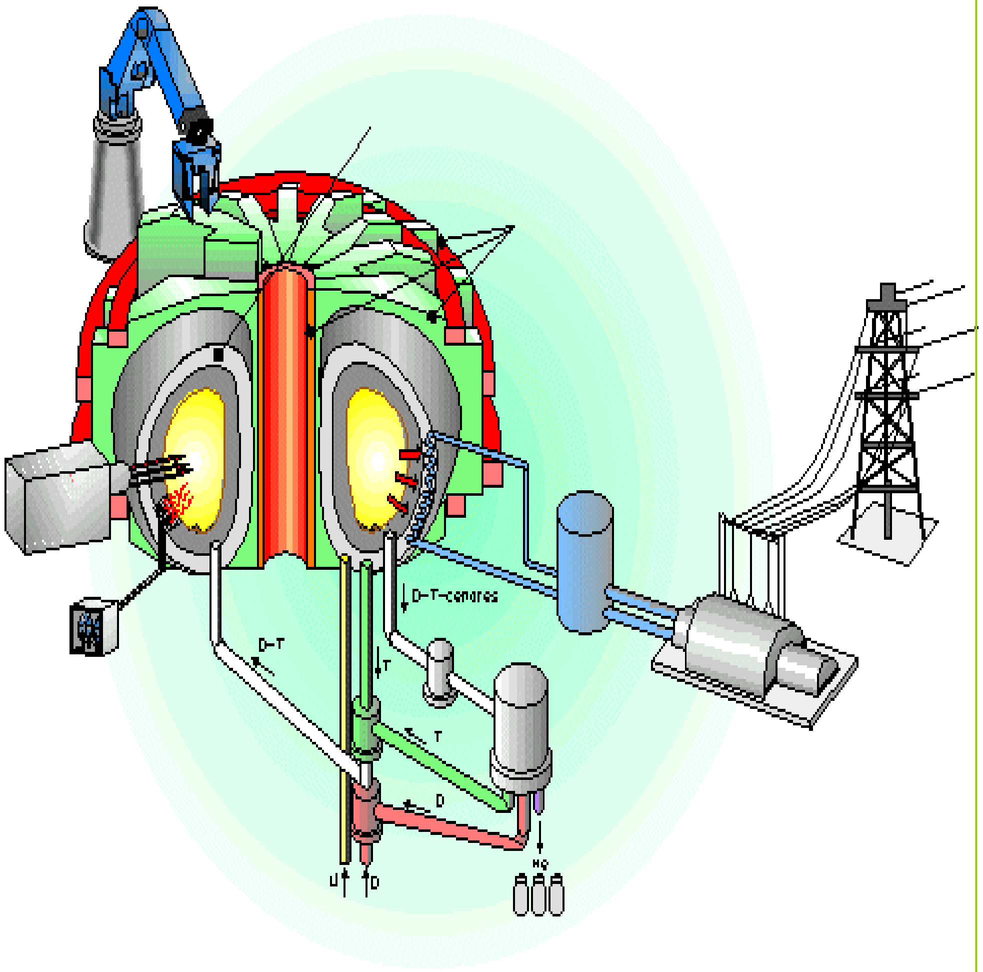
# Itinerary of ITER Components




ITER Site

= Itinerary of ITER Components

# Tritium Breeding Blankets functions in DEMO




### *Three crucial functions*

- **Convert** the neutron energy (80% of the fusion energy) in heat and collect it by mean of an high grade coolant to reach high conversion efficiency (>30%)
  ➔ in-pile heat exchanger
- Produce and recover **all Tritium** required as fuel for D-T reactors (300-500 g/days)
  ➔ Tritium breeding self-sufficiency
- Contribute to neutron and gamma **shield** for the superconductive coils
  ➔ resistance to neutron damages

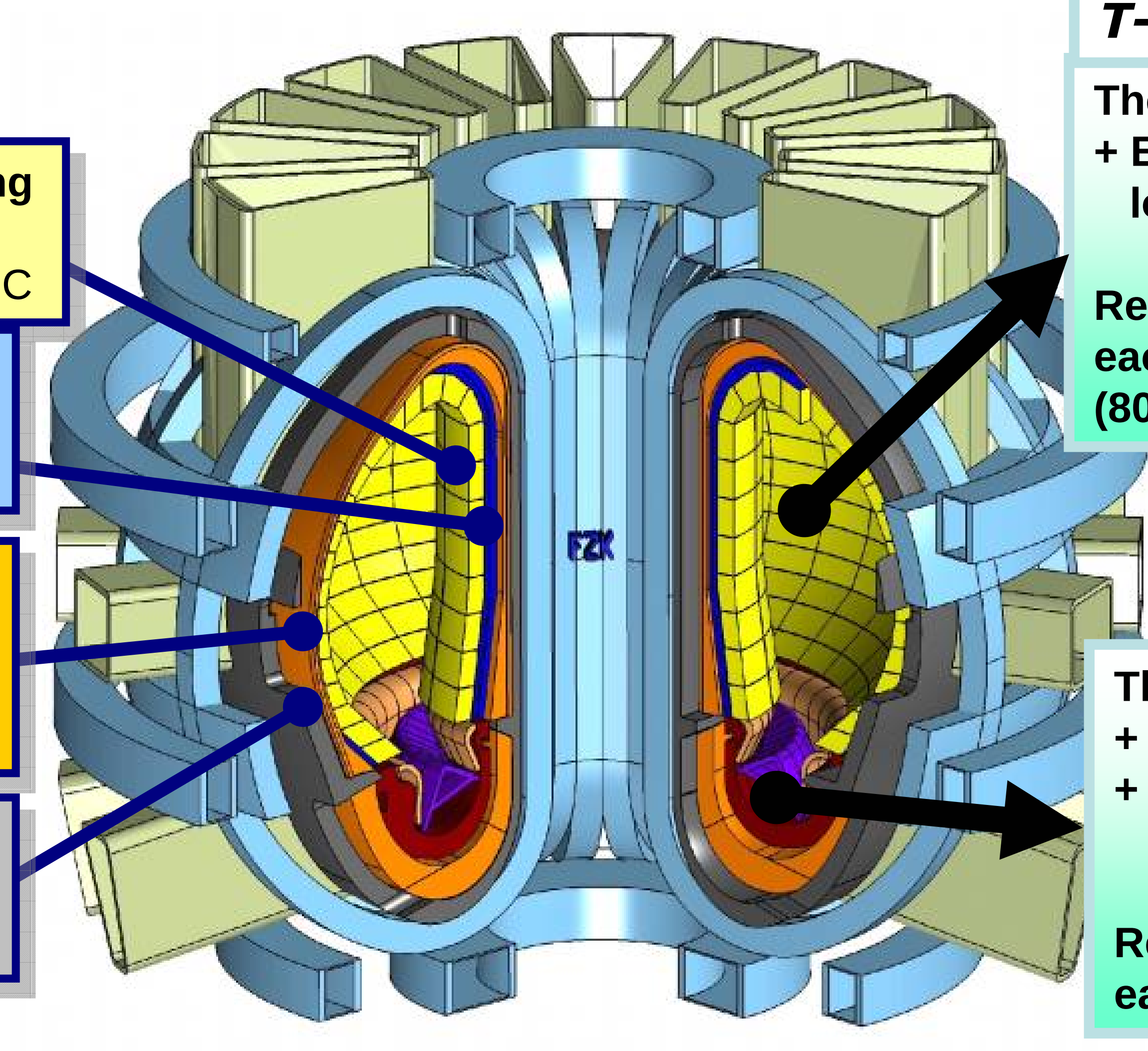
# Typical Temperatures in DEMO and constraints

**T-Breeding Blanket**
max: 550°C

**Vertical Manifold**
~320°C

**Strong Ring Shield**
~320°C

**Vacuum Vessel**
~100°C




***T-Breeding Blanket***

**Thermal transients**
**+ Electro-Magnetic (EM) loads**

**Remote replacement each 3 - 5 years (80...150 dpa)**

***Divertor***

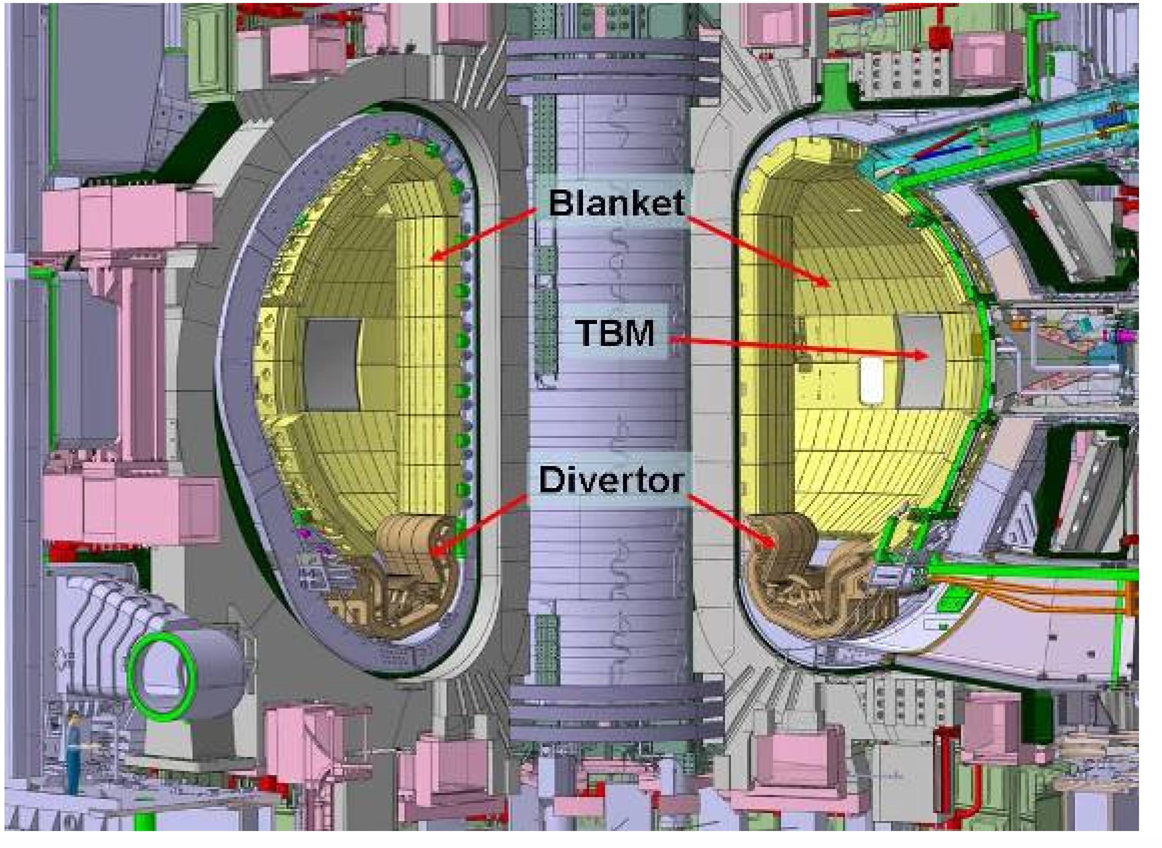
**Thermal transient**
**+ EM loads**
**+ large surface heat flux**

**Remote replacement each 1.5 - 2.5 years**

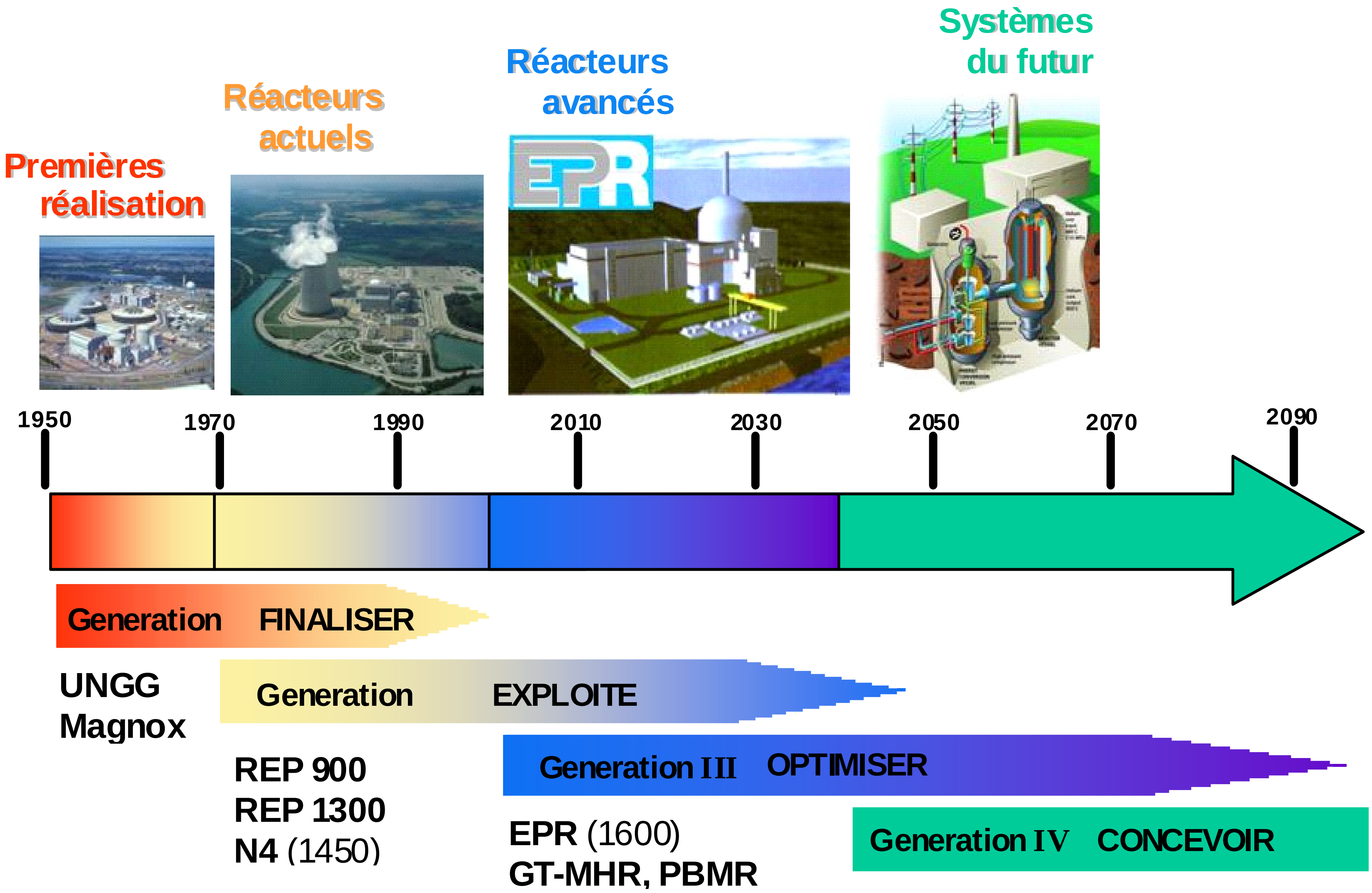
**DEMO = Demonstration Fusion Reactor Plant**

# Tritium Breeding Blankets Testing in ITER

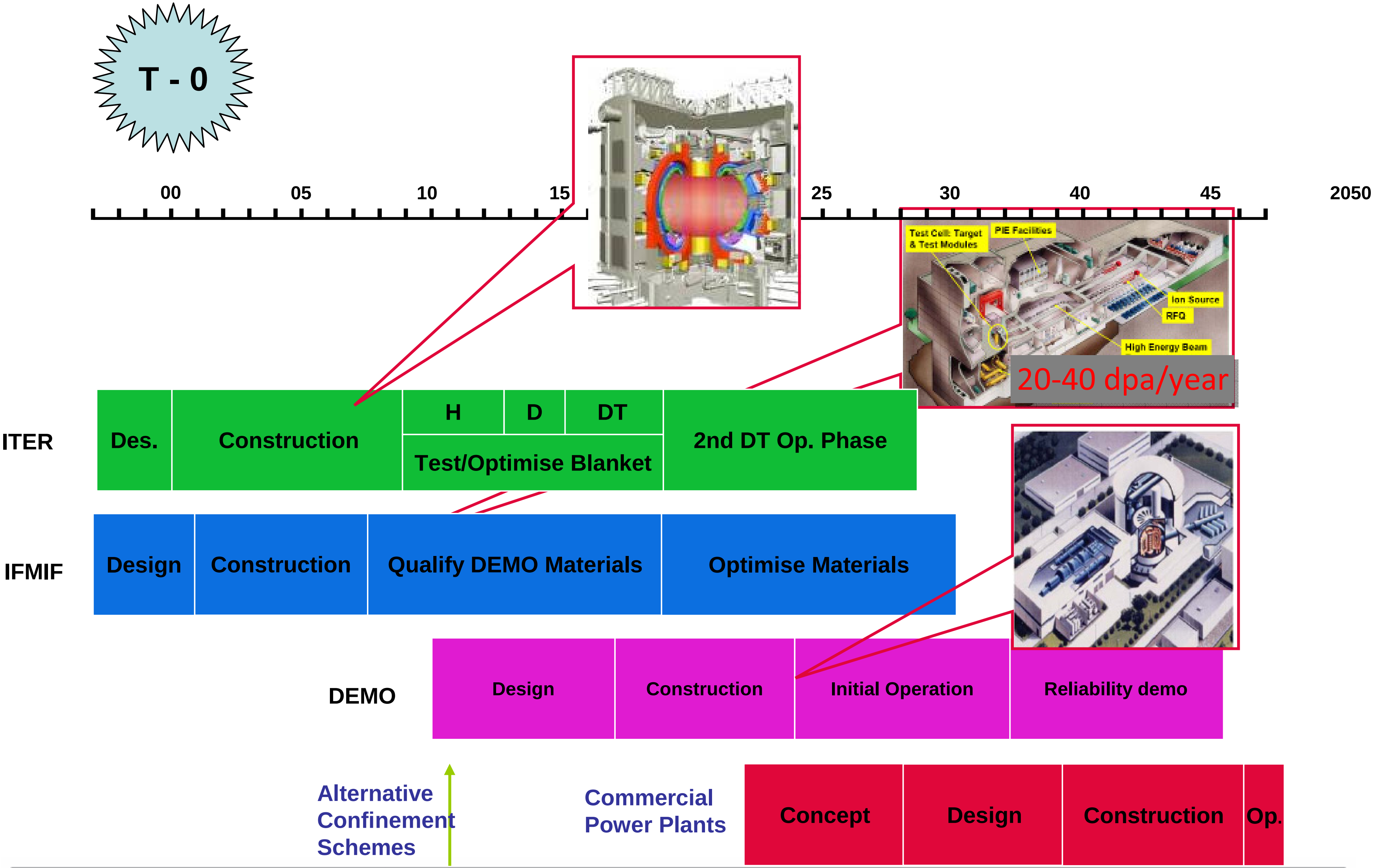
- All ITER Members participate to the TBM Program
- TBM Intellectual Property Right is especially treated



# The Roadmap Beyond ITER



# The Roadmap Beyond ITER



# What if ?

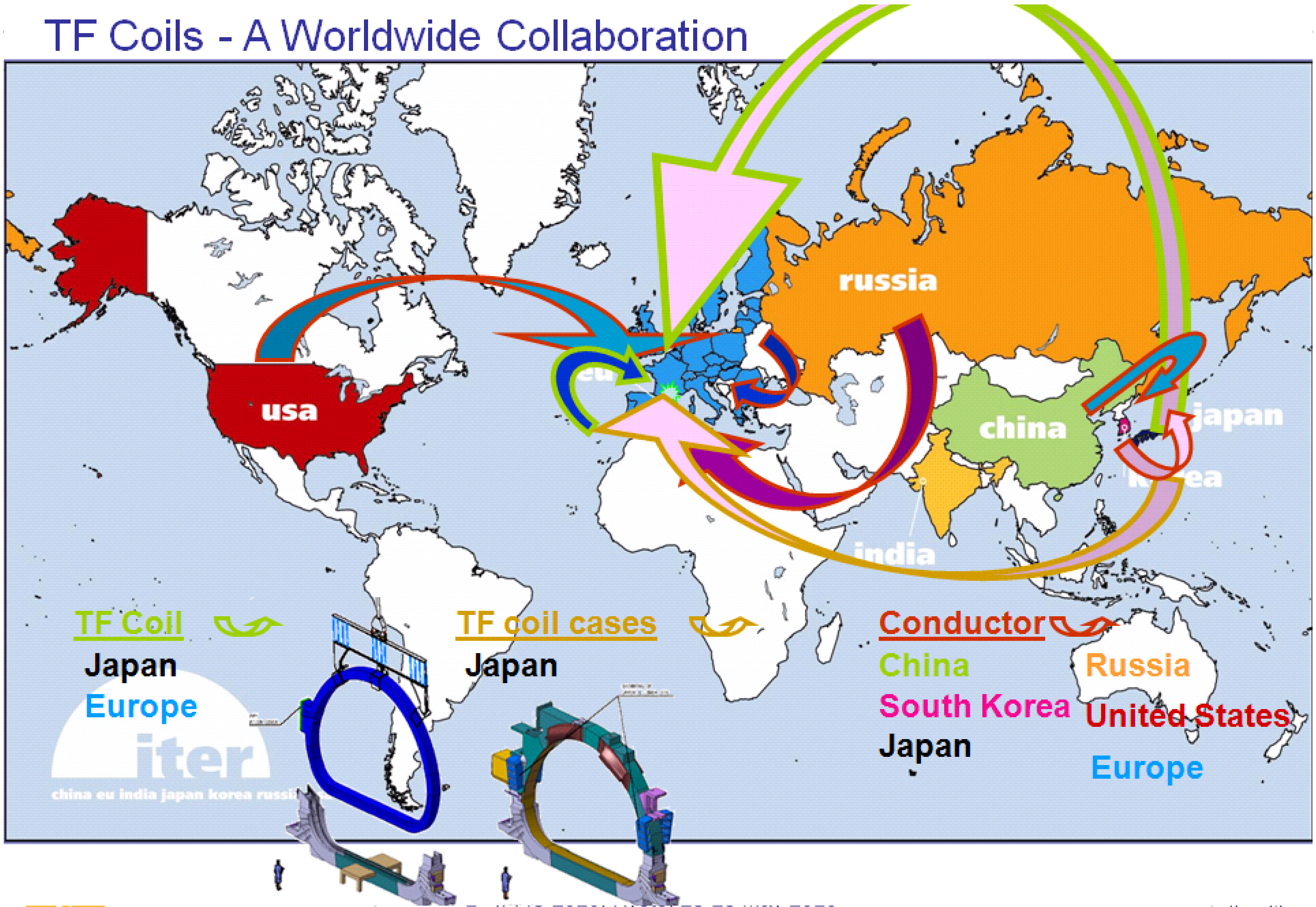
- Q>10 sustained operation is not possible
- Material development will not produce sustainable maintenance strategy
- Substantial heating system will be required with low efficiency (overall efficiency is too low!!!)

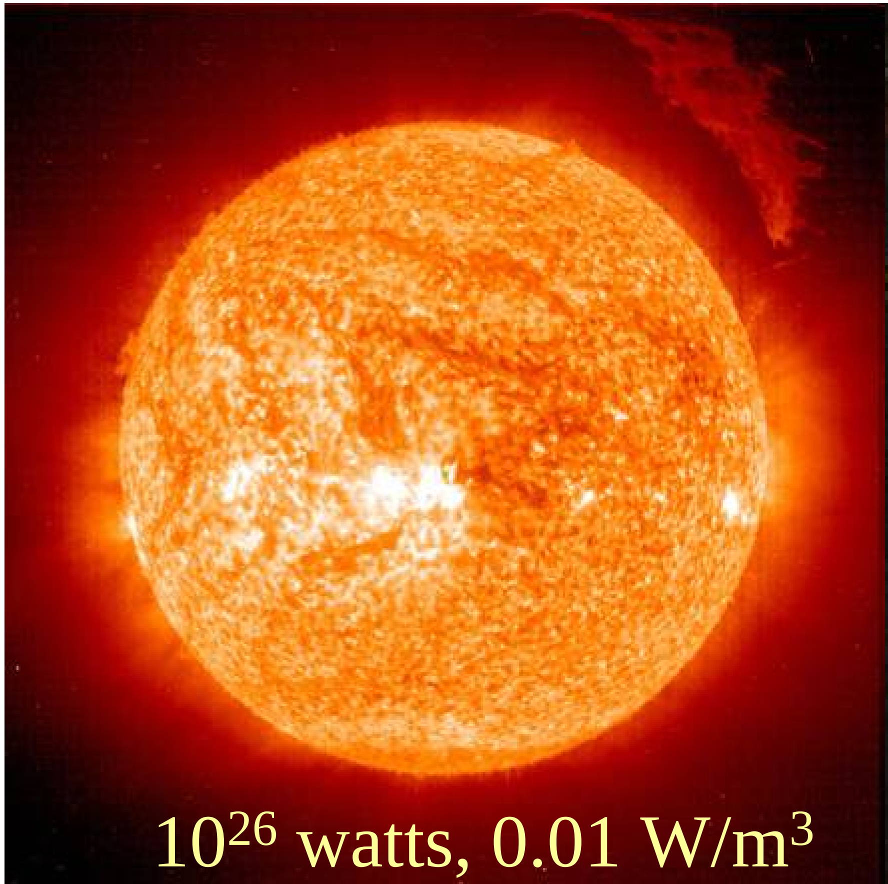
1. Nuclear fusion based on Tokamaks is not to be further developed as a direct energy source
2. Stellarator technology will need to be pushed much harder
3. There is another possibility….. The hybrid

   [http://en.wikipedia.org/wiki/Hybrid_nuclear_fusion](http://en.wikipedia.org/wiki/Hybrid_nuclear_fusion)

# backup

# TF Coils - A Worldwide Collaboration

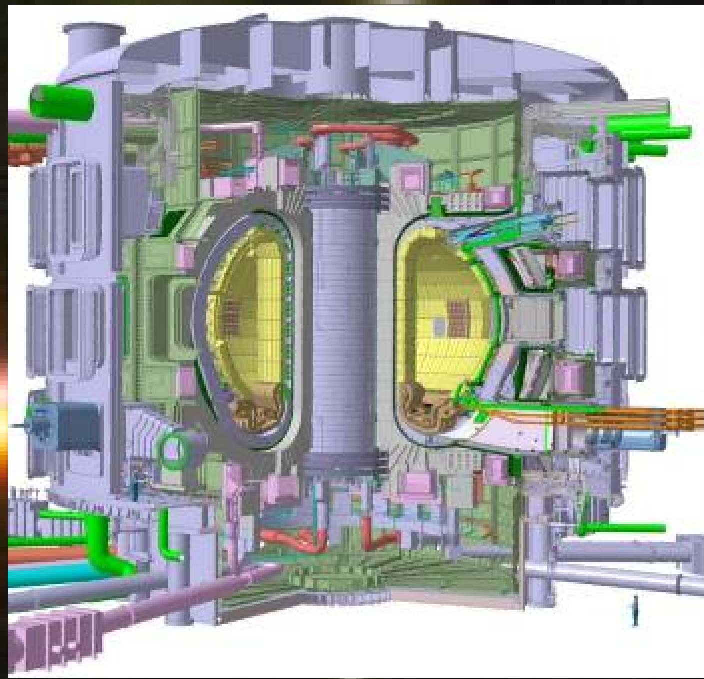




$10^{26}$ watts, 0.01 $W/m^3$

- The Sun has a radius of 0.7 Million kilometer
- A core temperature of 10 Million deg
- A surface temperature of ~4000 deg

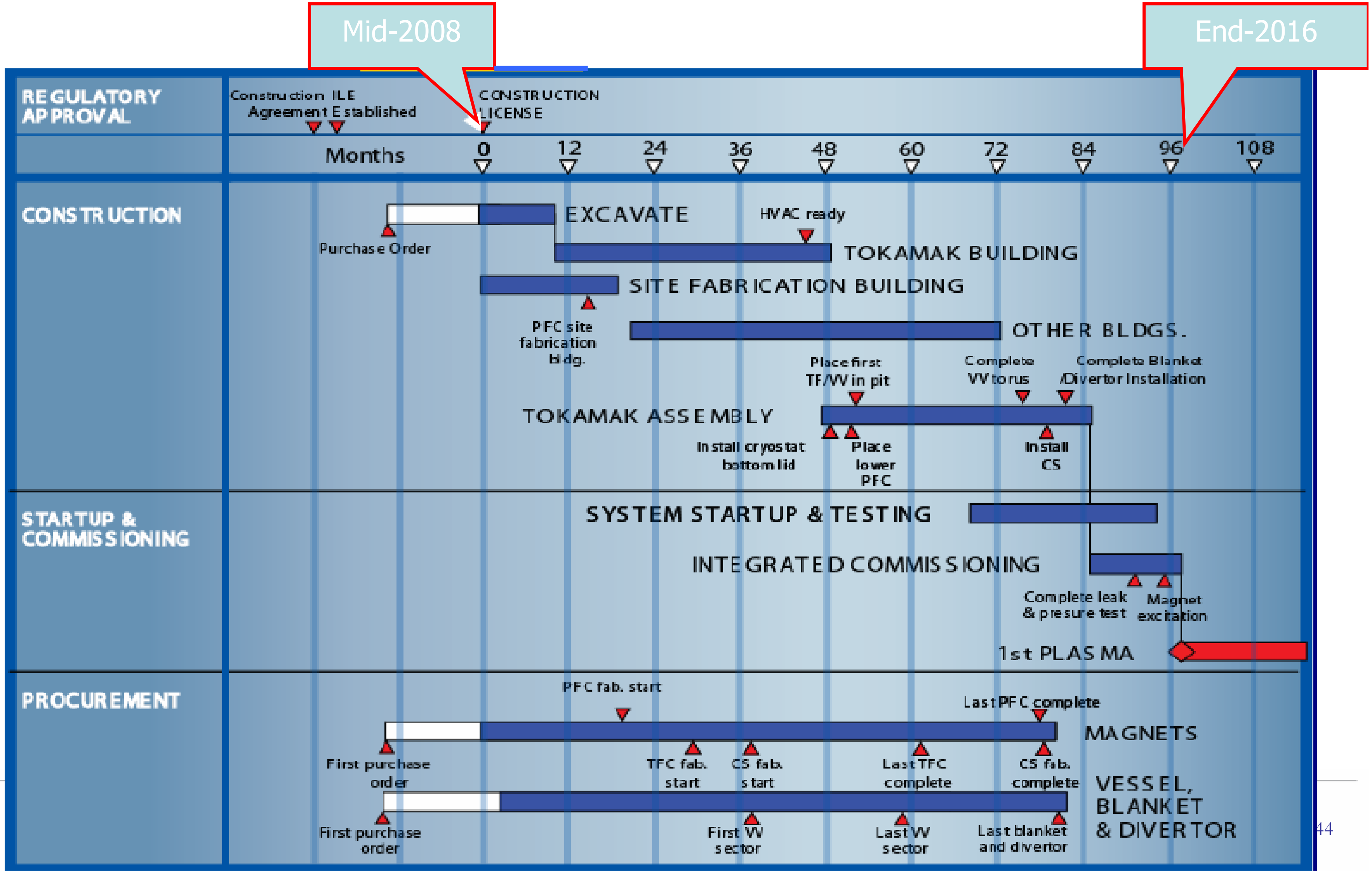
- The Tokamak chamber has a radius of 2 meter
- A core temperature of 100 Million deg
- The wall surface has a temperature of ~1000 deg



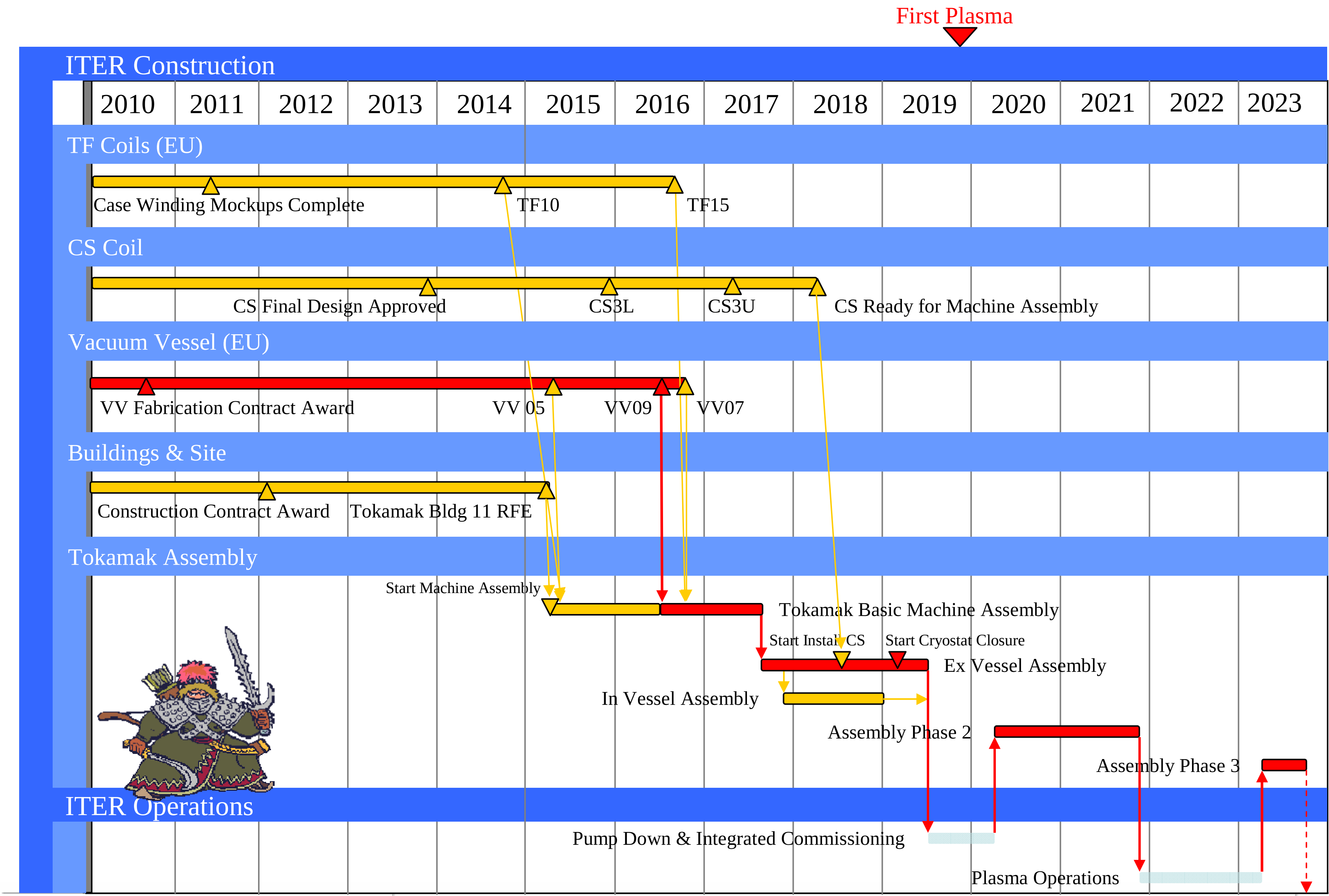
$5.10^8$ watts, $5\ 10^5$ $W/m^3$

# EPAC 2006: Construction schedule

- Construction license expected about 2 years after IO established (mid 2008).



# Schedule: 4 M€ / day in 2013 → can ITER do that?

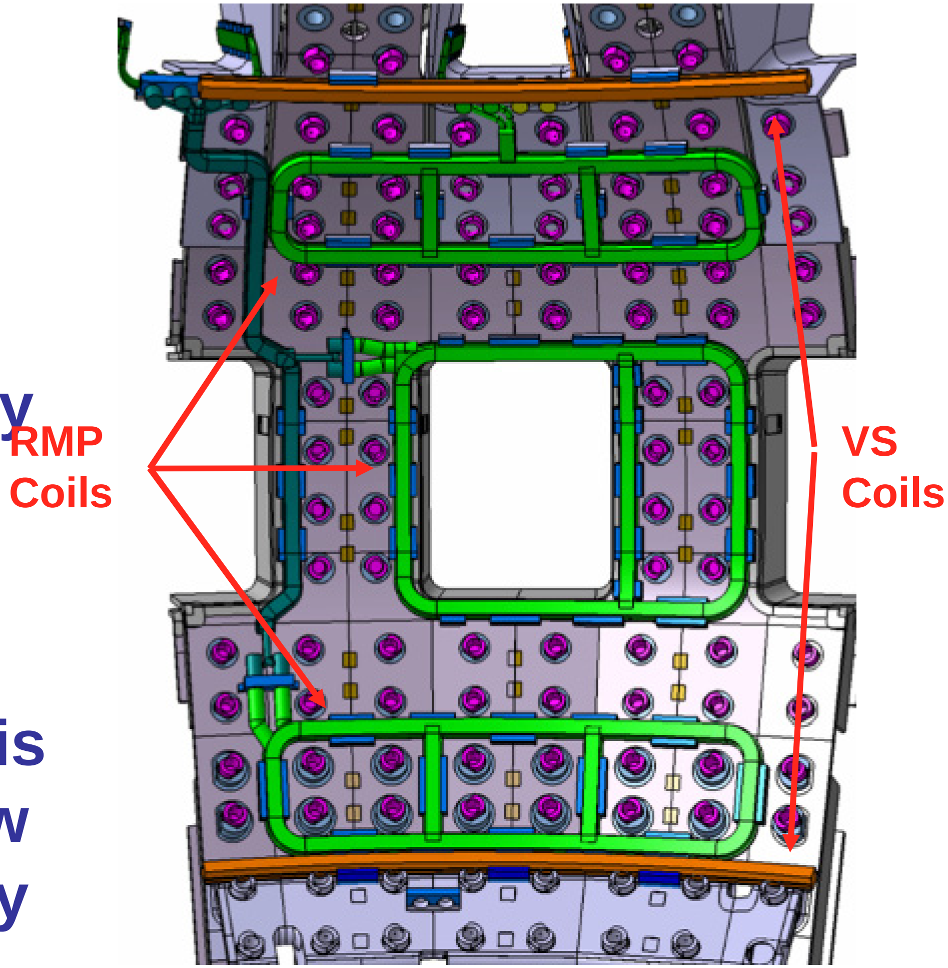


# Edge Located Mode Control/ Mitigation

- **ELMs were identified as potential show stoppers in 2004**

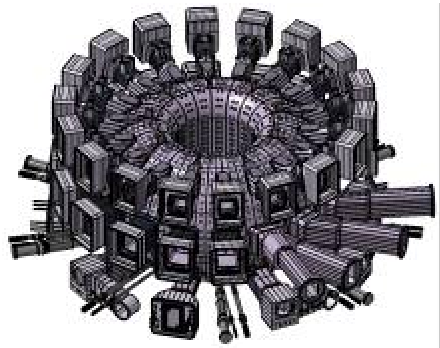
- **Between 20-40 MJ of Energy per burst can hit the wall locally**

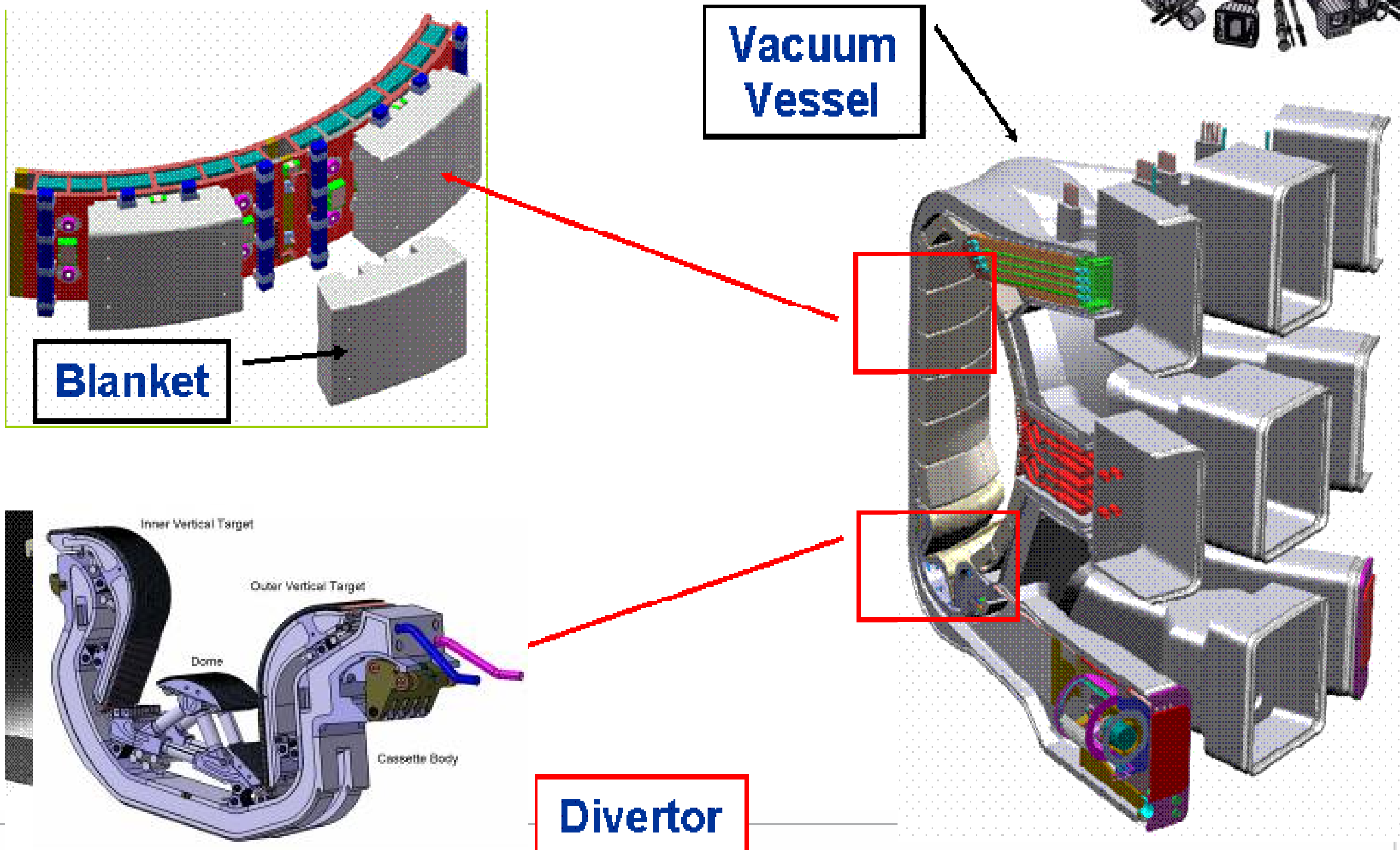
- **The outside magnetic field is randomly perturbed to allow constant diffusion of energy**



# VV and In-Vessel Components

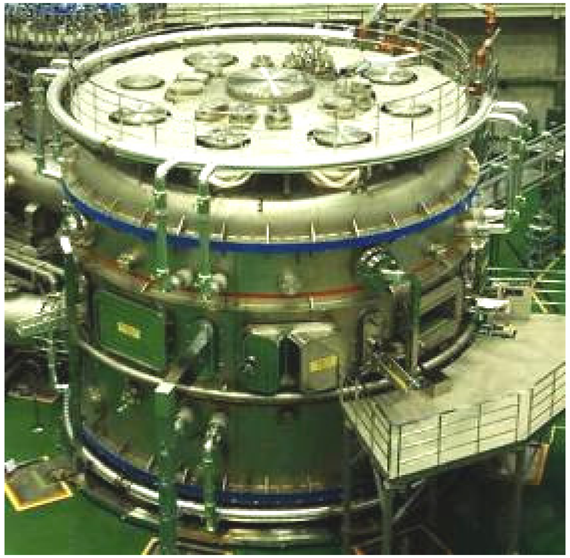
- Key issues resolved:
- Blanket loads on VV
- Neutron shielding
- Blanket manifold design & interface with VV
- ELM coil design & interface with VV
- VV manufacturability



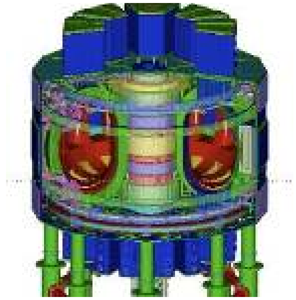


# Four New Superconducting Tokamaks will Address Steady-State Advanced Tokamak Issues in Non-Burning Plasmas

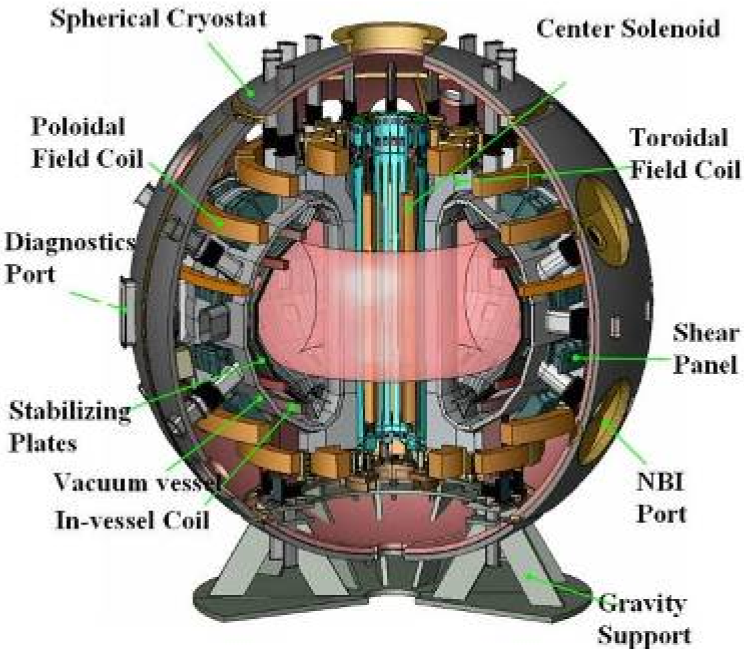
EAST: R = 1.7m, 2MA, 2006



KSTAR: R = 1.8m, 2MA, 2008



SST-1: R =1.1m, 0.22MA, 2008




JT-60SA: R = 3m, 5.5 MA, 2014

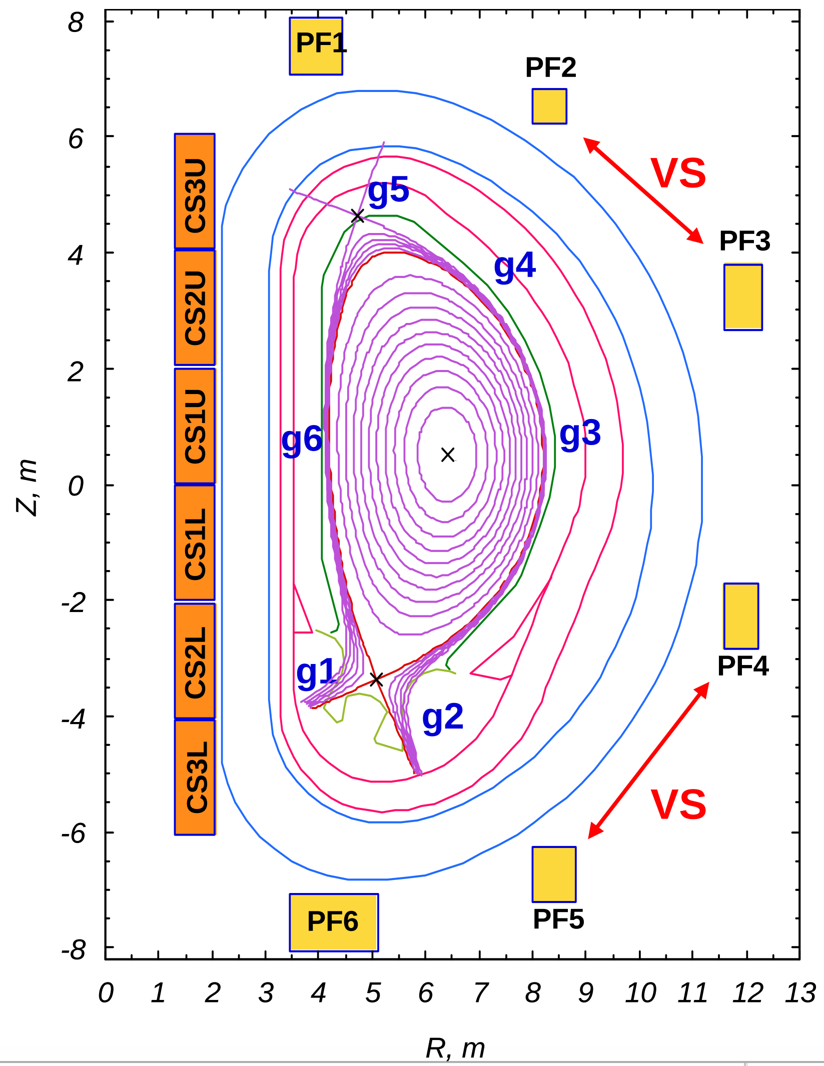
**+**

**= Energy**

- **Take the lithium from the battery of a single laptop computer, add half a bathtub of water, and it can give you 200,000 kilowatt hours of electricity**
- **That's enough to power one person in the UK for 30 years, including their share of industrial electricity.**

# R&D for Projects: Poloidal Field Control in ITER

- Control of the Plasma operation through magnetic fields
- Slow feedback loop through PF coil system:
  - control of plasma current, shape,
  - coil currents, separatrix separation, etc. (5-10 s)
- Fast feedback loop through in vessel coil:
  - stabilization of plasma vertical position (<1 s)



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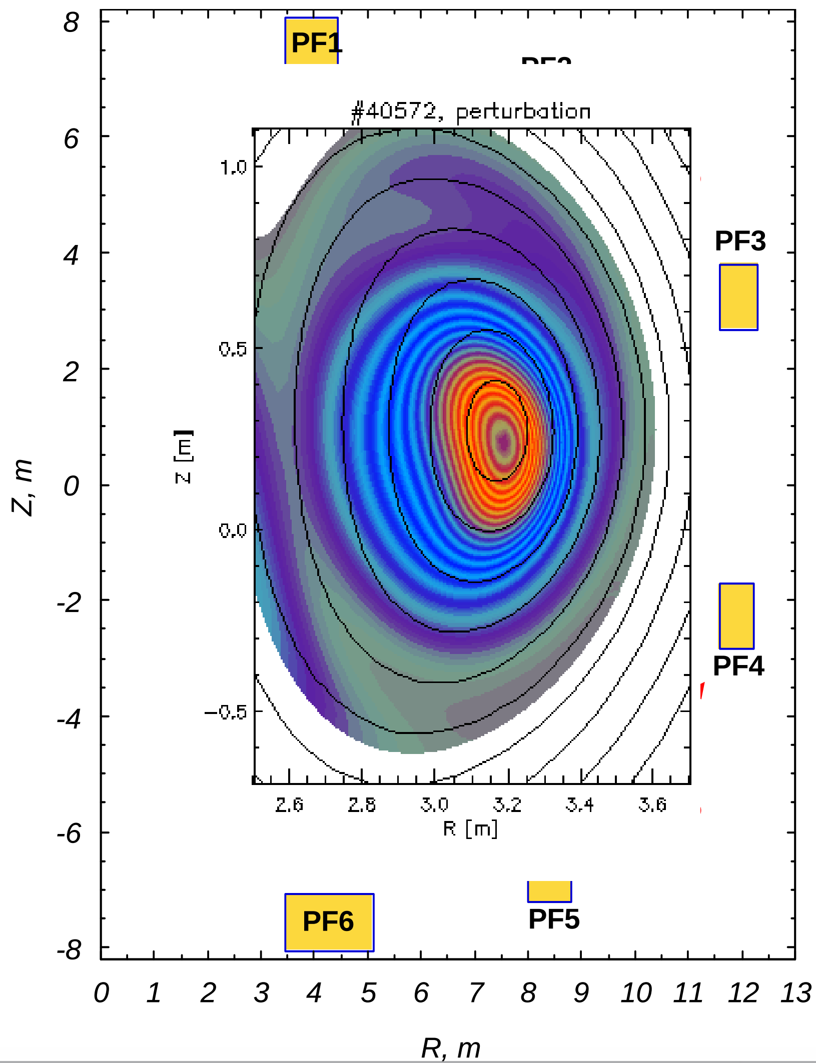
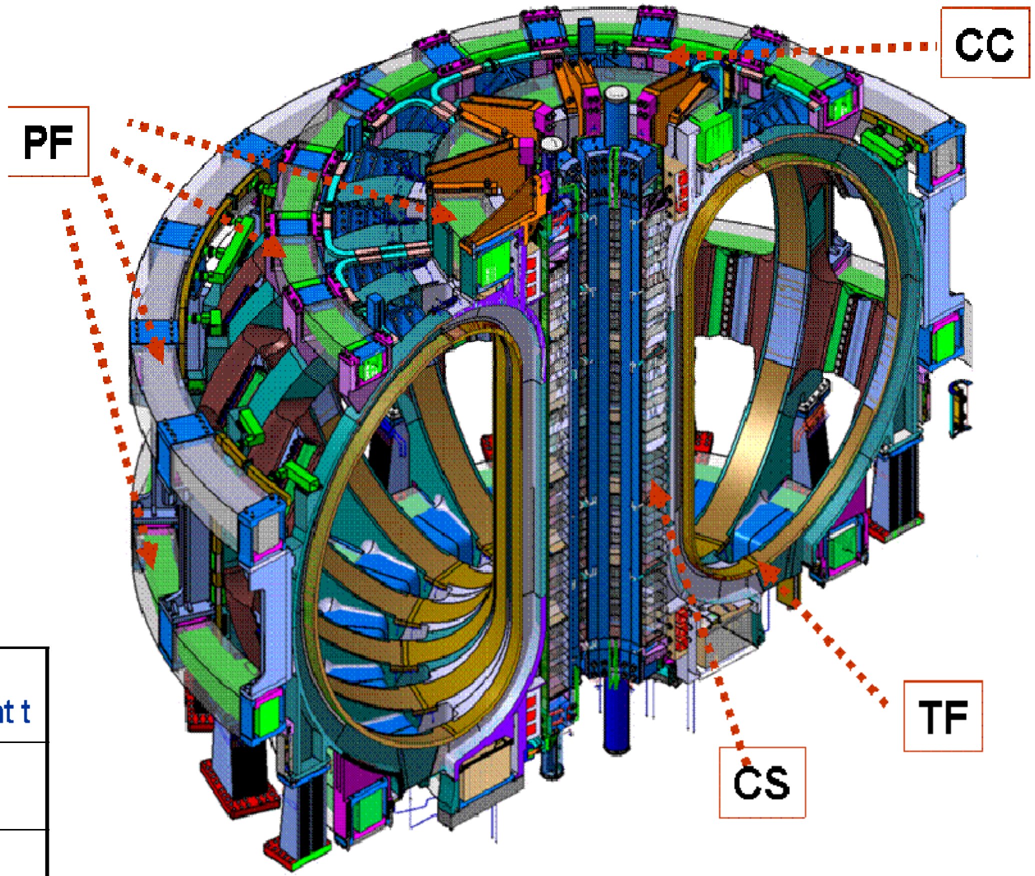


# Overview of the Magnet System

## 48 superconducting coils

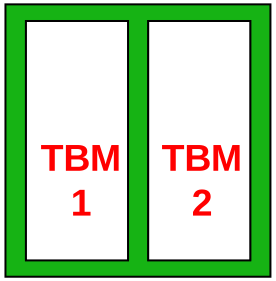
- 18 TF coils
- 6 CS modules
- 6 PF coils
- 9 pairs of CC

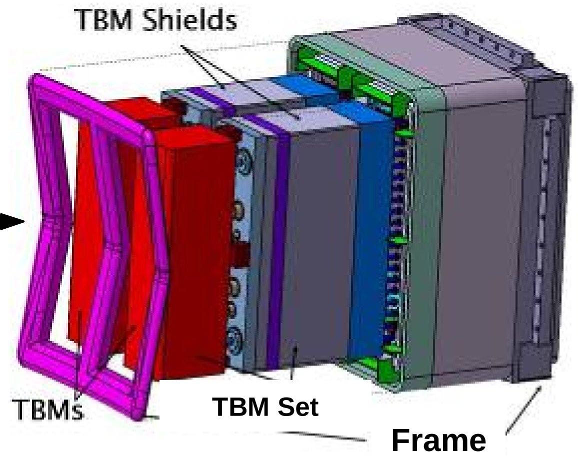



| System | Energy GJ | Peak Field | Total MAT | Cond length km | Total weight t |
|---|---|---|---|---|---|
| Toroidal Field TF | 41 | 11.8 | 164 | 82.2 | 6540 |
| Central Solenoid | 6.4 | 13.0 | 147 | 35.6 | 974 |
| Poloidal Field PF | 4 | 6.0 | 58.2 | 61.4 | 2163 |
| Correction Coils CC | - | 4.2 | 3.6 | 8.2 | 85 |

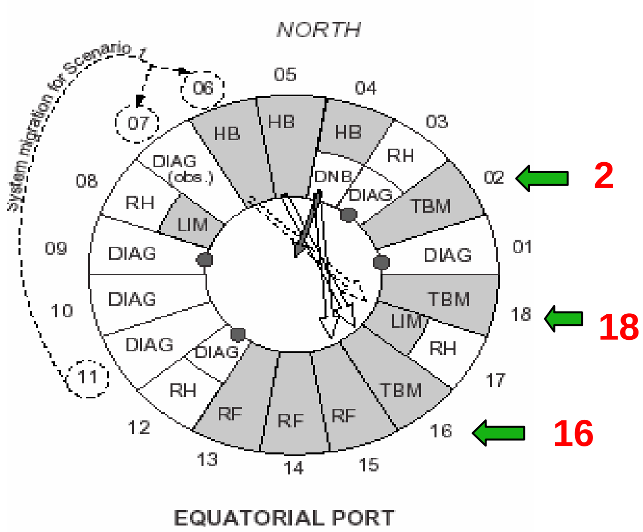
# Tritium Breeding Blankets Testing in ITER

- **3 ITER equatorial ports** (opening of 1.75 x 2.2 m$^2$) devoted to TBM testing
- TBMs installed within a water-cooled steel frame (thk. 20 cm), half-port size ➔ **6 TBMs**

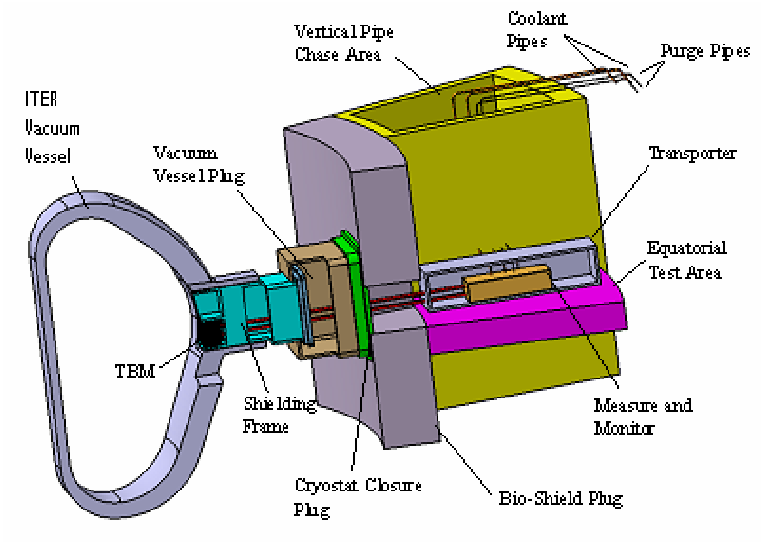



Exploded view of a TBM Port Plug

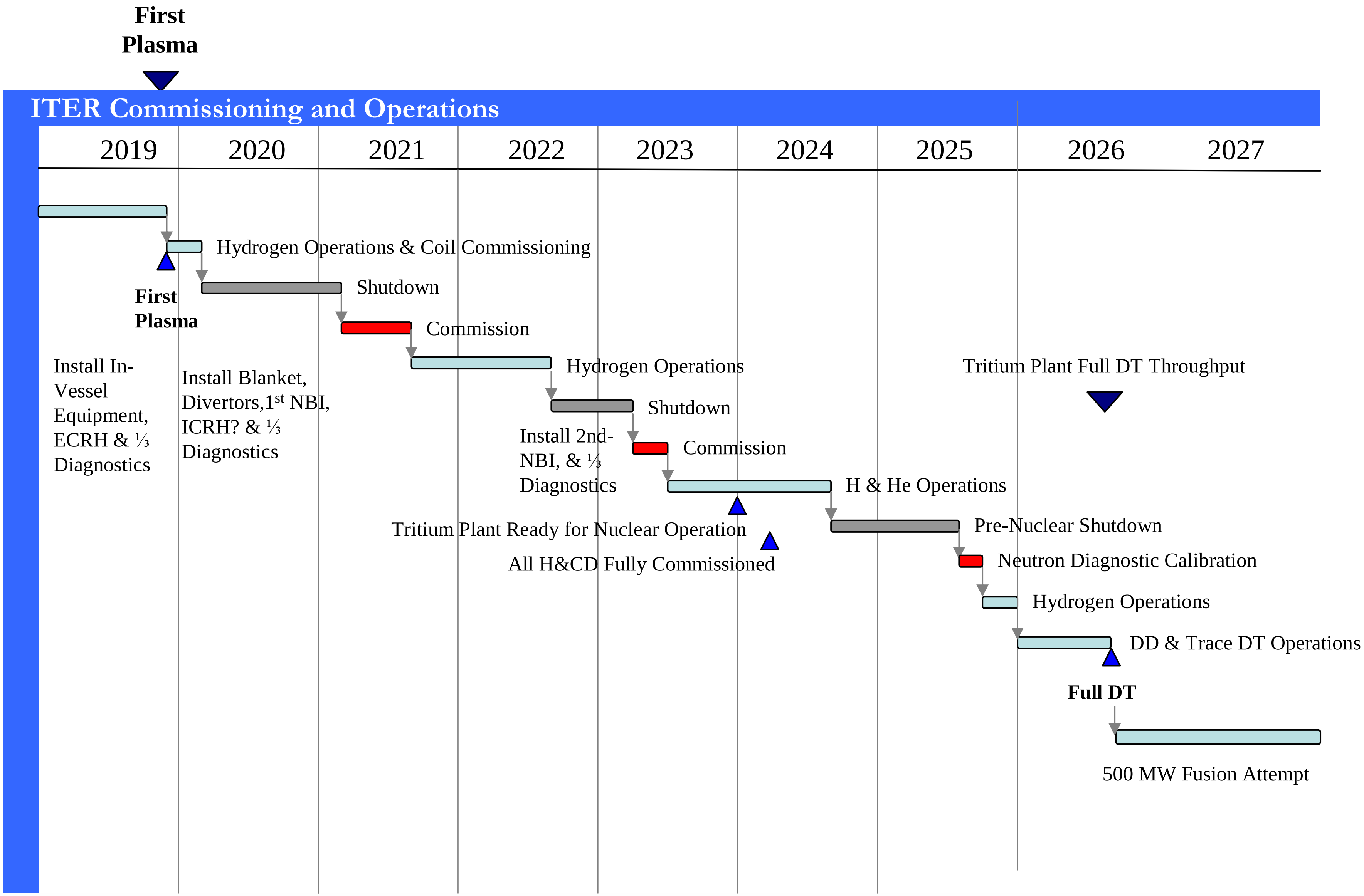



**TBM PORTS**




Example of Test Blanket Systems Locations

# ITER Schedule Following First Plasma: Path to DT in 2026



# ITER Licensing Process

- Accordance with French regulations **ITER is a “basic nuclear facility”** (*Installation Nucléaire de Base, INB*) e.g. labs, fuel plants, *not* fission reactors. Compliance with international standards of safety (IAEA)

- Licensing process:
  - Safety options report submitted and reviewed 2002
  - Series of informal technical meetings with the authorities (ASN) and their technical advisors (IRSN), 2006 – 2008.
  - License application documents were submitted January 2008
    - Request for authorisation (*Demande d’Autorisation de Création, DAC*), including Impact Study
    - Preliminary Safety Report (*Rapport Préliminaire de Sûreté, RPrS*)

- Examination of files submitted in January 2008
  - Authorities (ASN & IRSN) reviewed our files for acceptability
  - In July 2008, they requested detailed additional information in the files
  - DAC and RPrS are now being updated, for re-submission in 2010

- **Next**: Public Enquiry. Then examination by panel of independent experts (*Groupe Permanent*) to advise ASN.

# Current status

- **All RPrS chapters and Impact Study are in first draft**
  - Some require completion with the outcome of safety analyses in progress, or design information from baseline documents to be fixed

- Many annexe documents completed
  - Translation into French under way

- **Reviews of RPrS to be held October – December**, by technical ROs, Safety Control Division (“second level” check), and in review including external experts - English version to be finalized by end of 2009

- **Translation in French and final checking**
  - **Submission expected end of February 2010**

- **Should lead to issue of decree allowing “creation” of facility.**
  - Further processes will follow to obtain authorisation for commissioning and start-up.

# Broader Approach Agreement

***Annex I***
***IFMIF/EVEDA***

*1.In accordance with this Agreement, the Parties, subject to their laws and regulations, shall conduct the Engineering Validation and Engineering Design Activities (hereinafter "EVEDA") to* ***produce a detailed, complete, and fully integrated engineering design of the International Fusion Materials Irradiation Facility (hereinafter "IFMIF") and all data necessary for future decisions on the construction, operation,***

# Broader Approach Agreement

***Annex I***
***IFMIF/EVEDA***

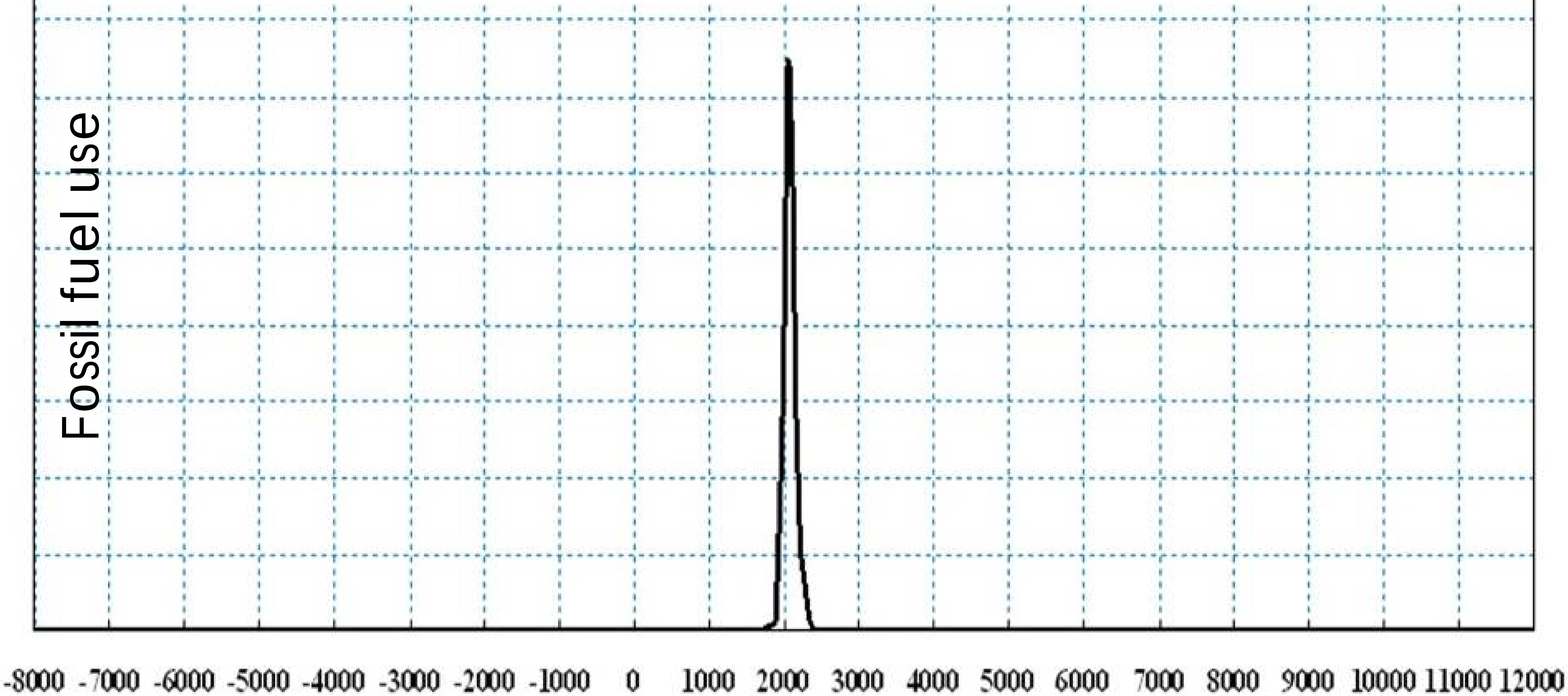
**“Produce a detailed, complete, and fully integrated engineering design of IFMIF and all data necessary for future decisions on the construction, operation, exploitation and decommissioning of IFMIF**

*the Engineering Validation and Engineering Design Activities (hereinafter “EVEDA”) to* ***produce a detailed, complete, and fully integrated***

**Validate continuous and stable operation of each IFMIF subsystem”**

***Materials Irradiation Facility (hereinafter “IFMIF”) and all data necessary for future decisions on the construction, operation,***

# ITER: The Quest for New Energy Sources!




**Fossil Fuel Use**

**a brief episode in the world's history**

**View from a High Energy Physics Theorist: C.L. Smith**

# ITER Organization Structure