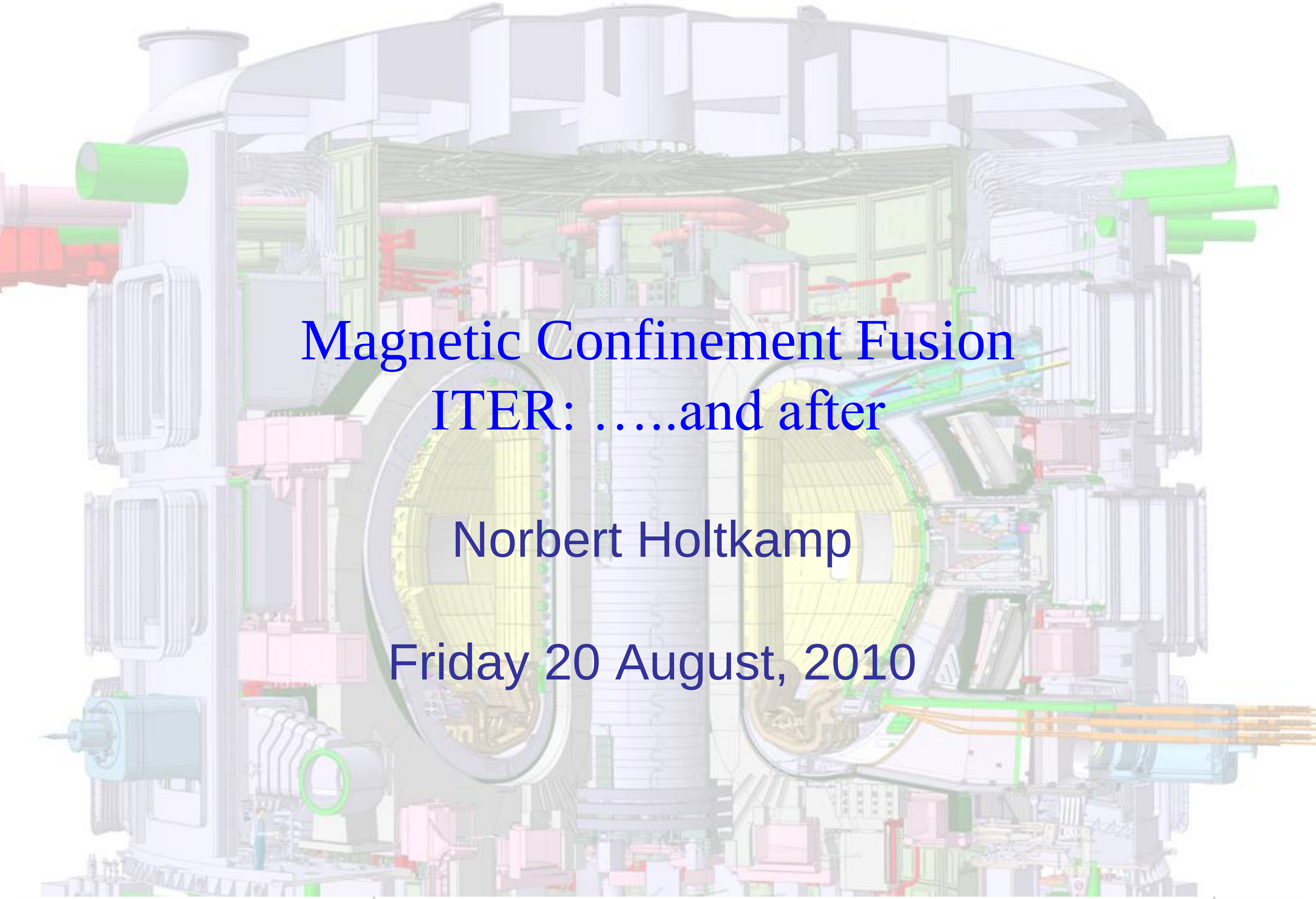
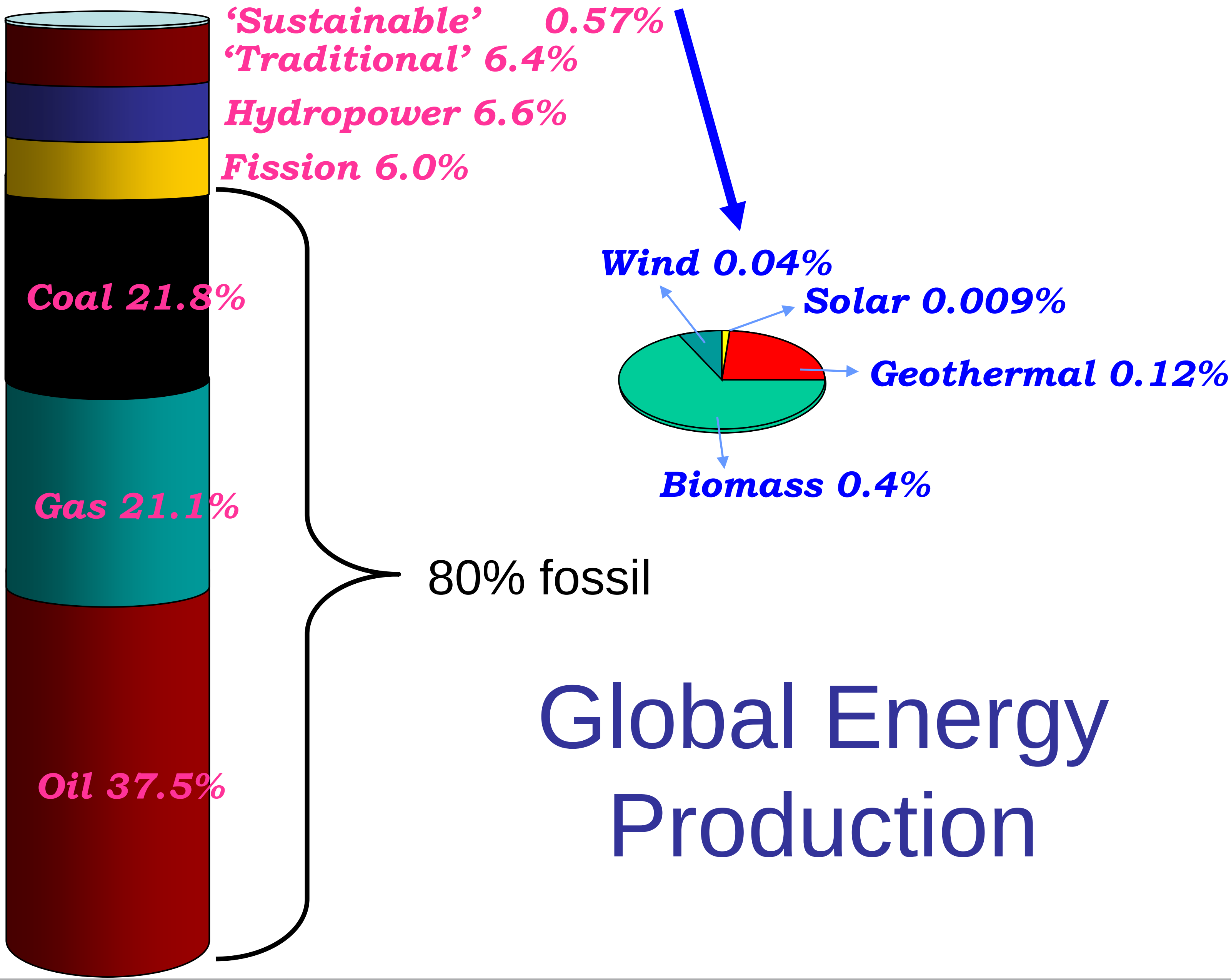


Magnetic Confinement Fusion
ITER: …..and after

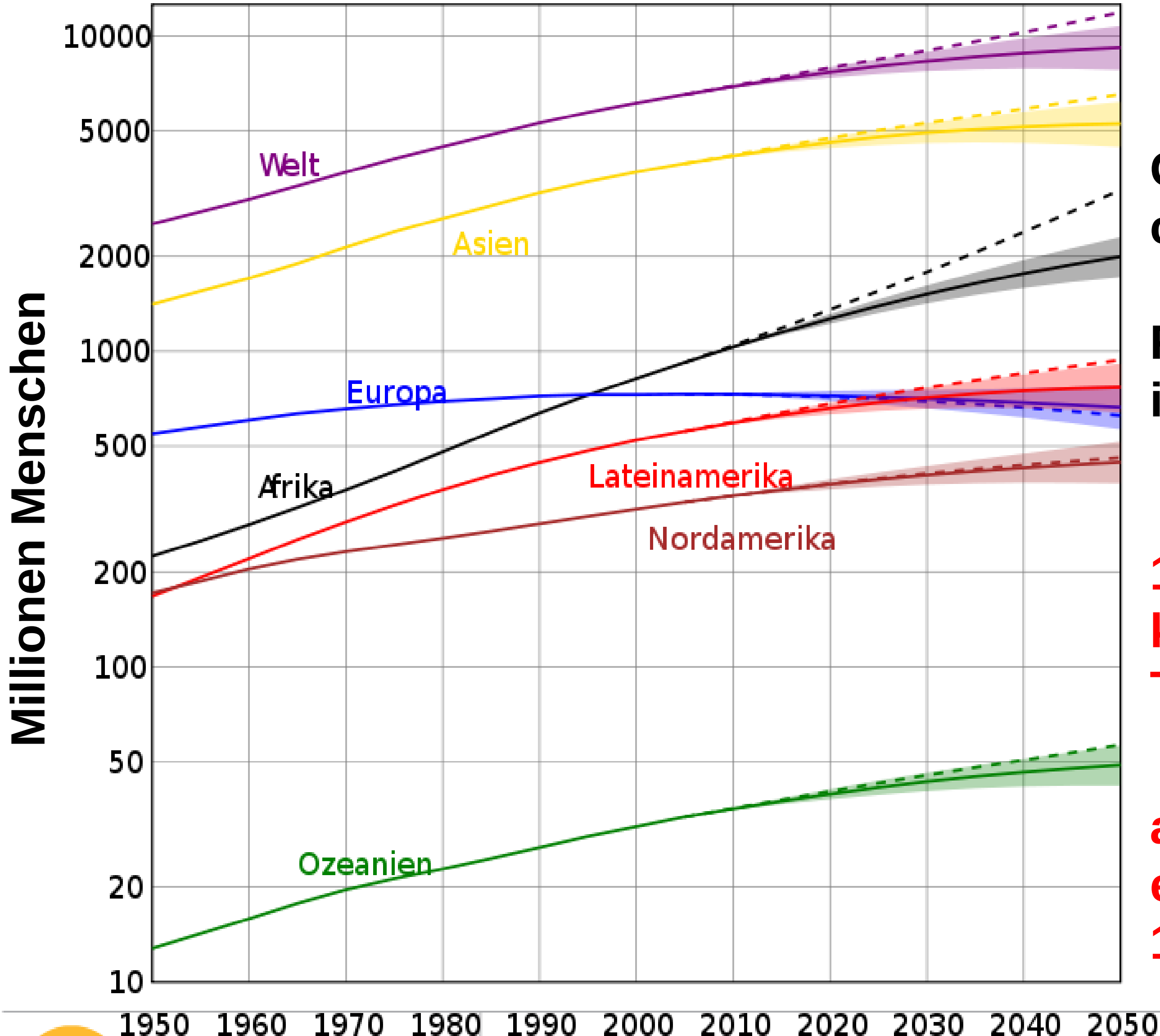
Norbert Holtkamp

Friday 20 August, 2010



Global Energy Production

Global Population



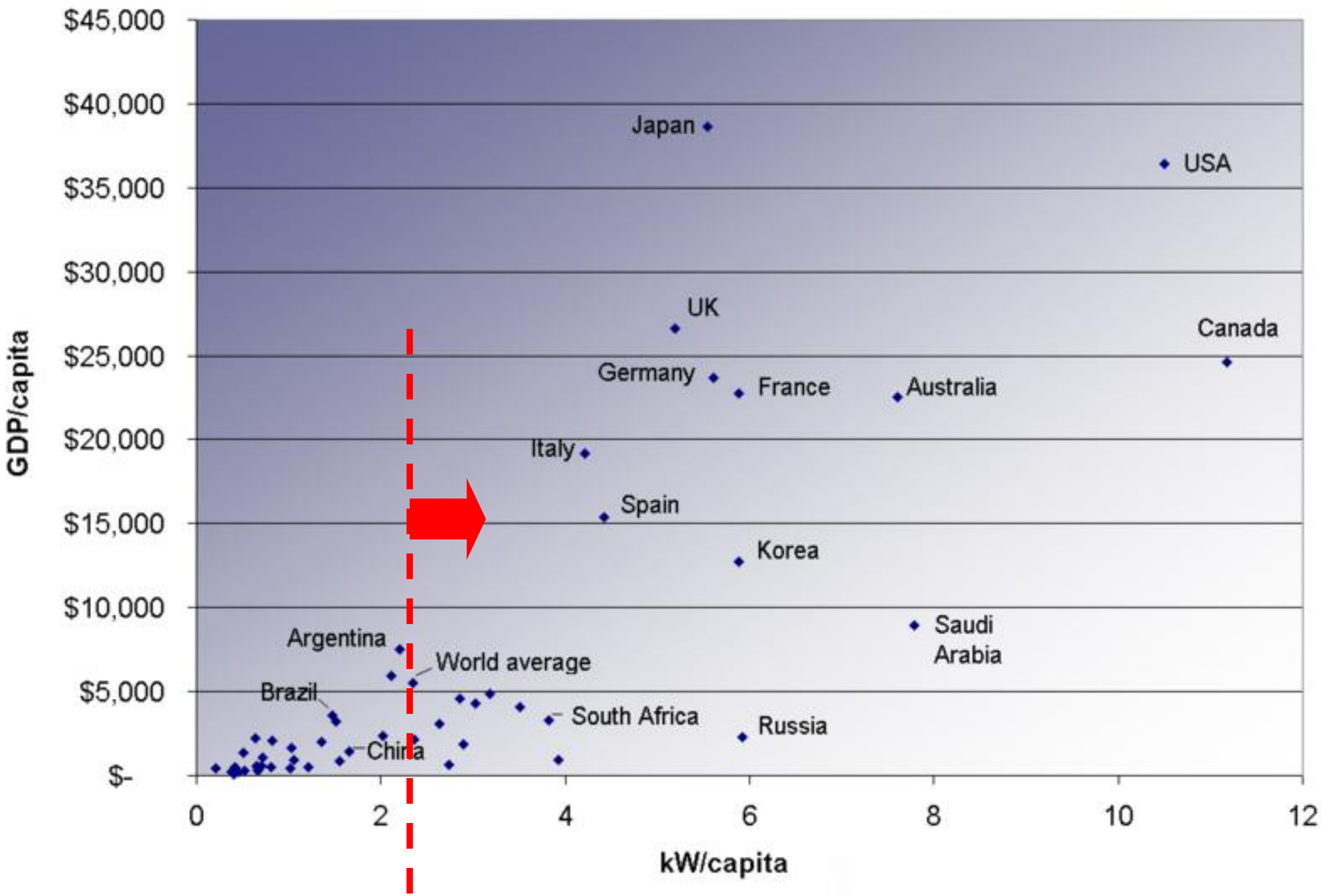
Growth in fast growing countries

Flat in high industrilized areas

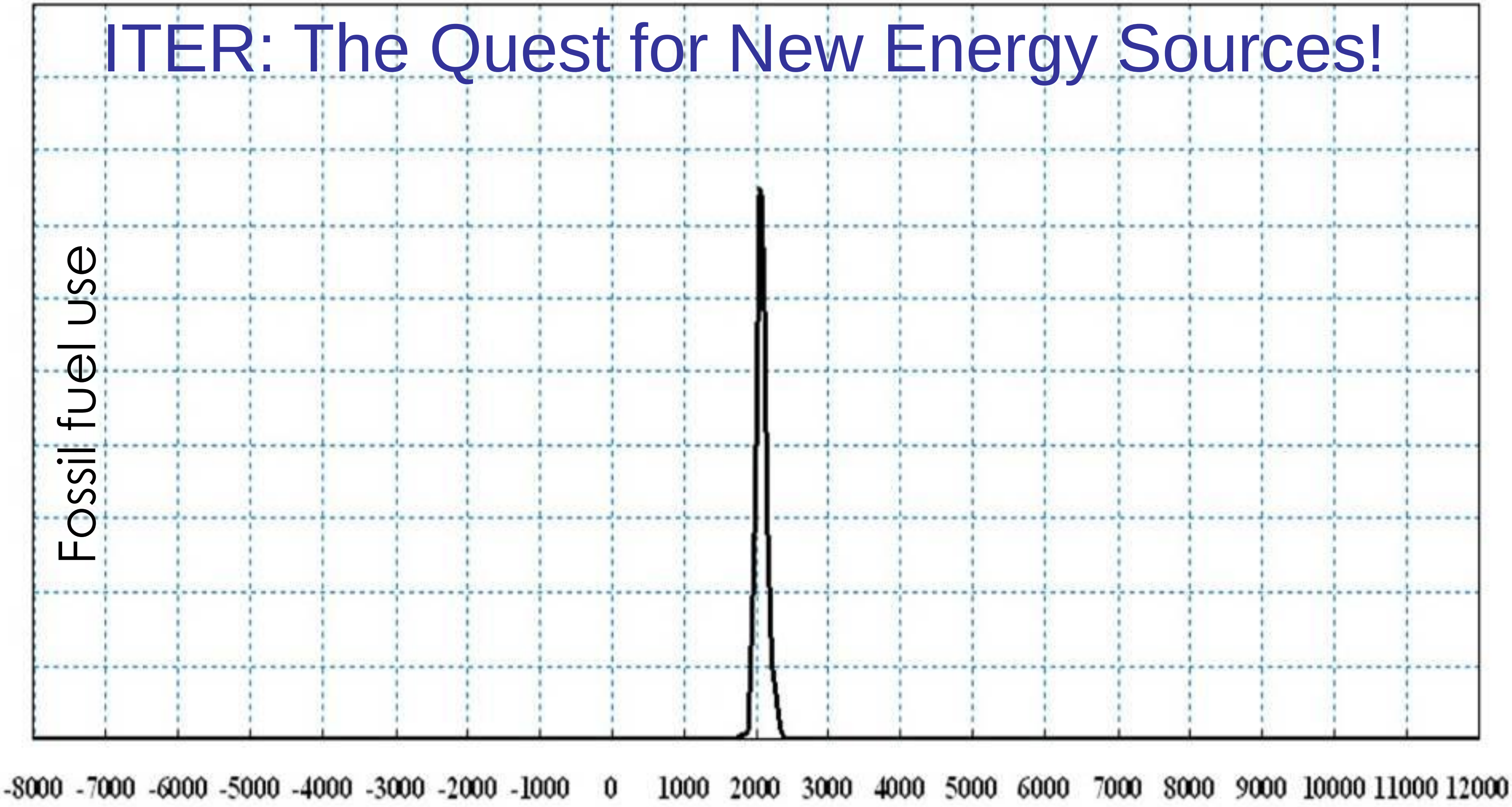
10 Billion poeple with 3 kW/person need 30 Terawatt (TW) power

approx 12 TW of electricity: 1.000.000.000.000 Watt

The Energy Dilemma



ITER: The Quest for New Energy Sources!



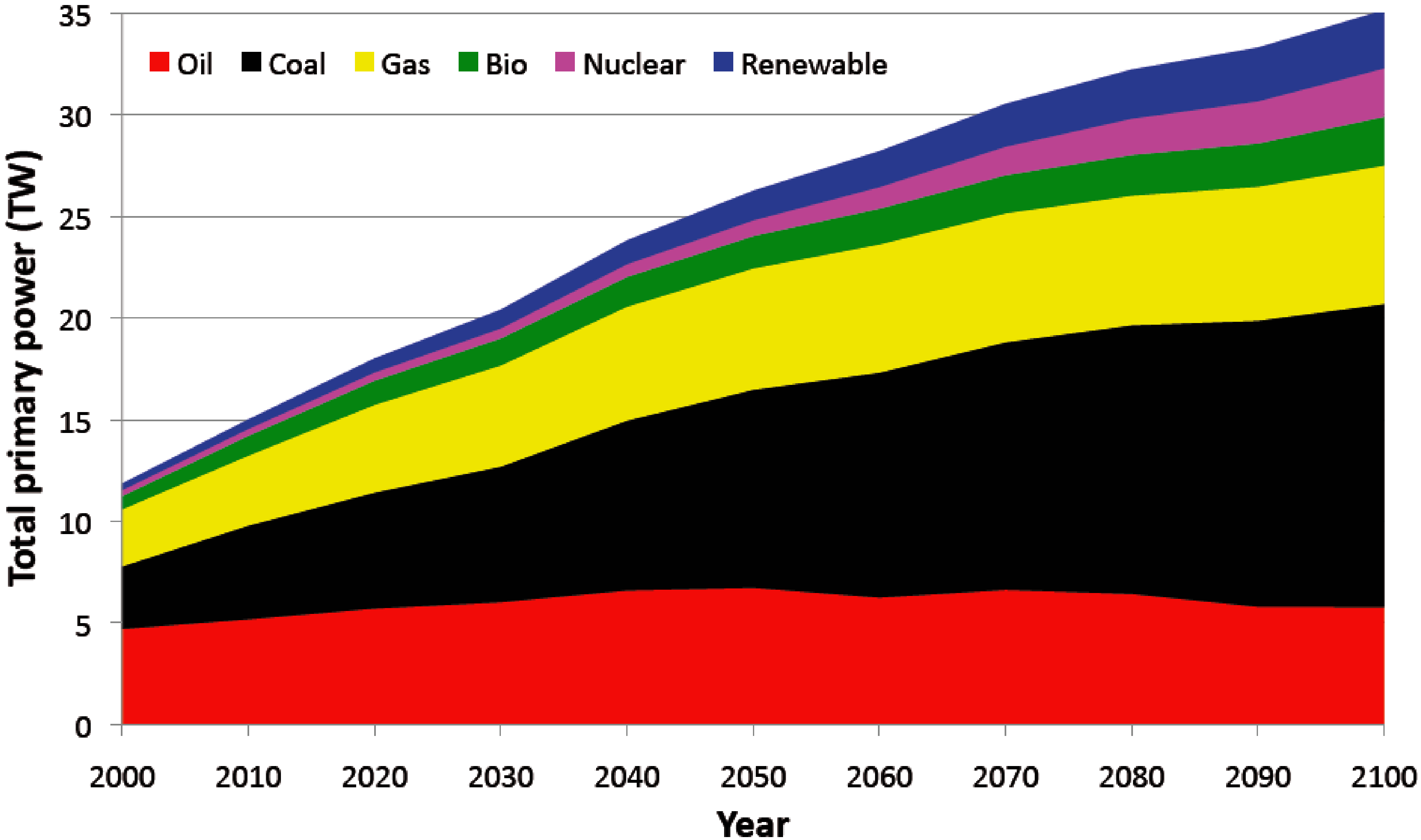
Fossil Fuel Use

a brief episode in the world's history

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

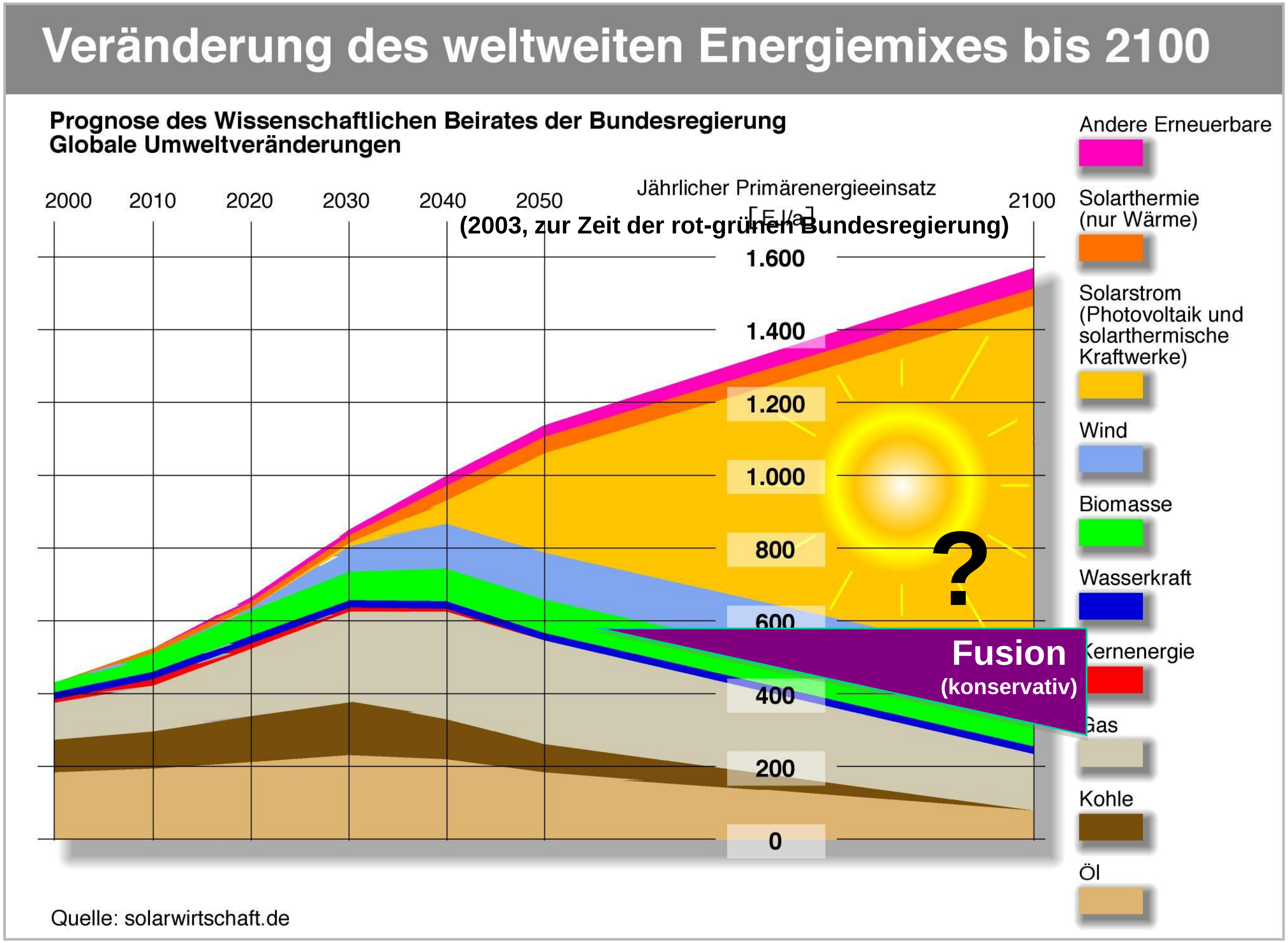
„Business like usual“ Scenario:

Clarke, Edmonds, Krey, Richels, Rose, Tavoni; Energy Economics 31, S64 (2009)



→Requires 8000 new Coal fired plants, approx. 2 per week until - CO_2-Emission leads to approx 4-6° climate change

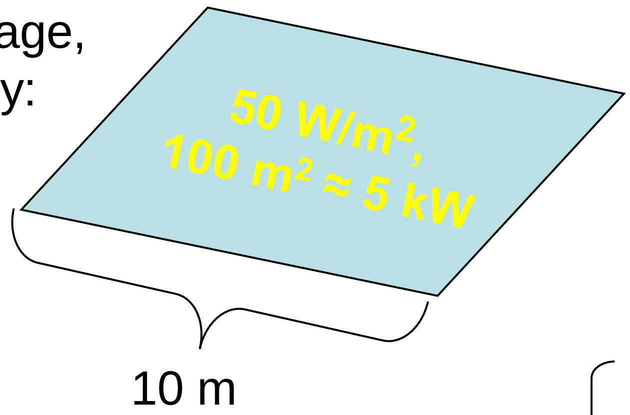
There is not a single solution !



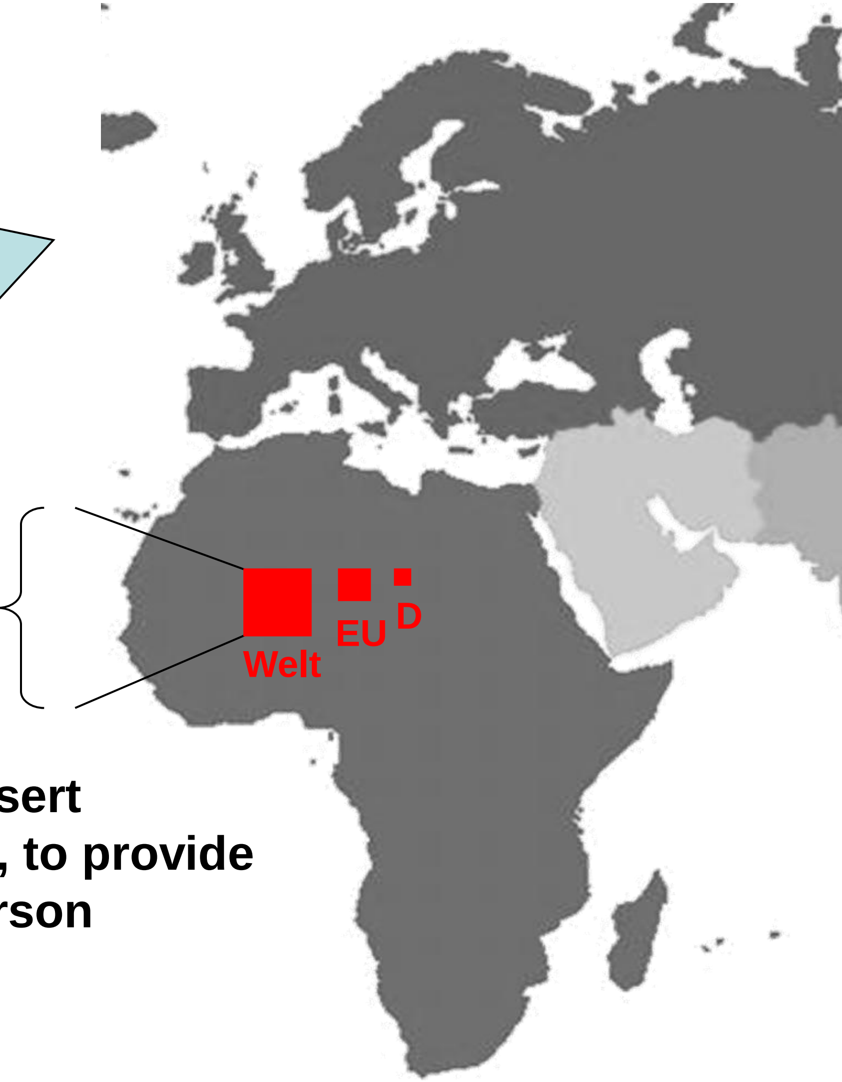
There is plenty of Energy... In principle

www.desertec.com

Sahara day and night on average, 10 % efficiency:



ca. 800 km



640.000 km² surface area in the desert (Germany: 360.000 km²) sufficient , to provide 10 billion people with 3 KW/per person

L-B-Systemtechnik

Quelle: LBST

High Voltage DC distribution

The Way to Fusion Power – The ITER Story

“For the benefit of mankind”

The idea for ITER originated from the Geneva Superpower Summit on November 21,1985, when the Russian Premier Mikhail Gorbachev and the US-President Ronald Reagan proposed that an international project be set up to develop fusion energy “as an essentially inexhaustible source of energy for the benefit of mankind”.

The ITER Story II

1988-1991 Conceptual Design Phase

Start of common activities among EU, USSR, USA and Japan. Selection of machine parameters and objectives

1992-1998 Engineering Design Phase

Developed design capable of ignition, but large & expensive

1999-2001

USA withdraws from project

remaining parties search for less ambitious goal

=> New Design (moderate amplification at half the cost)

2003

USA rejoins, China & Korea are accepted as full partners

2005

Cadarache, France, selected as site

India joins the project

2006

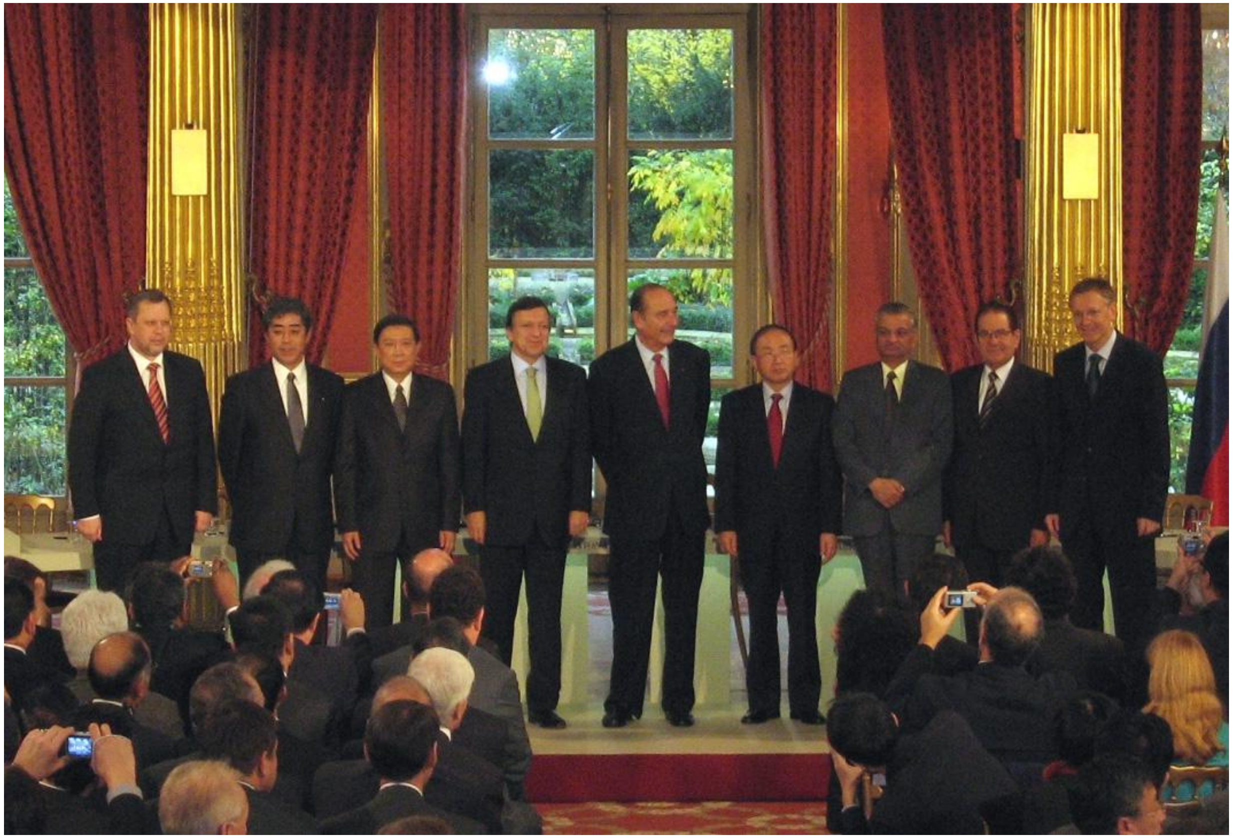
Official negotiation, under the auspices of IAEA end in May 2006 with initialing of the official documents in brussels

2007

October 24 ratification of the Joint ITER Agreement

The ITER Agreement

On November 21, 2006, the ITER Agreement was signed at the Elysee Palace in Paris by the seven parties China, Europe, India, Japan, Korea, Russian Federation and the United States of America.



„The stakes are considerable, not to say vital for our planet.“
Manuel Barroso, President of the European Commission

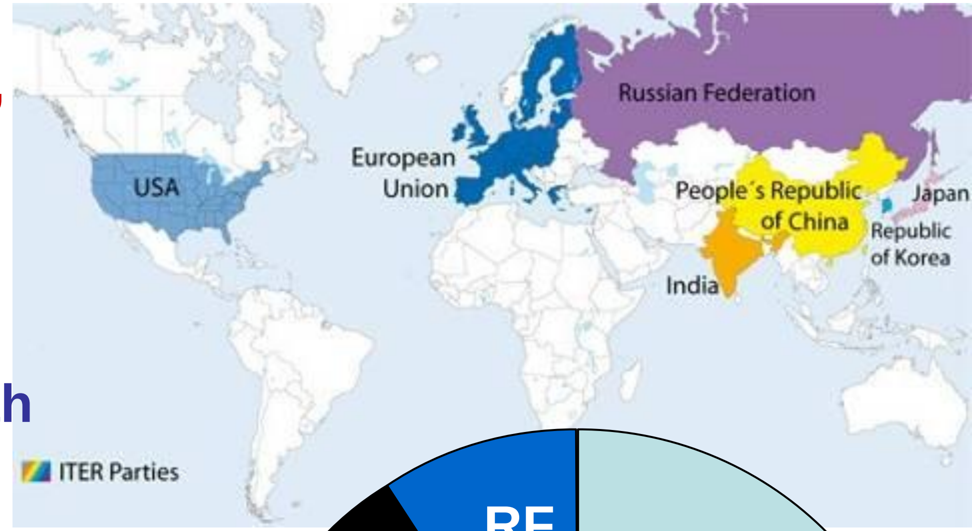
ITER – Key Facts

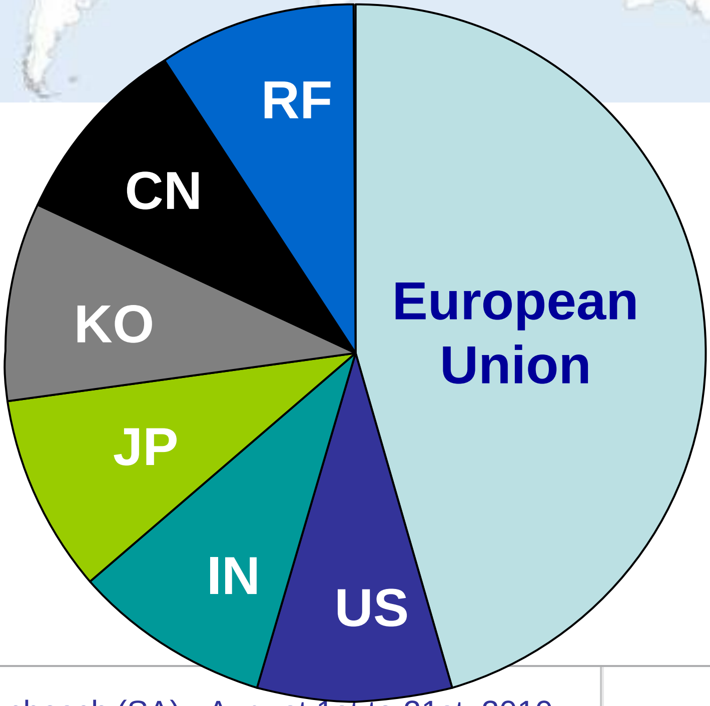
- **Mega-Science Project among 7 Members:**
  China, EU, India, Japan, Korea, Russia & US

- **Designed to produce 500 MW of fusion power for an extended period of time (300-3000 sec) with a Q of 10**

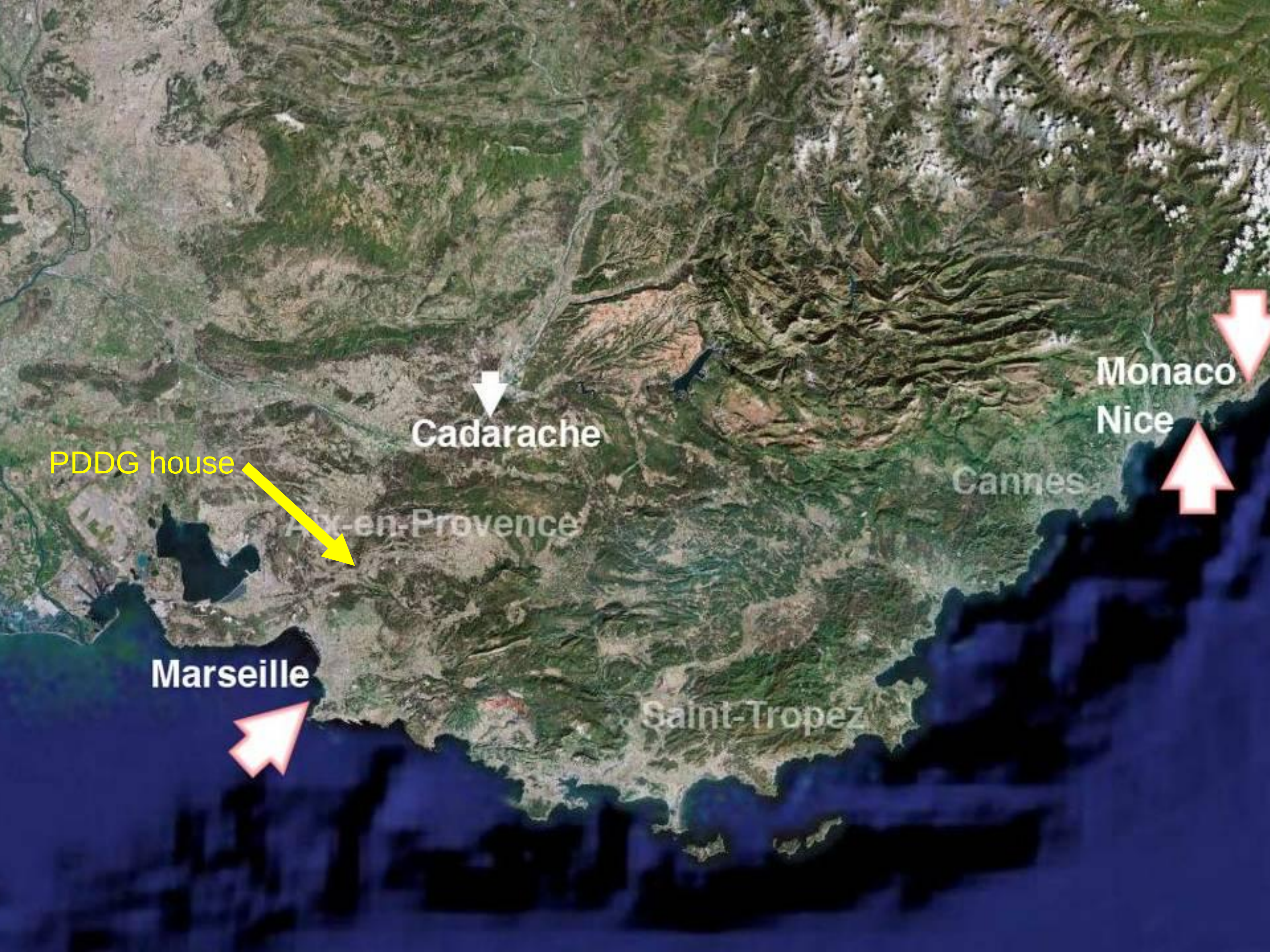
- **10 years construction, 20 years operation**

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





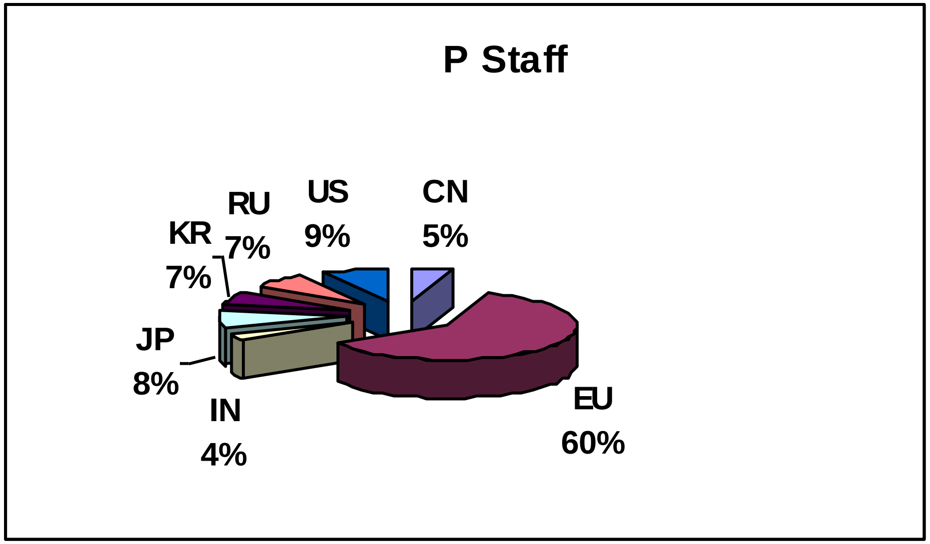
…based in Cadarache, Southern France


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

Staffing Status

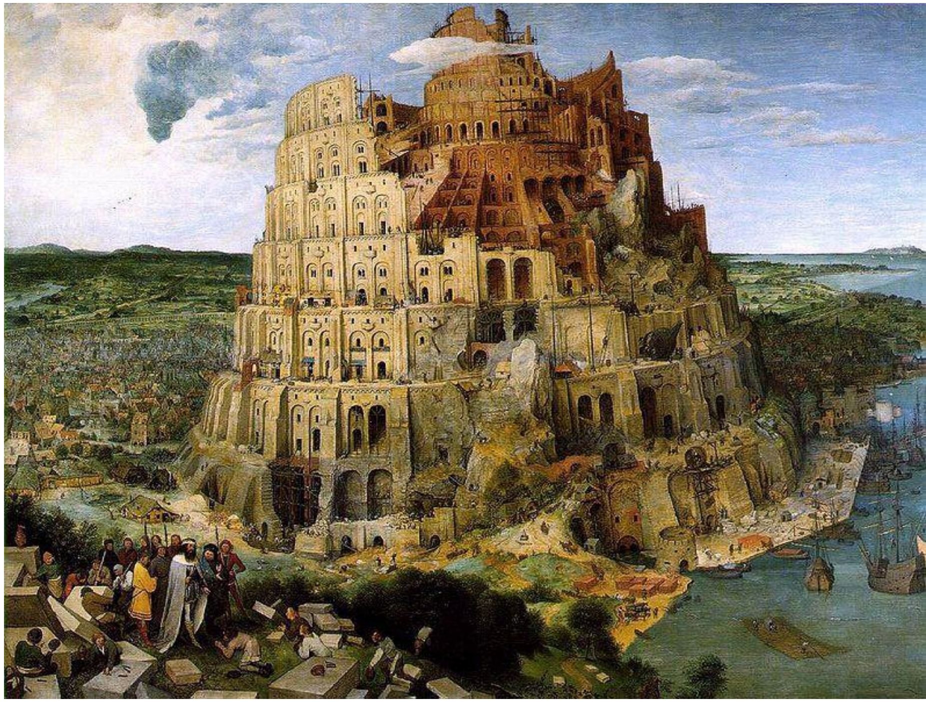
- By March 2010, the ITER Organization had a total of 430 staff members, comprising 291 professional and 139 technical support staff members. In addition, as of end of 2009 there were around 330 external contractors. 29 Nationalities are presented in the IO.

	Professional staff	Support staff	Total
CN	16	1	17
EU	175	106	281
IN	14	14	28
JA	22	6	28
KO	20	4	24
RU	21	2	23
US	23	6	29
Total	291	139	430



ITER is the most challenging technical program operated under an international collaboration

Deutsch: Turmbau zu Babel
Português: Torre de Babel
English: Tower of Babel
Français : La Tour de Babel
Español: Torre de Babel
中文: 巴别塔
日本語:バベルの塔
Русский: Вавилонская башня
:
한국어: 바벨탑



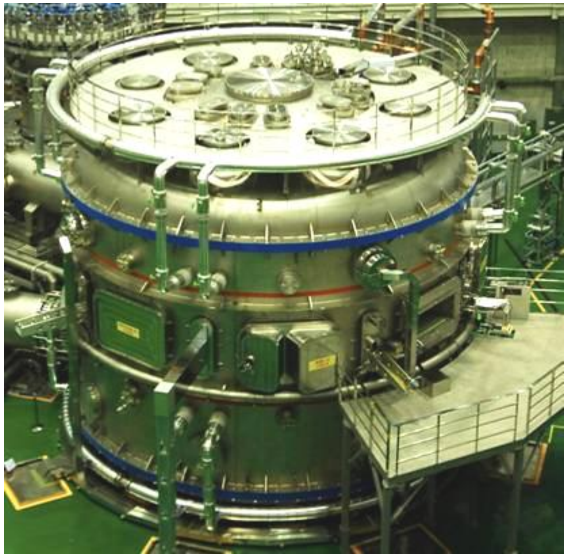
Communication is not the issue! Works just fine…

- The ITER Organization and the ITER Domestic Agencies

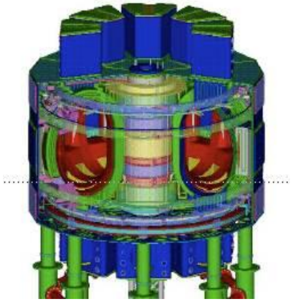
ITER -the way to fusion energy

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

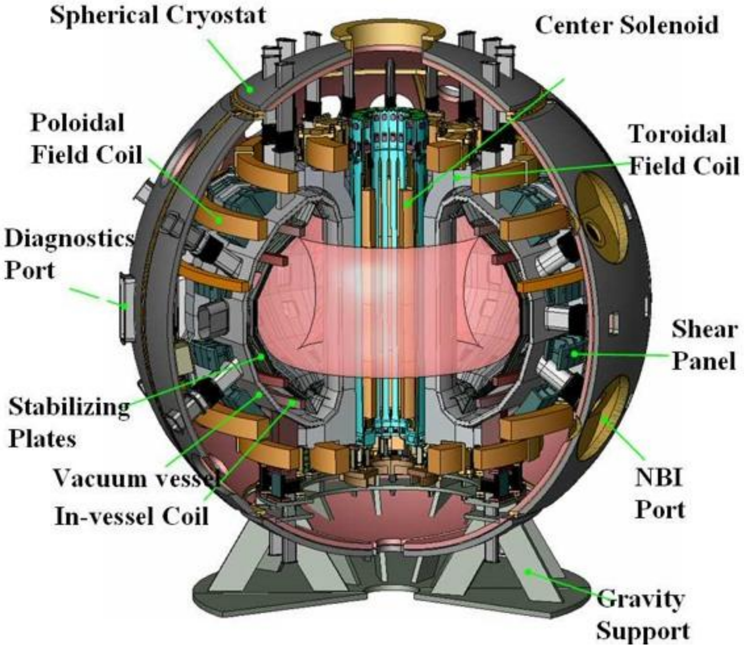
EAST: R = 1.7m, 2MA, 2006



KSTAR: R = 1.8m, 2MA, 2008

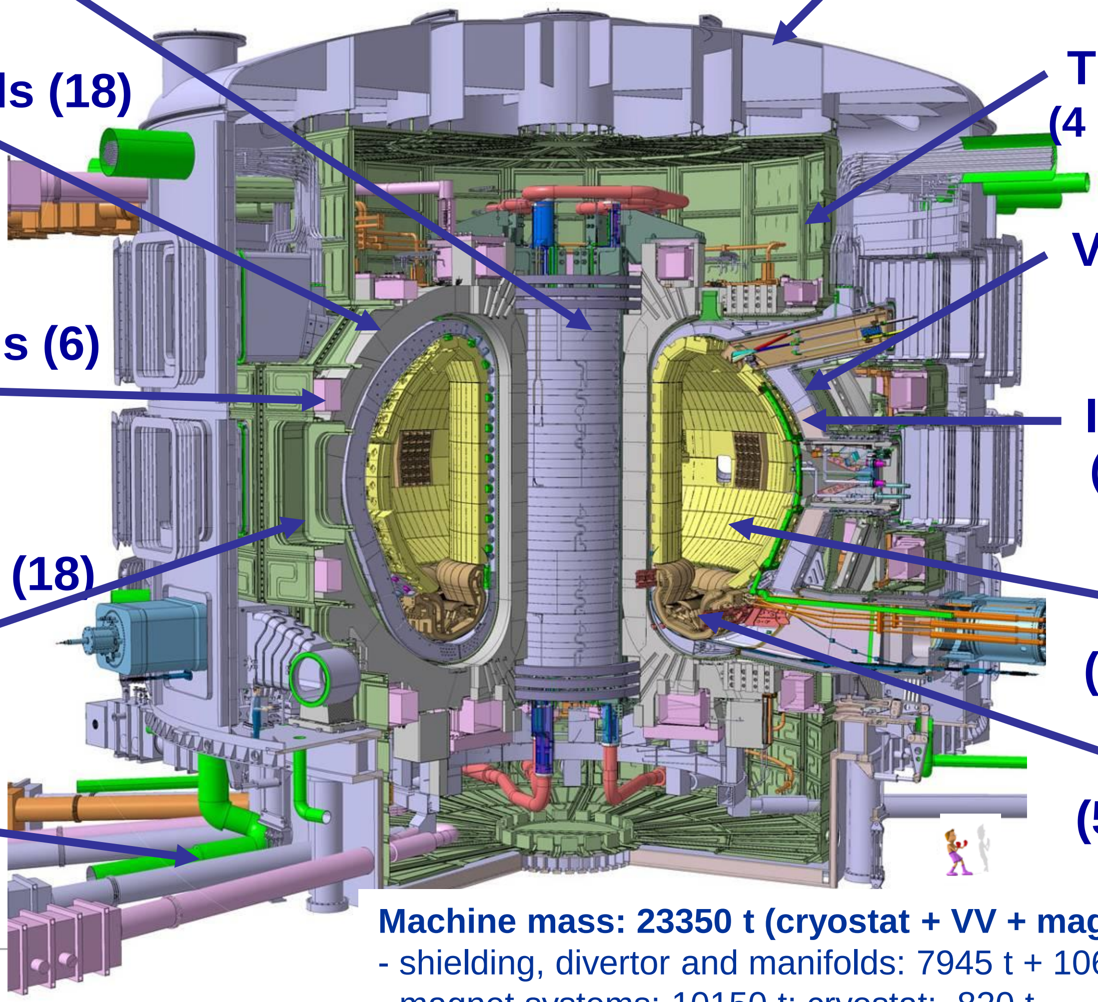


SST-1: R =1.1m, 0.22MA, 2008

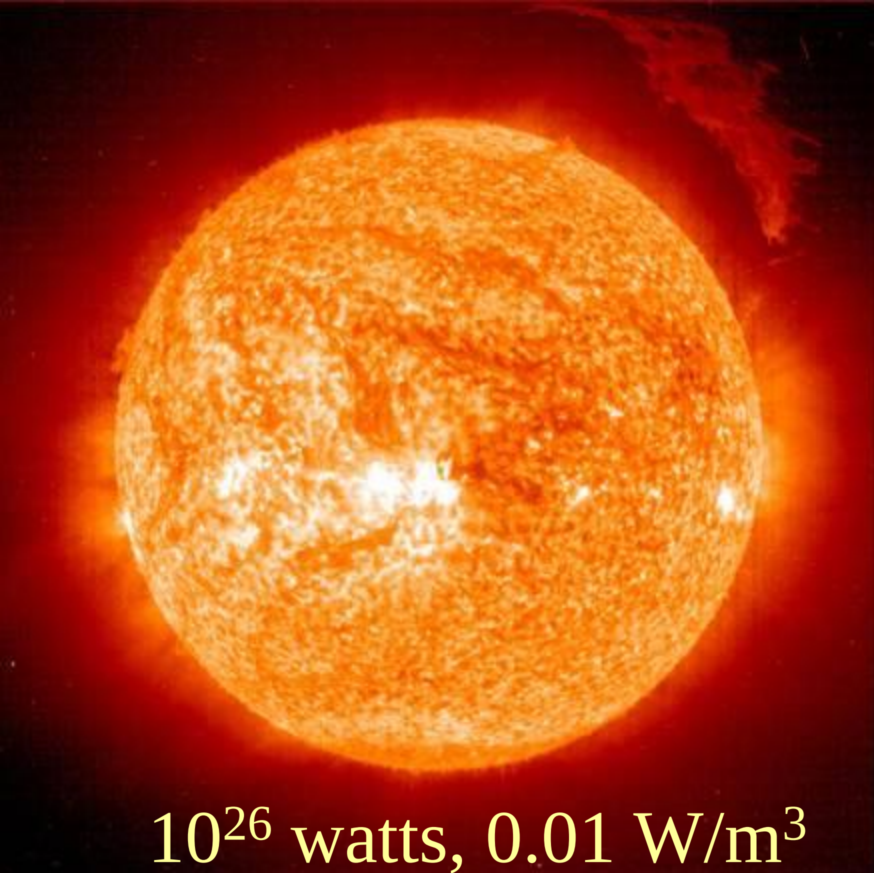


JT-60SA: R = 3m, 5.5 MA, 2014

The ITER Tokamak)



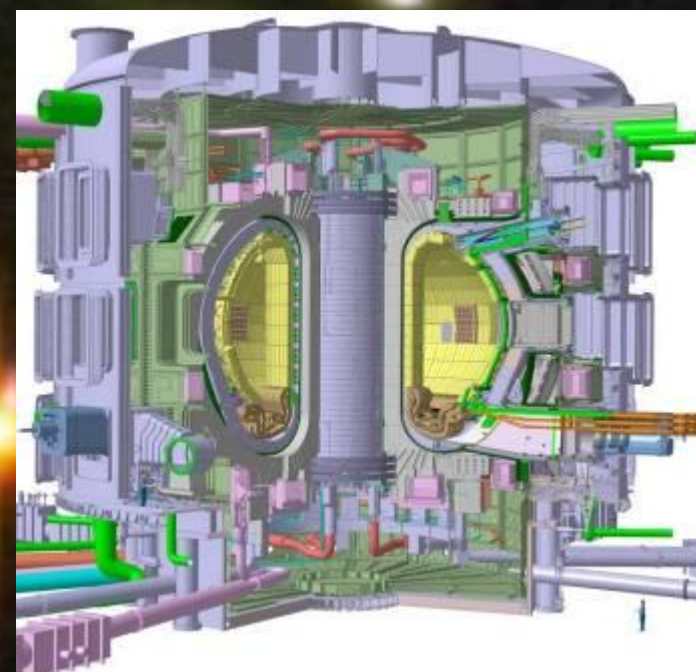
Machine mass: 23350 t (cryostat + VV + magnets)
- shielding, divertor and manifolds: 7945 t + 1060 port plugs
- magnet systems: 10150 t; cryostat: 820 t



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

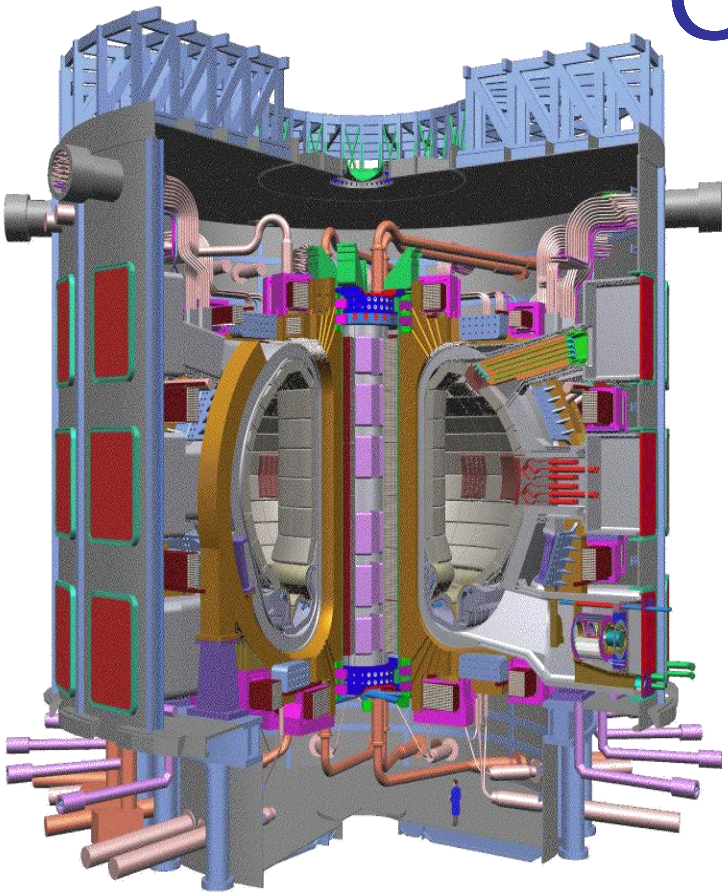
- The Sun has a radius of 0.7 Million kilometer
- A core temperature of 10 Million deg
- A surface temperature of ~4000 deg

- 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

ITER Tokamak - Mass Comparison

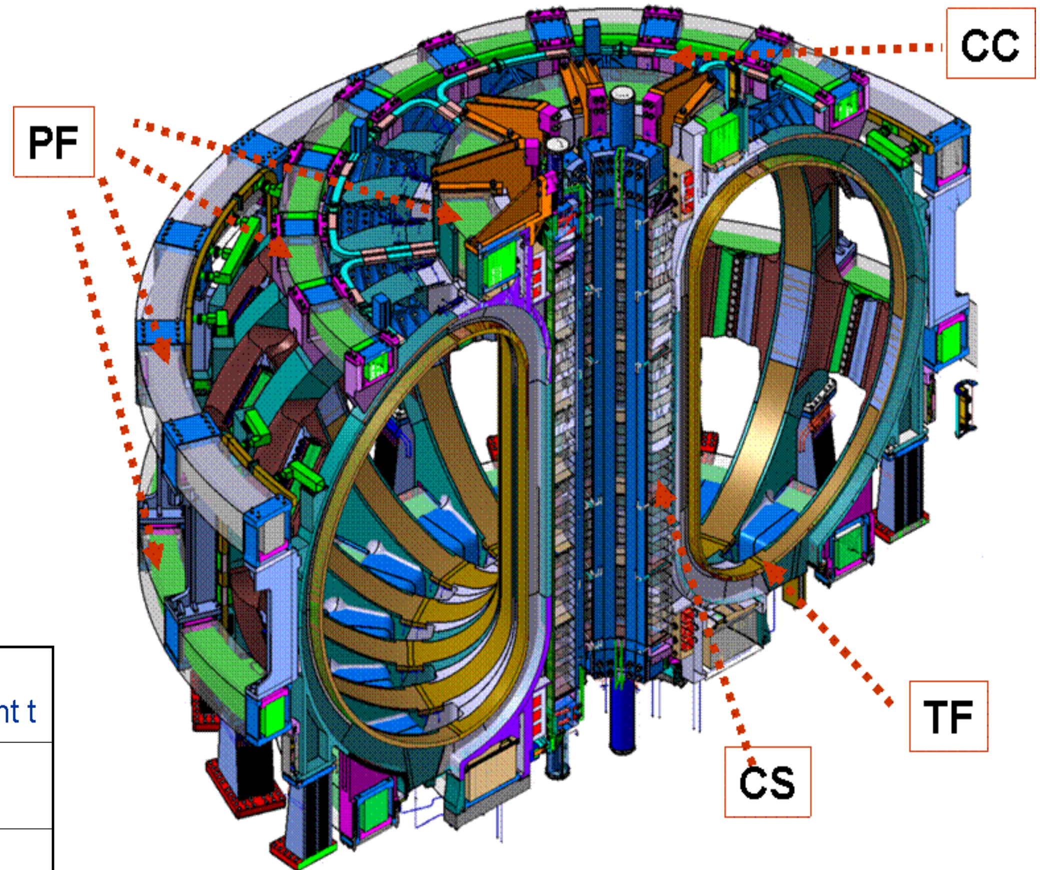


Charles de Gaulle mass:
~38000 t (empty)
856 ft (261 m) long
(Commissioned 2001)

ITER Machine mass:
~23000 t
28 m diameter x 29 m tall

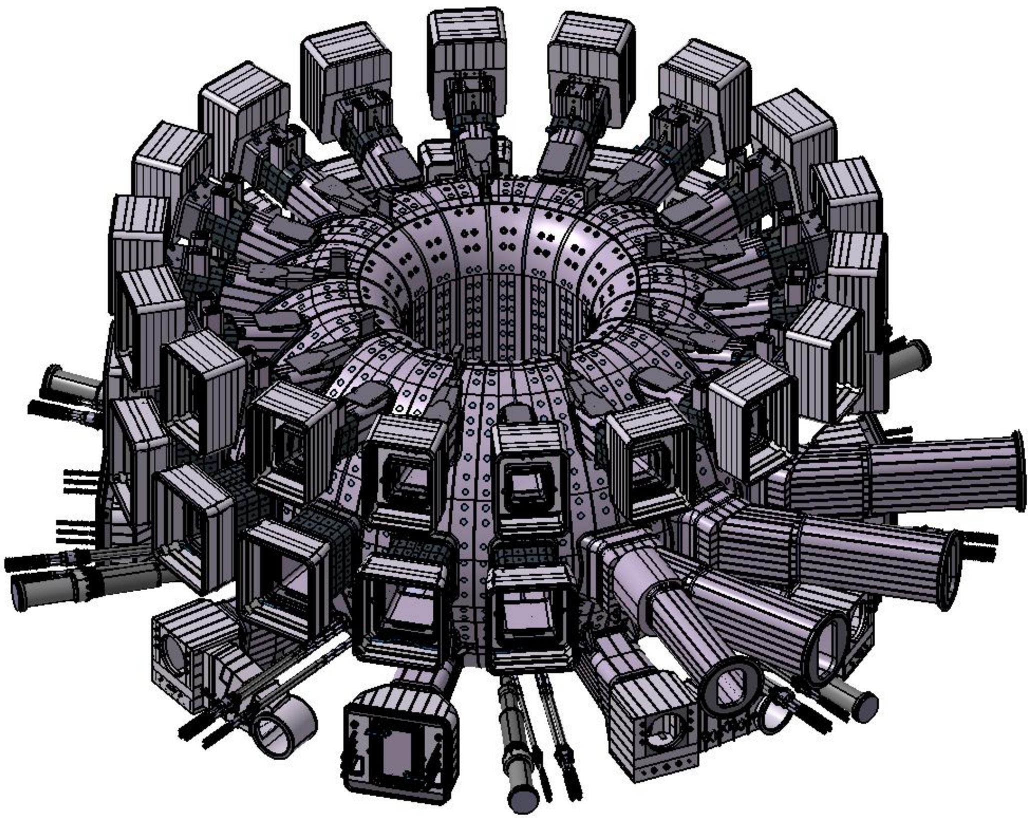
Overview of the Magnet System

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

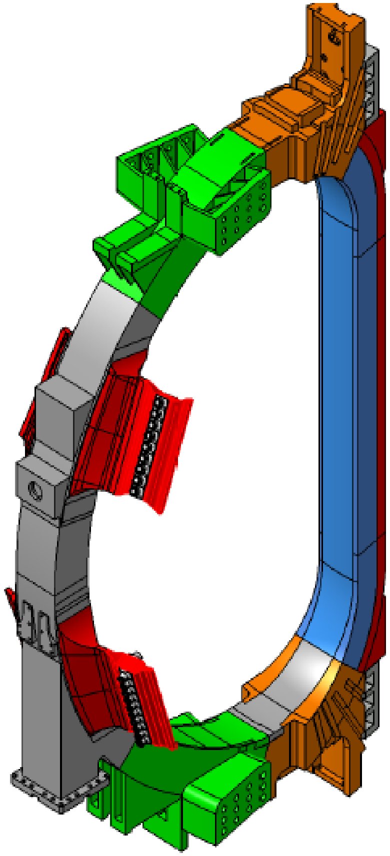
Vacuum Vessel Mass Comparison



VV & In-vessel components mass: ~8000 t
19.4 m outside diameter x 11.3 m tall

Eiffel Tower mass: ~7300 t
324 m tall
(Completed 1889)

TF Coil – Mass Comparison



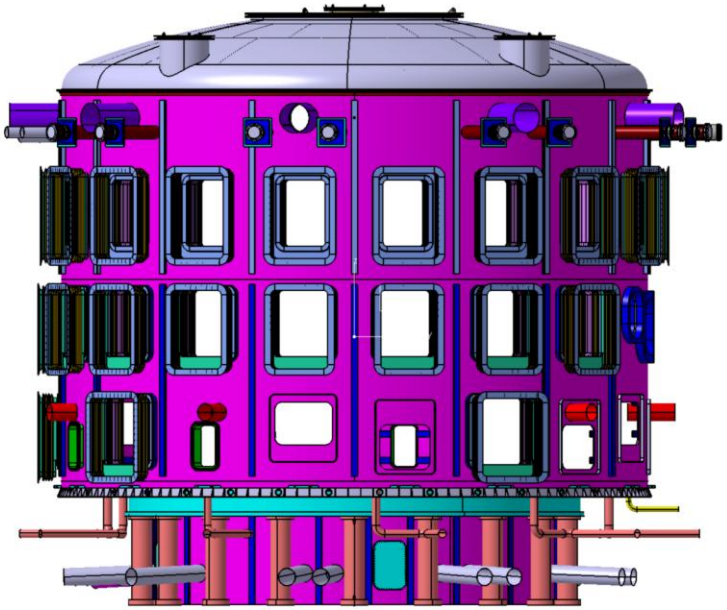
Mass of (1) TF Coil:

~360 t

16 m Tall x 9 m Wide

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

Cryostat Size Comparison

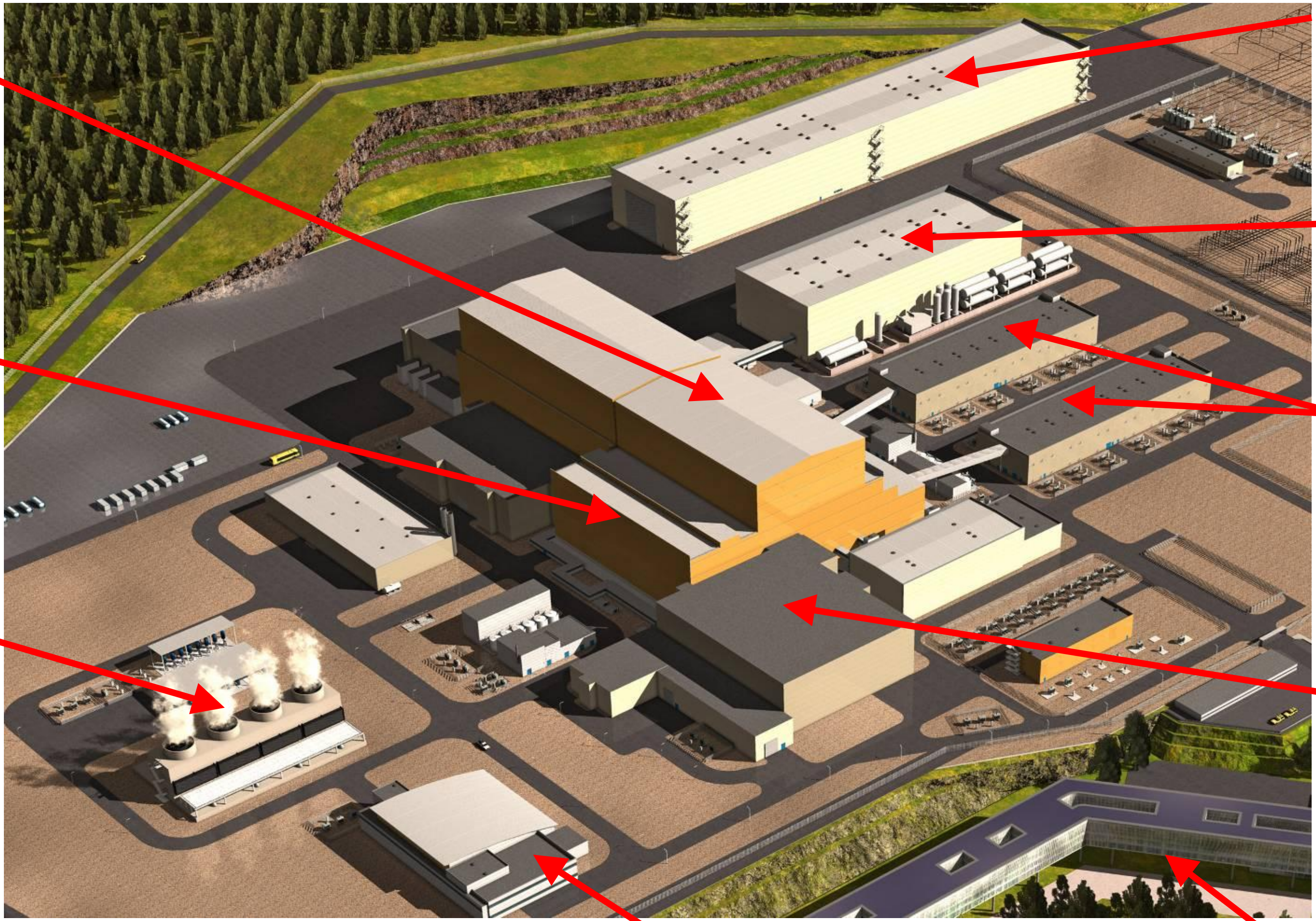


ITER Cryostat
~28 m Tall x
29 m Wide

Jefferson Memorial
(Washington DC)
~29 m Tall (floor to top of dome)

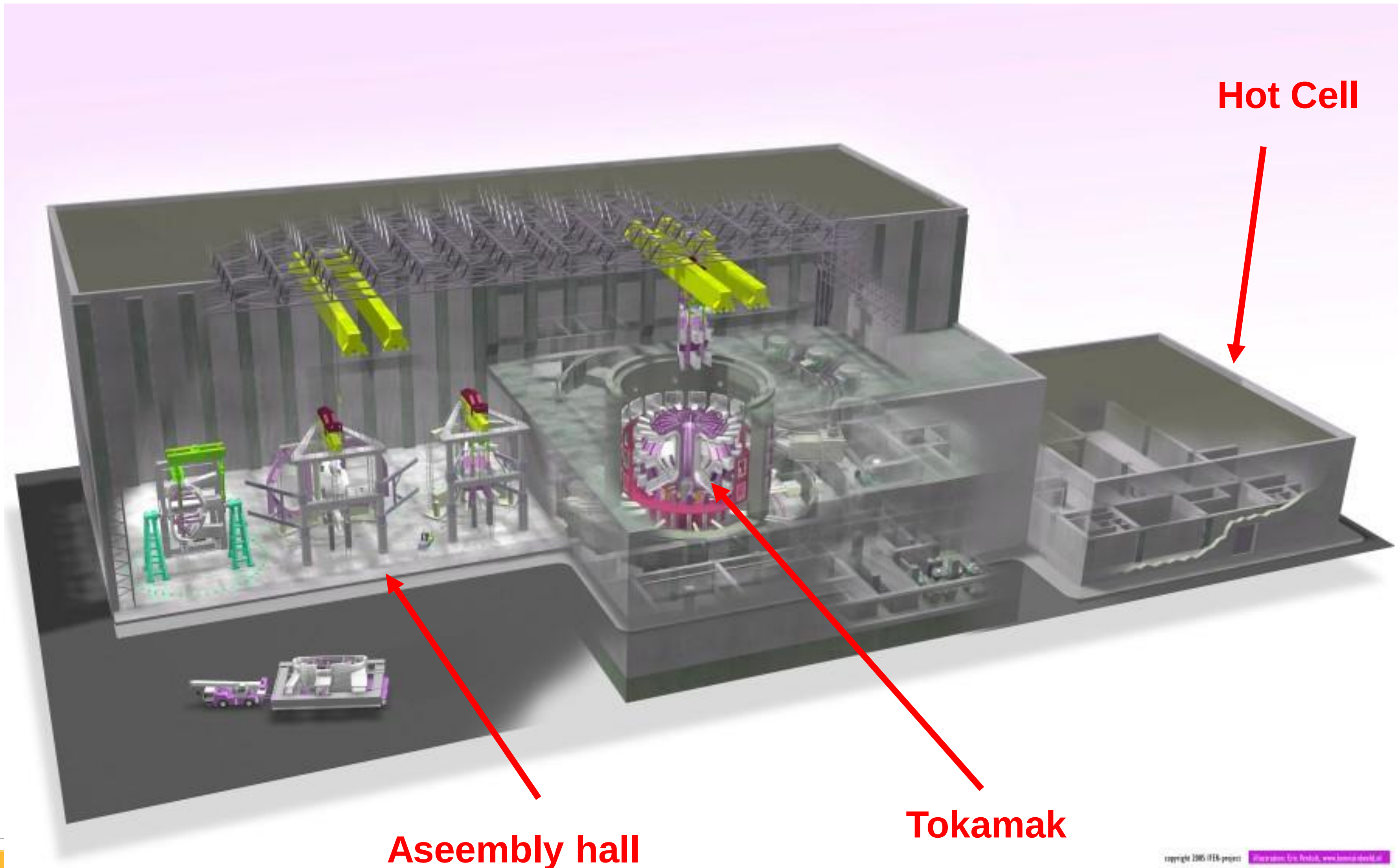
Main Buildings on the ITER Site

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



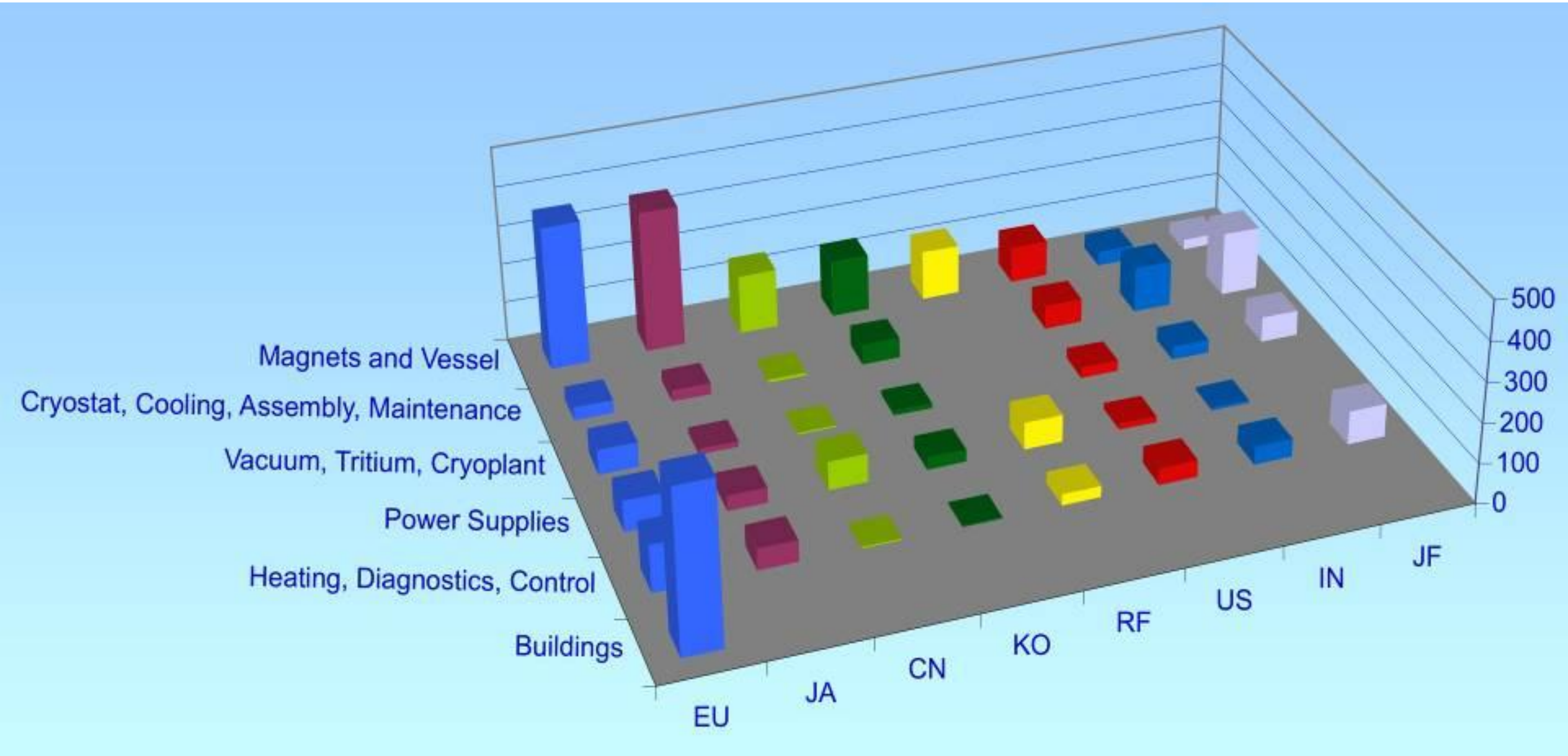
- Will cover an area of about 60 ha
- Large buildings up to 250m long
- Large number of systems

TOKAMAK Building



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.



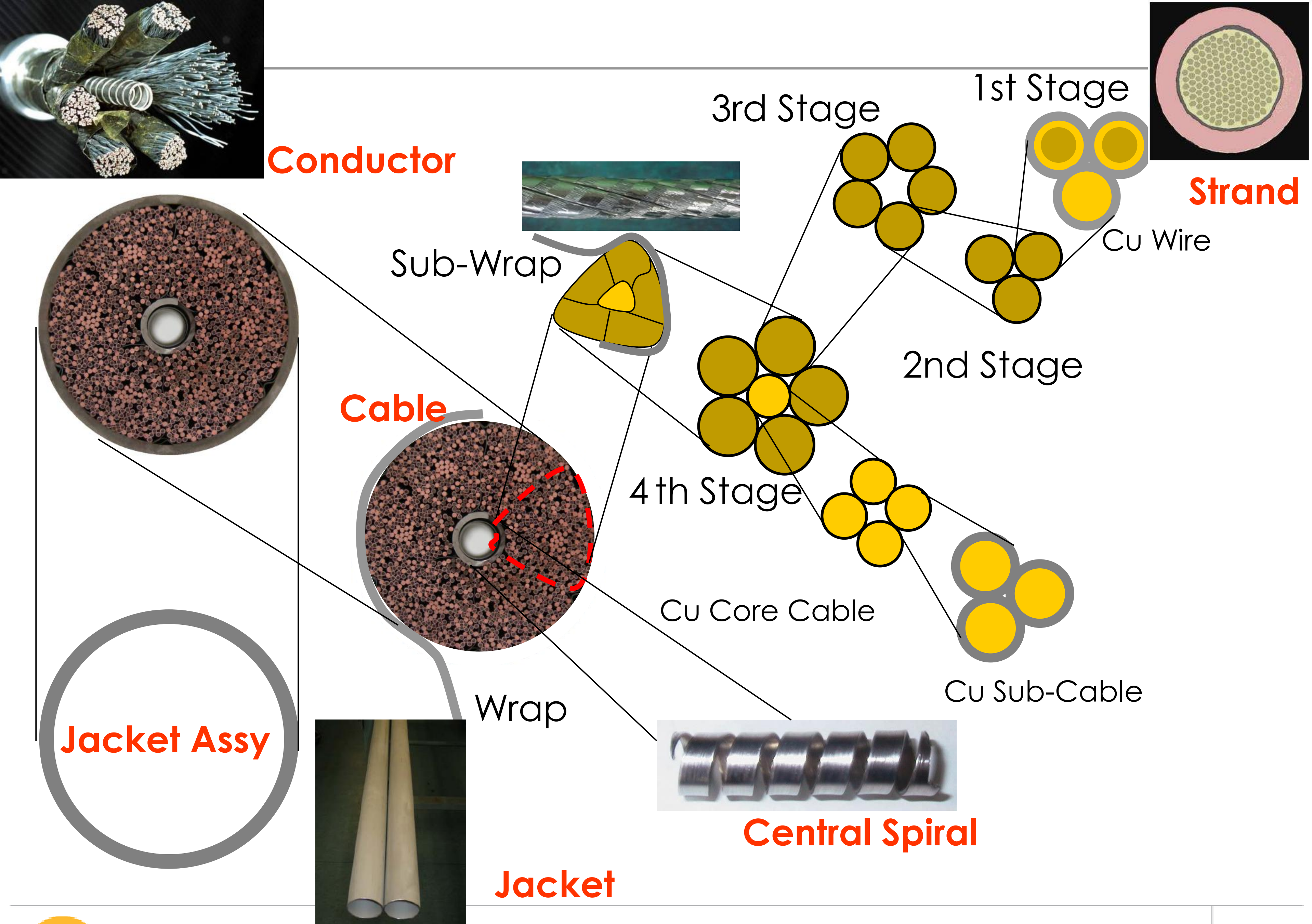
Integration between IO and DAs
- Basic Roles and Responsibilities -

ITER Organization	Seven Members (Domestic Agencies, DA)
– Planning / Design* – Integration / QA / Safety / Licensing / Schedule – Installation – Testing + Commissioning – Operation	– Detailing / Designing* – Procuring / Manufacturing – Delivering – Supporting installation – Conformance

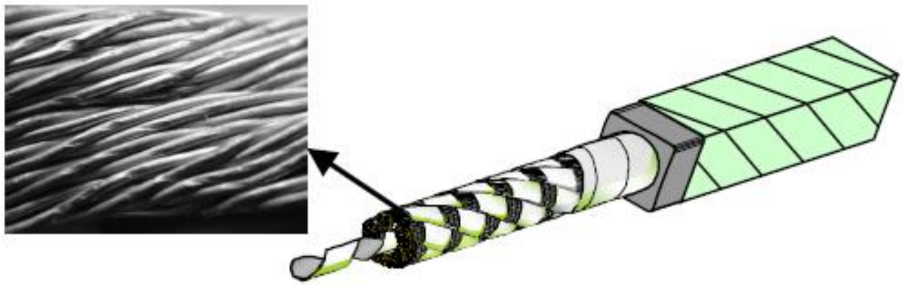
* Depending on type of specification
- Functional: Functional requirements by IO and design by DAs
- Detail design: Conceptual design by IO and detailed design by DAs
- Build-to-print: Detailed design by IO and fabrication/shop design by DAs

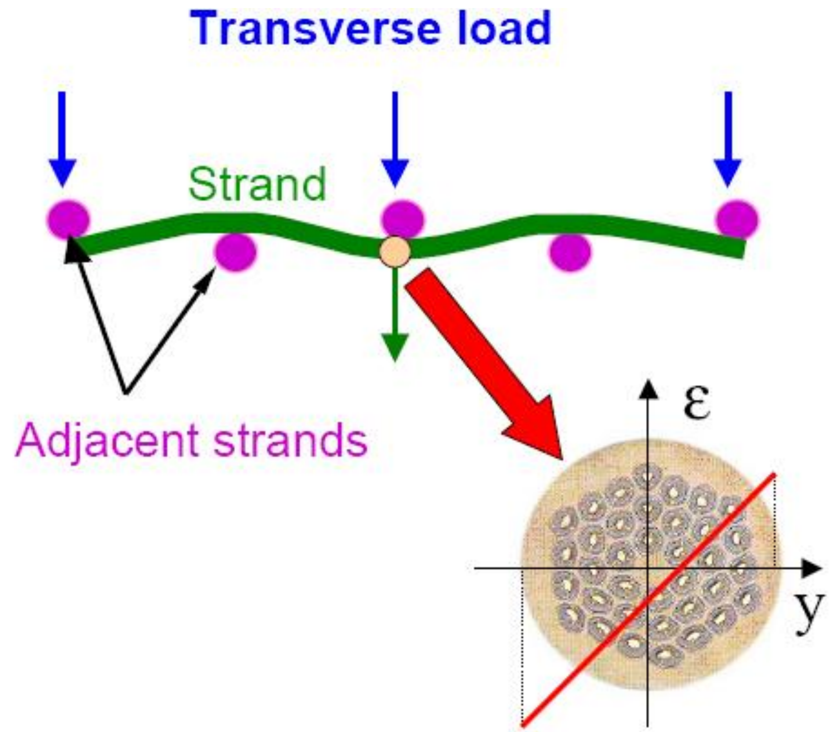
As of today, 44 Procurement Arrangements have been signed.

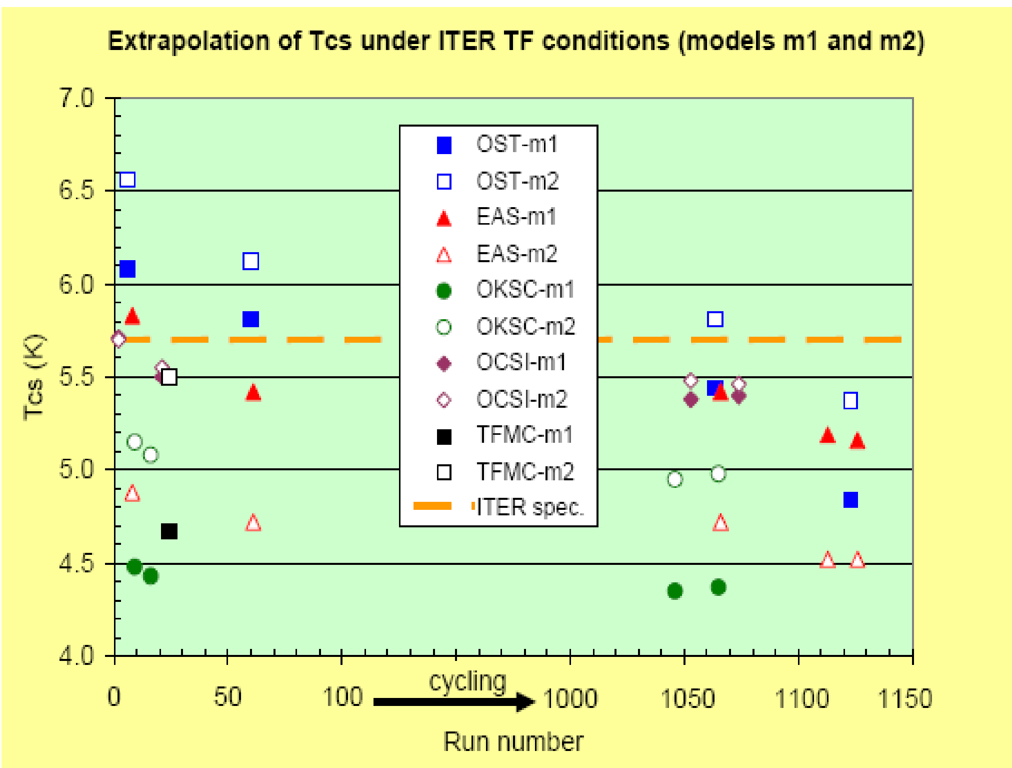
	REFERENCE	Signature date	kIUA value
1	1.1.P6A.JA.01 TF Conductors	28 November 2007	53.73
2	1.1.P6A.EU.01 TF Conductors	18 December 2007	43.39
3	1.1.P6A.RF.01 TF Conductors	12 February 2008	41.54
4	1.1.P6A.KO.01 TF Conductors	07 May 2008	43.39
43	6.2.P2.EU.05 Buildings Construction	14 May 2010	347.50
44	2.7.P1.KO.01.0 Thermal Shield	17 May 2010	26.883
	Total		**1728.944**


Conductor
Strand
1st Stage
3rd Stage
Sub-Wrap
Cu Wire
2nd Stage
Cable
4 th Stage
Cu Core Cable
Cu Sub-Cable
Wrap
Jacket Assy
Central Spiral
Jacket

2005: Use of new High Current Carrying capability cable: → Performance Degradation in High Field Magnets



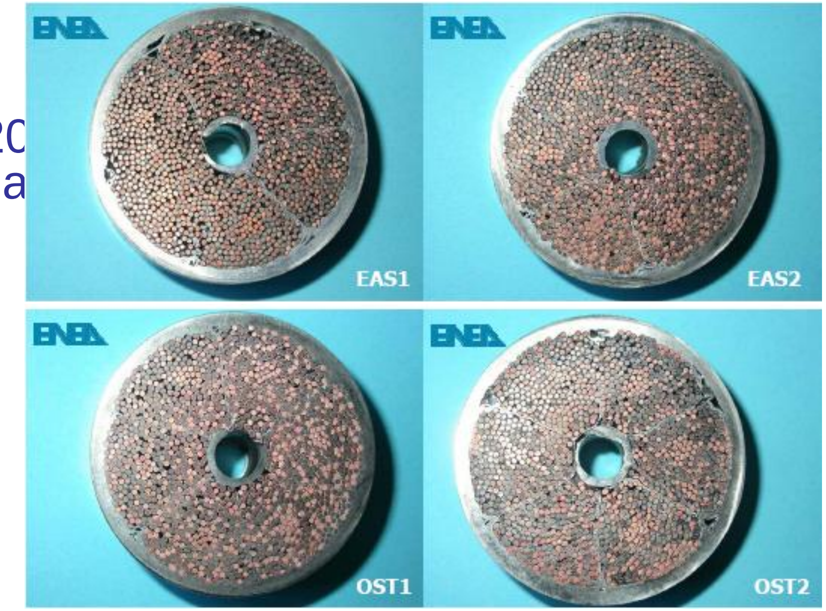




R&D for Projects

The Fix: Packing of the conductor wire…

- cables tested in 20
  showed substantia
  degradation



- Ongoing field-cycling stress tests showing very promising results

Cables from all 6 parties that make them are qualified now!

TF and CS Jacketing in JA



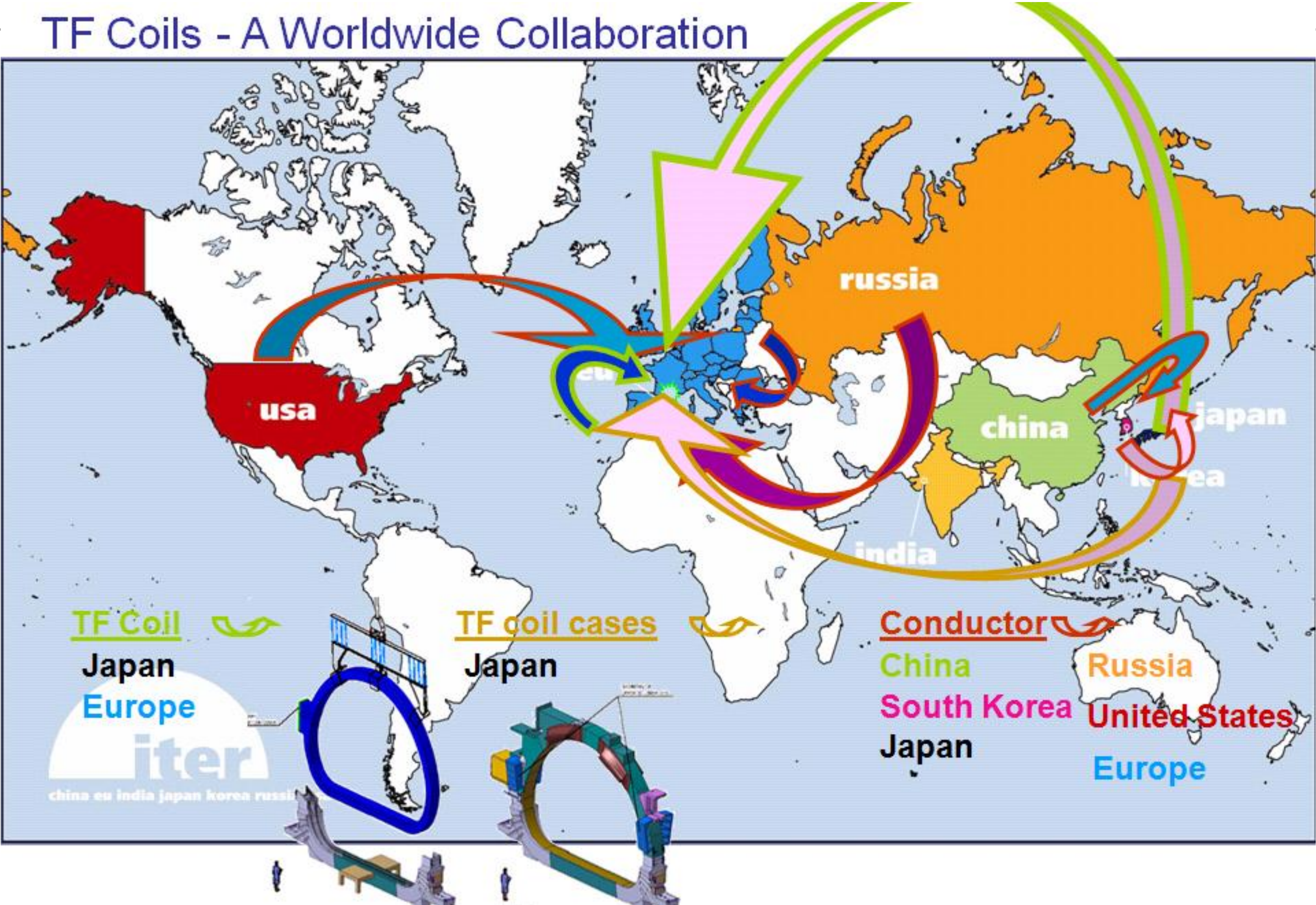
TF & CS Jacketing Lines (Jun. 09)

TF and PF Jacketing in CN

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

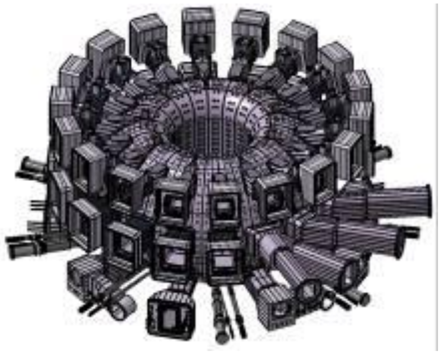
TF & PF Jacketing Lines at ASIPP (March−June 09)

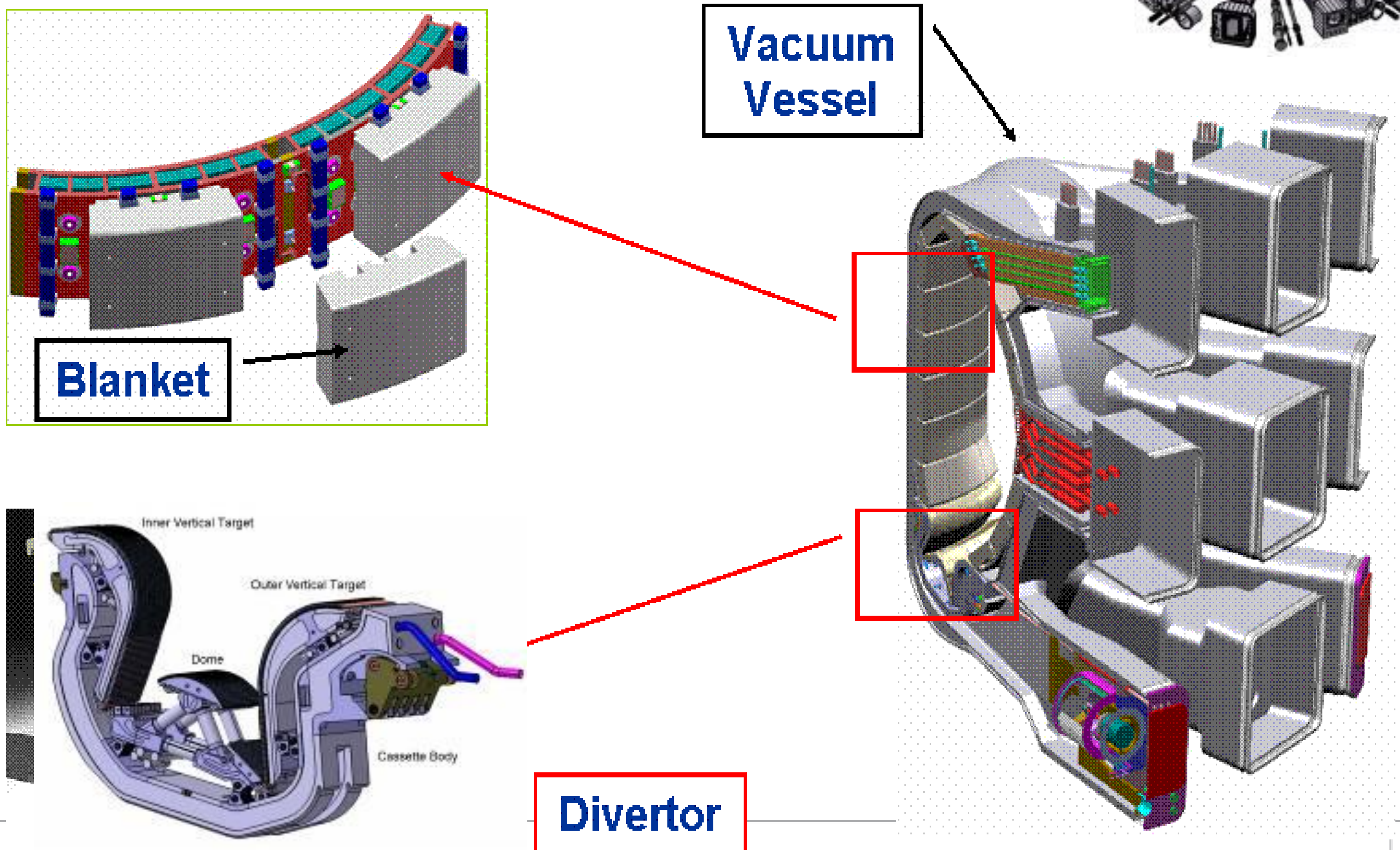
TF Coils - A Worldwide Collaboration

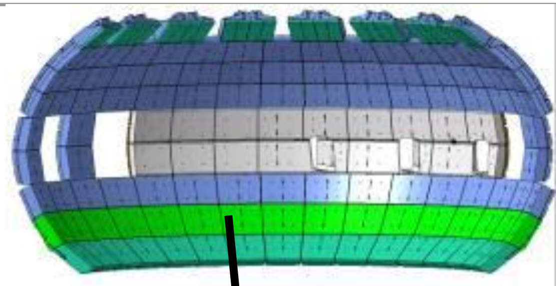


VV and In-Vessel Components

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





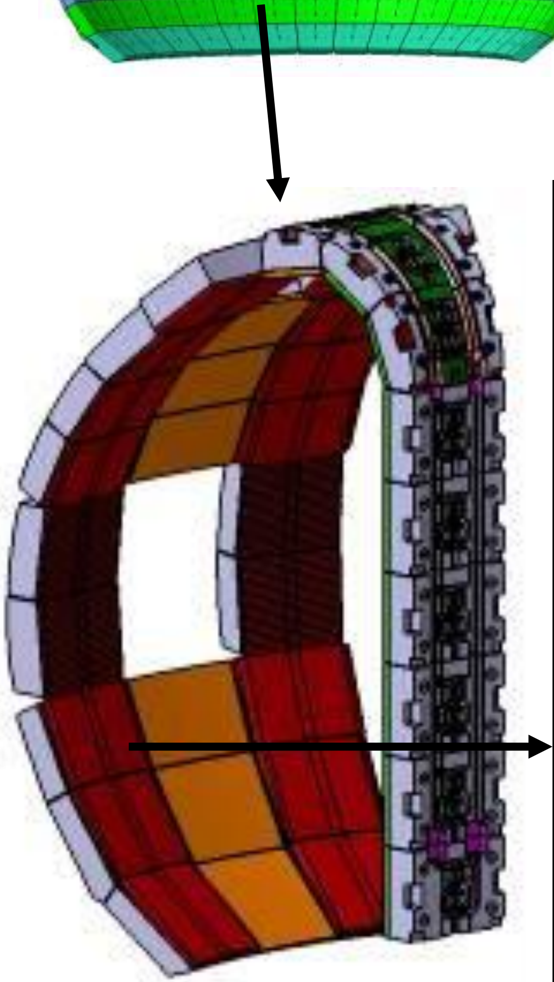


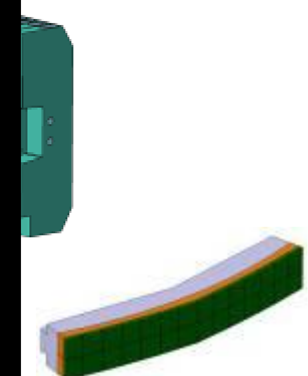
Blanket System

Scope

- **440 blanket modules at ~4 ton each**

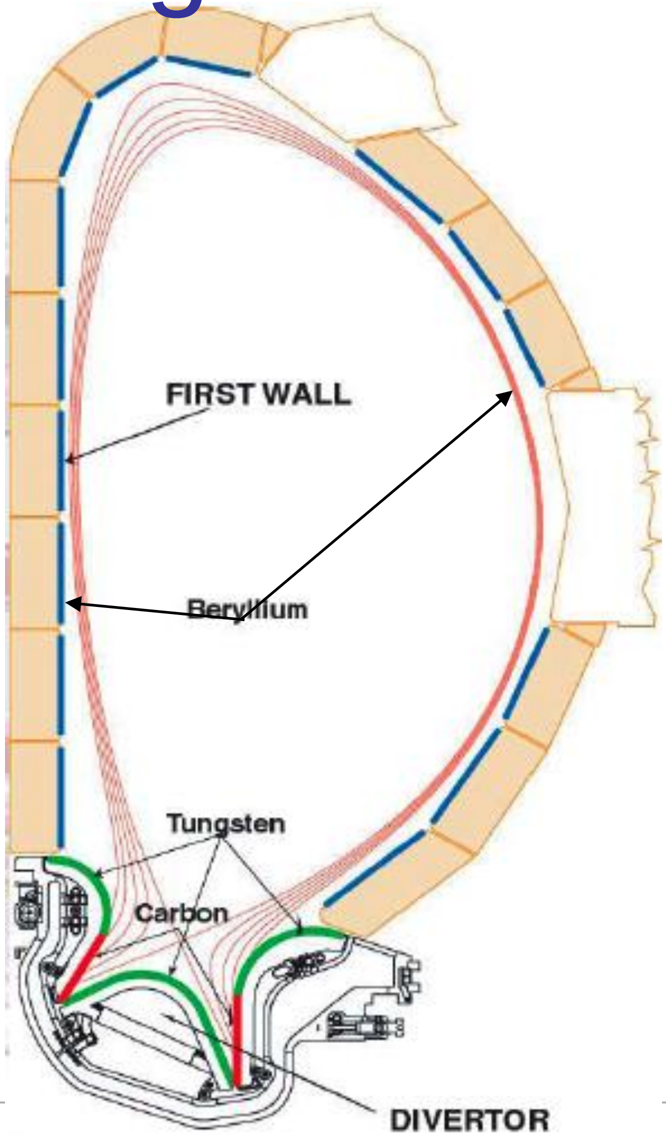
[redacted]





Plasma Facing Components - Challenges

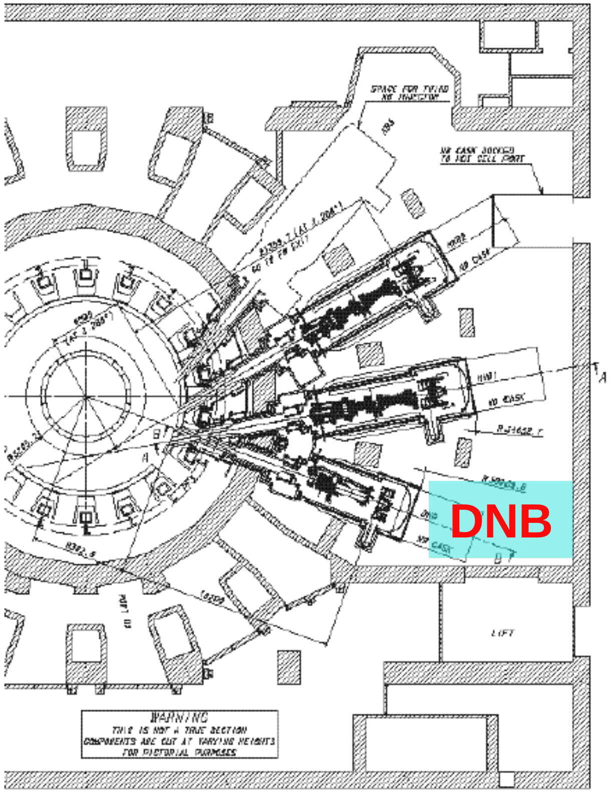
- CFC divertor targets (~50m^2):
  - erosion lifetime (ELMs!) and tritium codeposition
  - dust production
- Be first wall (~700m^2):
  - dust production and hydrogen production in off-normal events
  - melting during VDEs
- W-clad divertor elements (~100m^2):
  - melt layer loss at ELMs and disruptions
  - W dust production - radiological hazard in by-pass event



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 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		126 or 170GHz
Diagnostic Beam (100keV, H^-)	>2		

NBI Layout

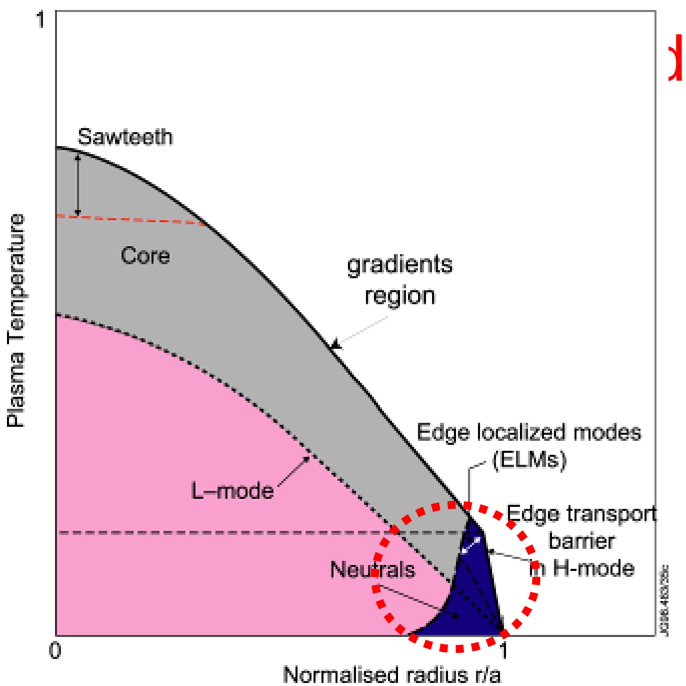


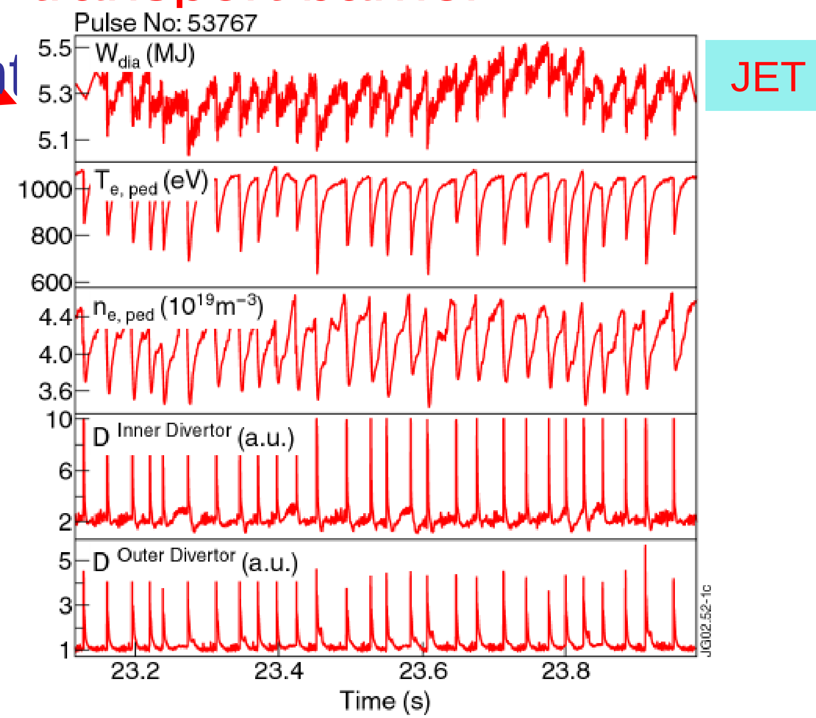
P_{aux} for Q=10 nominal scenario: 40-50MW

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

des maint



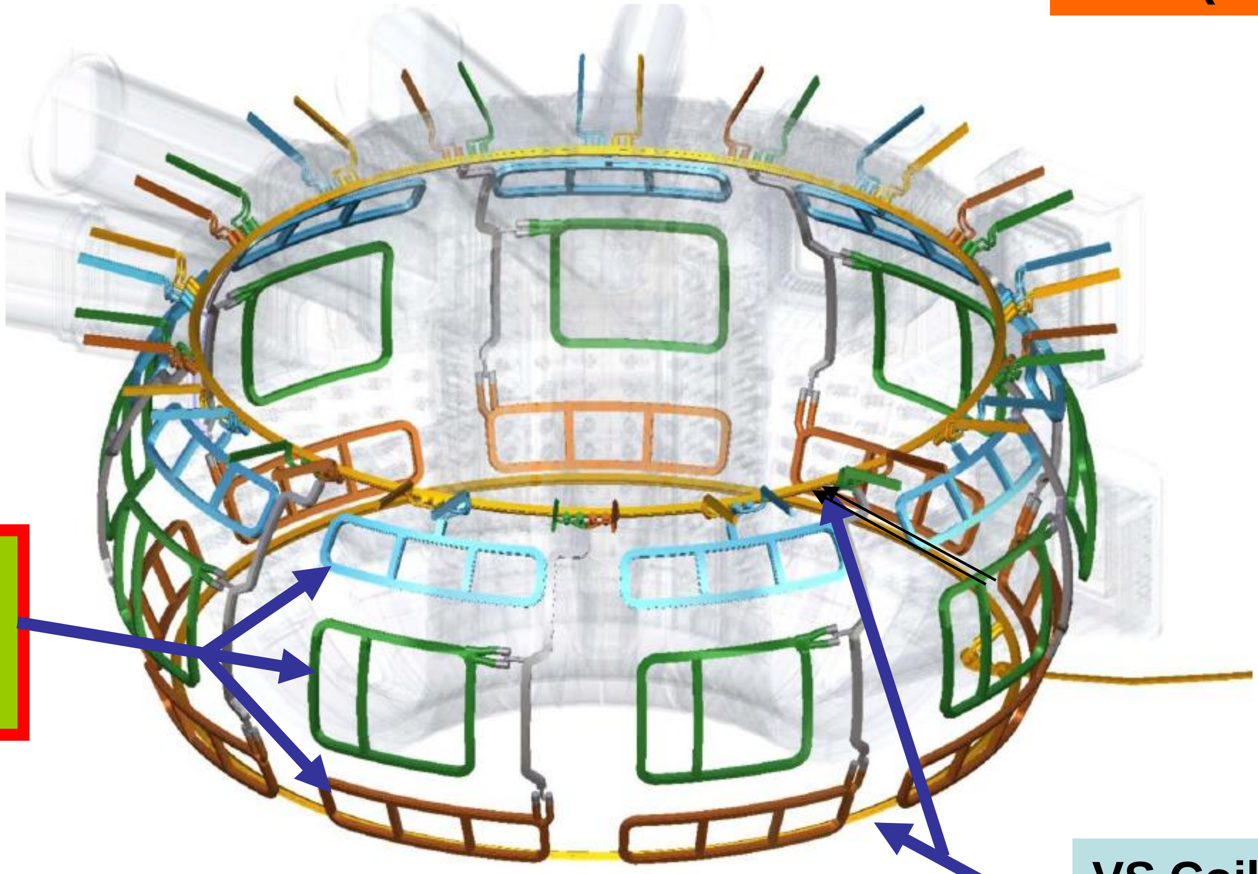


ELM- and VS- coils

ELM Control

Resistive Wall Mode (RWM) Control

Vertical Stabilization (VS)

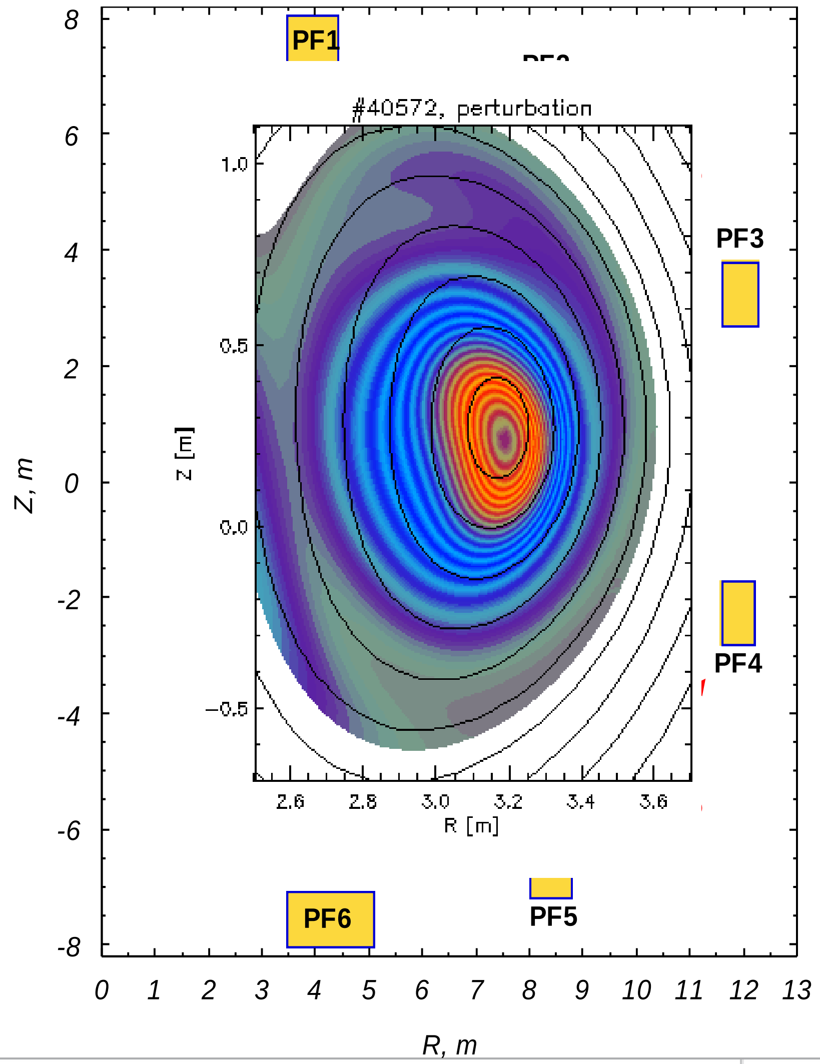


ELM/RWM Coils (9 groups of 3)

VS Coils (upper & lower ring coils)

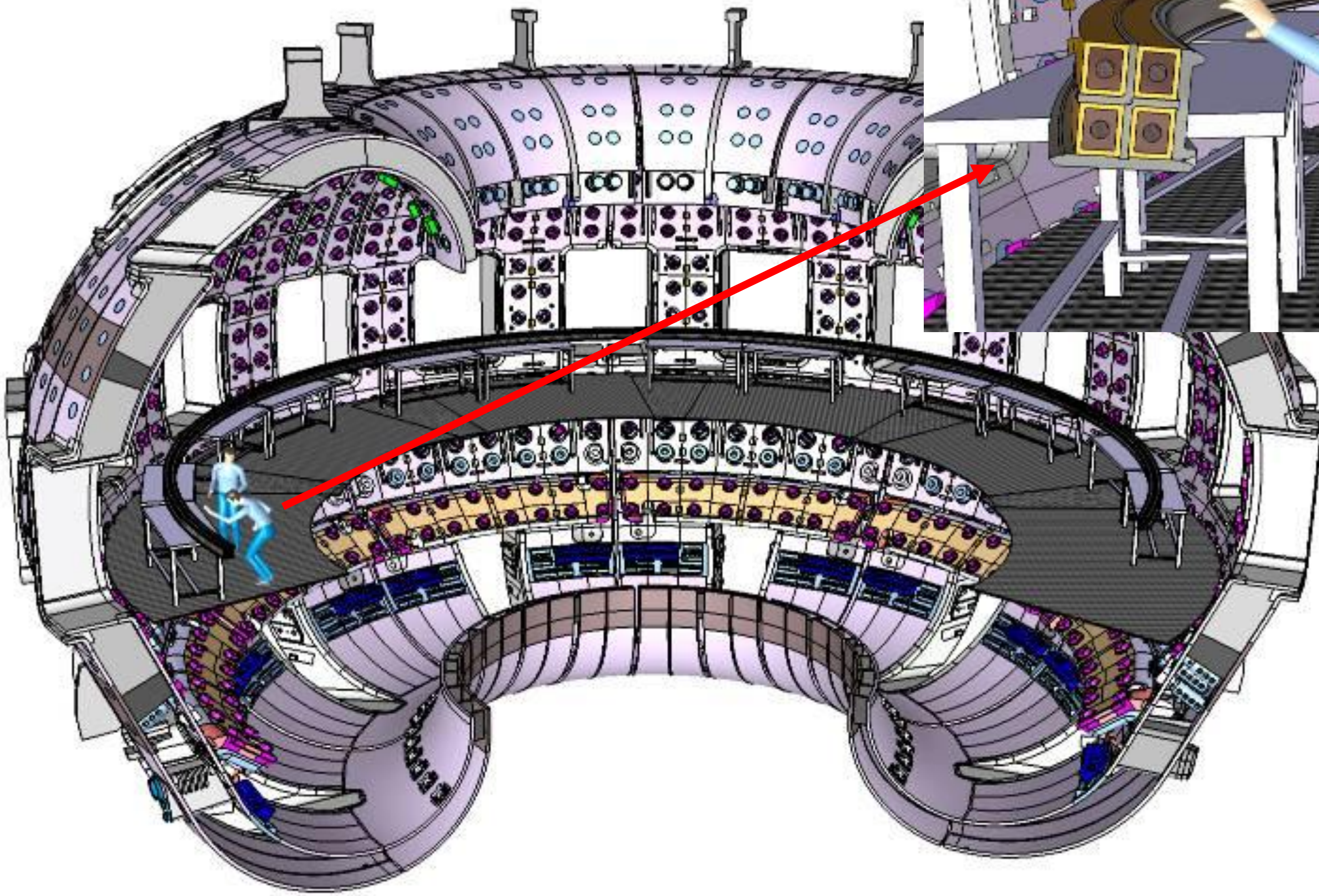
R&D for Projects: Poloidal Field Control in ITER

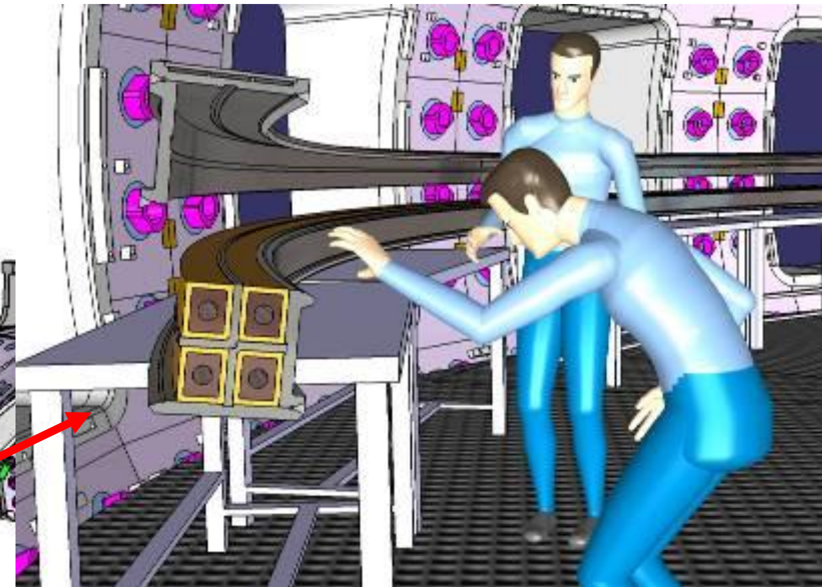
- Control of the Plasma operation through magnetic fields
- Slow feedback loop through PF coil system:
  - control of plasma current, shape,
  - coil currents, separatrix separation, etc. (5-10 s)
- Fast feedback loop through in vessel coil:
  - stabilization of plasma vertical position (<1 s)



Internal Feedback Coil

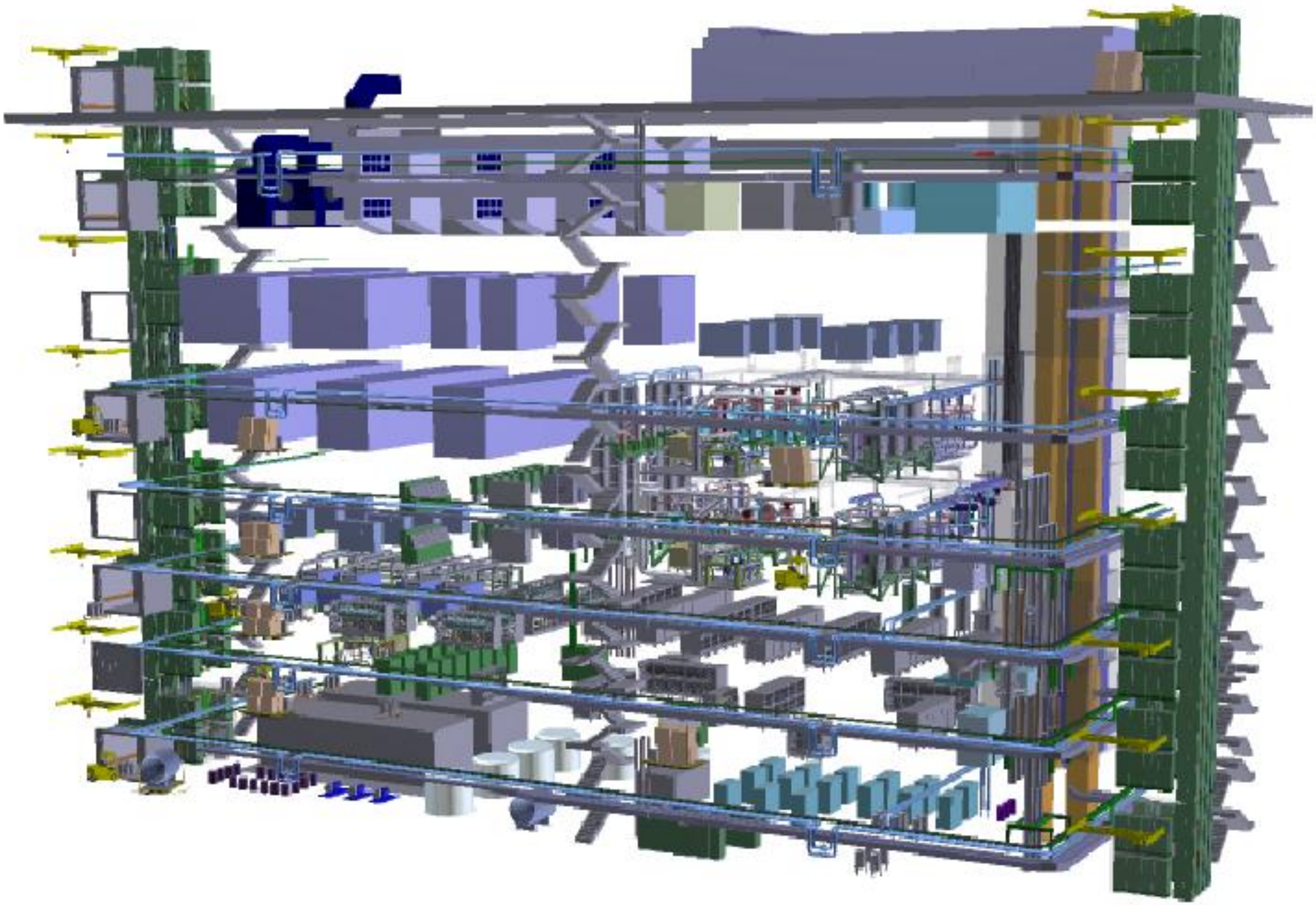
In Vessel coils for Vertical Stability



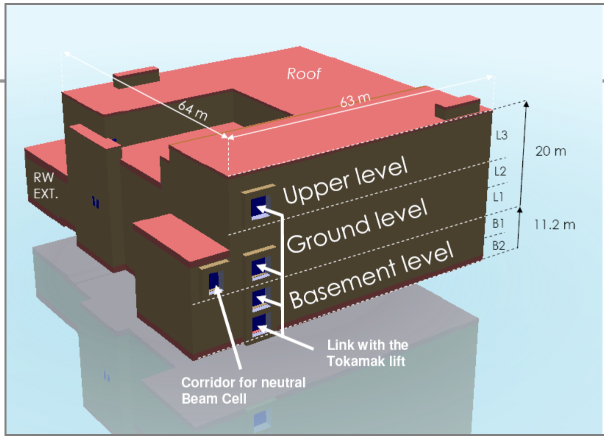


Ongoing R&D for the project

Tritium Plant Building Systems Layout



Hot Cell design



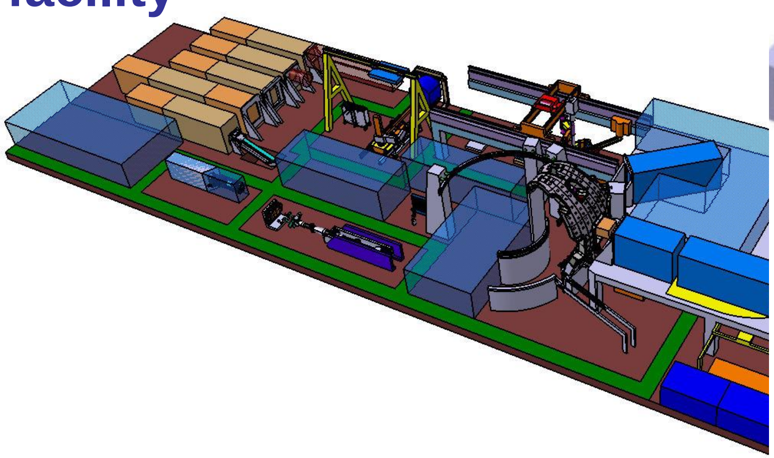
The HC RH system will have the following equipment:

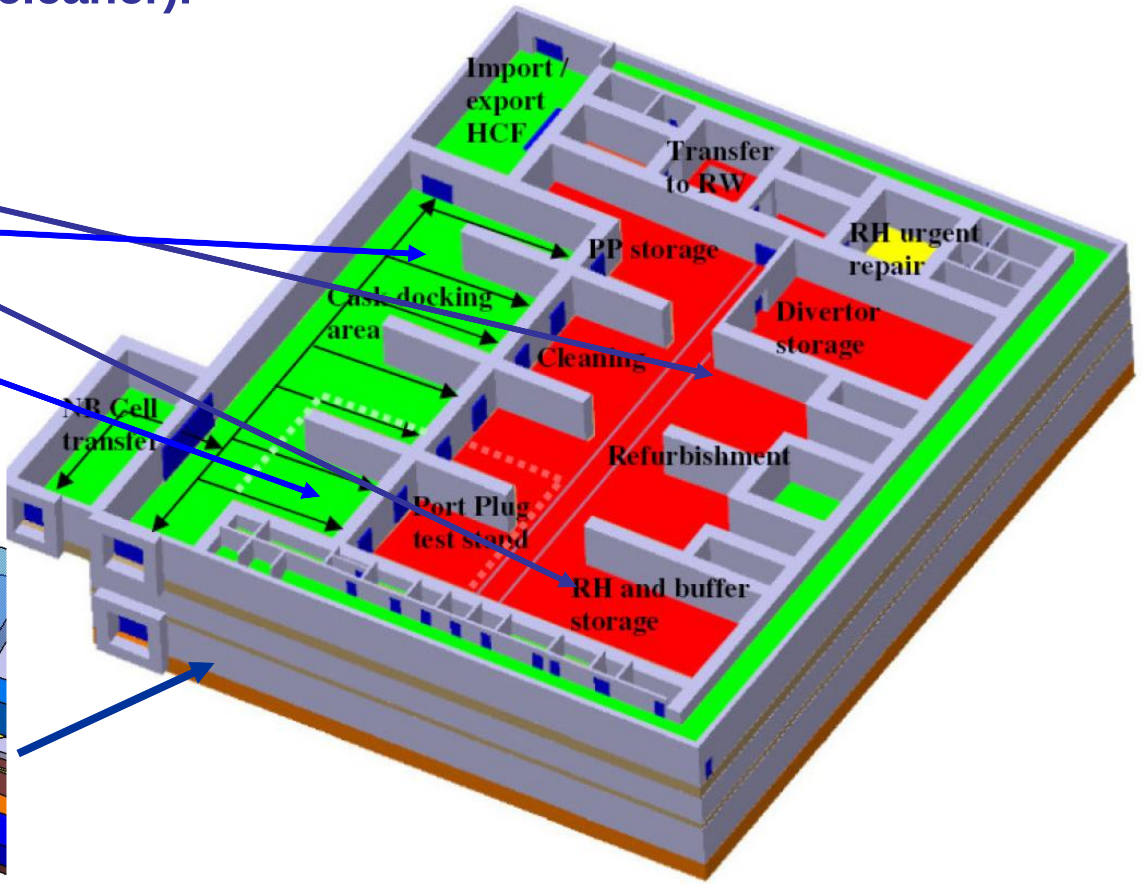
- Boom-style RH transporter(s)
- Jib cranes transporters
- Lifting jigs
- Dexterous telemanipulators) end effectors
- Direct viewing telemanipulators
- Inspection equipment (including weld NDT, visual inspection, metrology)
- Cleaning equipment (Vacuum cleaner).

refurbishment & test

Cask Docking

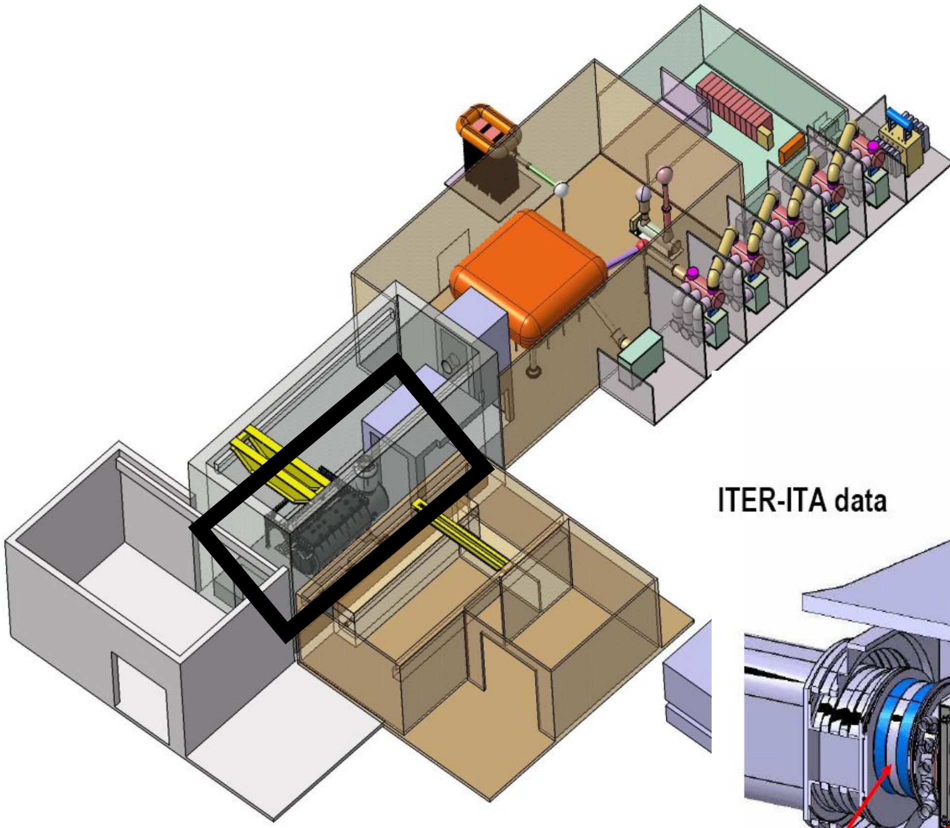
Hot- RH Test facility



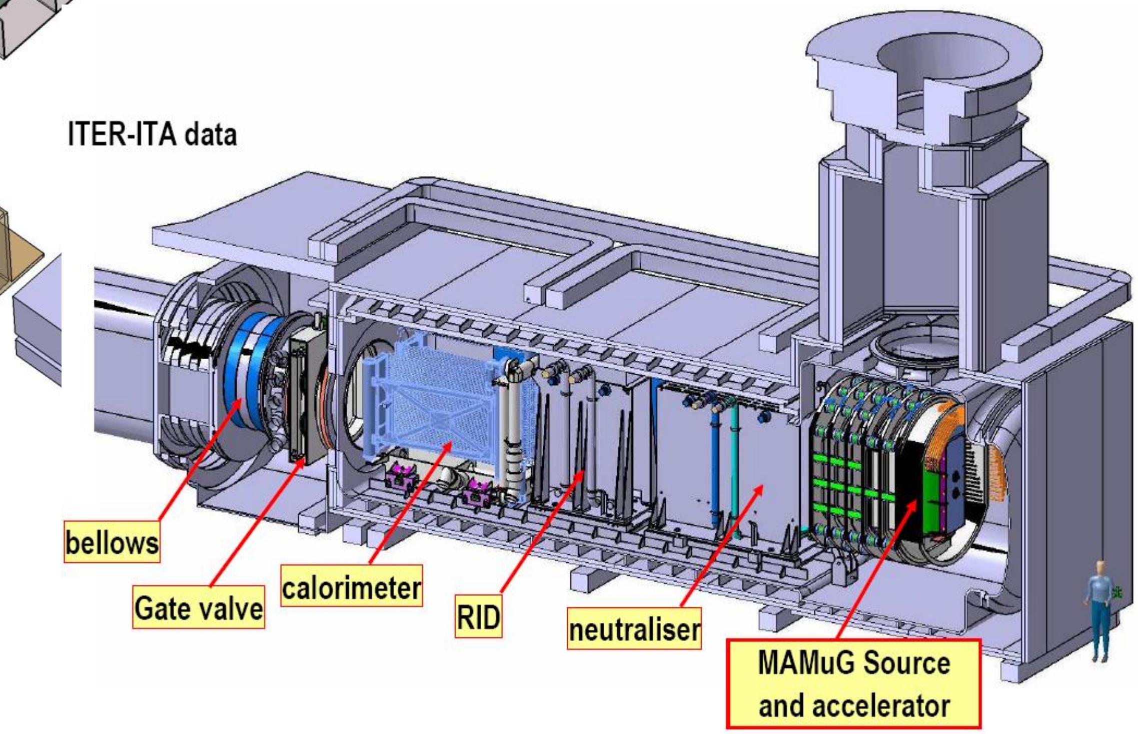


Lay Out Of The Neutral Beam Test Facility in Padua

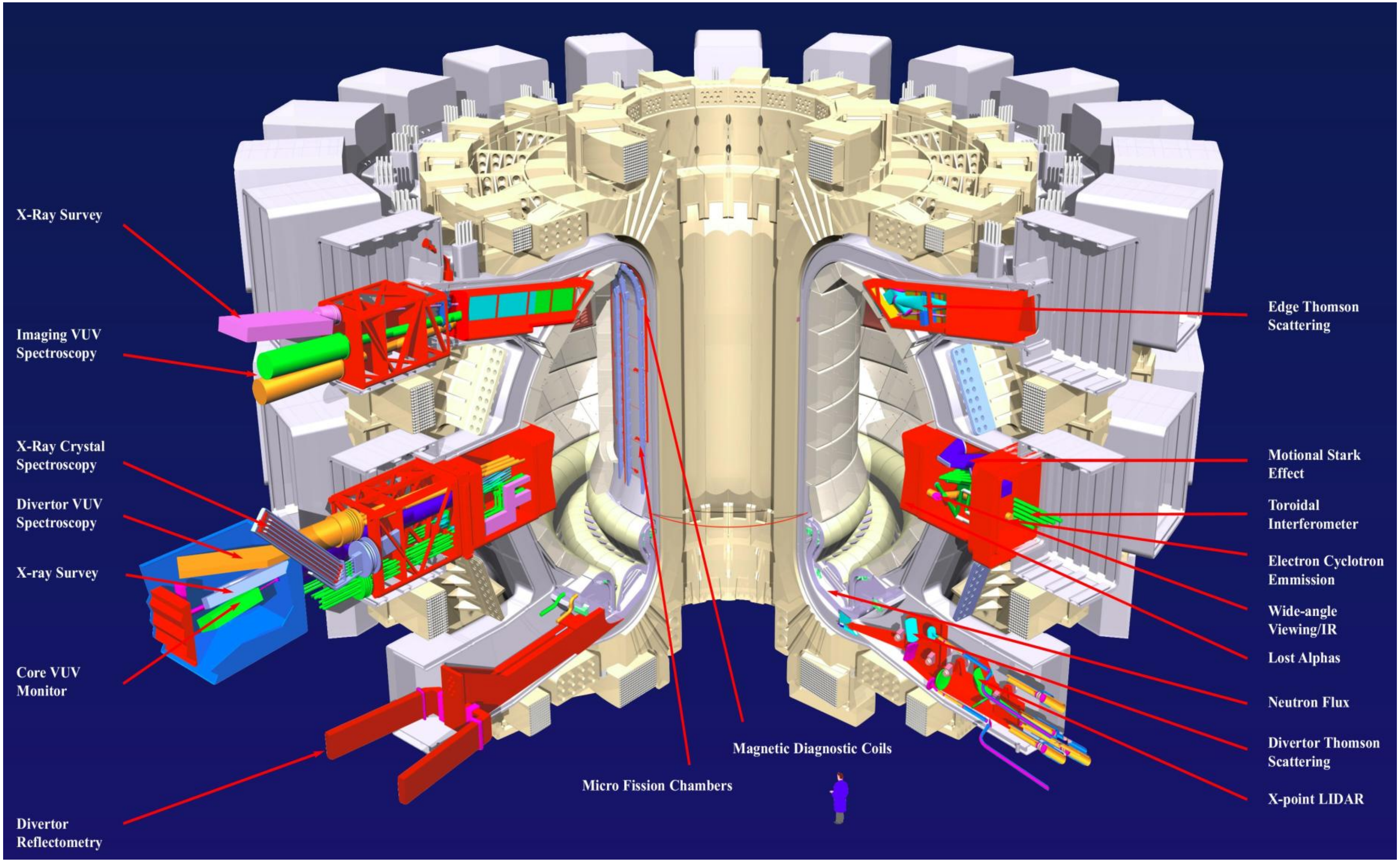
ITER NB Heating System
1 MV DC
~40 A of H^- current
20 MW delivered to Plasma
Up to 3 systems on ITER



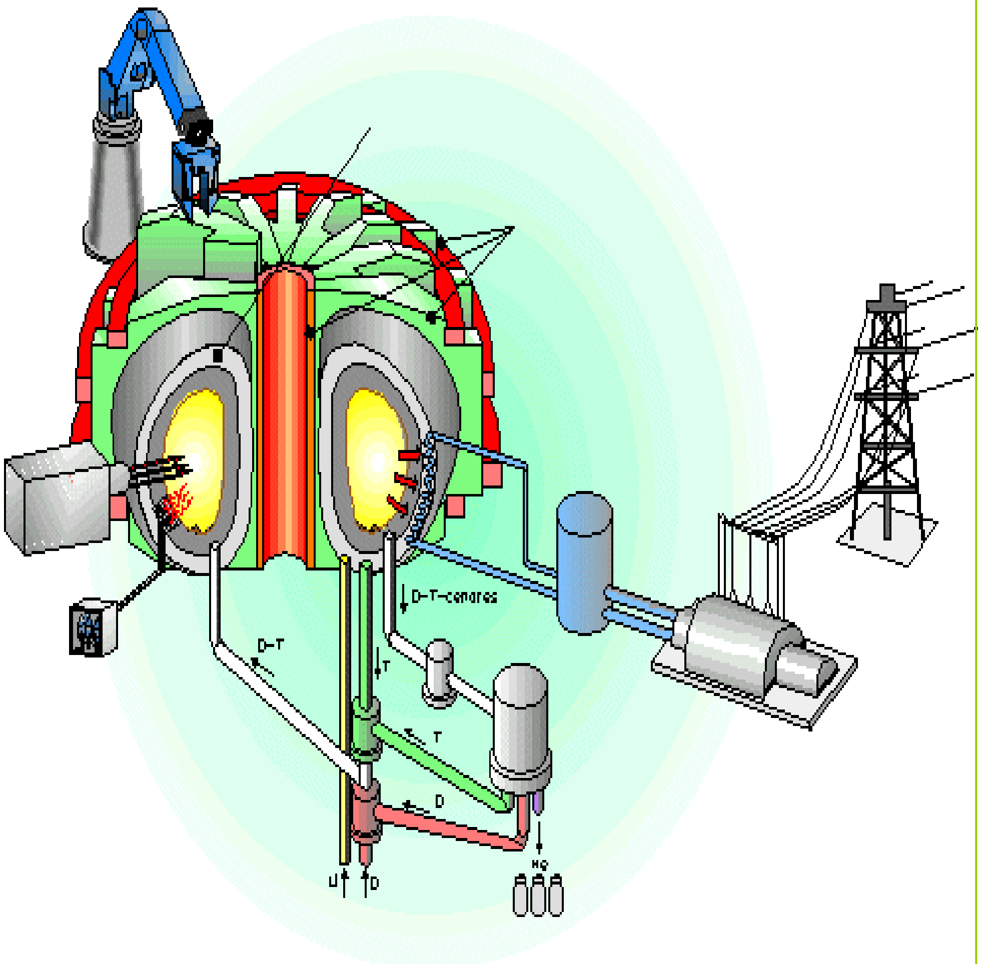
Neutral Beam Test Facility



Diagnostics



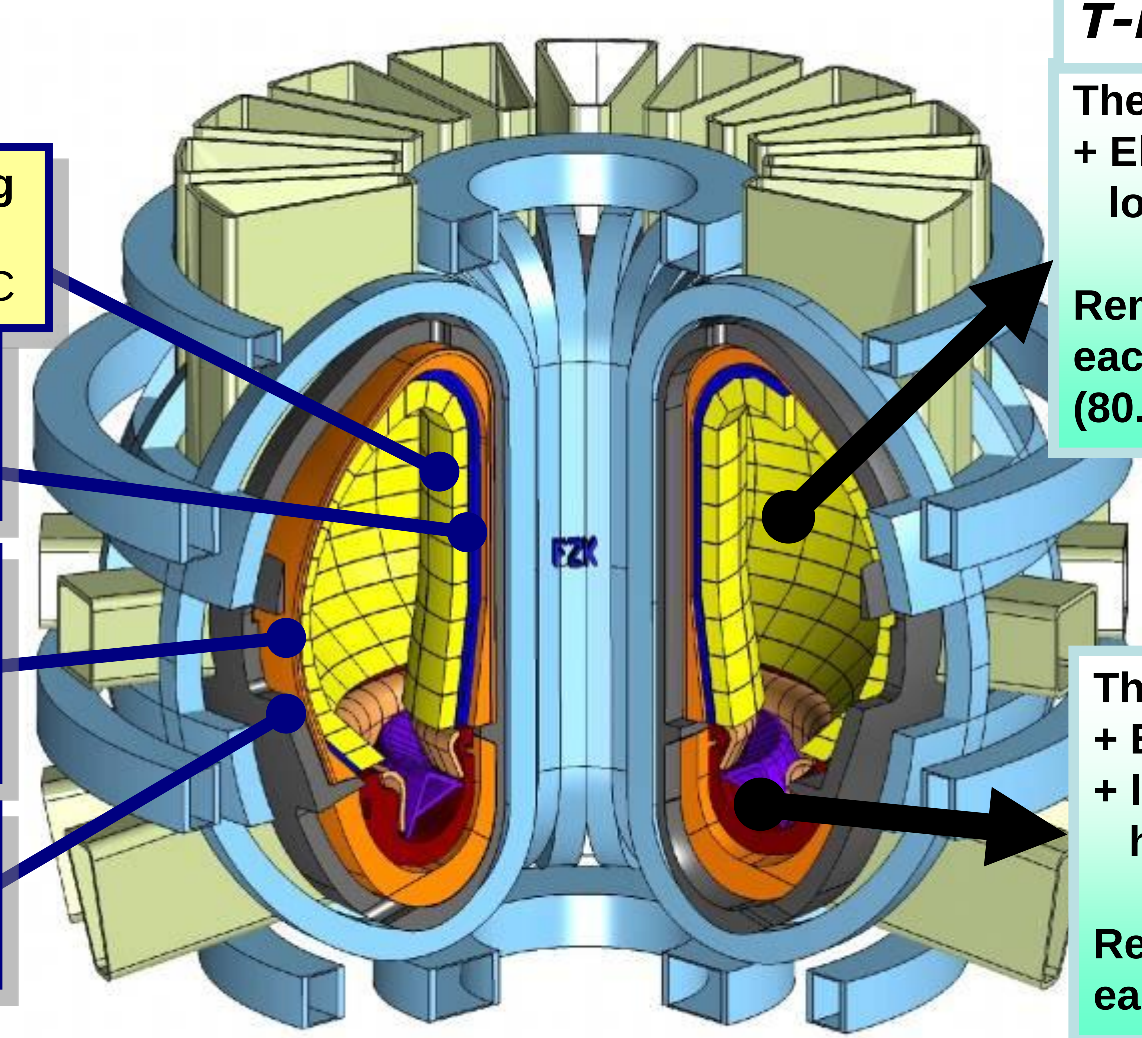
Tritium Breeding Blankets functions in DEMO



Three crucial functions

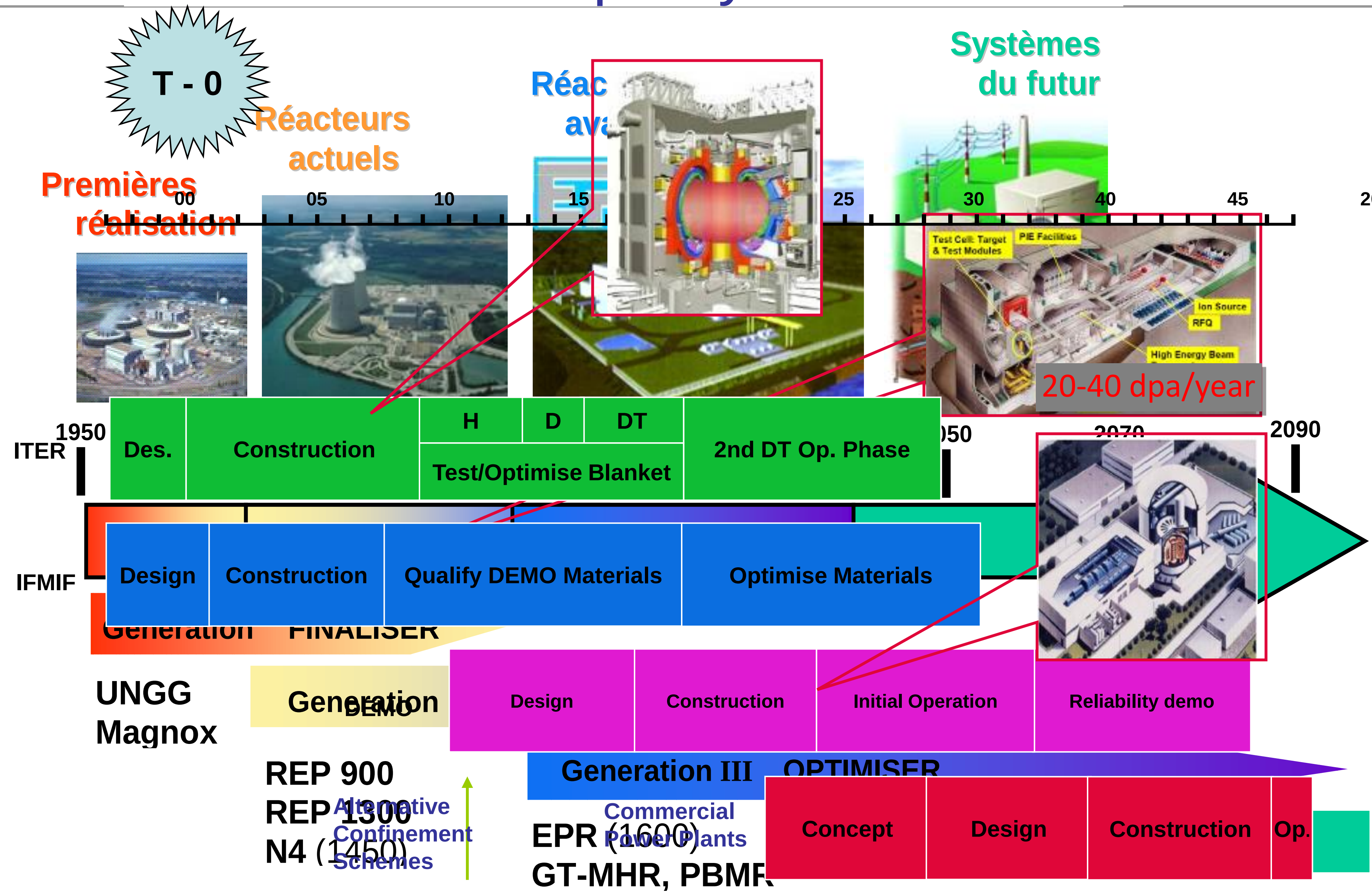
- **Convert** the neutron energy (80% of the fusion energy) in heat and collect it by mean of an high grade coolant to reach high conversion efficiency (>30%)
  ➔ in-pile heat exchanger
- Produce and recover **all Tritium** required as fuel for D-T reactors (300-500 g/days)
  ➔ Tritium breeding self-sufficiency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

Typical Temperatures in DEMO and constraints



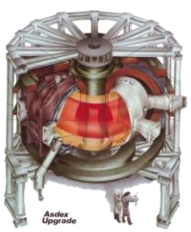
DEMO = Demonstration Fusion Reactor Plant

The Roadmap Beyond ITER

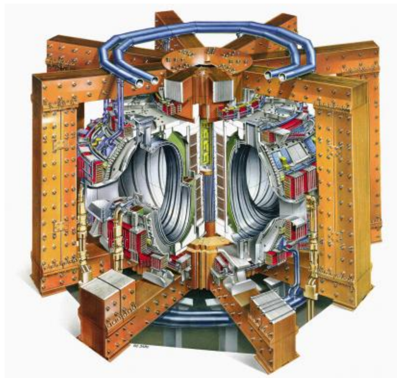


Tokamaks und Stellarators

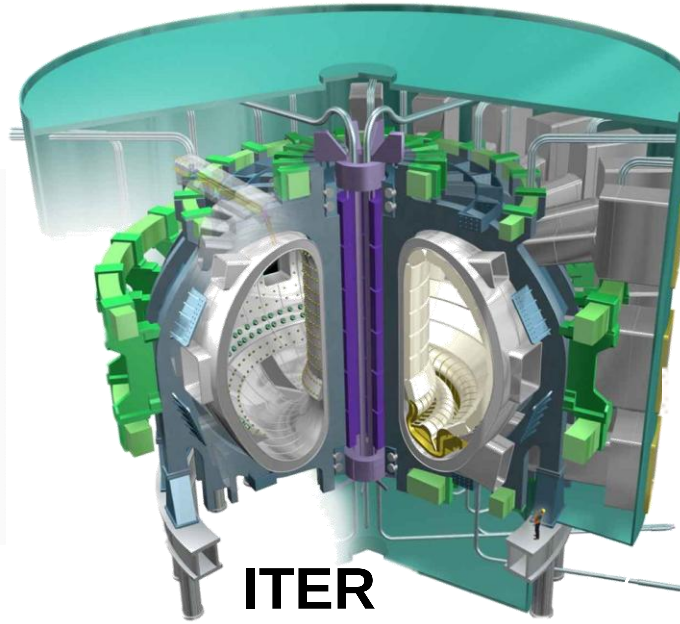
Tokamaks



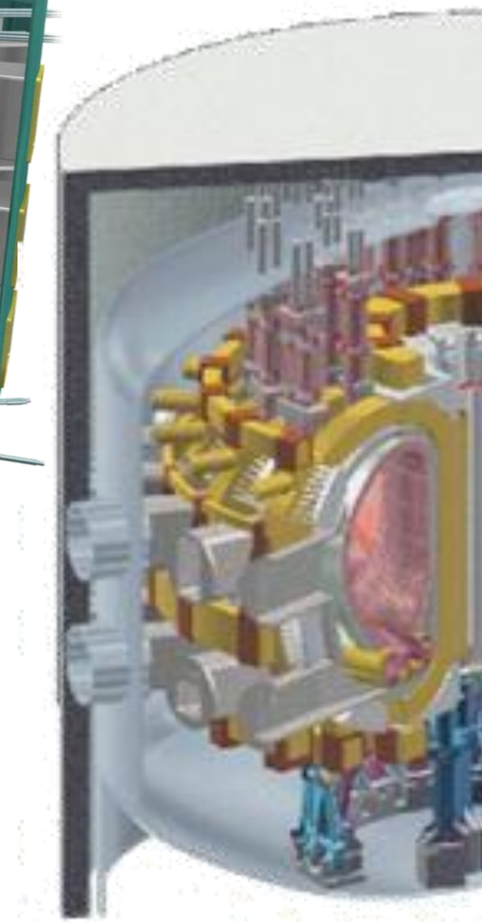
ASDEX Upgrade
Garching



JET
Culham

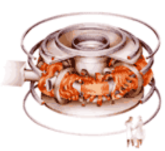


ITER
Cadarache

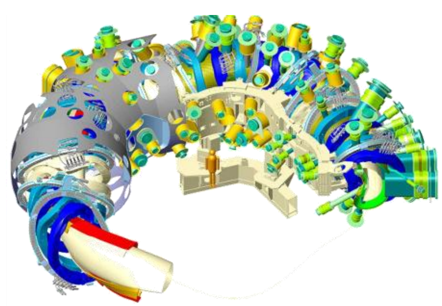


DEMO

Stellaratoren



Wendelstein 7-AS
Garching



Wendelstein 7-X
Greifswald

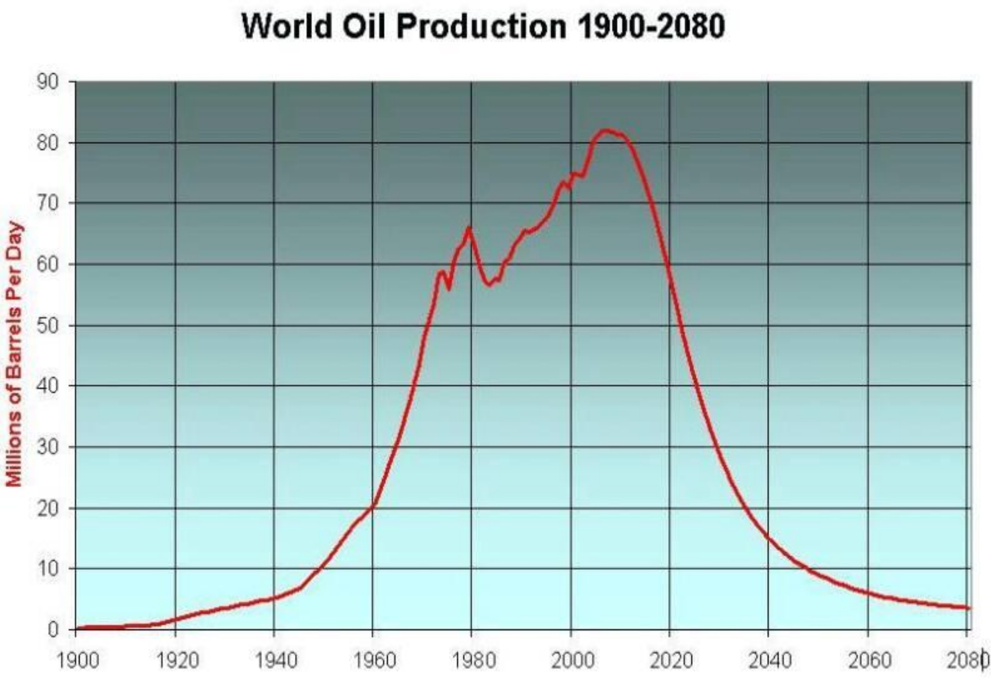
What if..?

- ITER does not work?
  - Magnetic fusion on the basis of TOKAMAKs is not an option for the future. The answer is clear.

- If cost go up, schedule slips, technical issues arise?
  - ITER Council: “manage the cost, minimize any delay but get us there as soon as possible”

- What if DEMO takes longer?
  - Still many energy resources exist. Mostly fossile. There will be enough for about another 100-150 years…. but

ITER – a Global Challenge



„The stakes are considerable, not to say vital for our planet.“

Manuel Barroso, Former President of the European Commission