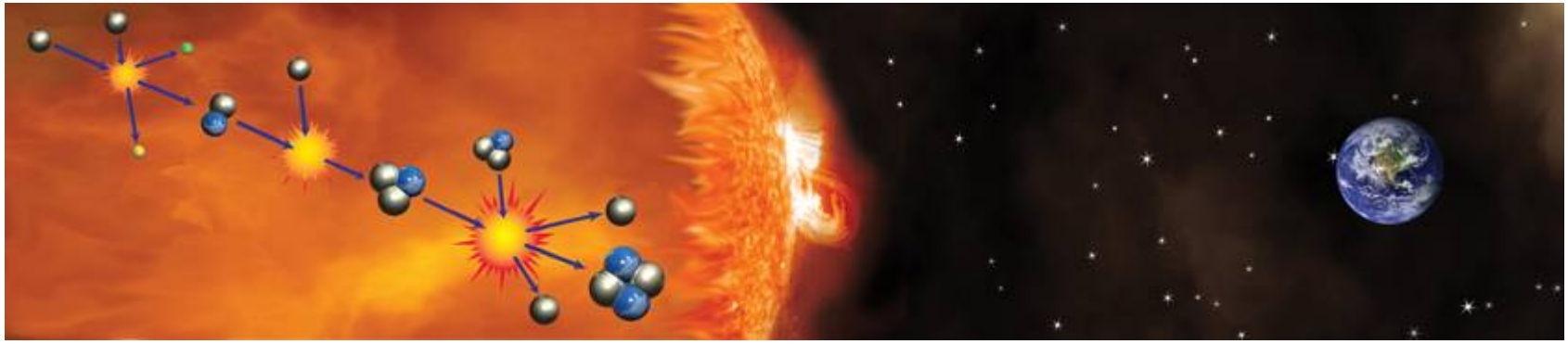
Overview of the Status of the ITER Project

Norbert Holtkamp

Principal Deputy Director General of the ITER Organization

Acknowledgements: ITER team, Domestic Agencies and all collaborating institutions

Fusion powers the sun and the stars
"…Prometheus steals fire from the heaven"

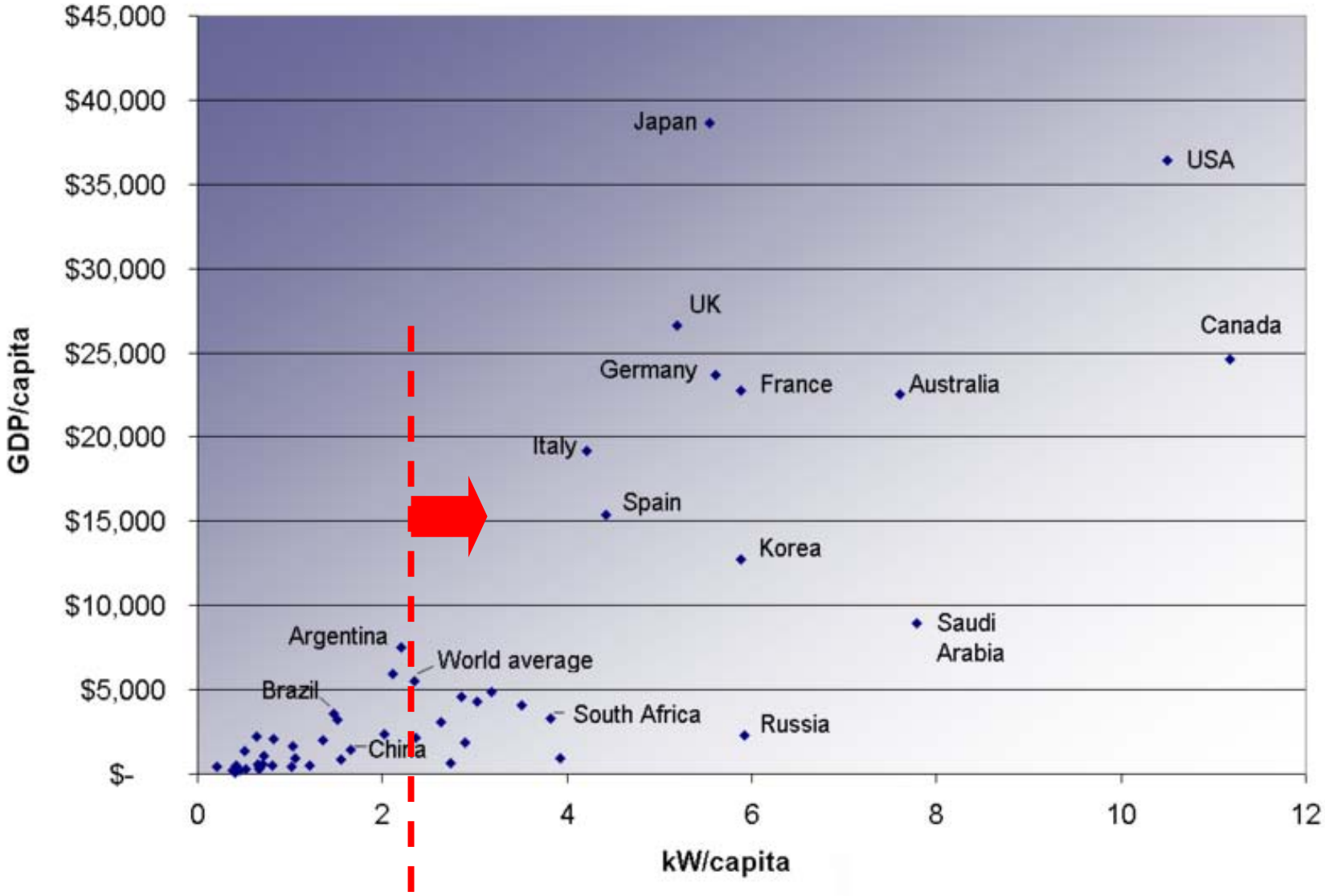


On Earth,

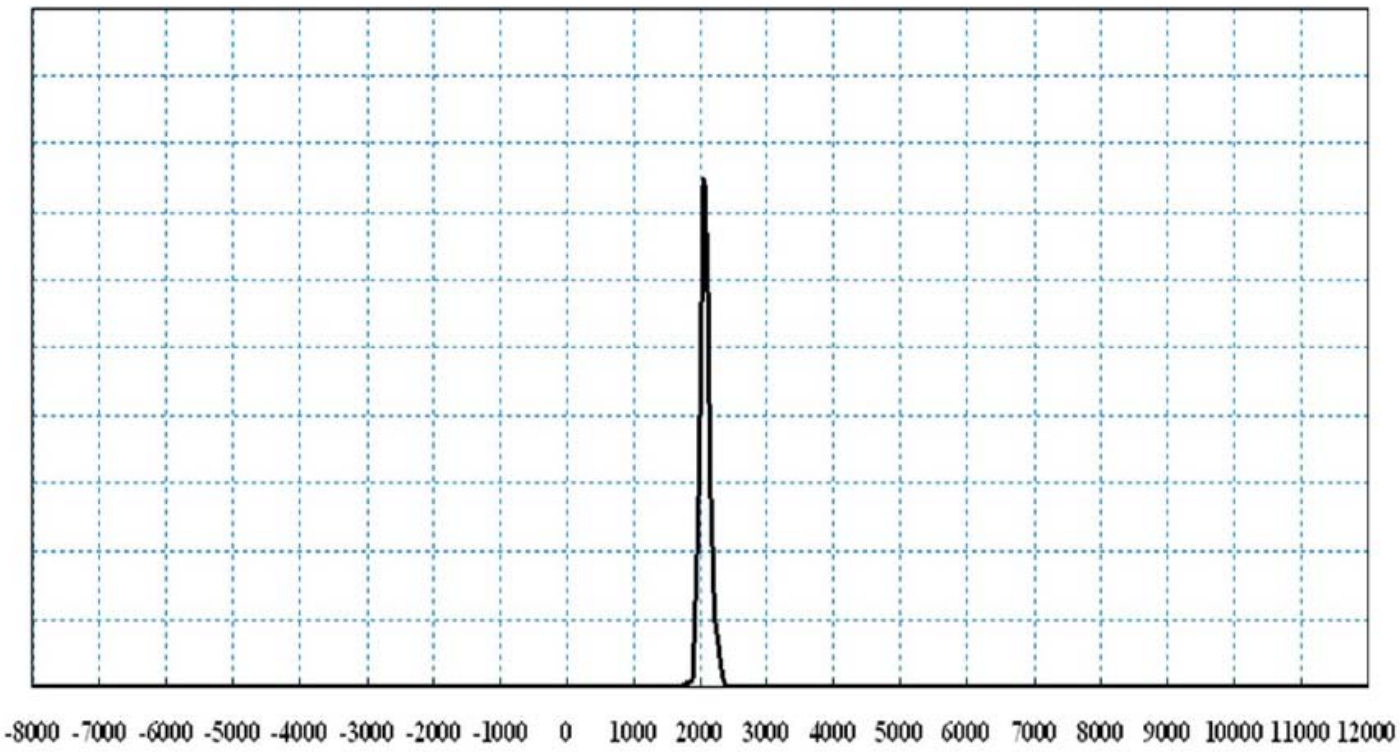
fusion could provide:

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

The Energy Dilemma



Theorist's view of the History of Fossil Fuel Use….



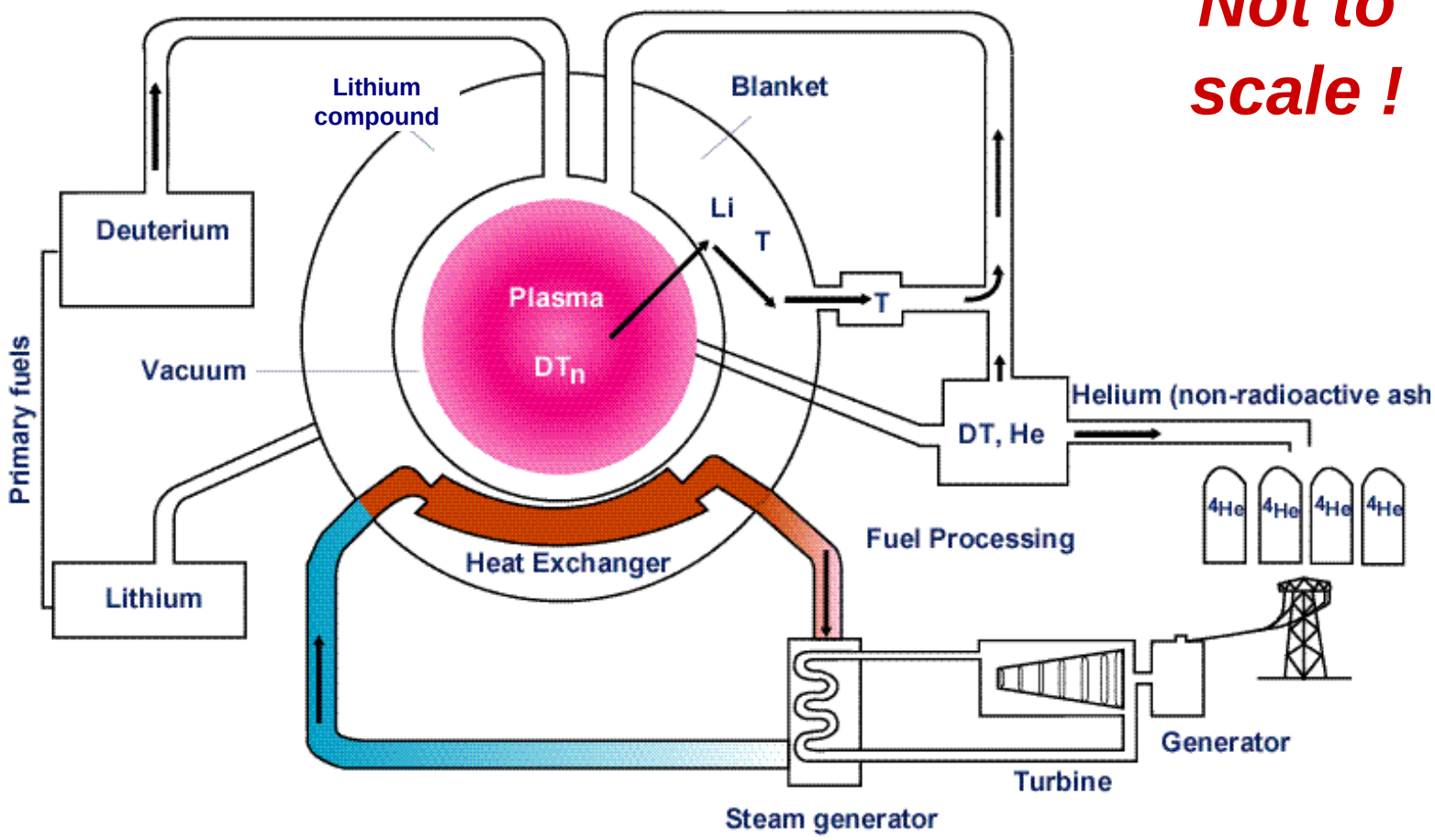
Fossil Fuel Use

- a brief episode in the world's history

C. Llewellyn-Smith

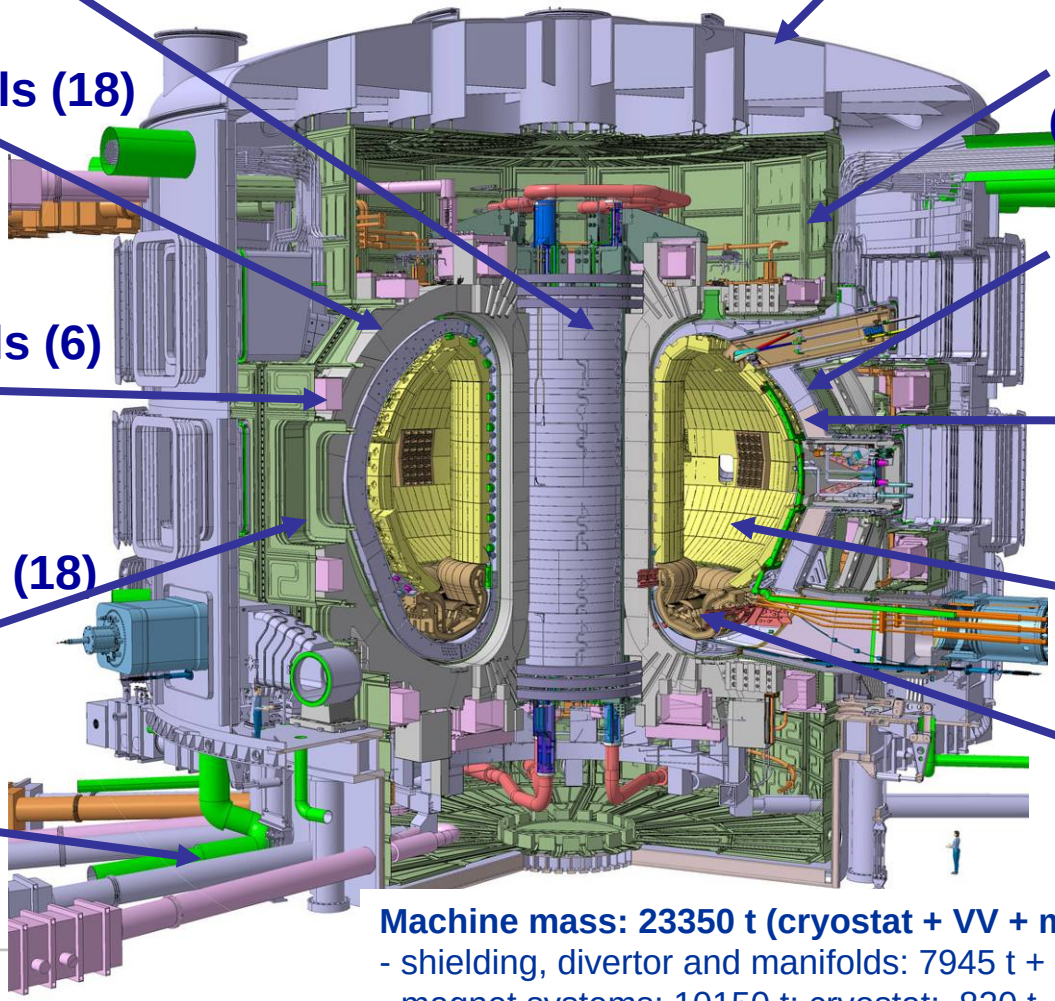
A Fusion power plant would be like…

Not to scale !



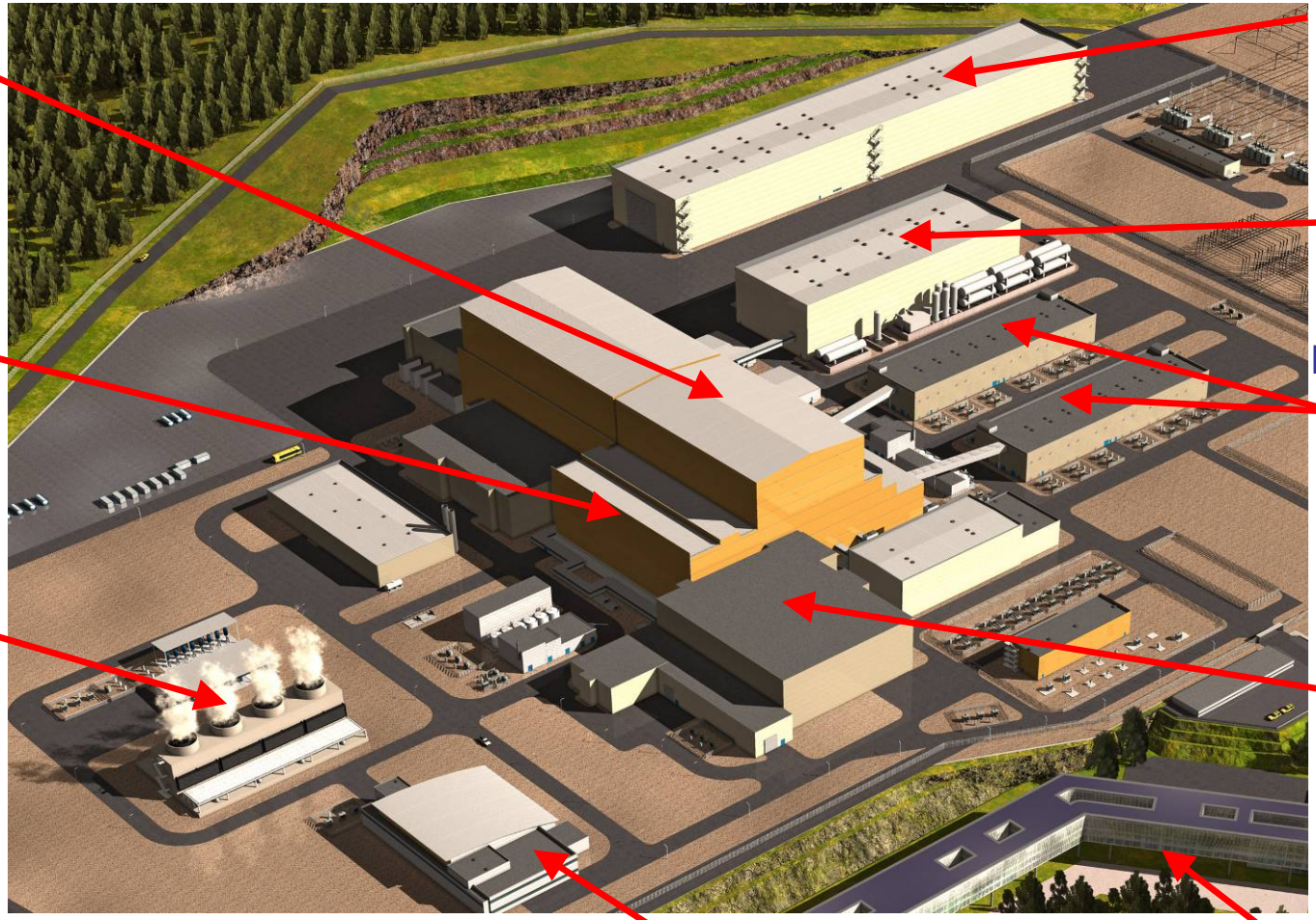
Status of ITER's technical progress (highlights)

Fusion gain Q = 10, Fusion Power: ~500MW, Ohmic burn 300 to 500 sec
Goal Q=5 for 3000 sec



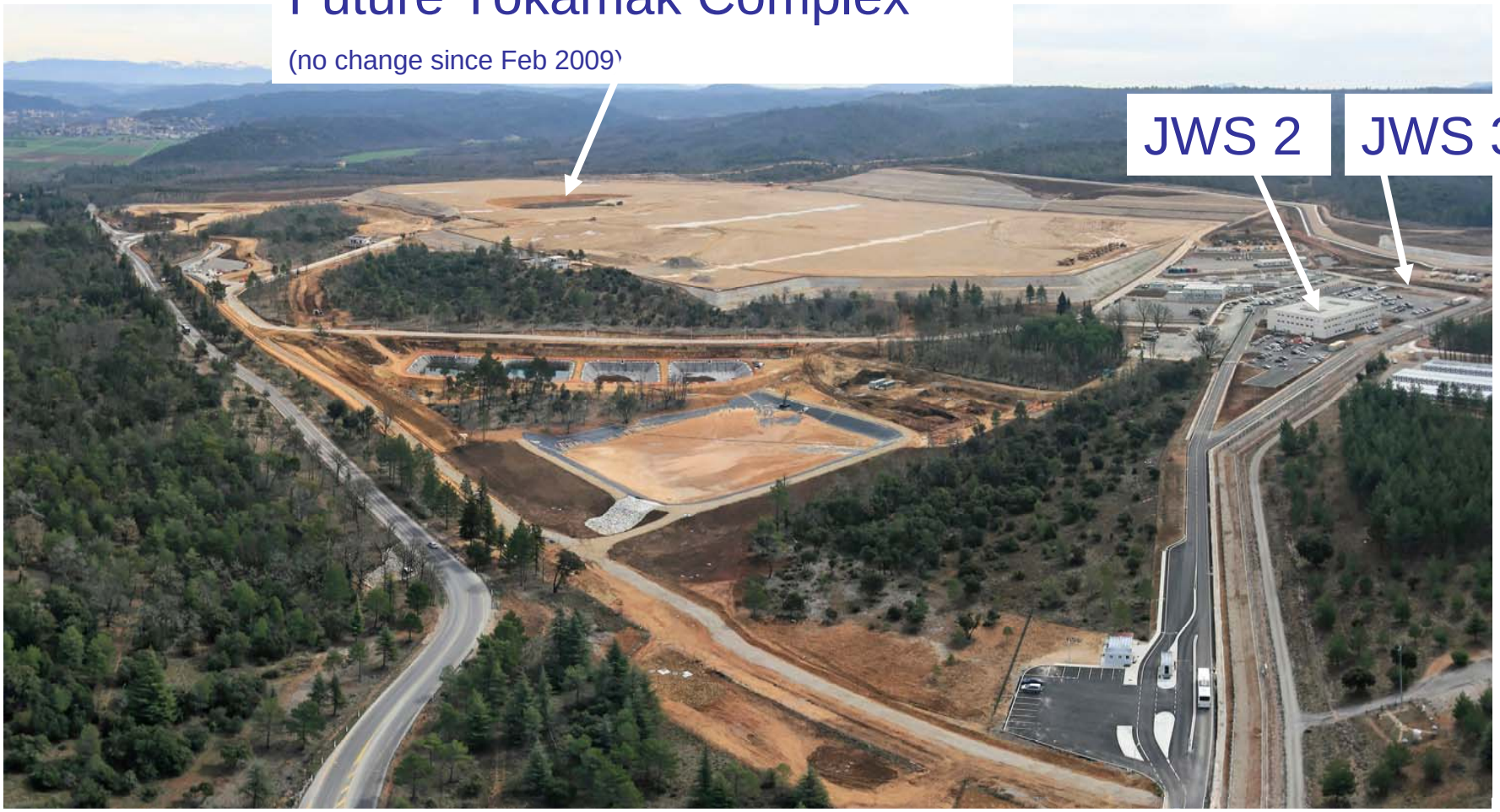
Machine mass: 23350 t (cryostat + VV + magnets)
- shielding, divertor and manifolds: 7945 t + 1060 port plugs
- magnet systems: 10150 t; cryostat: 820 t

Main Buildings on the ITER Site



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

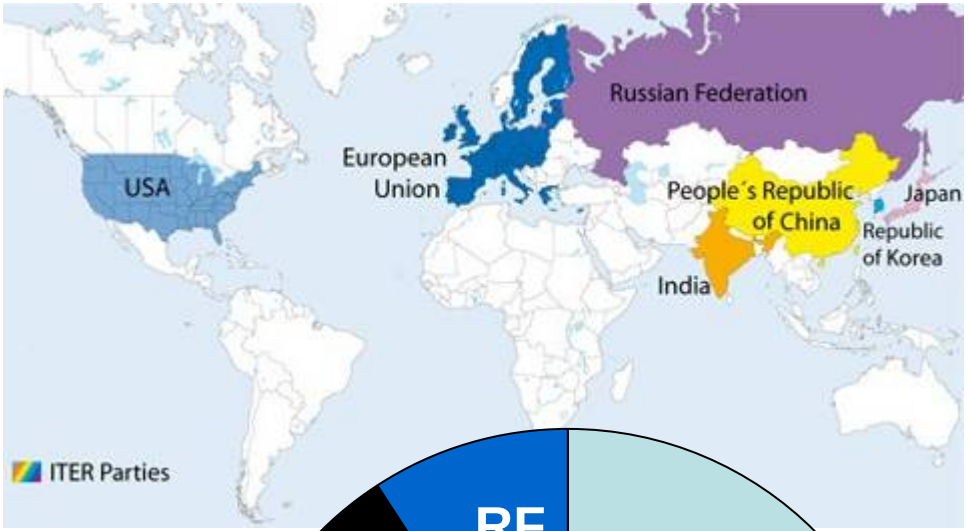
Present ITER Construction Site

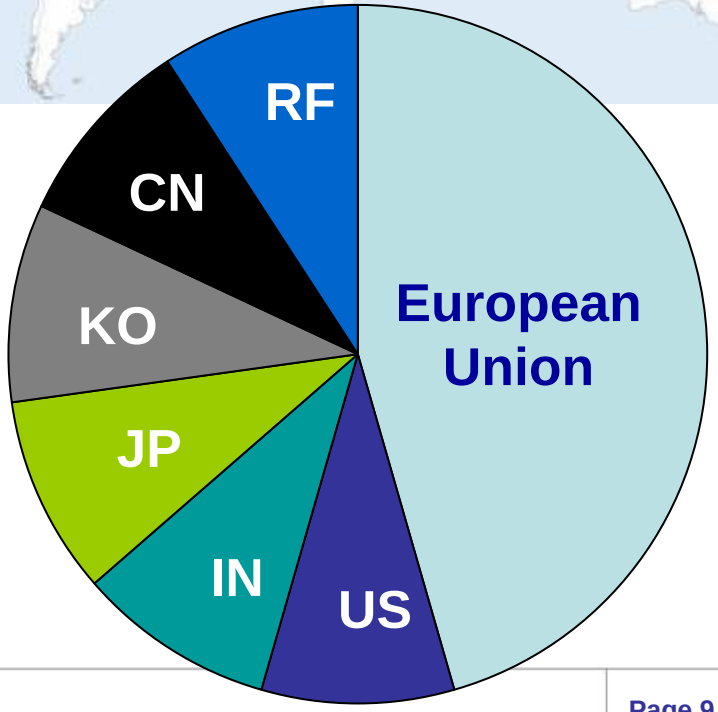


The creation and improvement of 106 kilometres of access roads from Fos harbour to Cadarache will be finished by February 2010.

ITER – Key Facts

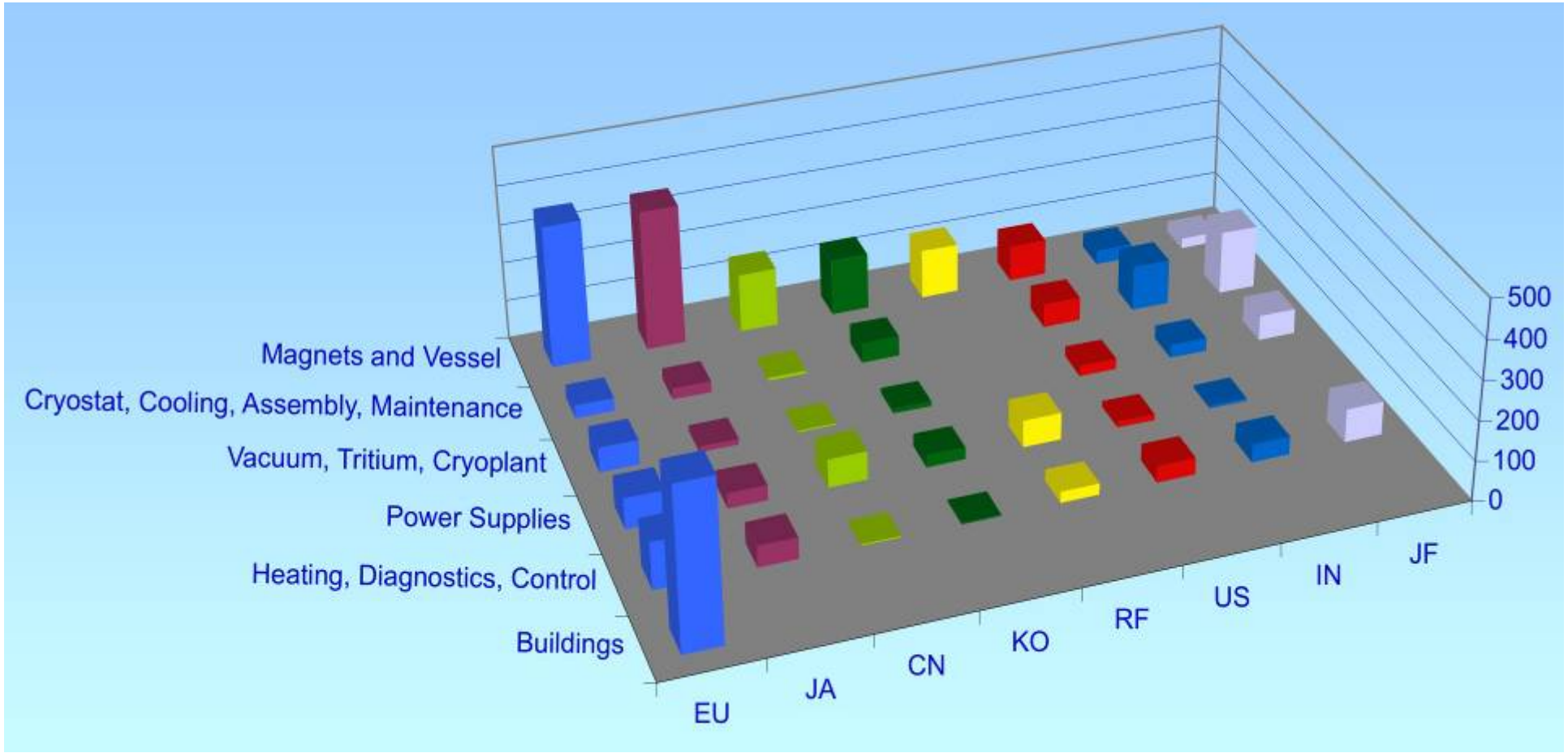
- **Mega-Science Project among 7 Members:**
  China, EU, India, Japan, Korea, Russia & US
- **Designed to produce 500 MW of fusion power for an extended period of time**
- **10 years construction, 20 years operation**
- **Cost: ~5.4 billion Euros approved for construction, and ~5.5 billion for operation and decommissioning**
- **EU 5/11, other six parties 1/11 each. Overall reserve of 10% of total.**

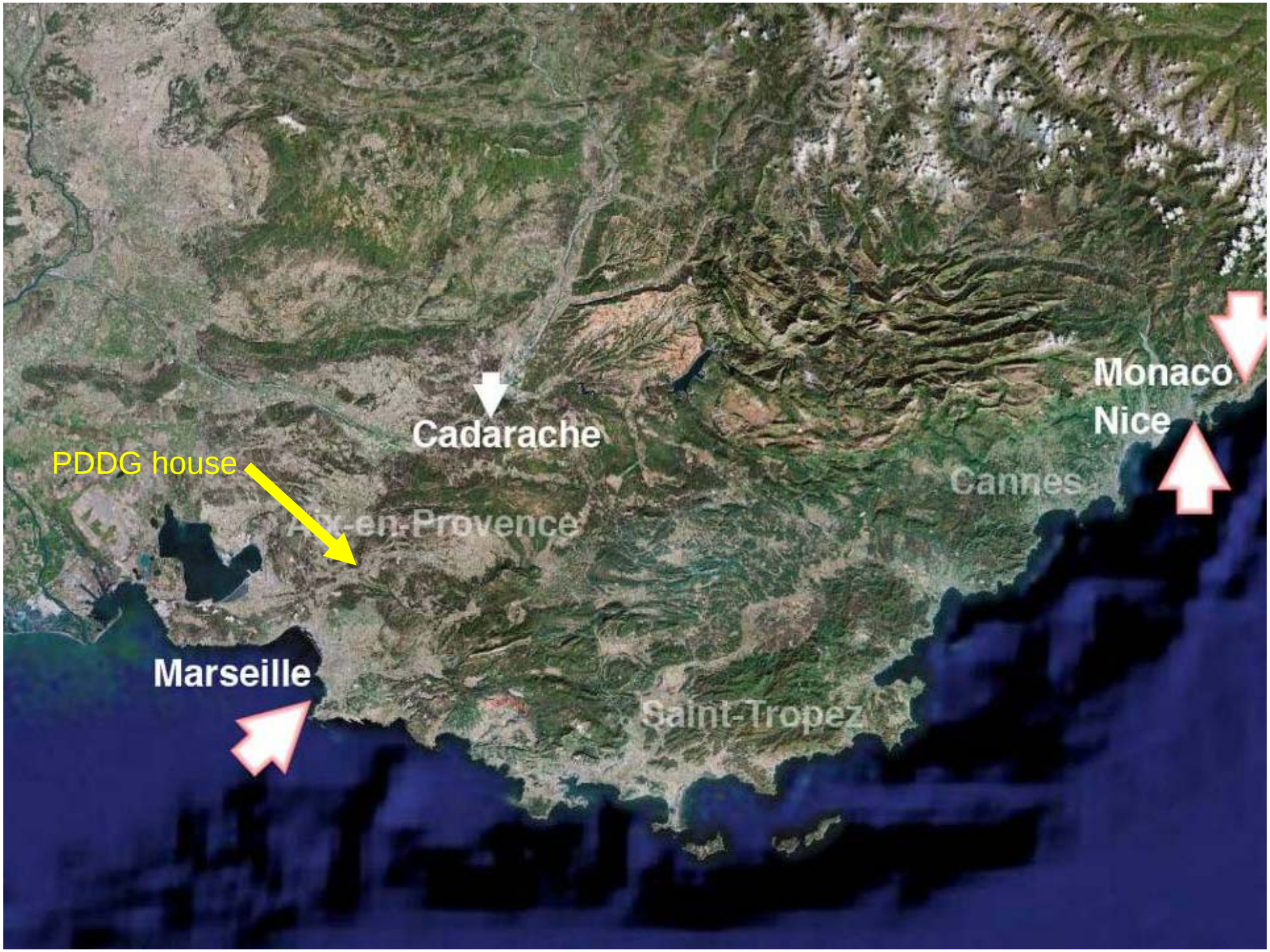




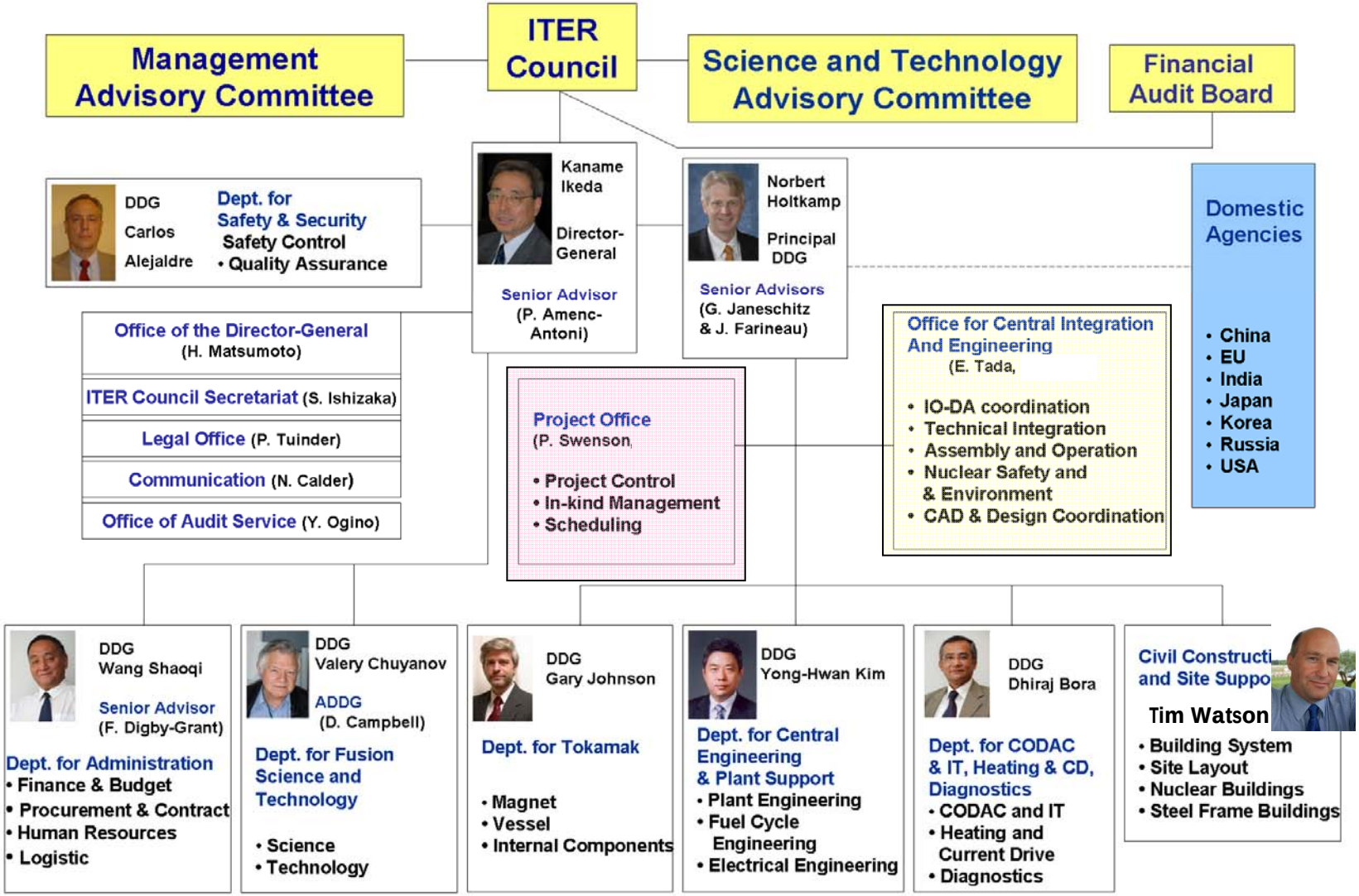
Procurement Sharing

- A unique feature of ITER is that almost all of the machine will be constructed through *in kind* procurement from the Parties with essentially every party involved in every component.




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

ITER Organization Structure

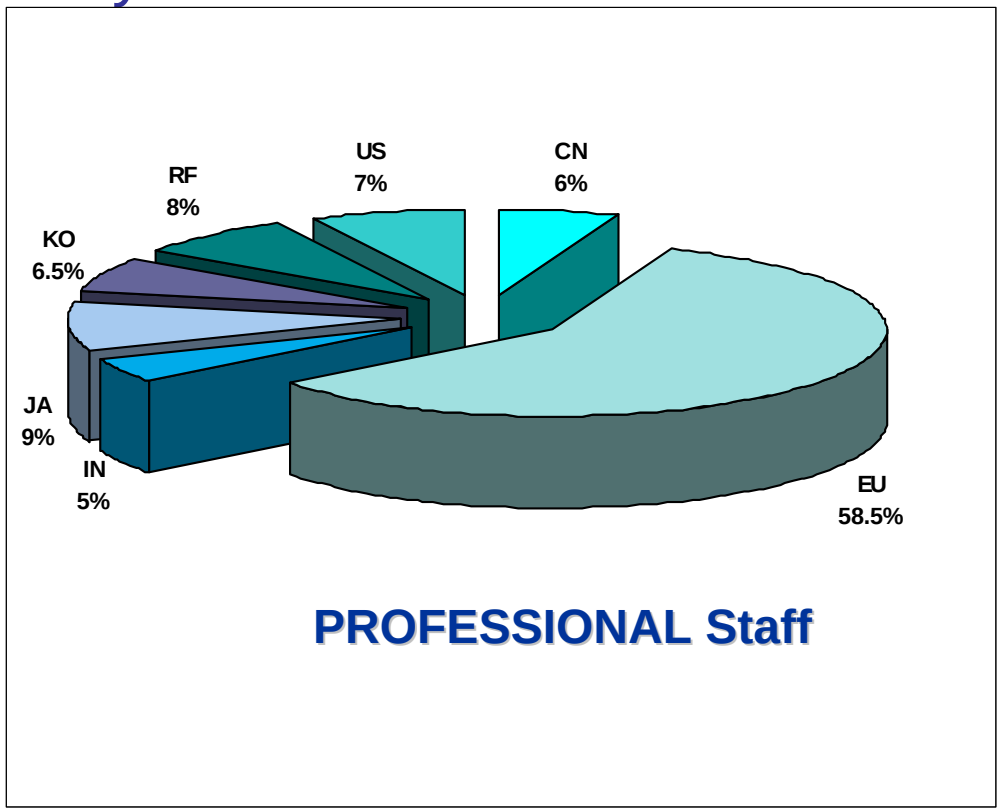


ITER as a start up -> Staffing

- As of 31 May 2009, the ITER Organization has a total of 364 staff, including 254 professional and 110 technical support staff.
- In addition approximately 250 contract staff

Professional staff by Members at the end of May, 2009:

Total: 254



All staff recruited via video conf with more than 1500 interviews conducted in 2.5 years

- The ITER Organization and the ITER Domestic Agencies

Integration between IO and DA's: Roles and Responsibilities for Construction

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

Major Risk Reduction resulting from Design Review

1	*Vertical Stability*	😐
2	*Shape Control / Poloidal Field Coils*	🙂
3	*Flux Swing in Ohmic Operation and CS*	😐
4	*ELM Control*	😐
5	*Remote Handling*	😐
6	*Blanket Manifold Remote Handling*	😐
7	*Divertor Armour Strategy*	🙂
8	*Capacity of 17 MA Discharge*	🙂
9	*Cold Coil Test*	😐
10	*Vacuum Vessel / Blanket Loading Condition Test*	🙂
11	*Blanket Modules Strategy*	😐
12	*Hot Cell Design*	🙂
13	*Heating Current Drive Strategy, Diagnostics and Research Plan*	🙂

🙂 =solved

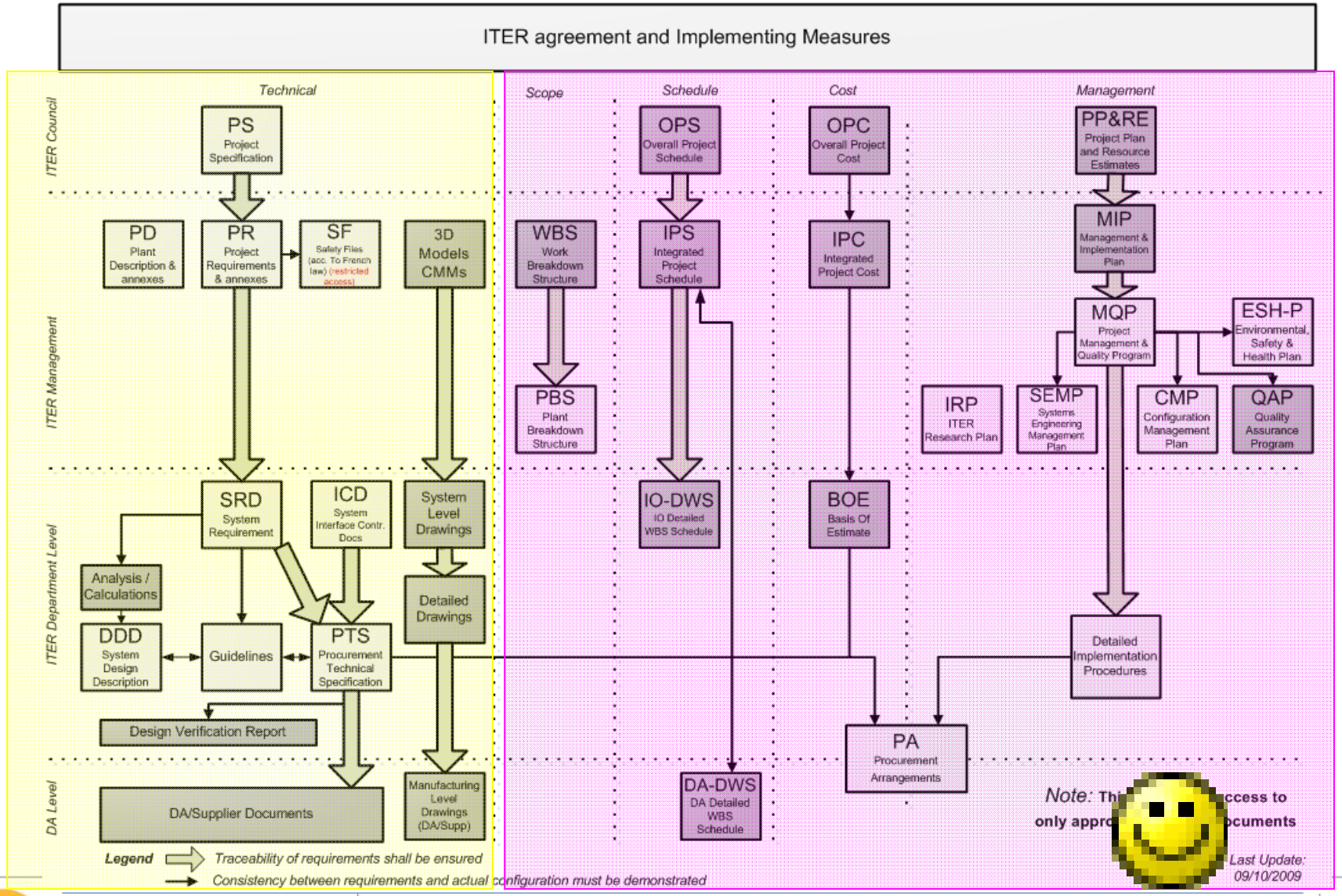
😐 =path forward clear

☹ =not solved

The overall cost increase as a result of site adaptation, changes from the design review and improvements to the operation space is ~15%

Configuration Baseline: https://portal.iter.org/baseline/Pages/BLmap.aspx

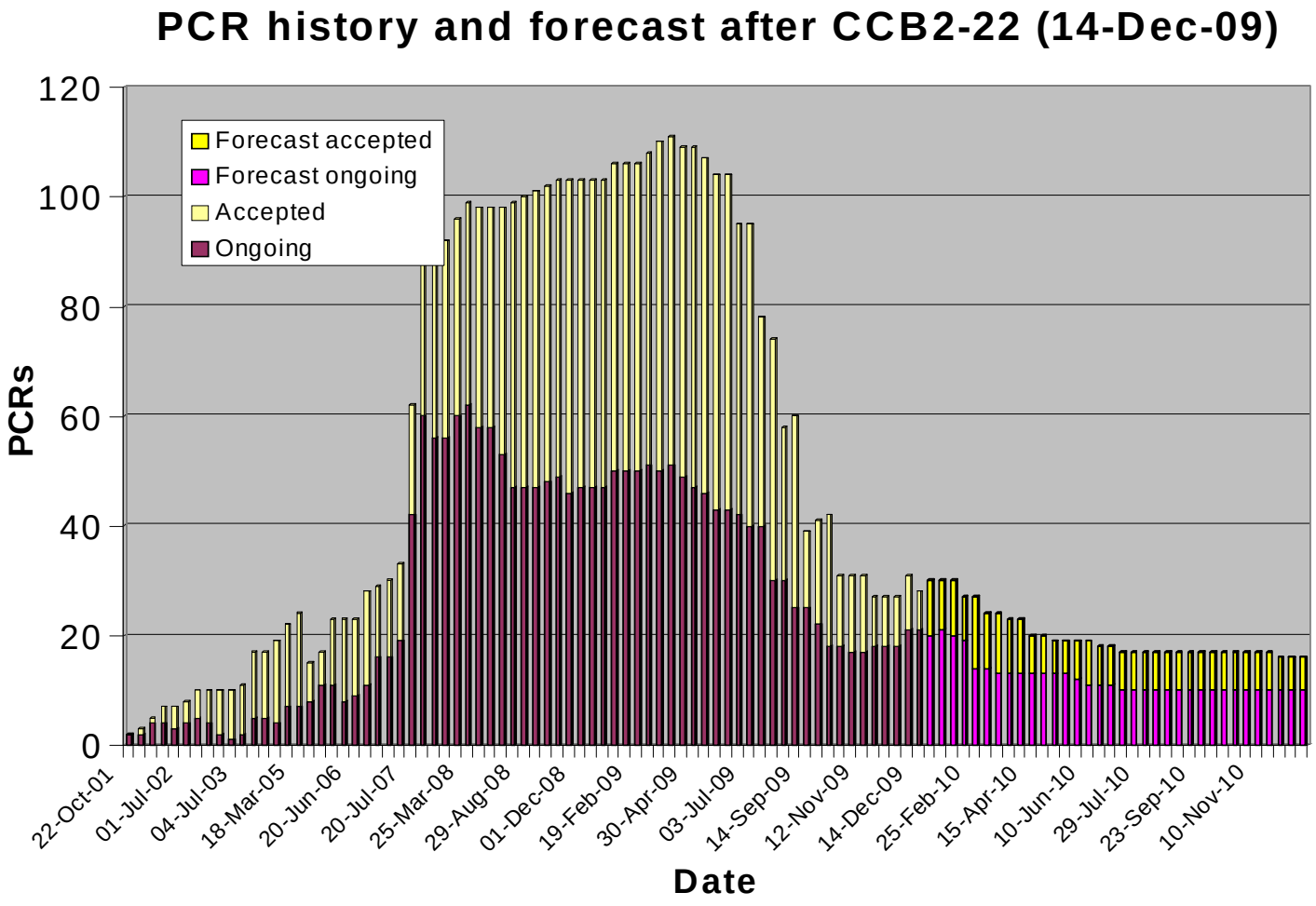
Reference Baseline Documents



Baseline of ITER stabilizes

https://user.iter.org/?uid=27LHNK

Very detailed list of all changes and together with the back up data



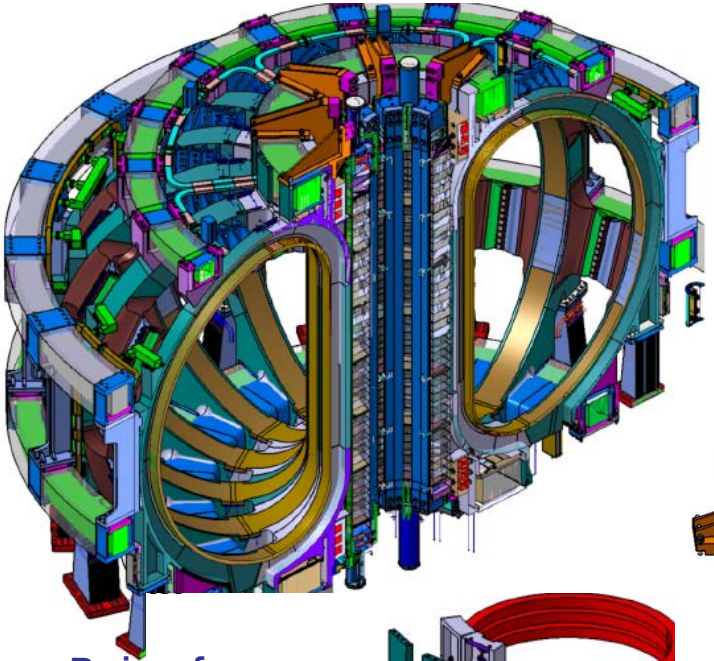
ADI - Today's Summary

- Council Approval in November 2009 done.
- Later presentation to council when cost is established completely (2010)

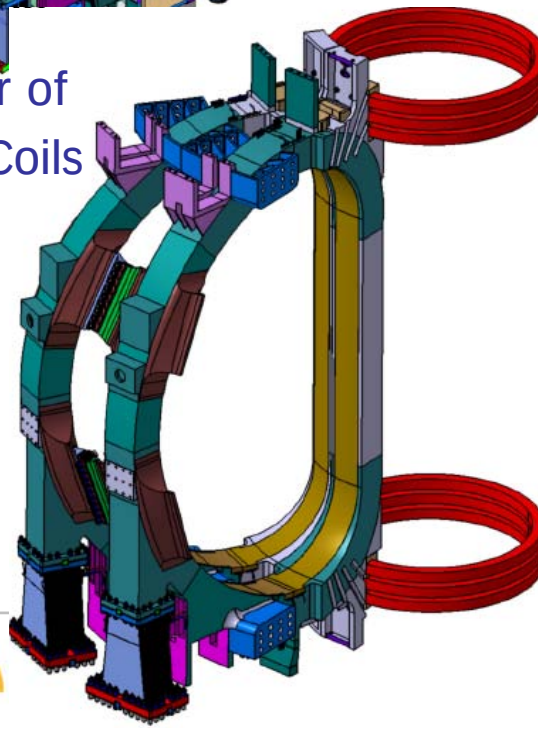
ADI Summary Table October 2009	kIUA	M€
Closed ADI, specifcally including:	78.44	121.39
PCR 183 Additional 180 degree rail system for IVT	18.55	28.71
PCR 170 Neutral Beam Test Facility	60.00	92.86
PCR 035 Hot Cell Design Modification	72.24	111.80
PCR 163 Facility for Qualification of the CS Nb3Sn Conductor	19.74	30.55
Sub Total	**248.97**	**385.30**
	kIUA	**M€**
Open ADI, specifically including	22.00	34.05
PCR 199 Priority 1 Spares Strategy	30.00	46.43
PCR 187 ac/dc converter & reactive power compensation	20.00	30.95
PCR 166 In vessel ELM & Vertical Stabilization Control Coils	142.30	220.22
PCR 157 4K Cold Test on Coil Winding Packs	58.06	89.85
Sub Total	**272.36**	**421.50**
Open STAC & Improvement	10.47	16.20
Sub Total	**10.47**	**16.20**
Total	**531.80**	**823.00**

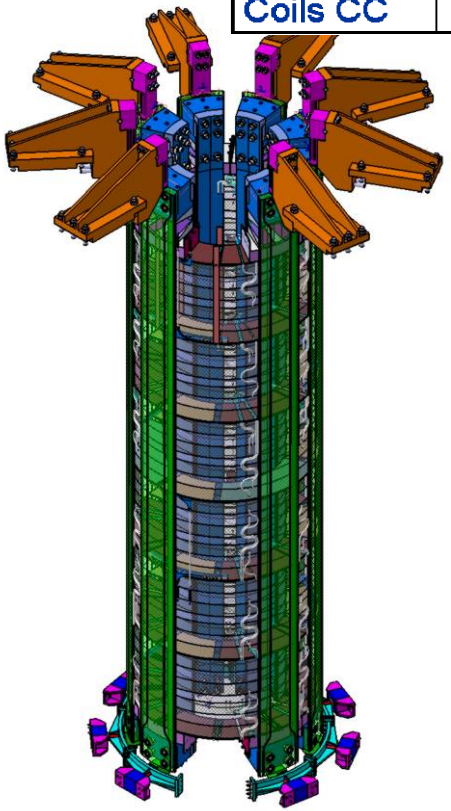
ITER Magnet System

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

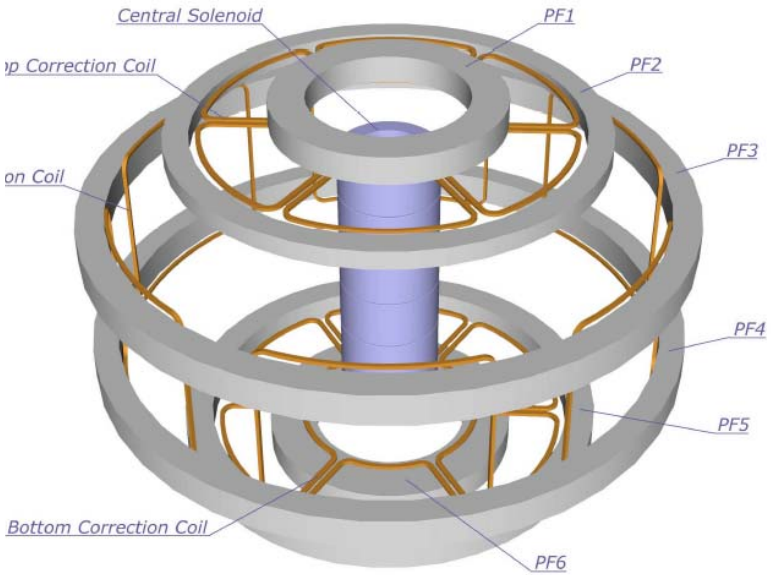


Pair of TF Coils



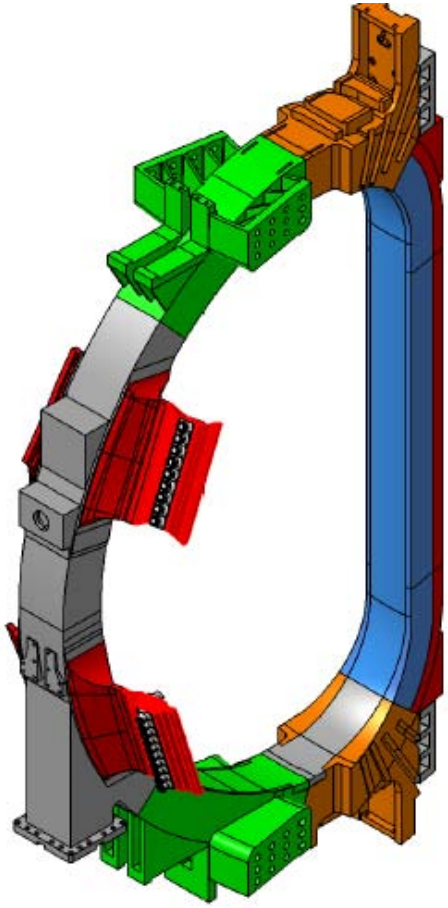


CS Coil



PF & CC Coils

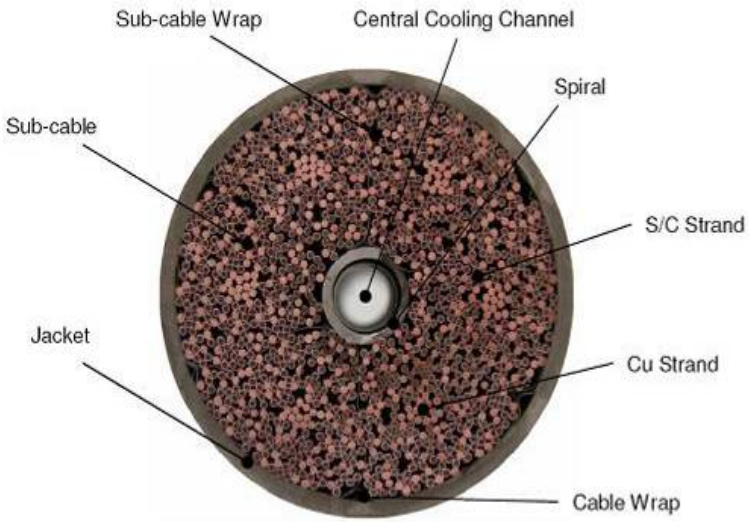
TF Coil – Mass Comparison



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

D8 Caterpillar Bulldozer
~35 t

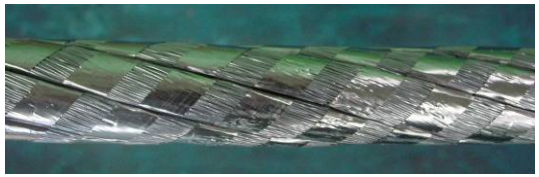
ITER Conductors



X-section of 70kA ITER TF Conductor (CEA)

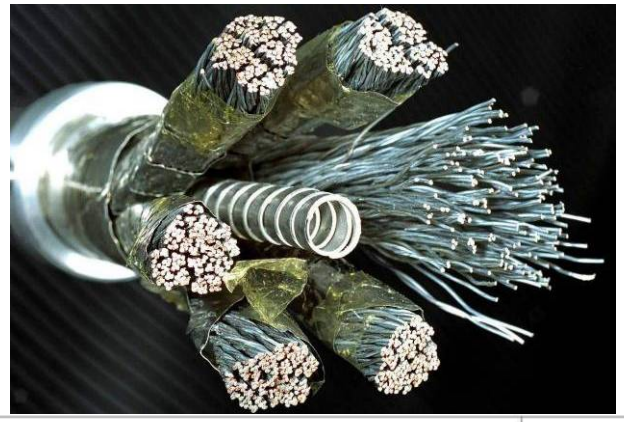
- ITER coils are wound from Cable-In-Conduit Conductors (CICC's), relying on superconducting multifilament composite strands mixed with pure Cu strands/cores.
- The strands are assembled in a multistage rope-type cable around an open central cooling spiral.
- The cable and its spiral are inserted inside a stainless steel conduit which provides helium confinement.

Cooling Spiral



Final-Stage Cable (NFRI)

Stainless Steel Conduit (ASIPP)

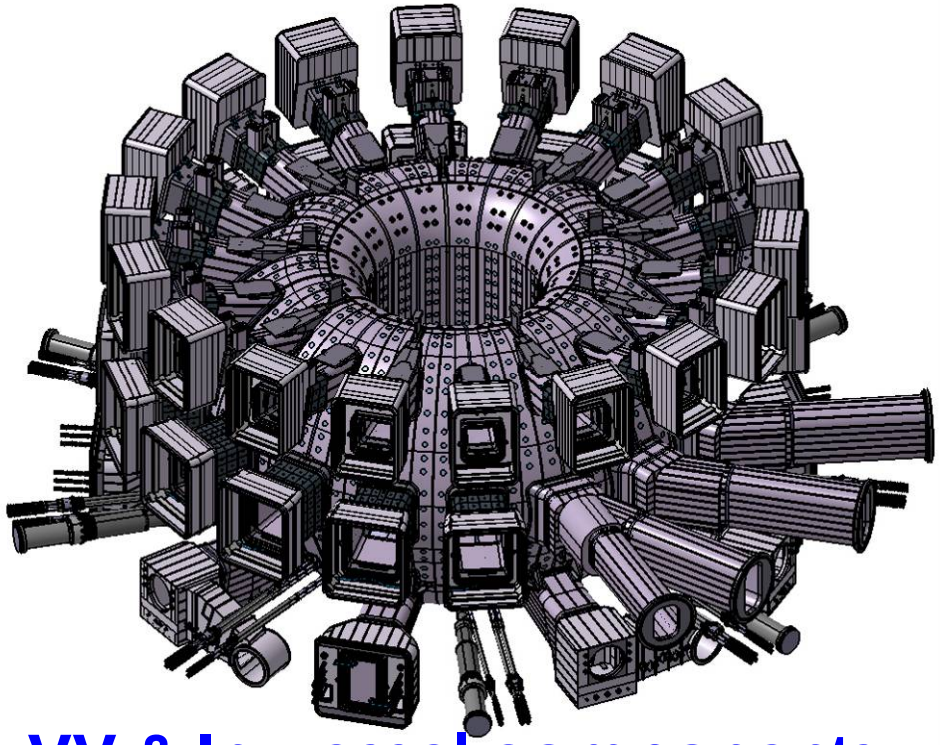


TF and PF Jacketing in:

Vacuum Vessel Mass Comparison

Europe is going out for tender this week

Korea has already selected the company



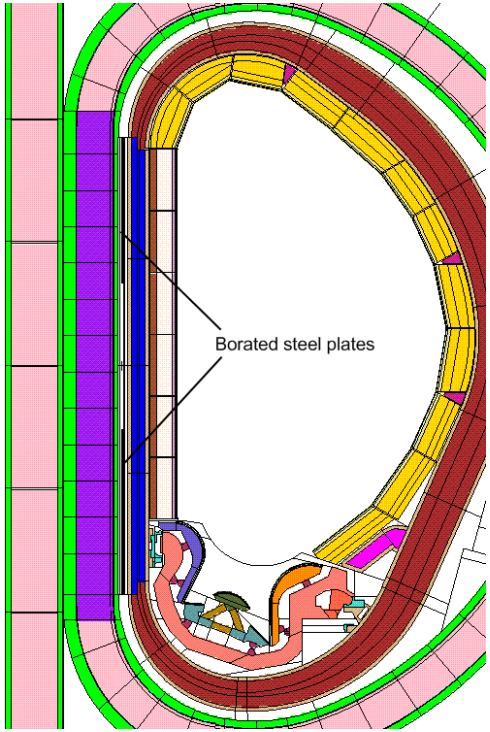
VV & In-vessel components mass: ~8000 t

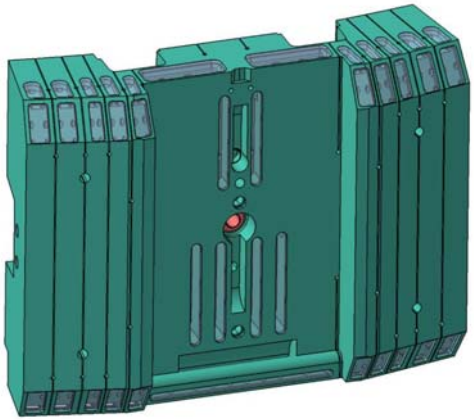
19.4 m outside diameter x 11.3 m tall

Eiffel Tower mass: ~7300 t

324 m tall

Issues and Design studies for VV

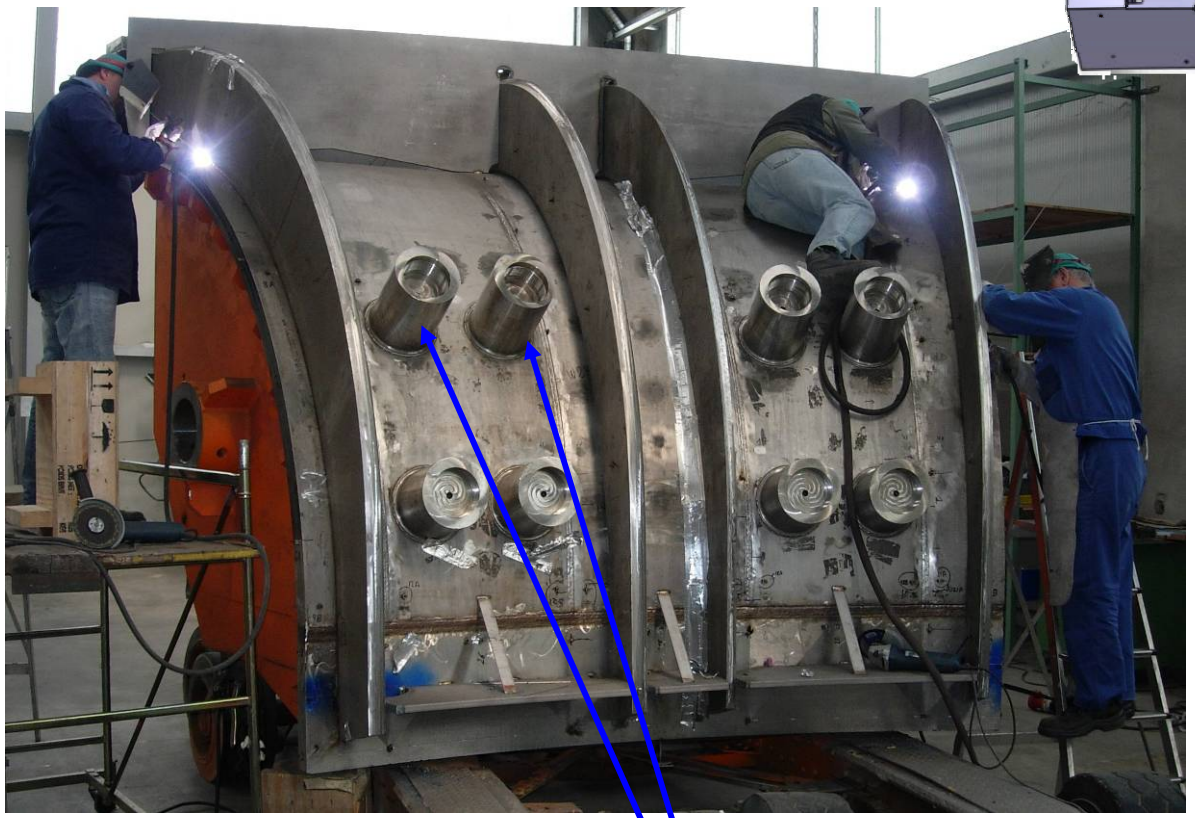


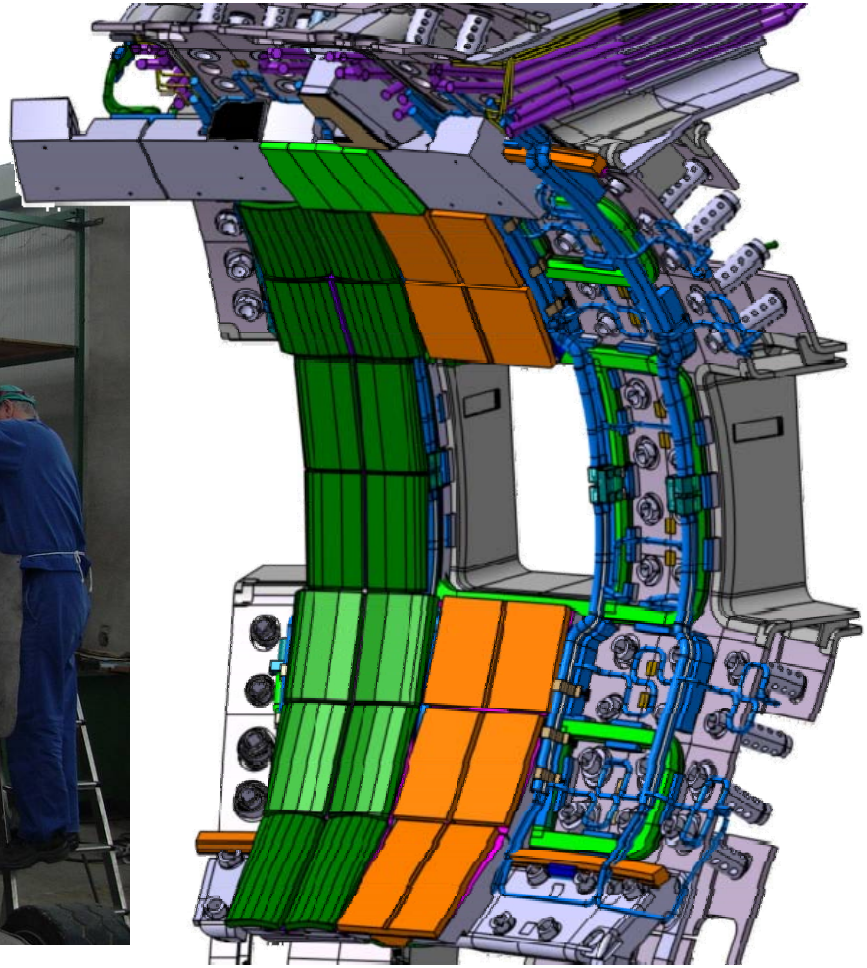


Four major issues remained after the design review for the VV and were tackled in 2009

1. **Insufficient shielding for TF coils at inner leg**
   - Required 14 kW, without mitigation 23 kW
2. **Electromagnetic loads on the blanket modules**
   - Was factor 2 too high – reduced by slotting shield module
3. **Manufacturability of VV considering tight tolerances**
   - Some minor design changes after significant effort for studying also more drastic changes
4. **Integration of the ELM and VS coils**
   - 40 mm more space made available by 3-D shaping of inner shell and thinning the VV at the outer leg

R&D for the ITER VV and major Interfaces





Partial VV Mock-up: Curved (Left) and Straight (Right) Sections (EU)

Electron Beam welding on the inner shell

VV-interfaces with ELM coils, feeders, manifold, blanket

Vertical Stabilization - Design Studies

Experiments suggest that:

$\Delta Zmax/a > 5\%$ is "reliable"

$\Delta Zmax/a > 10\%$ is "robust"

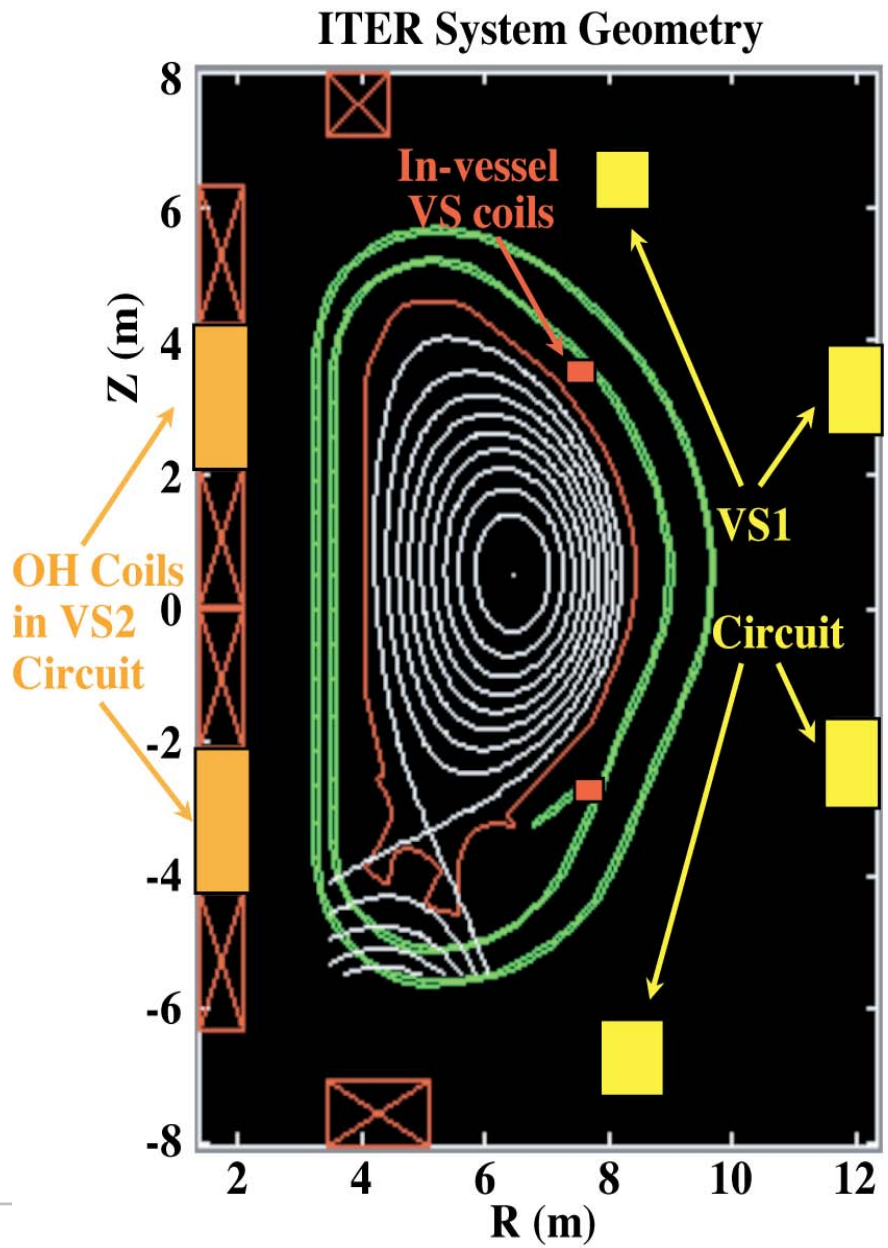
For "worst case" conditions (li(3) = 1.2), original ITER system:

$\Delta Zmax/a = 2\%$

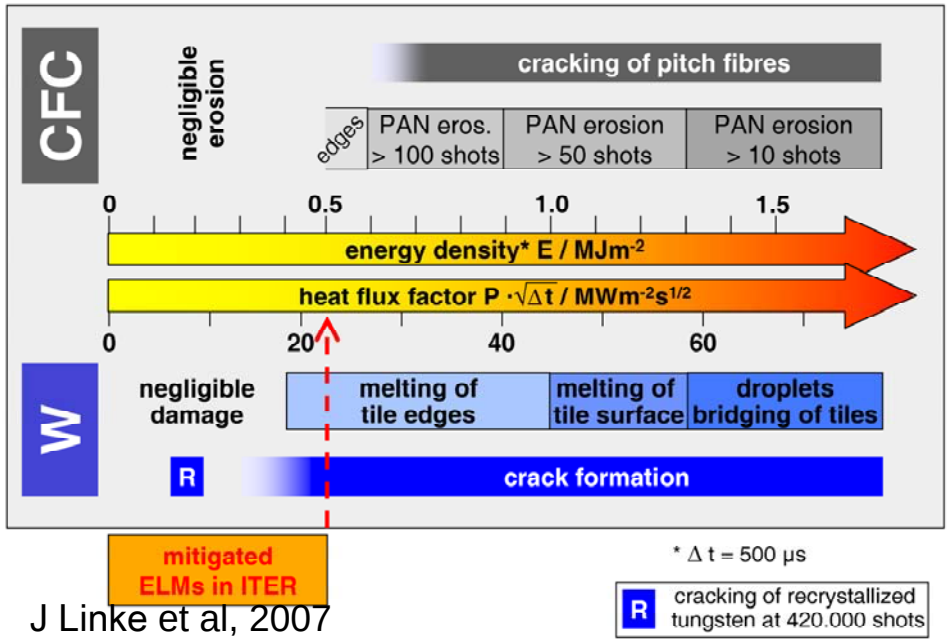
large overshoot in ΔZ due to vessel time constant

- **Reliable operating window for ITER operation requires improvements in vertical stabilization of ITER plasmas**

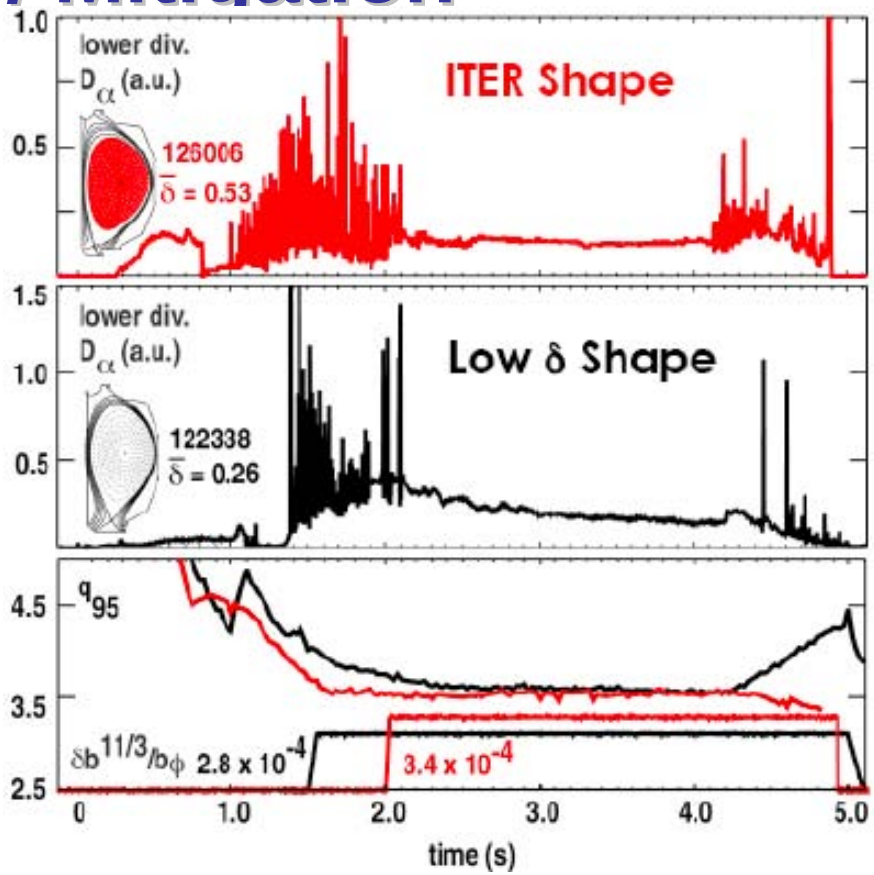
- **Implemented Changes:**
  - Increase VS1 voltage (to ±9kV)
  - Introduce VS2 circuit (±6kV)
  - Improve passive stabilization
  - **Use in-vessel coils as additional vertical stabilization circuit**



ELM Control / Mitigation



J Linke et al, 2007



- **Recent predictions indicate that uncontrolled ELM heat pulse amplitude in ITER will produce energy densities at the divertor target of ~10MJm^{-2} - an order of magnitude above tolerable level for divertor PFCs:**

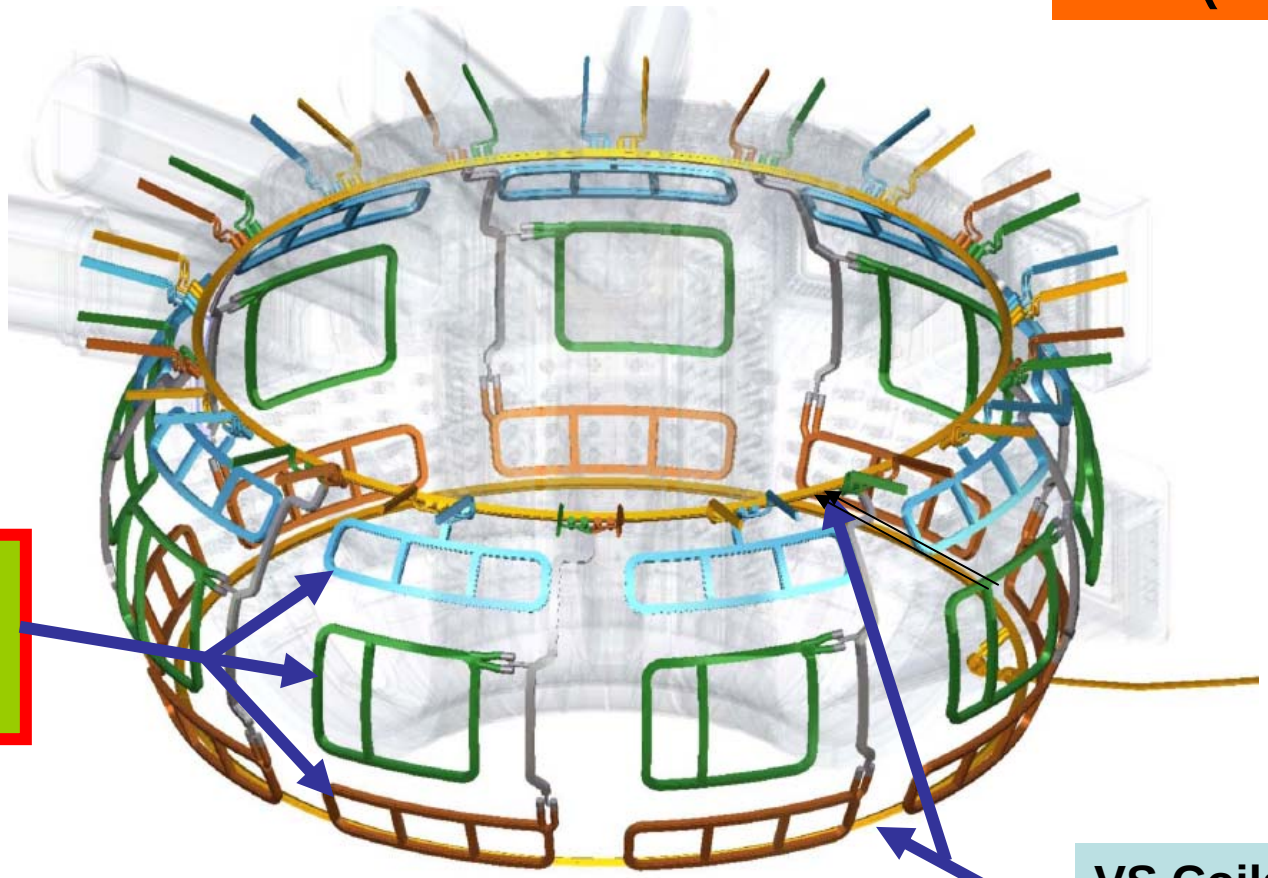
- ELM Mitigation by edge ergodization
  - by RMP coils – see foreseen ELM-coil layout below

ELM- and VS- coils

ELM Control

Resistive Wall Mode (RWM) Control

Vertical Stabilization (VS)

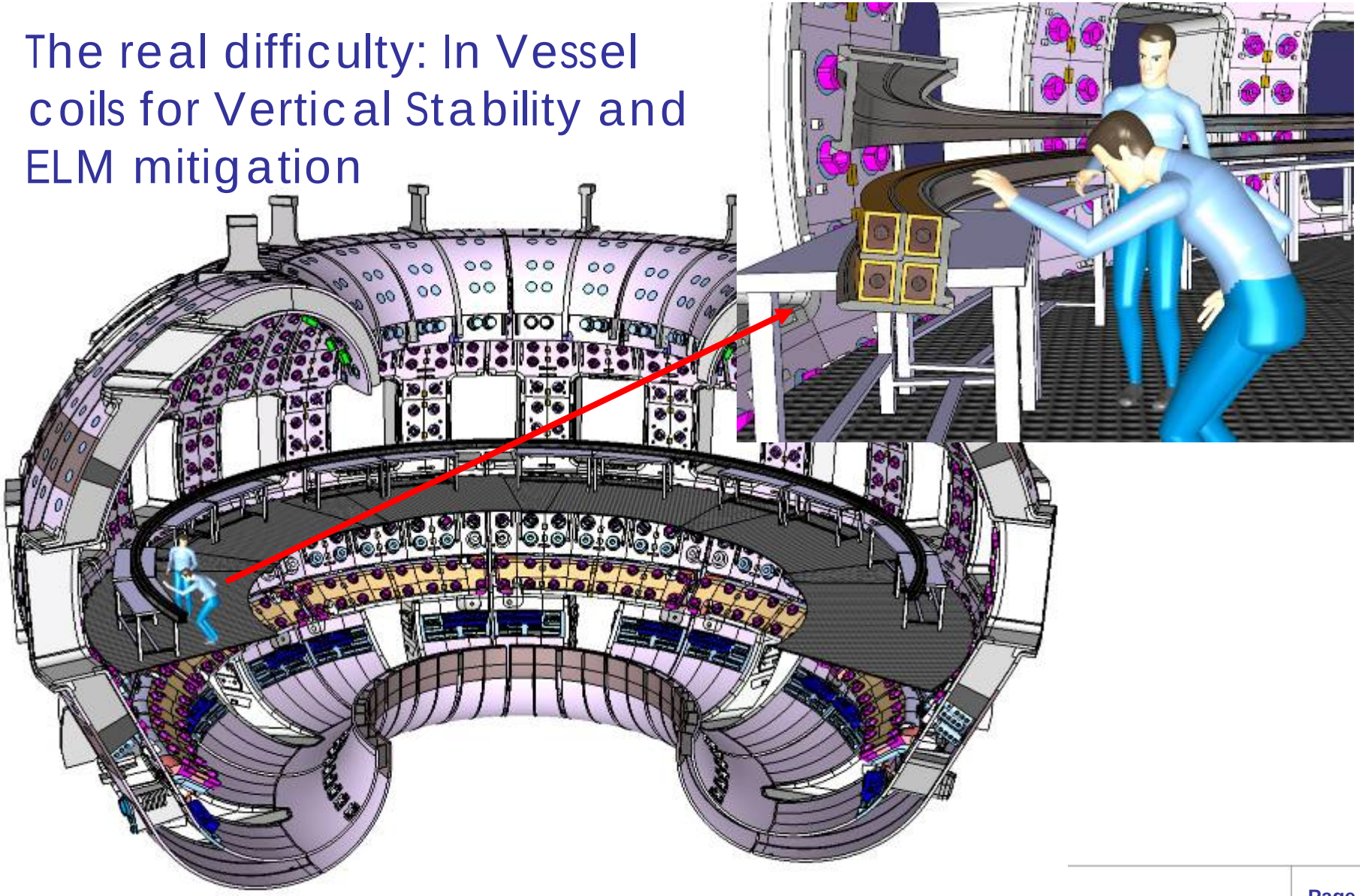


ELM/RWM Coils (9 groups of 3)

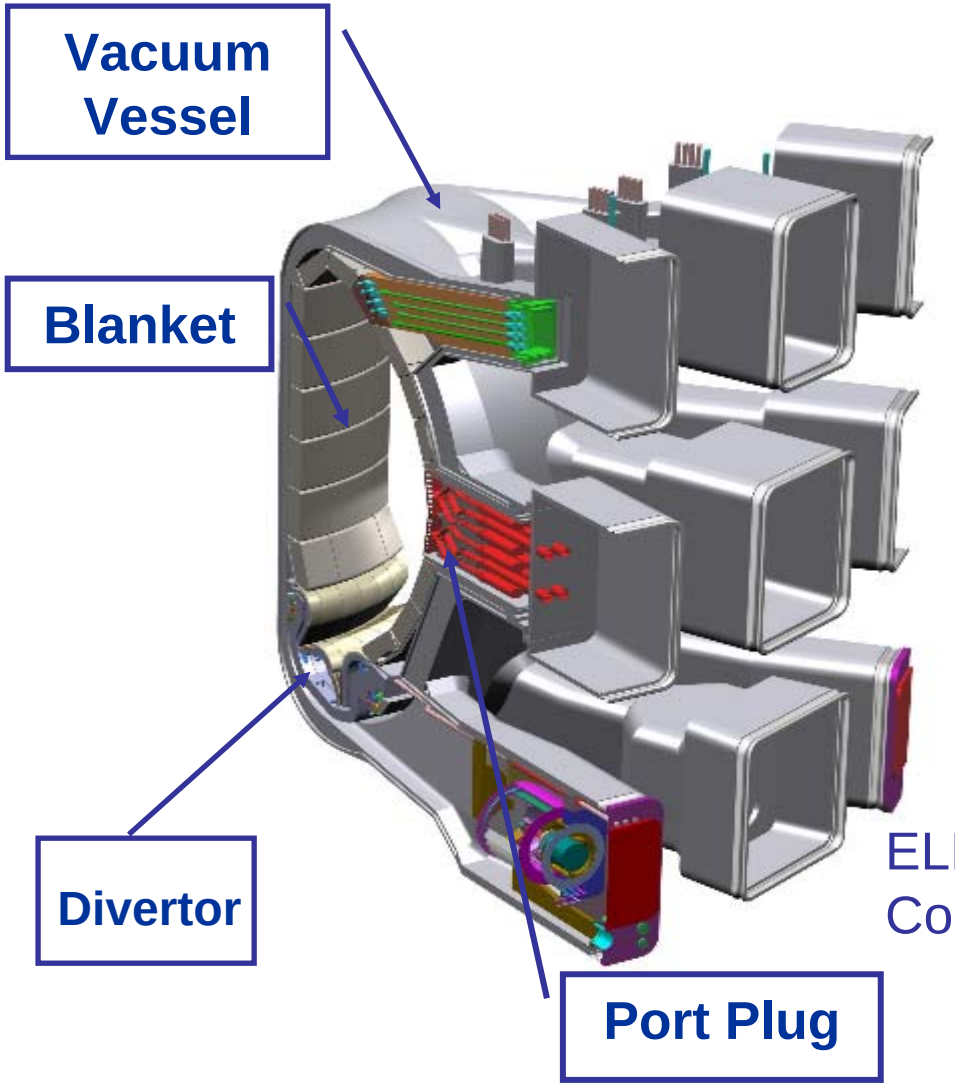
VS Coils (upper & lower ring coils)

VS Coil Construction and Assembly Concept

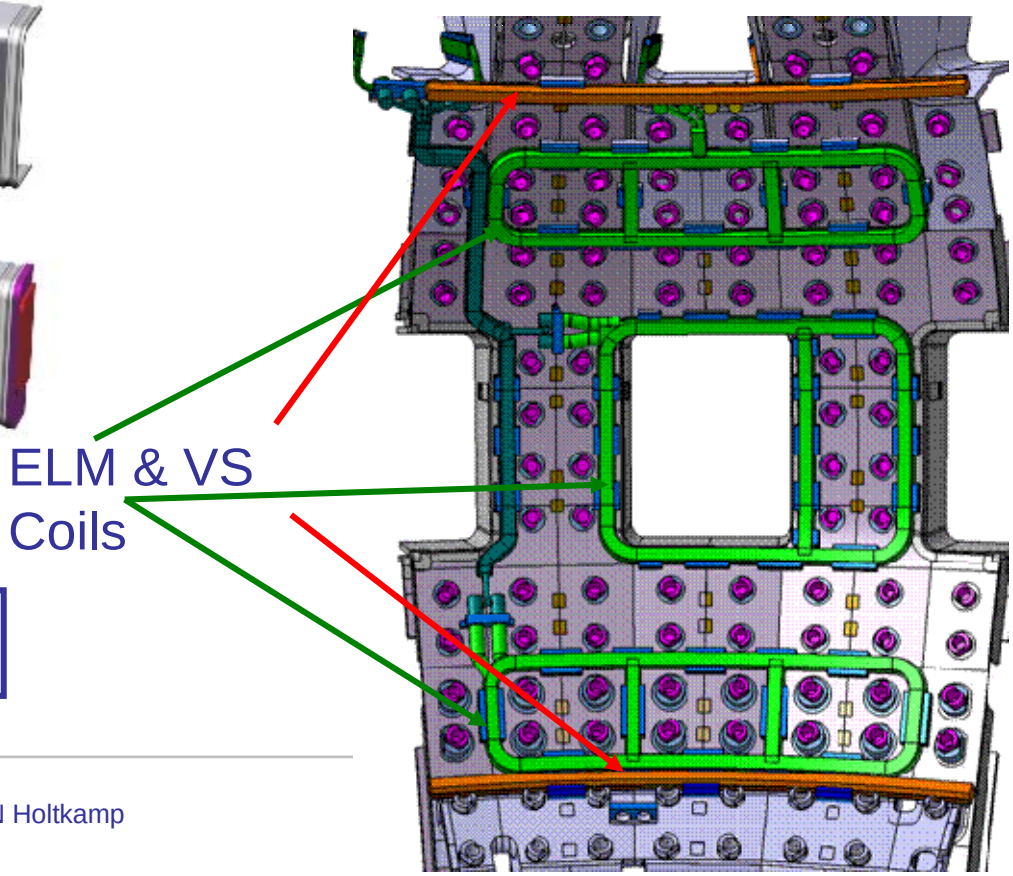
The real difficulty: In Vessel coils for Vertical Stability and ELM mitigation



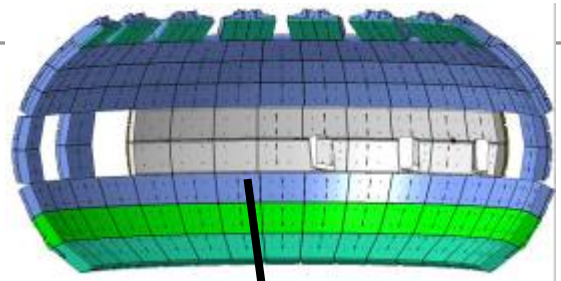
ITER Vacuum Vessel supports all In-Vessel Components



•The vacuum vessel is lined by modular removable components: : **blanket modules, divertor cassettes, ELM / VS coils** and **port plugs** (heating antennae, diagnostics and test blanket modules)



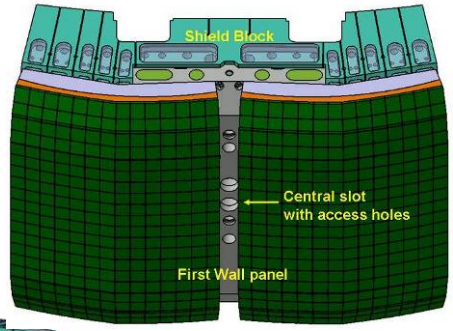
Blanket System



Challenge EM Forces, FW heatflux

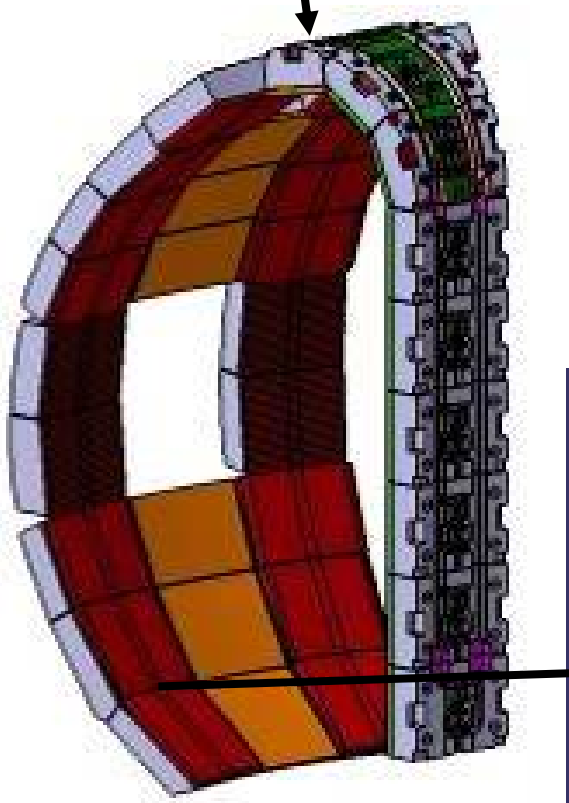
Scope

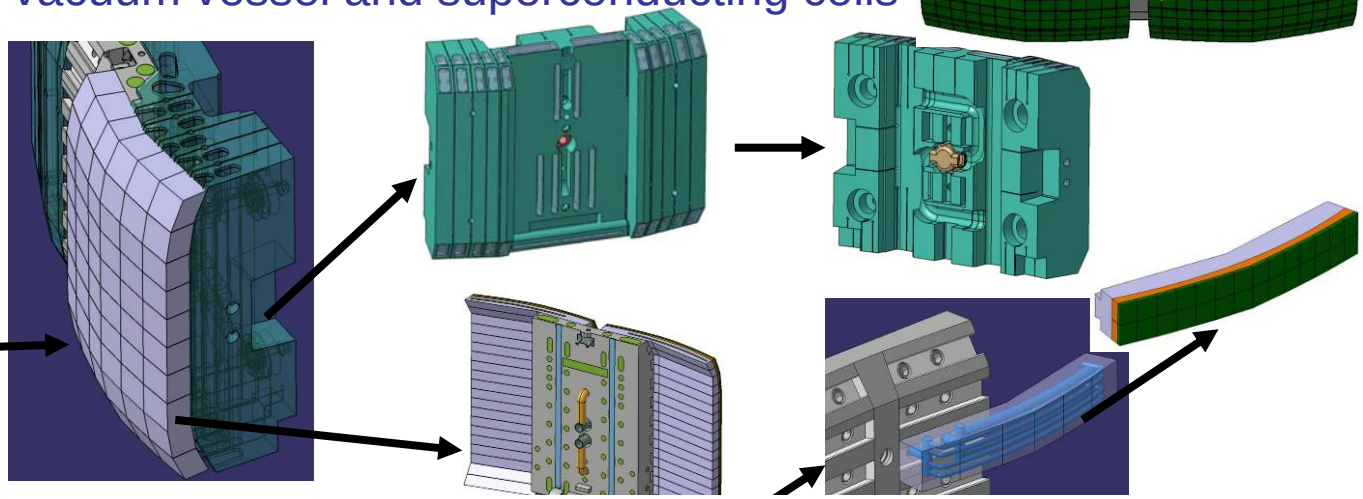
- 440 blanket modules at ~4 ton each
- ~40 different blanket modules



Blanket system main functions :

- Exhaust the majority of the fusion power
- Reduce the nuclear responses in the vacuum vessel and superconducting coils





FW shaped – avoid edges – 5 MW/m² in 60% of area
Separable FW module, shield module slotted to reduce EM forces

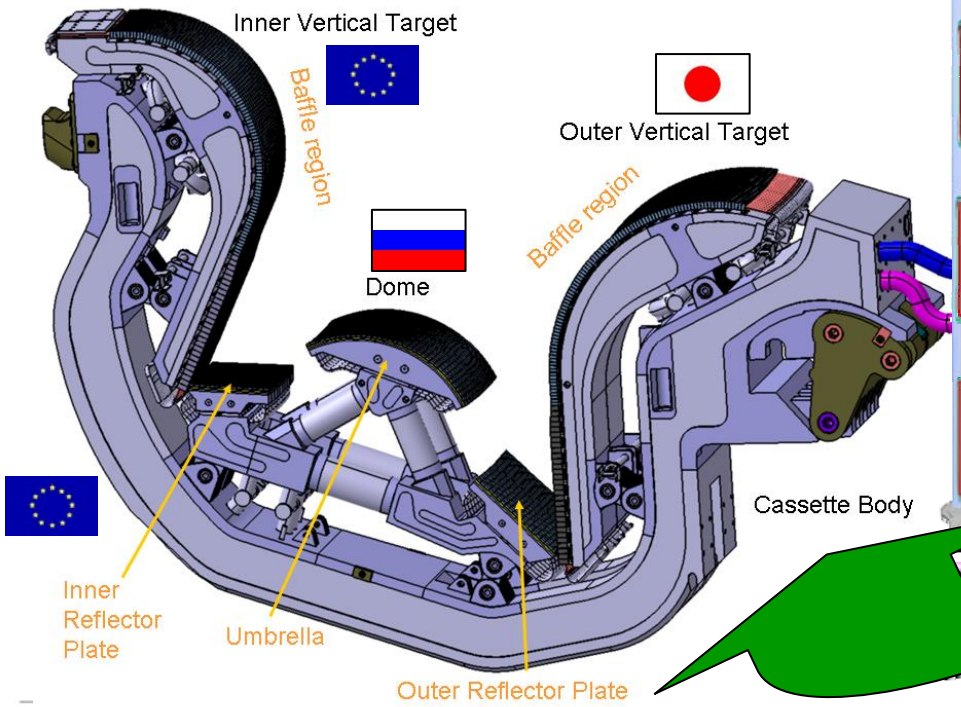
Divertor

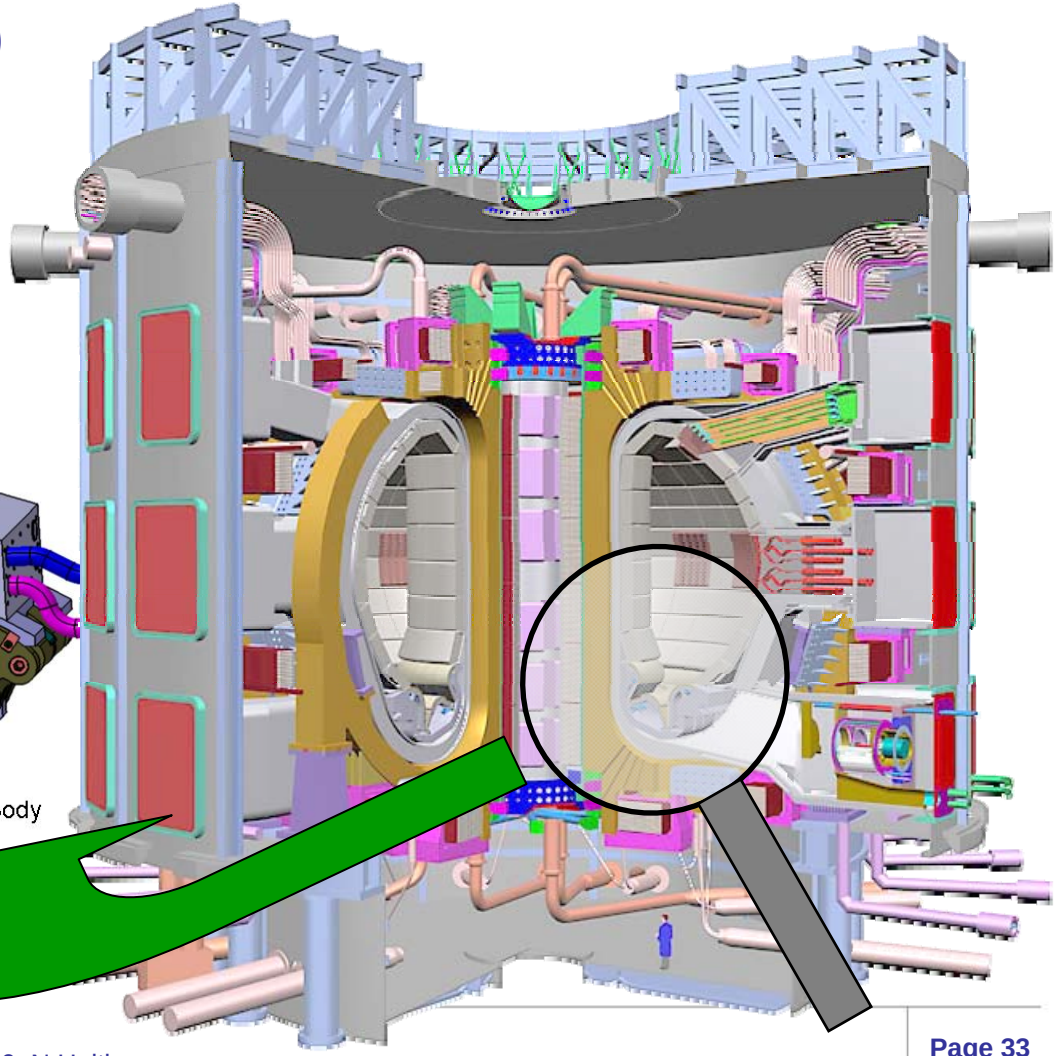
Divertor system main functions :

Exhaust the major part of the plasma thermal power (including alpha power)

• Minimize the helium and impurities content in the plasma

Challenge to develop HHF Componets capable of 20 MW/m²

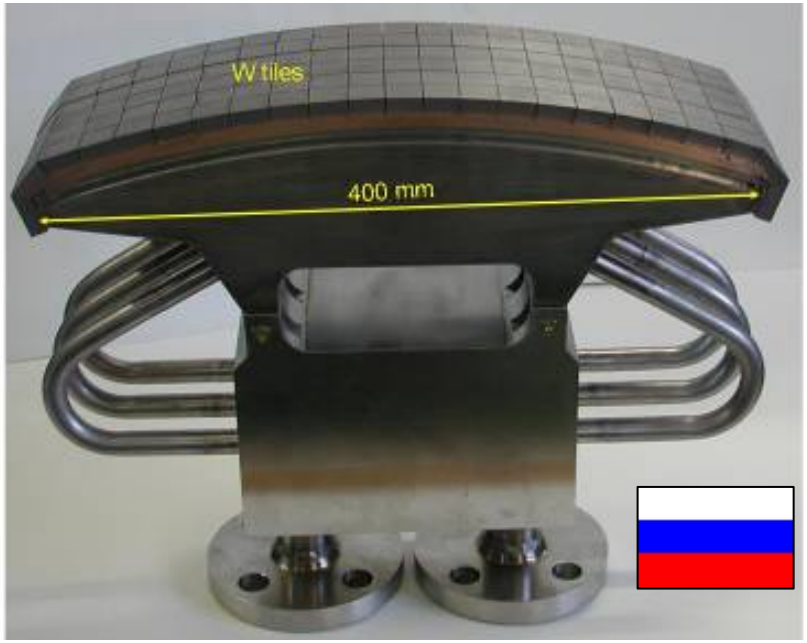


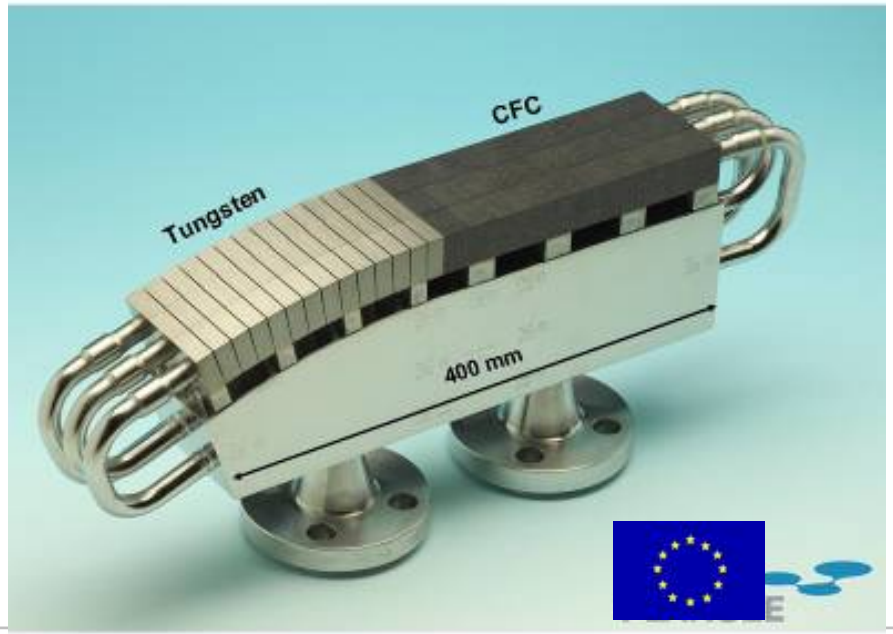


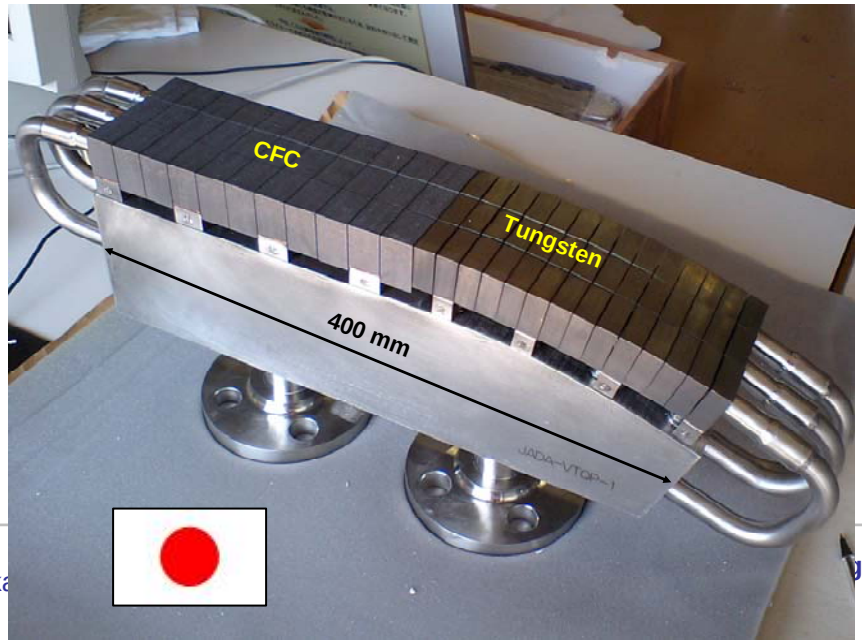
Divertor Qualification Prototypes

A qualification is "*…needed for the critical procurement packages shared by multi-Parties…*", including the divertor

All the 3 DAs have qualified to start procurement



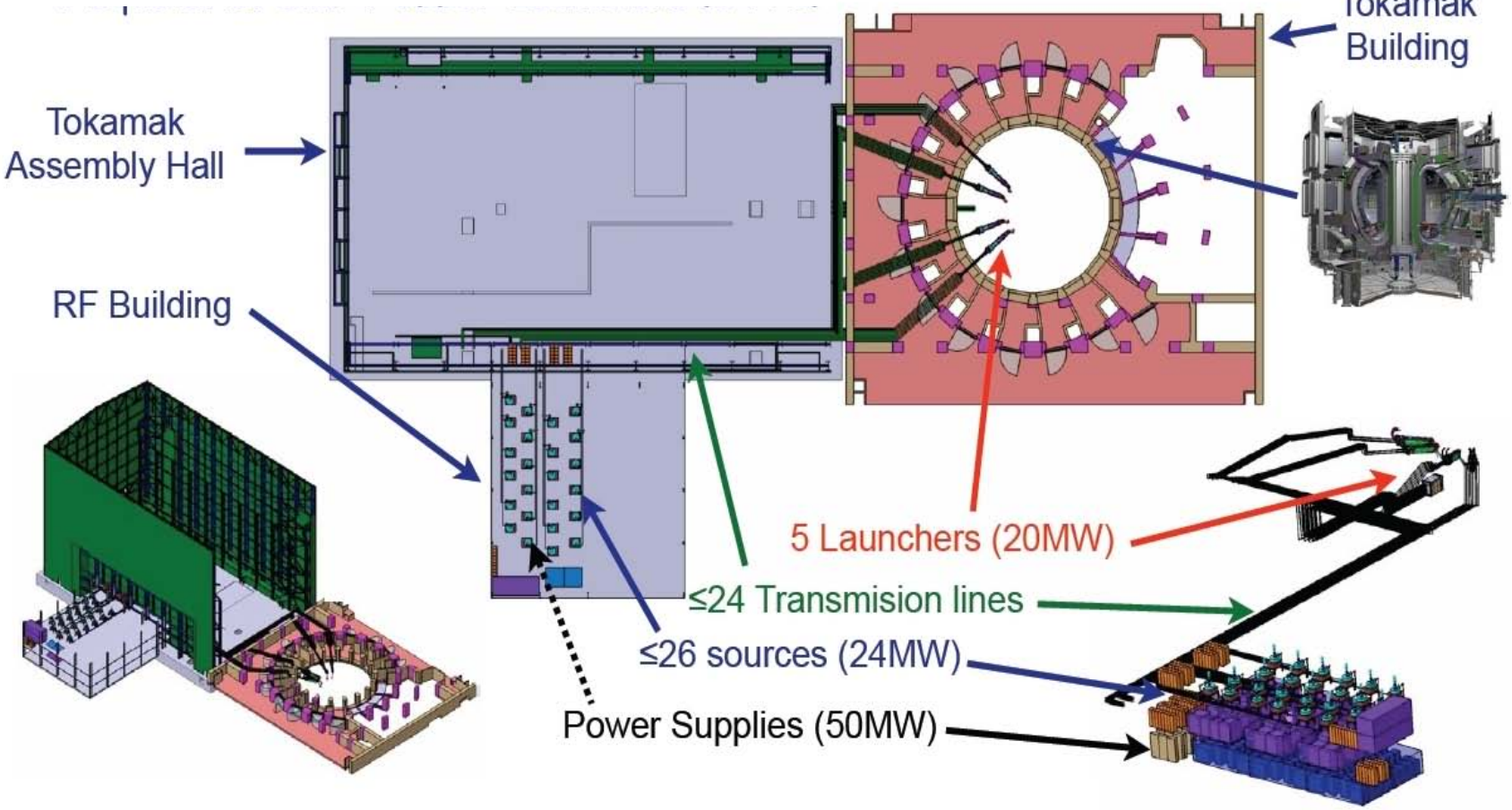




Overview of the EC system

The EC system consists of:

- Up to 13 High Voltage Power Supplies
- Up to 26 Gyrotrons
- 24 Transmission Lines
- 1 Equatorial and 4 Upper Launchers



H&CD Gyrotrons

- 4 different suppliers with at least 3 different types of gyrotrons:
  2 MW gyrotrons from EU, 1 MW from JA and RF and IN.

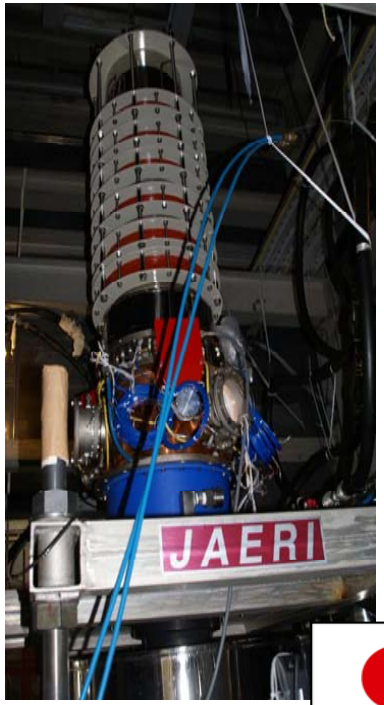
- Second generation prototypes to achieve longer pulse length (for RF and EU) improved reliability (for all tubes)

Short pulse prototype, to be refurbished.

Tests of new gun and launcher design on short pulse tube with good results

1.05MW 116s

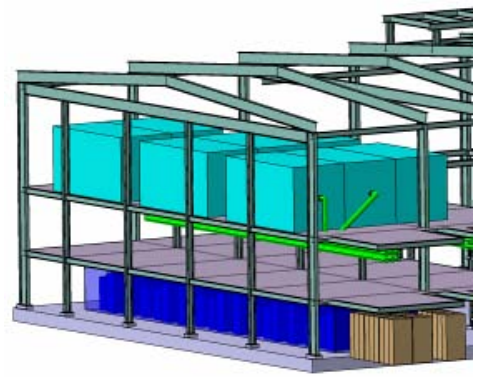
0.6 MW 800s on new test-bed

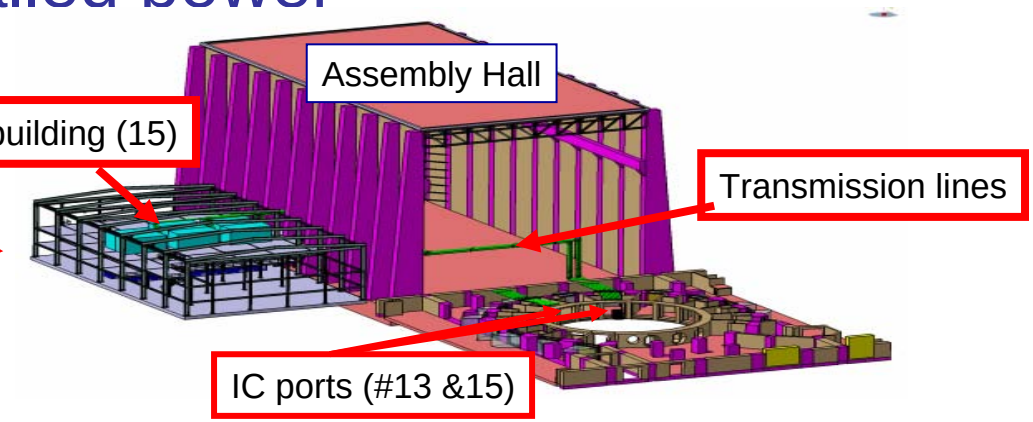


1MW 800s
0.8MW 1h

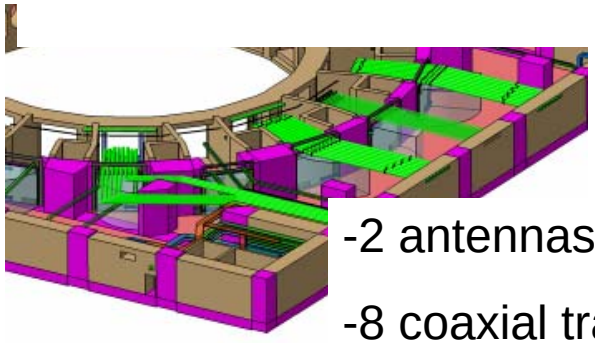
Modulation tests and first reliability tests performed.

ITER IC H&CD system
24 MW installed power

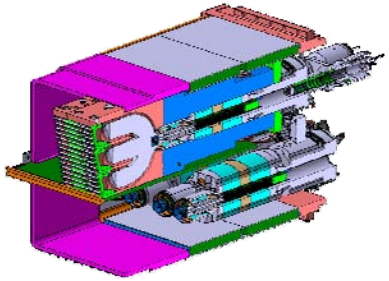




RF sources in RF building structure:
-16 amplifiers: 24 MW in VSWR=1.5 load
- same number of amplifiers as JET

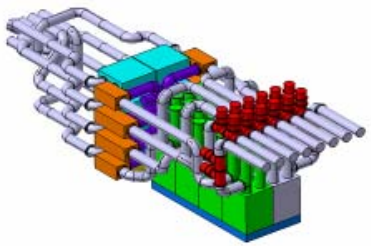


antenna



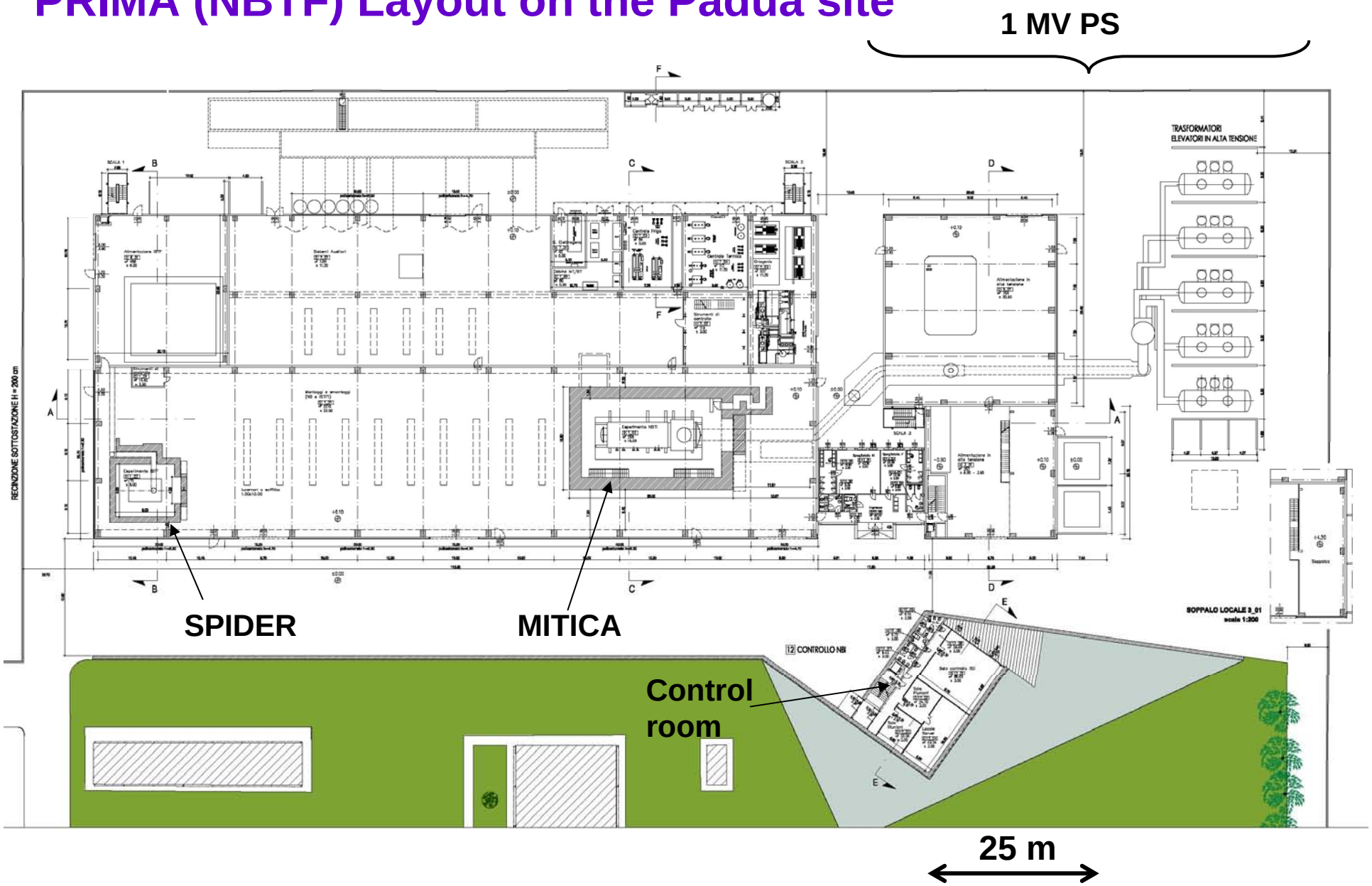
-2 antennas in equatorial port

-8 coaxial transmission lines and 8 matching circuits providing ELM tolerance in port cell

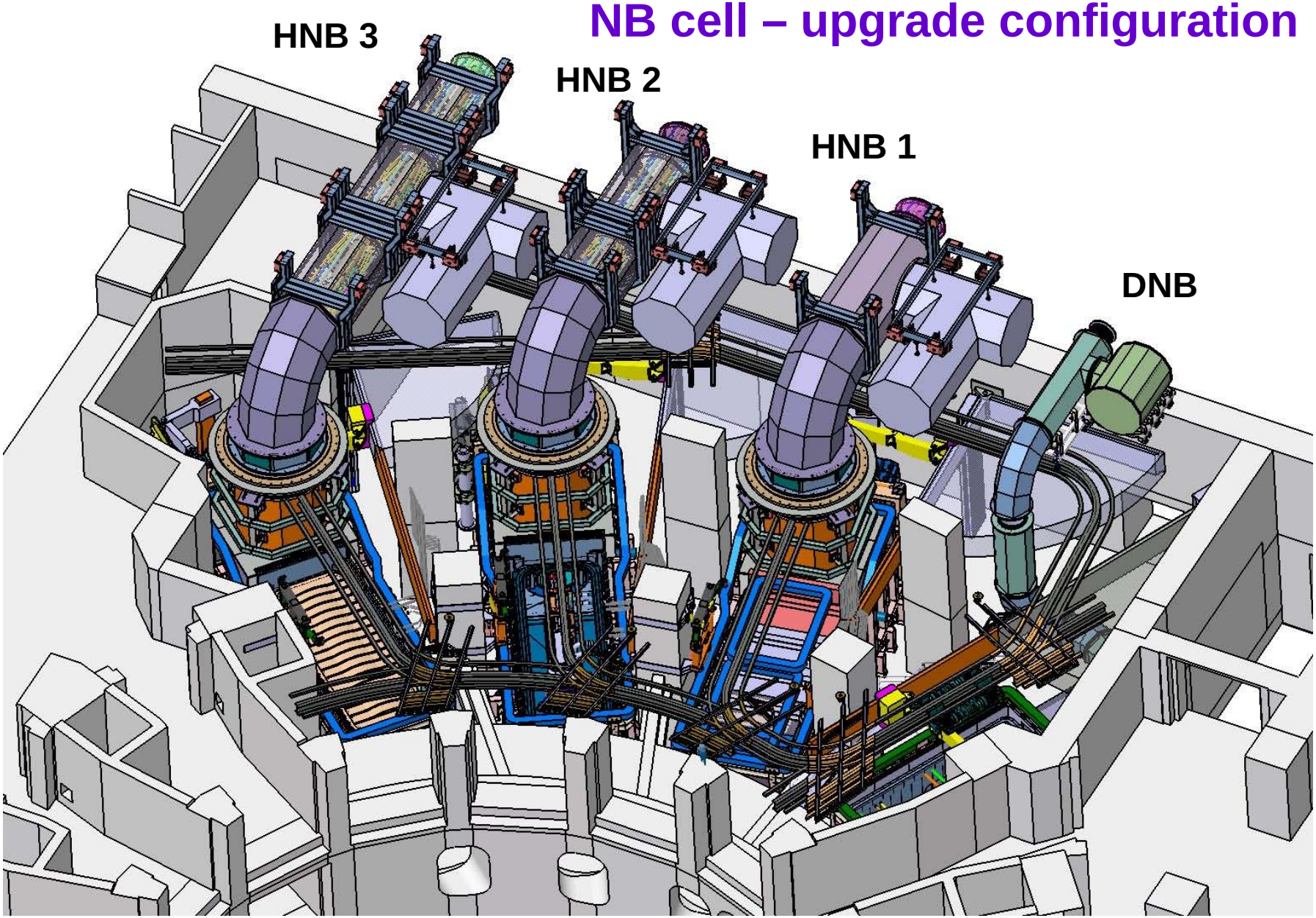


Matching network

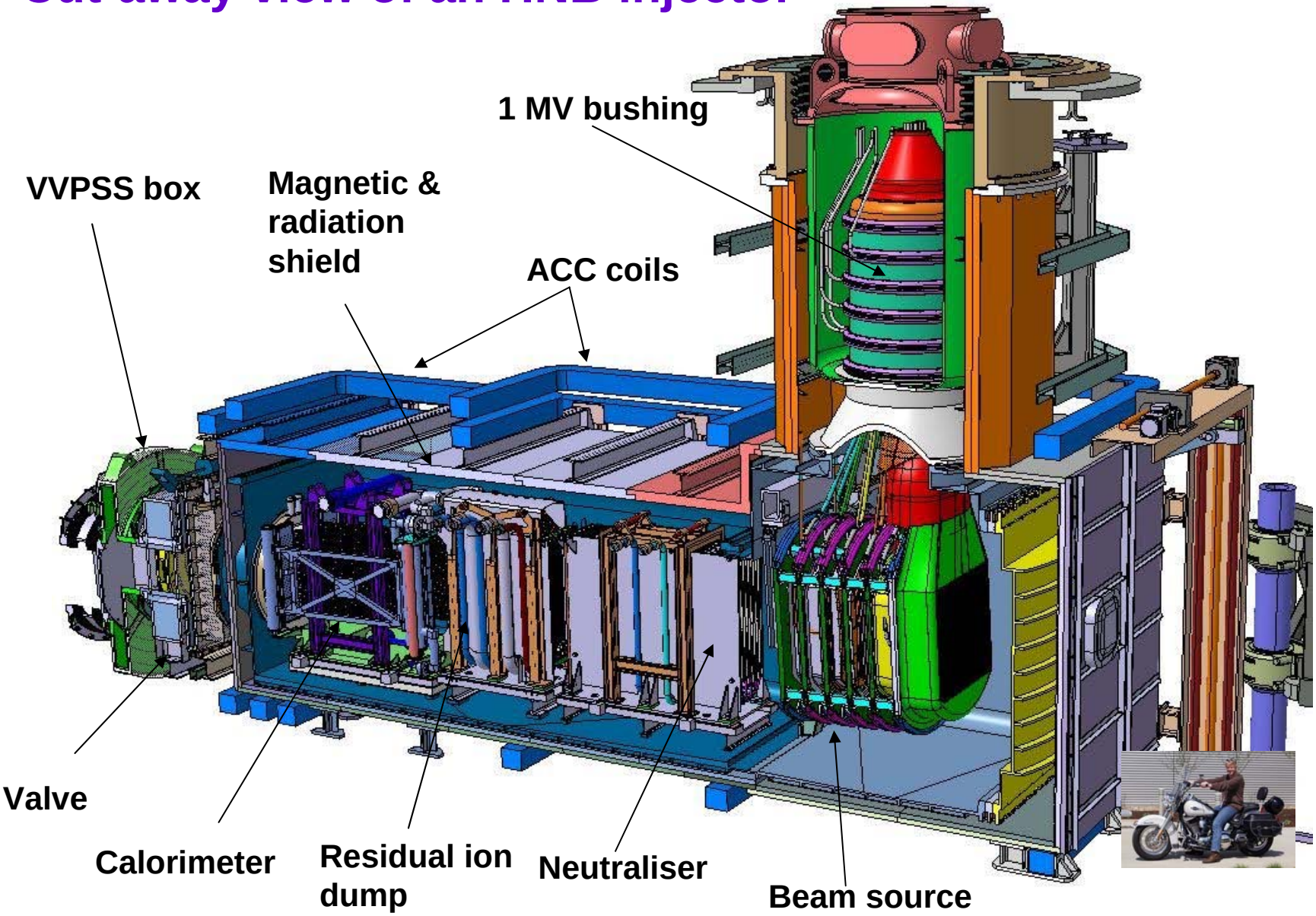
PRIMA (NBTF) Layout on the Padua site



NB cell – upgrade configuration



Cut-away view of an HNB injector



2009 Achievements

- Finalized the preliminary design of all buildings through Jacobs engineering contract;
- Established good integration between F4E and IO on building construction team providing full support;
- Proposed and integrated common Annex Building approach between, France, EU and IO;
- Finalized the close out of all Vacuum Vessel design issues; ☺
- Implemented a major Value Engineering program, especially on buildings, but also on all major components;
- Established Integrated Project Teams (IPTs) for virtually all areas of high integration;
- Distributed the new work scope (coming from Design Review and “missing items” among all DAs, maintaining the fair share;
- Developed a new schedule with all DAs which substantially reduces risk and flattens the manpower and cost profile;

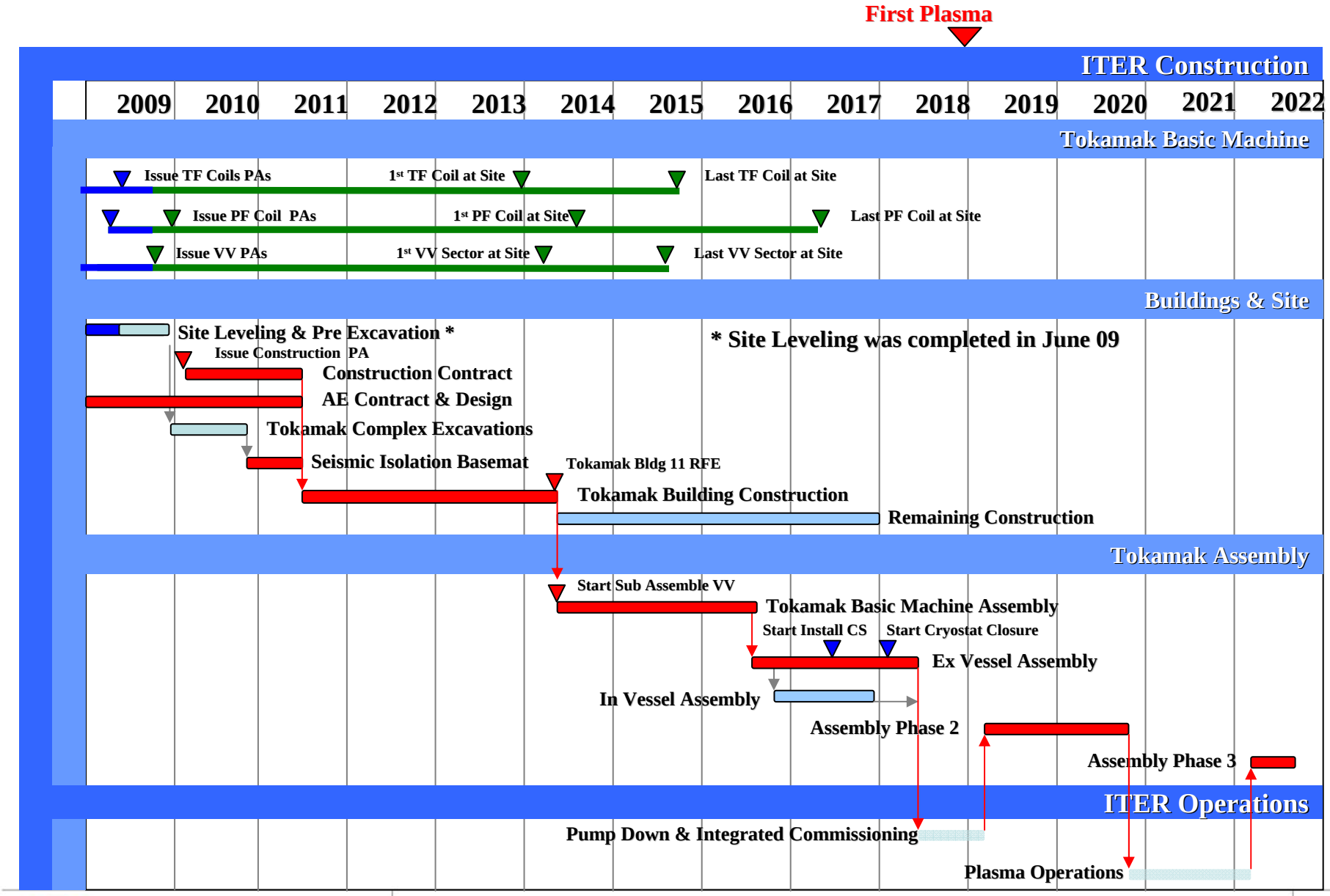
2009 Achievements and Directions

- Achieved detailed integration and hand-off between the DAs and IO on components as part of Integrated Project Schedule development; ☺
- Excellent progress on licensing with RPrS ready to go in February 2010 consistent with building construction start;
- Presented a full and consistent set of Baseline documents to: Management Assessor, Briscoe Review, Systems Integration Review, STAC and MAC. (>148 reviewers between Sept to November)
- The HOD in April and the Council in June, agreed on a Dec 2018 “First Plasma” date and the concept of phased commissioning, but in November, while a complete baseline was established, new direction on further developing the schedule with reduced risk was given. ☹
- The IO reduced the 2008 resource estimate (1550) already by 200M€ and IC expects us to cut by another 10% (~200M€). ☹

The ITER Baseline: Scope-Schedule-Cost

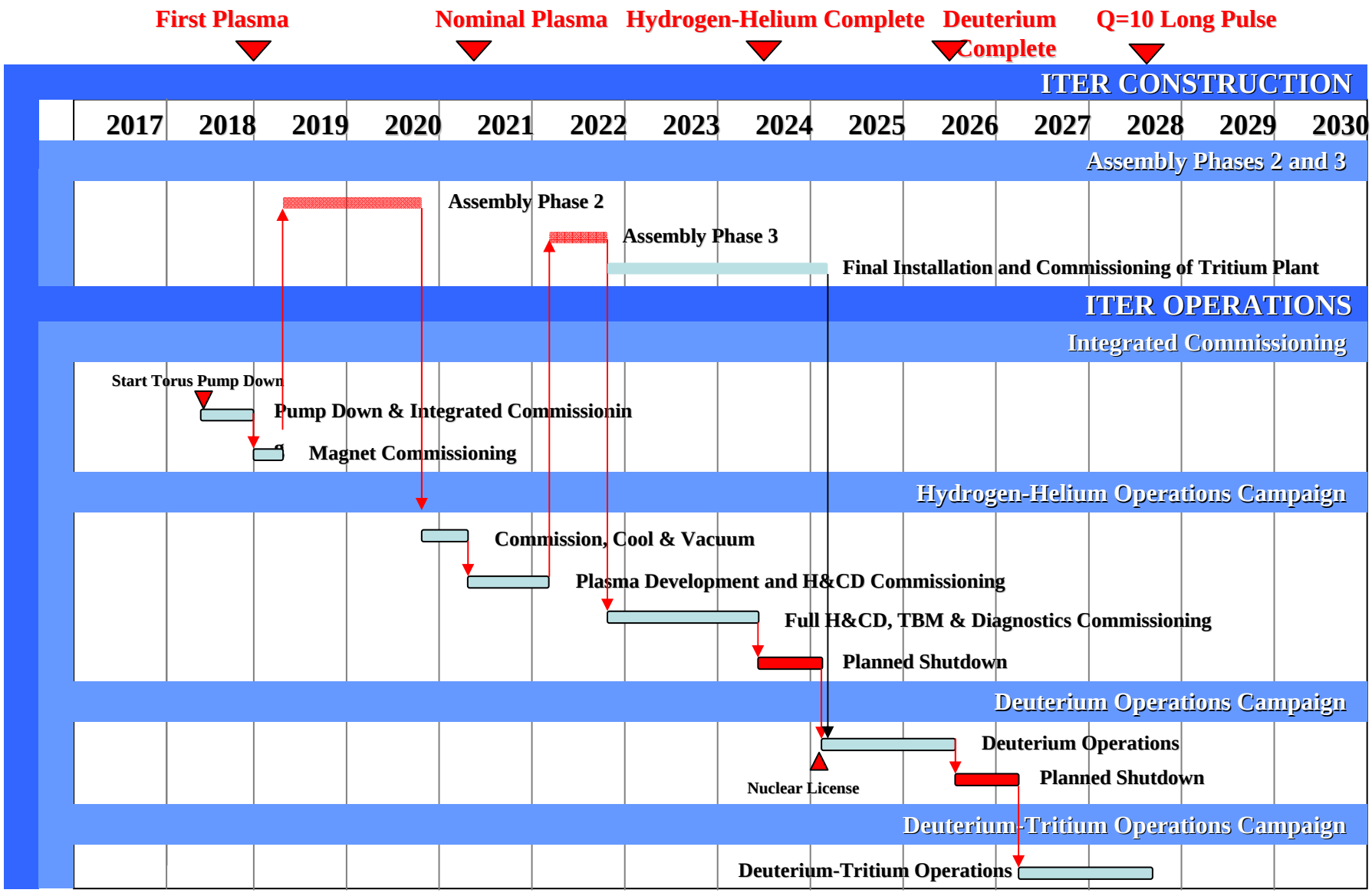
- Original Agreement was made on the basis of the 2001 Baseline design;
- In 2006 at IIC-1 all Members encouraged the IO to execute a Design Review as soon as possible;
- The ITER Design Review process started in December 2006 as an in-house activity with the involvement of more than 150 experts from the Members; It resulted in approximately 80 design changes as necessary, of which only a few have a major impact, e.g. cold test of the magnets, NBTF etc.
- STAC-2 in Nov. 2007 reviewed the results of Design Review and further identified 13 issues, such as ELM control, vertical stability etc. In May of 2008 STAC supported the IO proposal to incorporate design changes into the 2007 Baseline design; - **As a result, the Project Specifications was approved by IC-2 in June 2008.**
- Consistent with this scope and within the boundary conditions set by IC-4, IO has prepared an Integrated Project Schedule and a Cost estimate which forms a consistent set of documents.

Updated Schedule

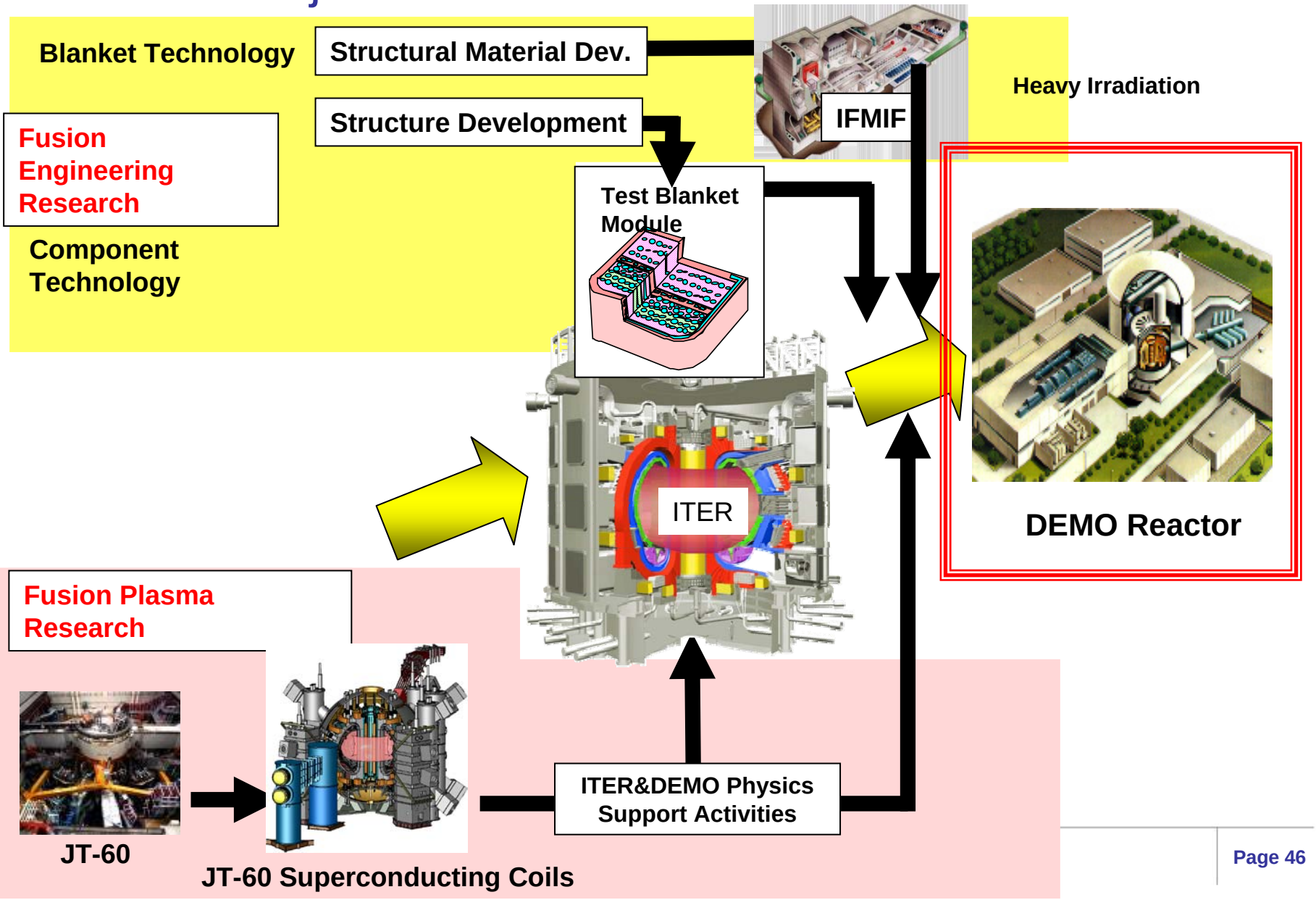


Approach to DT Operation

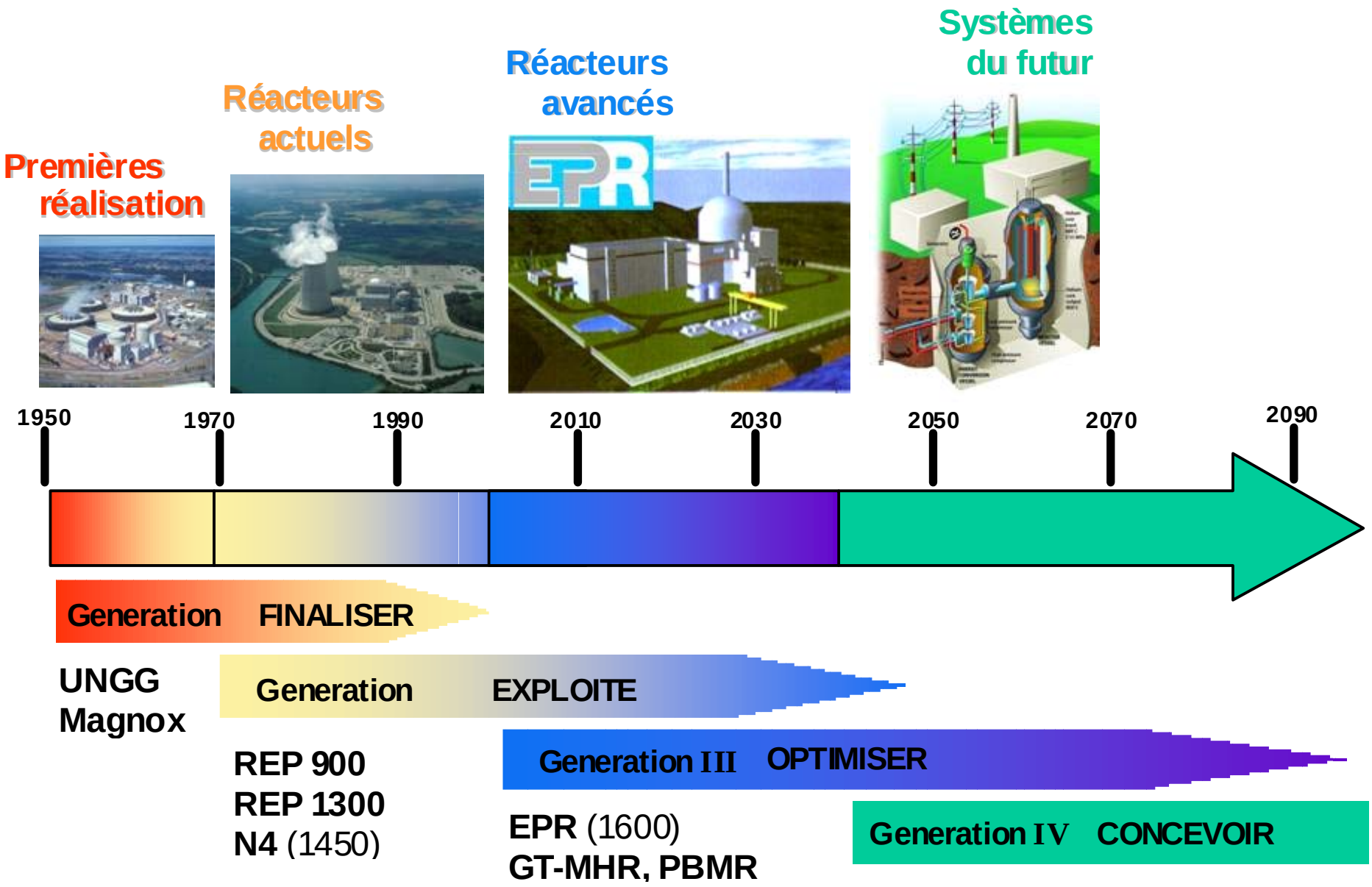
-First D-T Plasma foreseen at the end of 2026



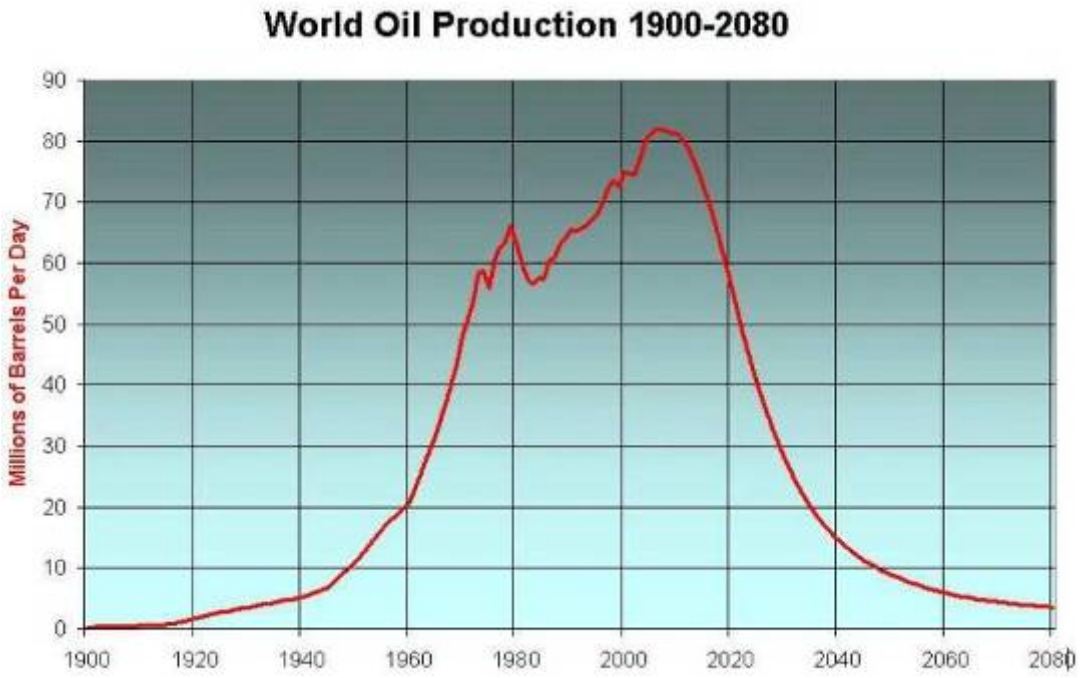
Gegenwärtige und zukünftige Projekte zur Fusion: der DEMO Reaktor



The Roadmap Beyond ITER



ITER – a Global Challenge



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

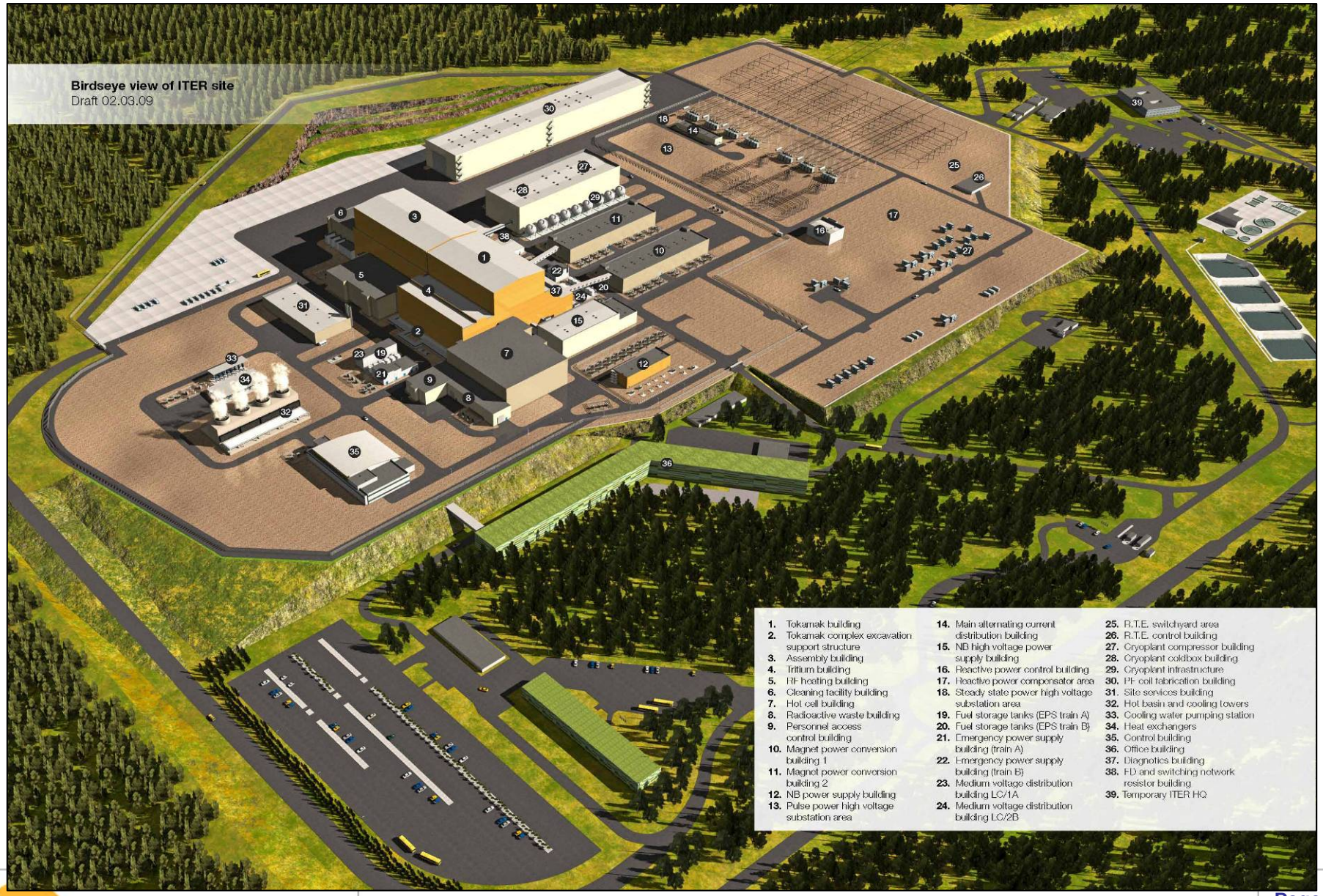
Conclusions

ITER is the key step towards the realization of fusion energy with magnetic confinement

- A new Baseline has been fully established but not fully agreed upon yet
  - **Technical Baseline**
  - **Detailed schedule – resource loaded**
  - **The ITER value including all the design improvements and the IO cost**
- The licensing process is not impinging on construction and going well…
- The IO together with the DAs is not only starting procurement but also closes out remaining design issues or consequent changes from the design review
- A realistic RH – Hot Cell concept and design exists today which also allowed to obtain a correct value for the Hot Cell (part of ADI)

Backup Material

ITER Project Site Layout: 3-D graphics view



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.

Progress of Procurement in kind

To date the following Procurement Arrangements (PAs) have been signed (**value: 964 kIUA** –> > 1500 MEuro):

- 6 PAs for the TF conductor (JA, EU, RF, KO,CN, US)
- 2 PAs for TF magnet winding (EU, JA)
- 1 PA for TF magnet structure (JA)
- 3 PAs for the PF conductor (CN, EU, RF)
- 1 PA for PF coil winding Building (EU)
- 1 PA for PF magnets (2,3,4,5,6) –> (EU)
- 4 PAs for VV (3 sectors), all ports, in wall shielding (KO, RF, IN)
- 2 PAs for Divertor Dome and Outer Vertical Target (RF, JA)
- 2 PAs for Architect engineering services, tokamak pit excavation, seismic isolation pads (EU)
- 2 PAs for power supplies of HNBI and DNBI (EU, IN)
- 1 PA for Tokamak cooling water system (US)
- 1 PA for machine assembly tooling (KO)

In addition 14 PAs to be signed until end 2009 – value: 388 kIUA

Schedule

- The agreement ratified in 2007 foresaw a First Plasma and construction complete with all subsystems and components installed within 10 years of construction begin. It was assumed to be 2016.

- In June 2008, after the Design Review, IO presented to the Council an IPS which foresaw First Plasma in 2018 and beginning of DT operation in 2026; In addition a significant increase in resources was indicated.

- However, the design effort to finalize the procurement arrangements was underestimated and they were delayed as a result; analysis showed that First Plasma would be delayed to 2021 without management action

- In order to maintain the date 2018, IO proposed an Updated Schedule with a different approach to assembly, which allows ITER to achieve a First Plasma operation in 2018 (Ip ~ 100kA, t_{plasma} ~ 100ms, Paux = 0 (except for ECRH breakdown power), B_{TF} = 80%, B_{PF} = 50%, B_{CS} = 50%).

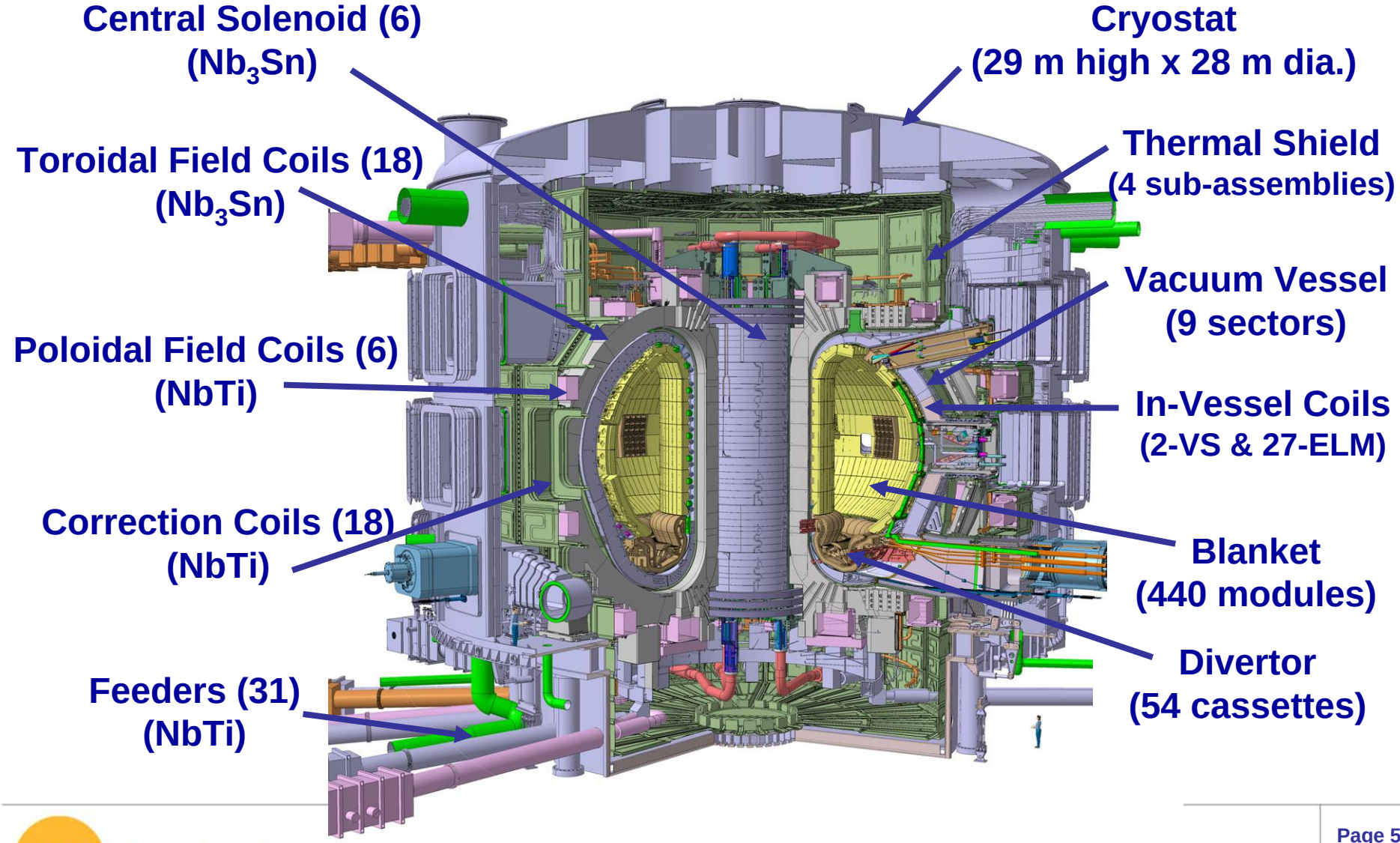
- Within this Updated Schedule, a construction and assembly sequence is proposed in which reduction of risk and cost to the project and maintaining D-T operation in 2026 are the key drivers.

Current status (October 2009)

- **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.

Status of ITER's technical progress (highlights)

Fusion gain Q = 10, Fusion Power: ~500MW, Ohmic burn 300 to 500 sec
Goal Q=5 for 3000 sec



Physics driven Facility Improvements

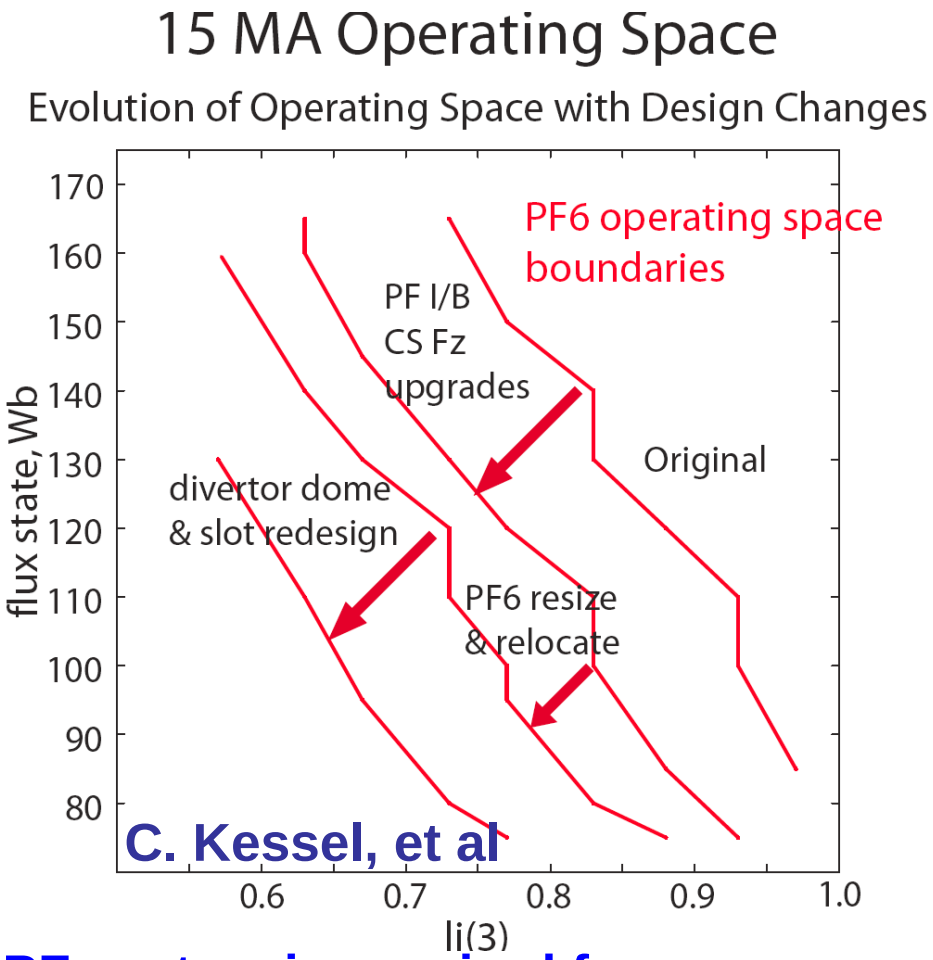
see also design review above

- **Significant <u>improvement in ITER operational flexibility</u> as result of Design Review:**
  - **shape control and vertical stabilization**
  - **in-vessel RMP coils** (ELM control, RWM control)
  - **toroidal field ripple:** converge on $\delta_{TF,separatrix}$ ~ 0.6-0.7%

    $\Rightarrow$ low value of $\delta_{TF,separatrix}$ over range 2.65T ≤ B ≤ 5.3T
  - **fuelling throughput:** increased to 200 Pam^3s^{-1} (ELM control)
  - **H&CD:** NBI shine-through armour, second ICRH antenna, ECRH transmission line hardening to 2MW, H&CD testing facilities
  - **Diagnostics:** rebaselining, eg improved DT capability, tritium retention,dust production
  - **divertor configuration:** improved equilibrium flexibility, extended tungsten baffle
  - **shielding blanket/ first wall:** redesign in progress - improved operational capability

ITER Operation Space (Equilibrium – CS – PF limits)

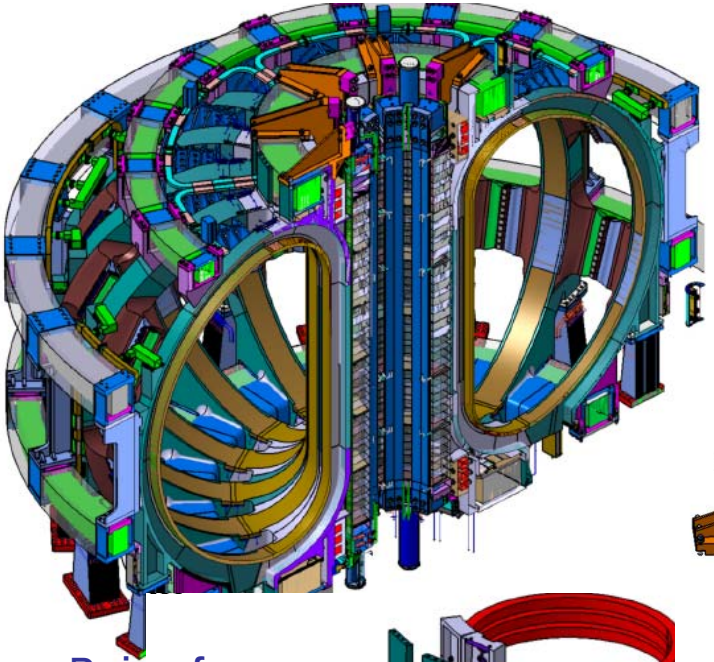
- After Design- and STAC review (2008) changes to CS and PF system permits ITER to operate in the li(3) versus flux space shown →
- PF coil current capability increased by ~20%
- CS separation forces (~120 MN) and total vertical forces (60 MN (180 MN)) increased
- PF Force limits increased (up to ~160 MN – e.g. PF6)



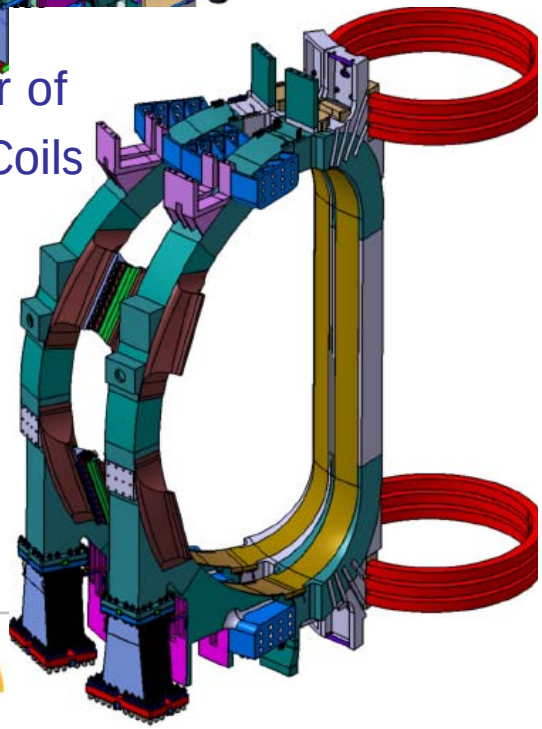
The enhanced performance of the CS, PF system is required for a successful operation of ITER – i.e. for achieving Q=10 – H-mode operation

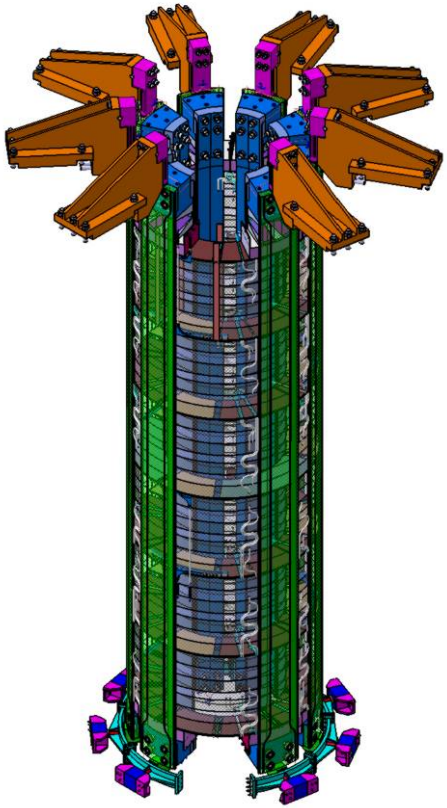
ITER Magnet System

- The ITER magnet system is made up of
  - 18 Toroidal Field (TF) Coils,
  - a 6-module Central Solenoid (CS),
  - 6 Poloidal Field (PF) Coils,
  - 9 pairs of Correction Coils (CC).

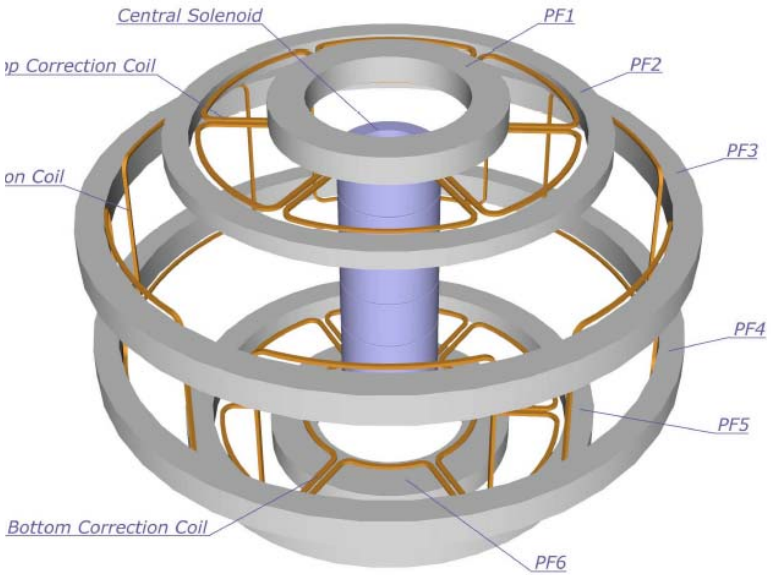


Pair of TF Coils





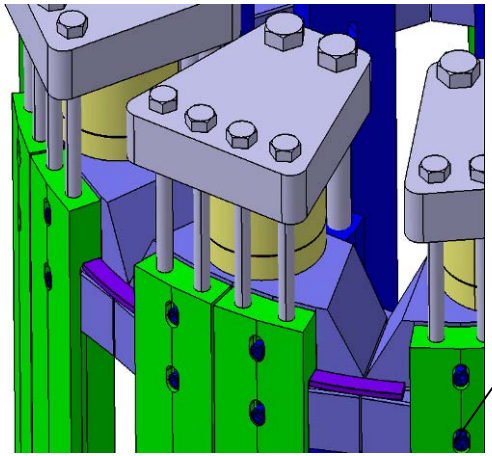
CS Coil

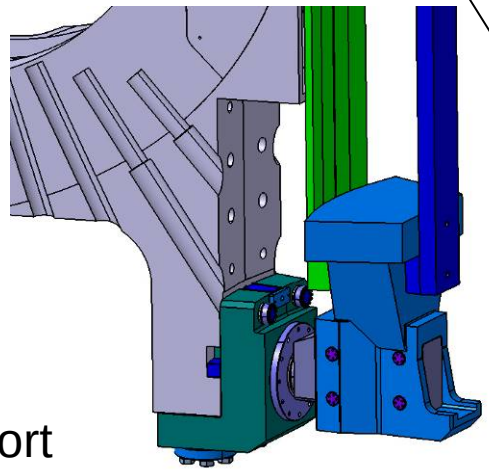


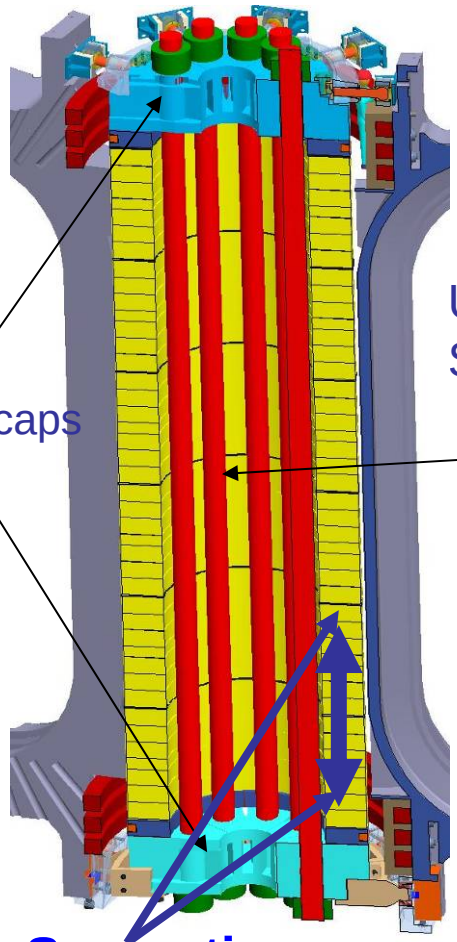
PF & CC Coils

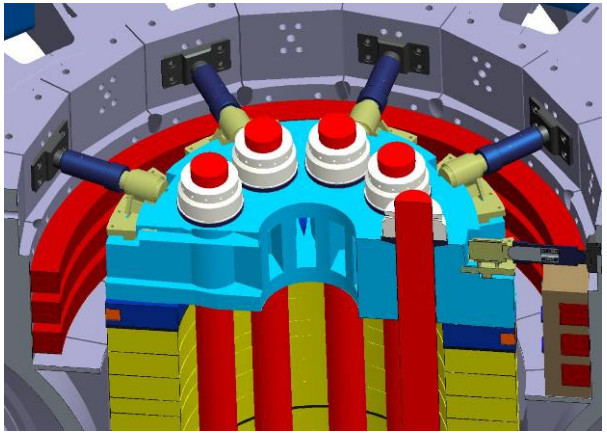
CS design – IO and US-DA final design concept end of 2009

CS is multipurpose coil system! => Ip, VS, Shaping





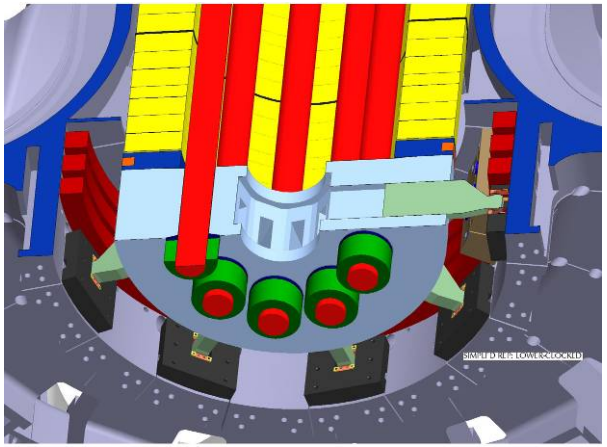




Upper centering device w/ SuperNut® precompression

End caps

Tension rods



Lower support structure

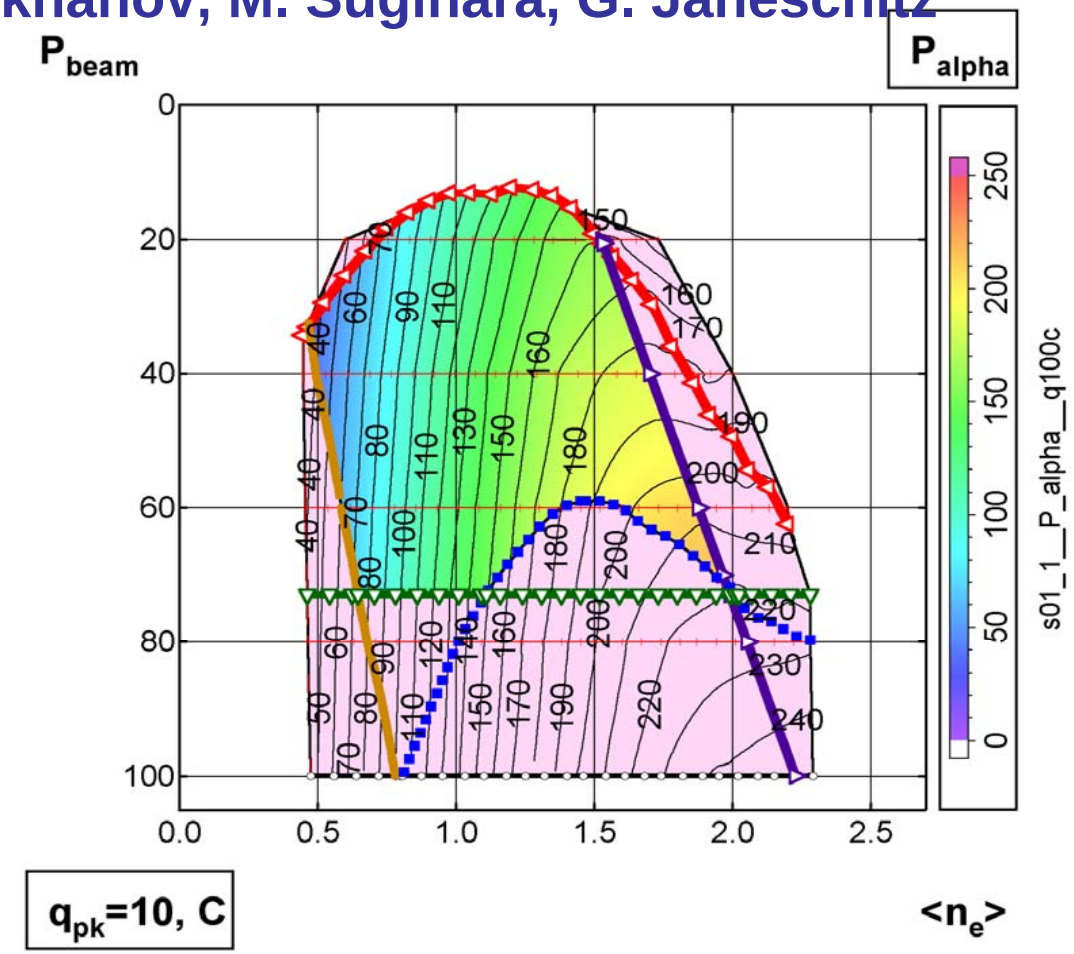
Force applied
+/- 60 MN/Support

Separation Force ~120 MN

ITER Operation Space (Fusion Performance) in H-mode predicted by an Integrated Plasma Model

G. Pacher, H. Pacher, Y. Igitkhanov, M. Sugihara, G. Janeschitz

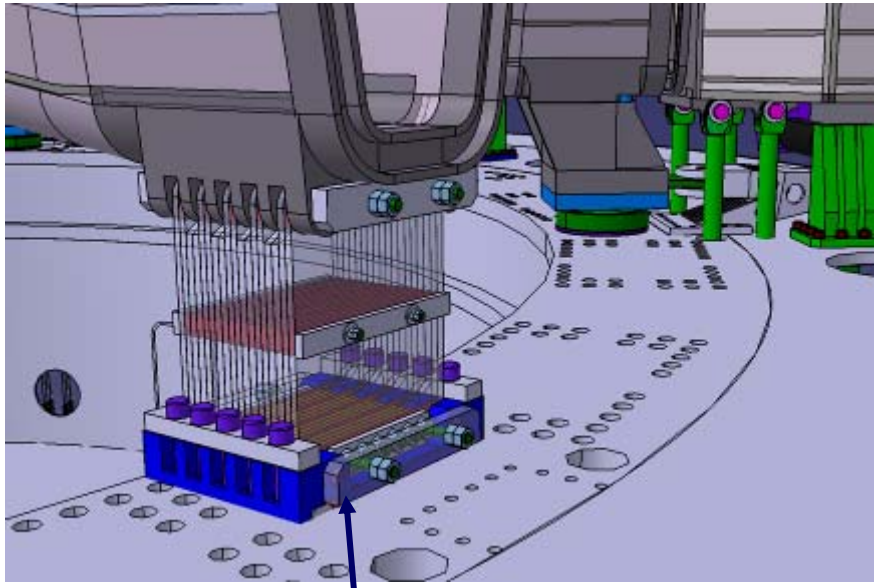
- One-dimensional modelling of the plasma core:
- Two dimensional modelling of the SOL and Divertor
- Physics based empirical model for the Pedestal
- Turbulence fluid model for the core
  - Multimode – Lehigh – University - Bethman



Operational and objective limits:

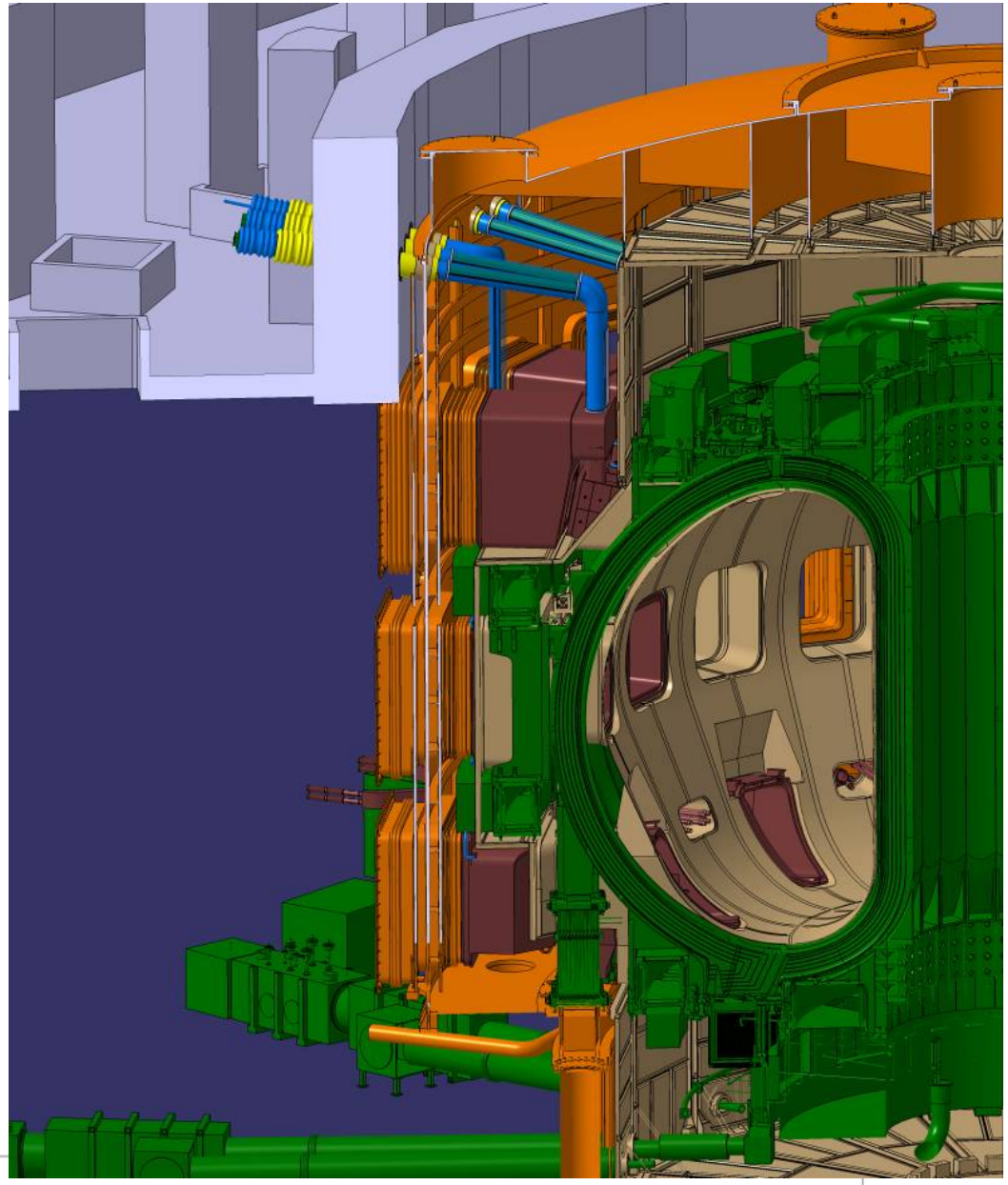
Q=5, LH transition, low temperature limit on alpha power, auxiliary power, edge density limit

Improvement of the VV Gravity Support and cryostat design



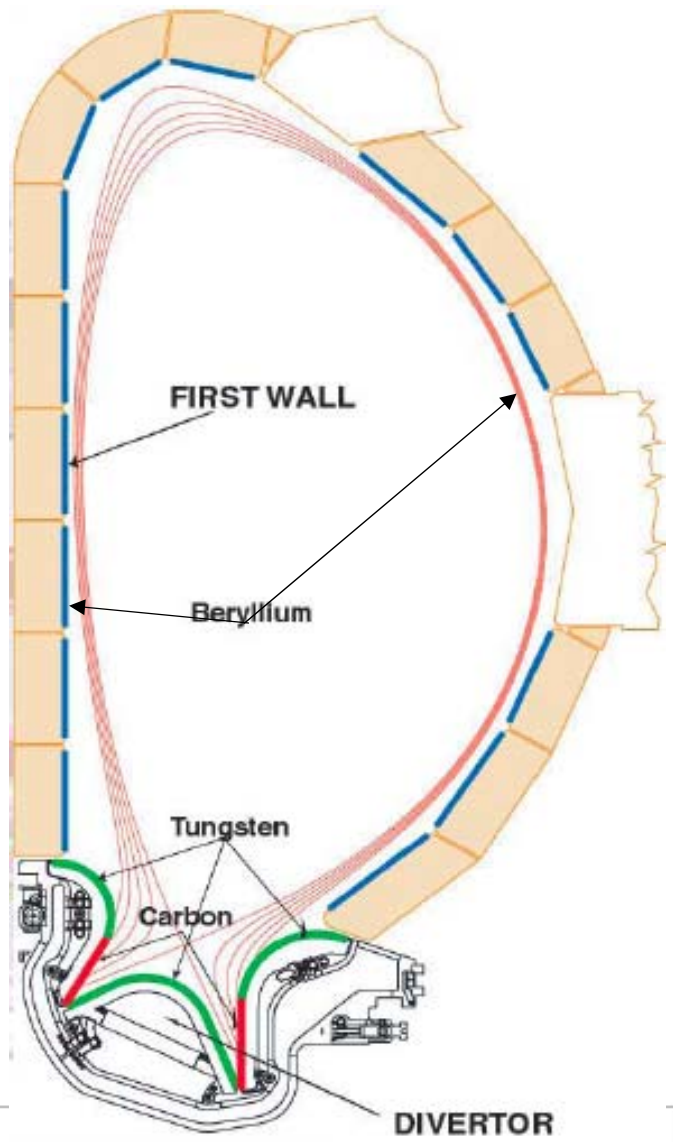
New proposed VV gravity support based on flexible plates concept as for TF coil support

In particular design improvements due to maintenance requirements are planned for cryostat and thermal shield

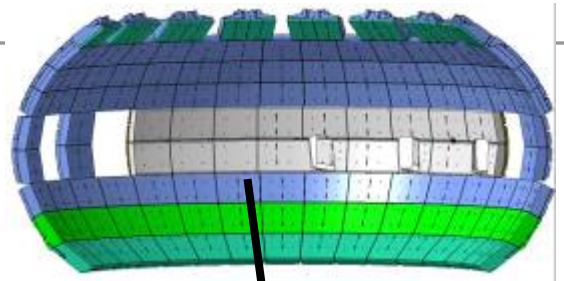


Plasma Facing Components - Challenges

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



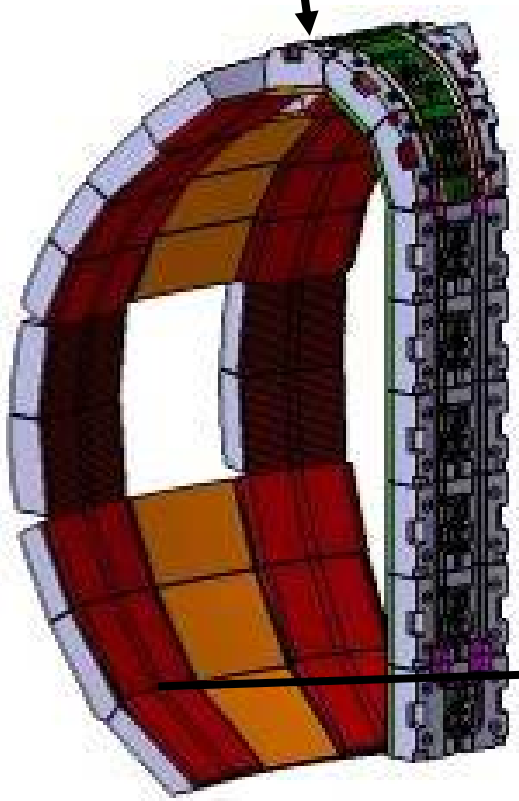
Blanket System



Challenge EM Forces, FW heatflux

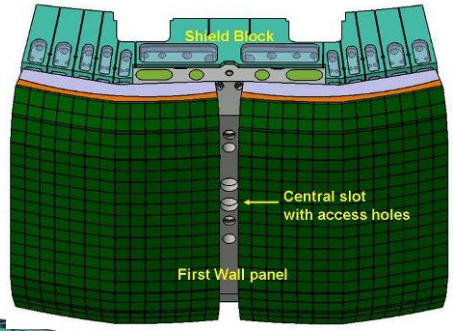
Scope

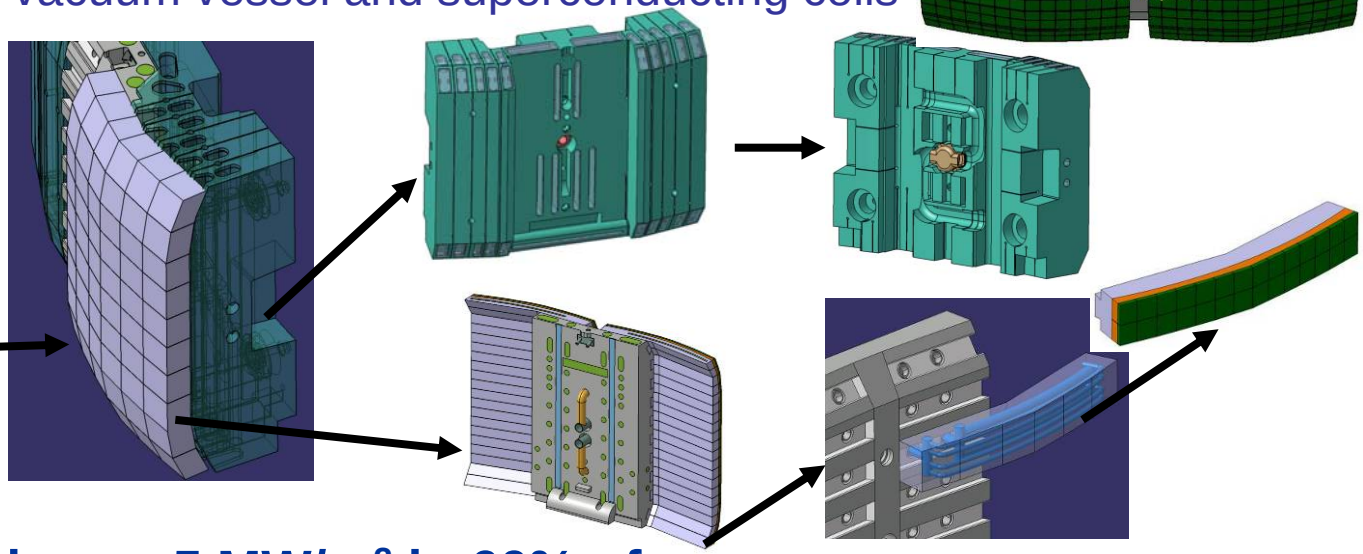
- 440 blanket modules at ~4 ton each
- ~40 different blanket modules



Blanket system main functions :

- Exhaust the majority of the fusion power
- Reduce the nuclear responses in the vacuum vessel and superconducting coils





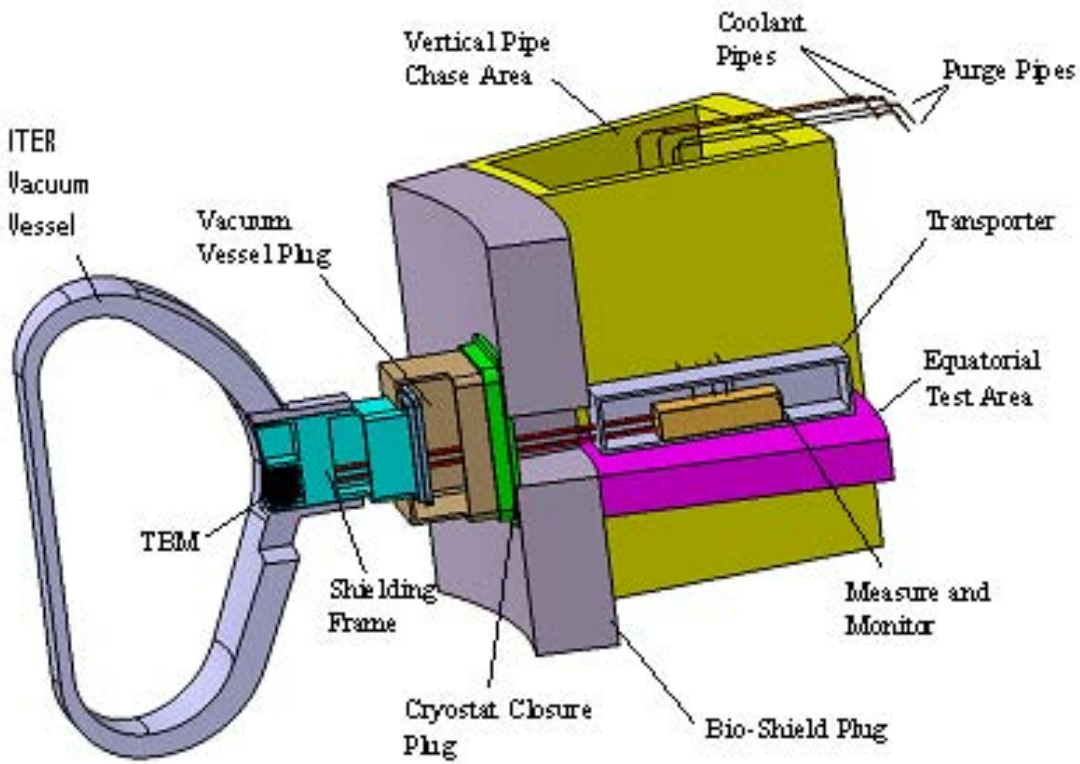
FW shaped – avoid edges – 5 MW/m² in 60% of area

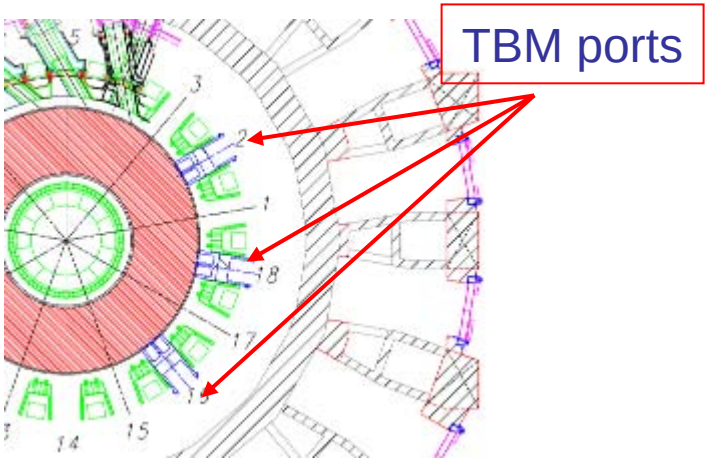
Separable FW module, shield module slotted to reduce EM forces

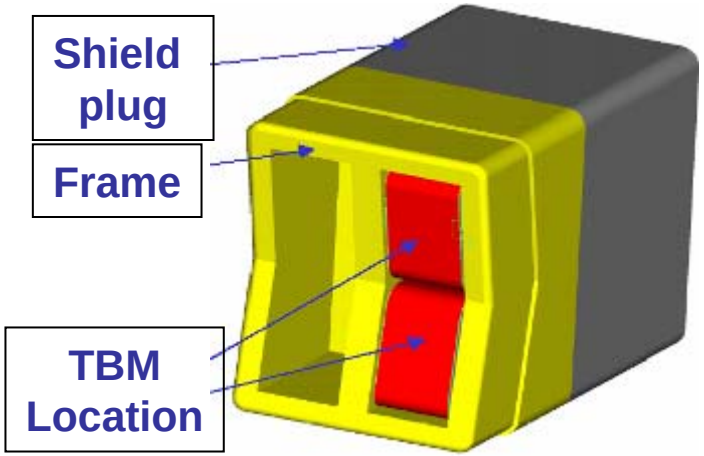
Test Blanket Modules - Tritium Breeding

$n + {}^{6}Li \rightarrow T + {}^{4}He + 4.8MeV$

$n + {}^{7}Li \rightarrow T + {}^{4}He + n - 2.47MeV$



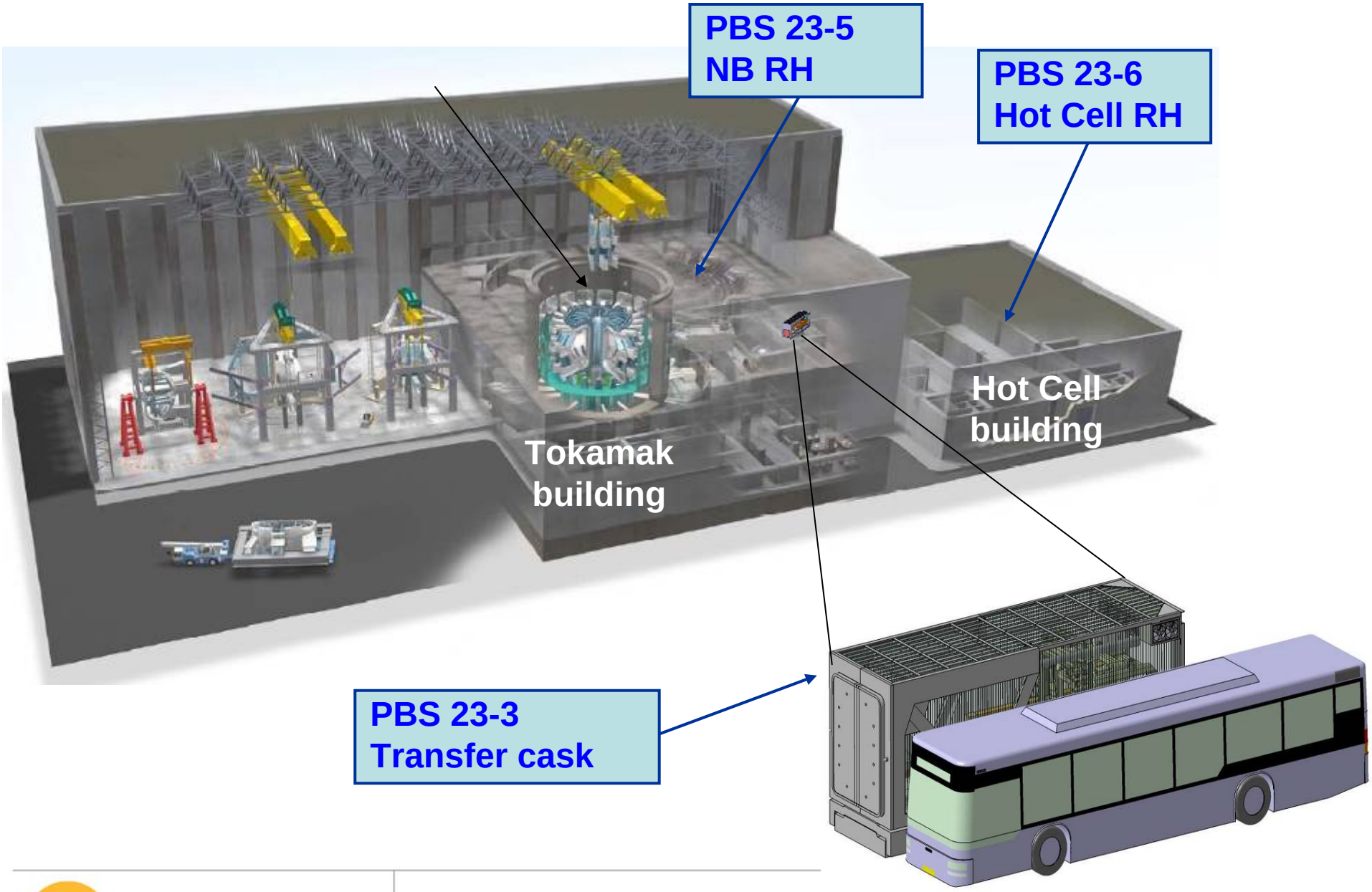




- **Three dedicated stations for testing up to six tritium breeding concepts**

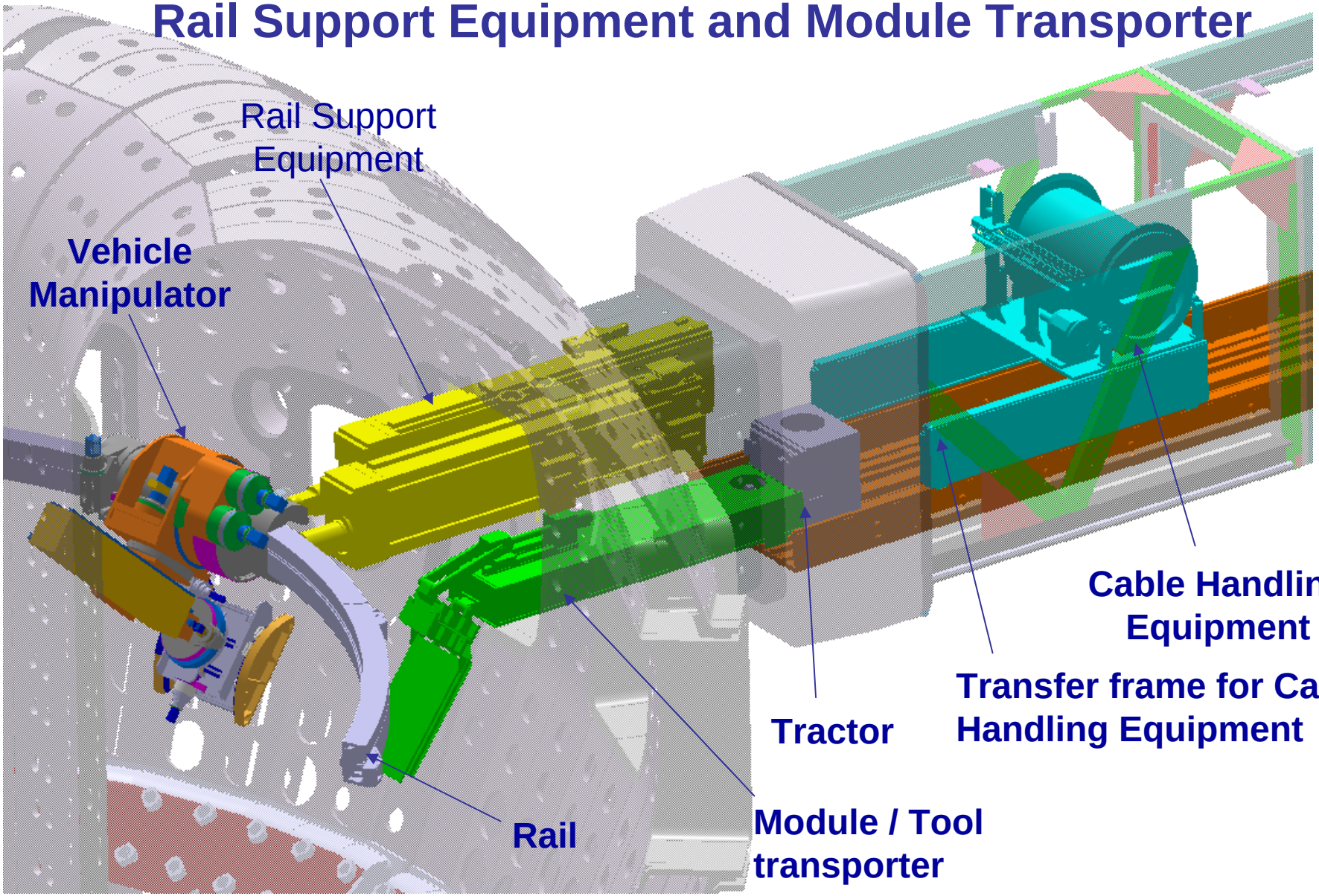
See also V. Chuyanov PL1 A1and L. Giancarli SO4 B2

ITER Remote Handling / Hot Cell

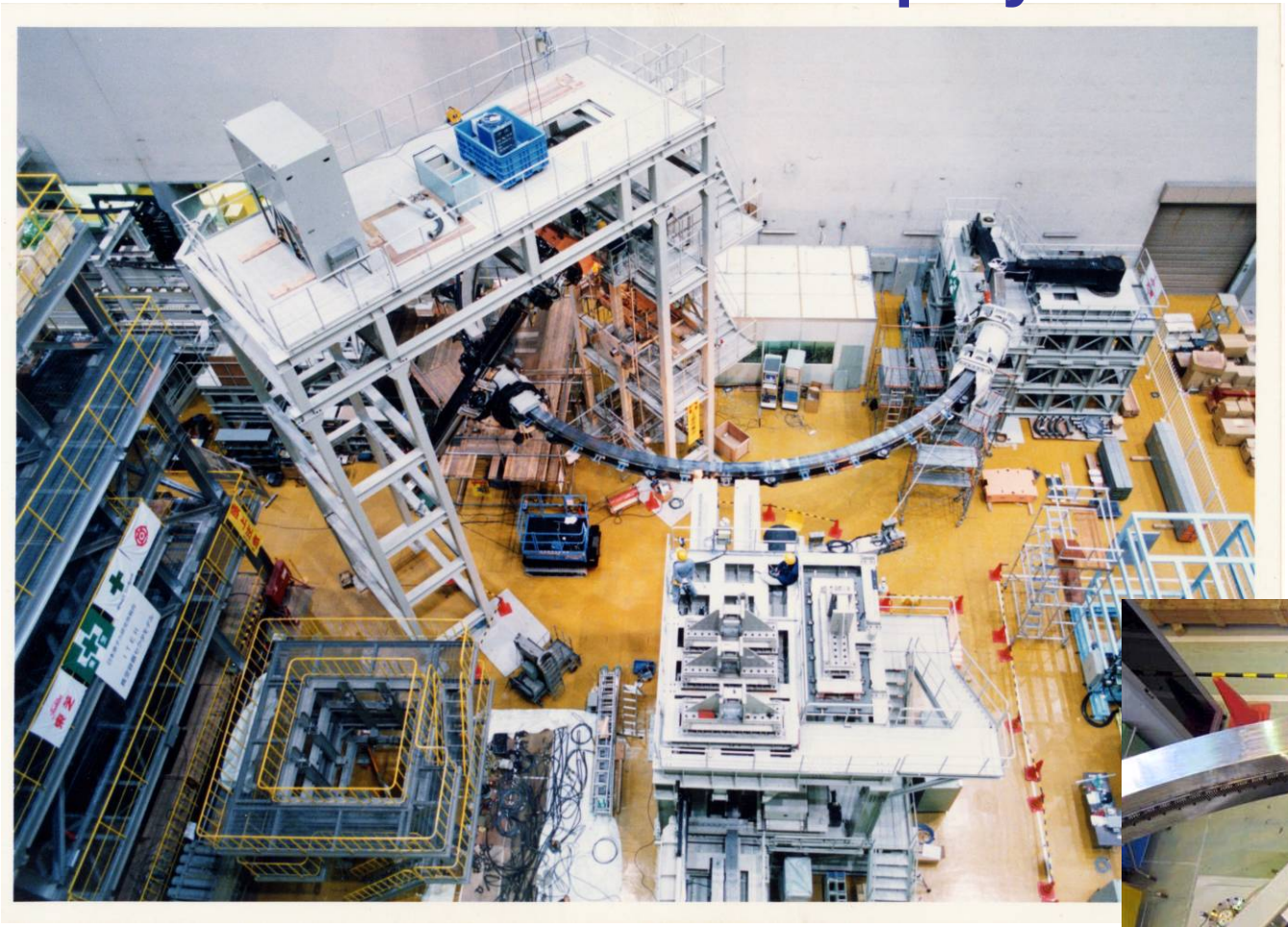


Blanket RH System

Rail Support Equipment and Module Transporter



Full scale 180° rail deployment test (1998)



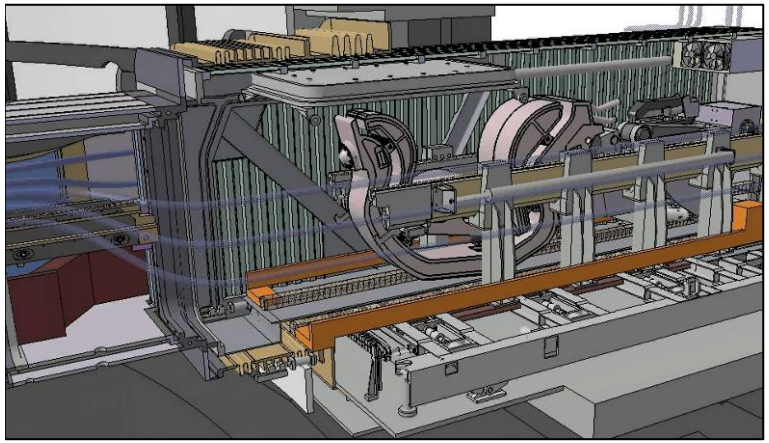
RH system for blanket has shown its ability to perform the job

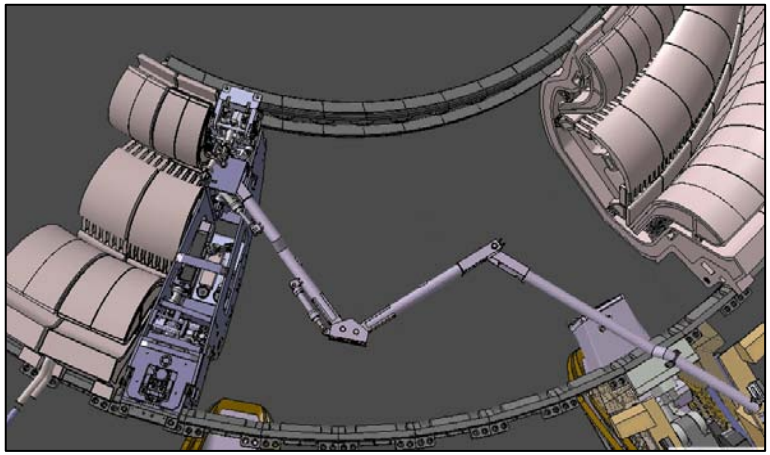
Some issues remain

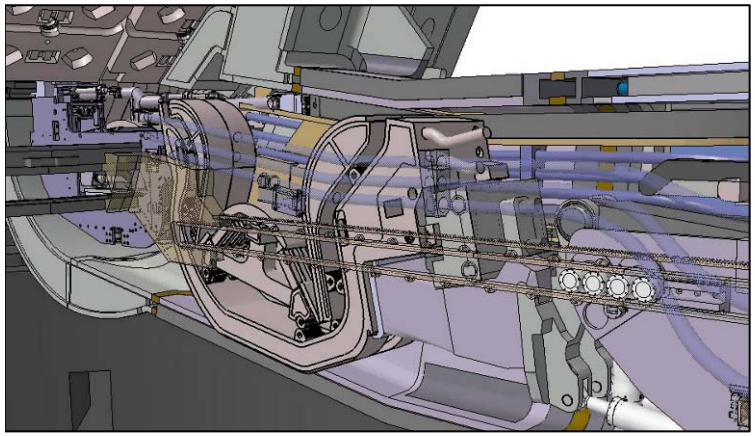
2 decades of development to provide demonstration of feasibility and reliability

In-port rail connection 2008-2009

Divertor RH Equipment demonstrated to work





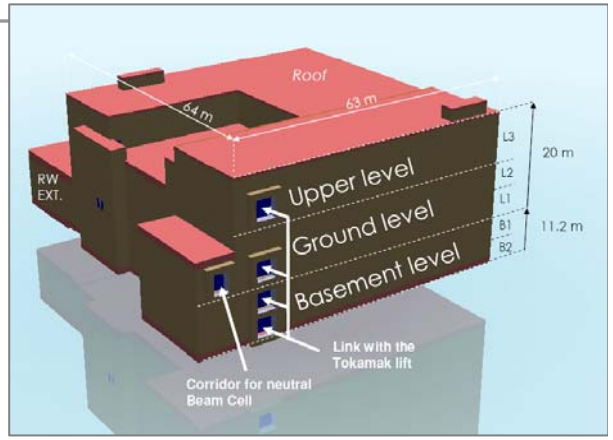


Divertor RH equipment is comprised of
Two main types of “cassette mover”:

- **Cassette Multi-functionl Mover (CMM)**
- **Cassette Toroidal Mover (CTM)**

Each are to be equipped with a dexterous manipulator arm and RH tooling.

Hot Cell design



The HC RH system will have the following equipment:

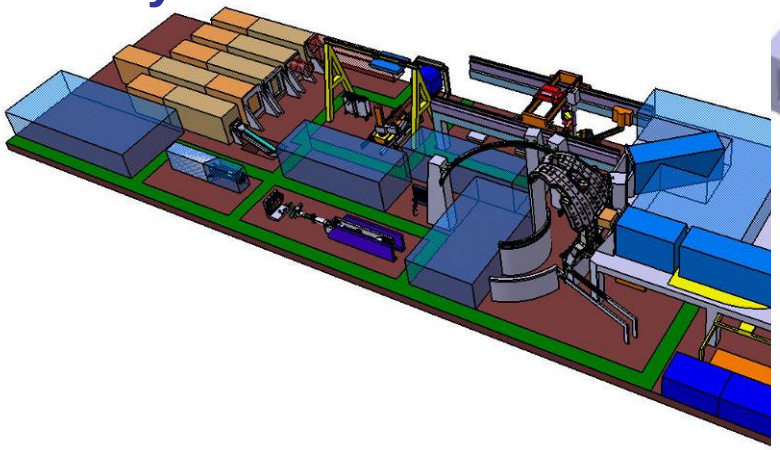
- **Boom-style RH transporter(s)**
- **Jib cranes transporters**
- **Lifting jigs**
- **Dexterous telemanipulators) end effectors**
- **Direct viewing telemanipulators**
- **Inspection equipment (including weld NDT, visual inspection, metrology)**
- **Cleaning equipment (Vacuum cleaner).**

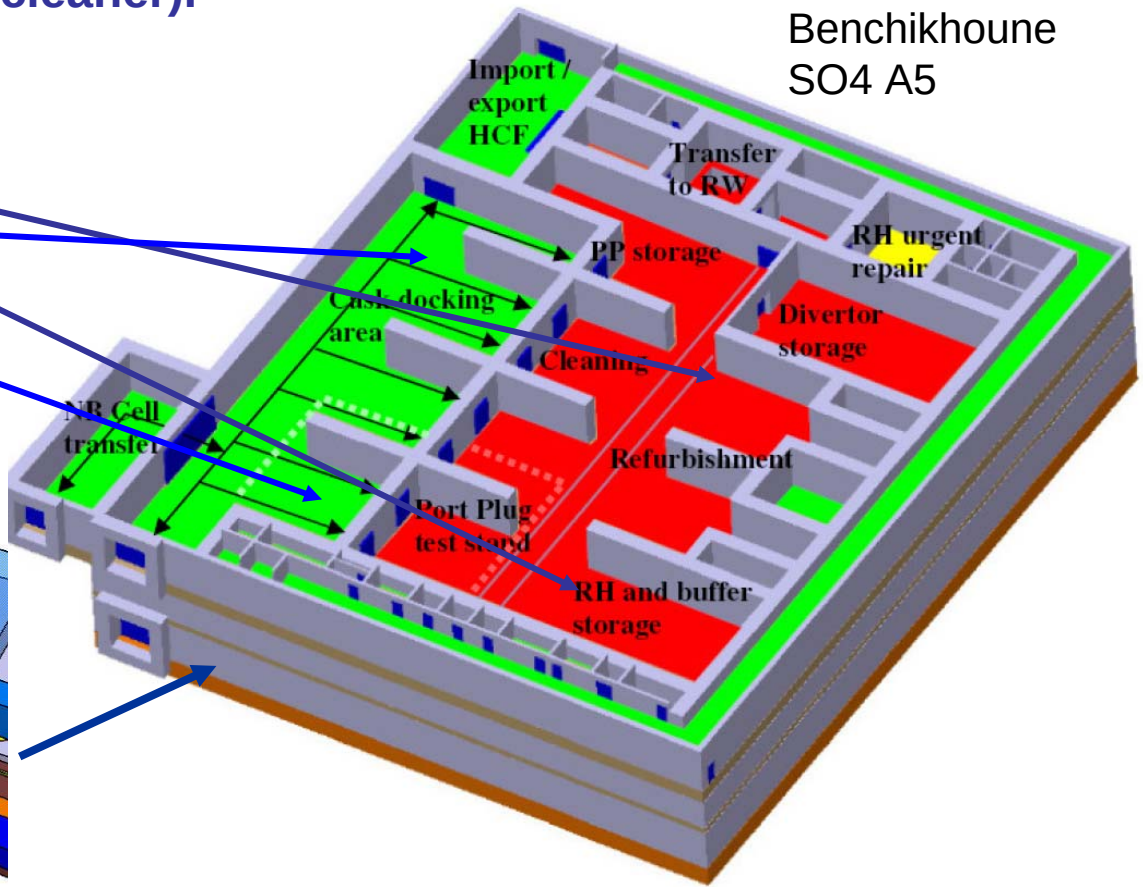
See also M Benchikhoune SO4 A5

refurbishment & test

Cask Docking

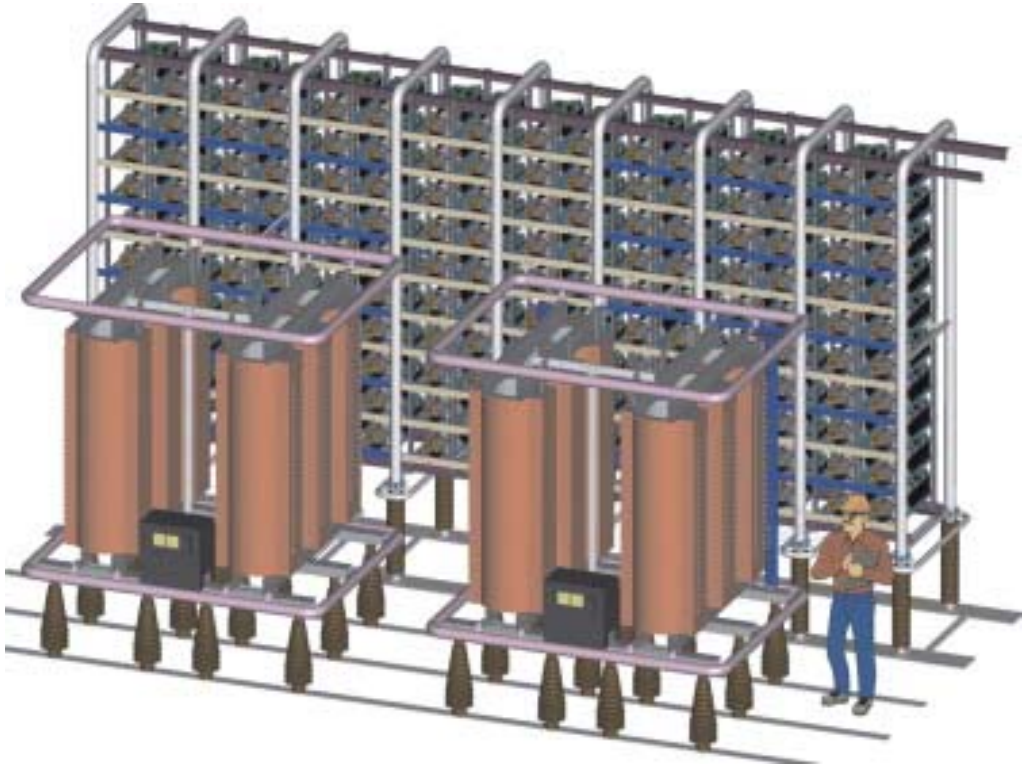
Hot- RH Test facility





High Voltage Power Supplies

- Existing PSM technology.
- Design based on equivalent system, already installed on existing W7-X system.



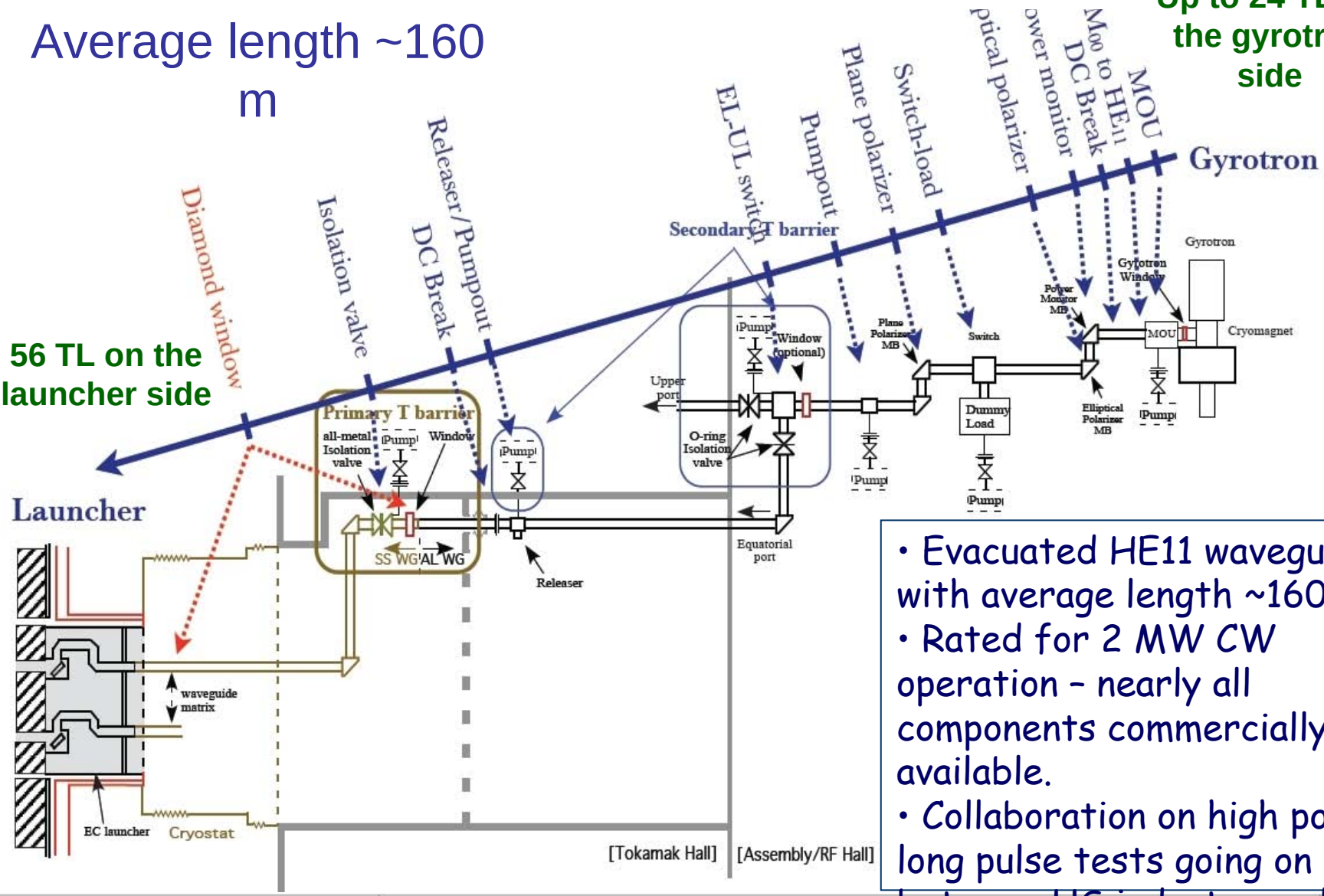
- Adaptable to 3 gyrotron types.
- 1 main Power Supply shared by 2 gyrotrons.
- Provides modulation for physics requirements.

Schematic Transmission Line

Average length ~160 m

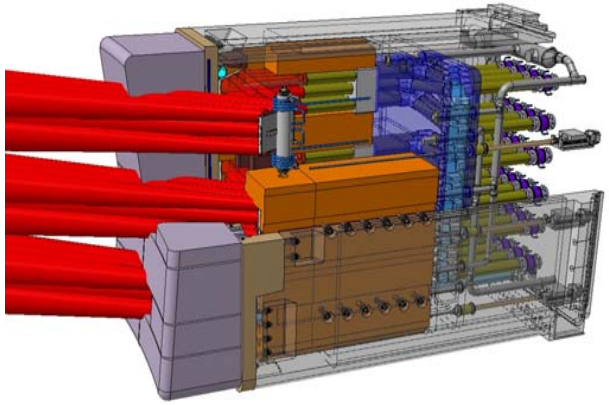
Up to 24 TL on the gyrotron side

56 TL on the launcher side



- Evacuated HE11 waveguides with average length ~160m.
- Rated for 2 MW CW operation – nearly all components commercially available.
- Collaboration on high power long pulse tests going on between US industry and JAEA.

EC Launchers

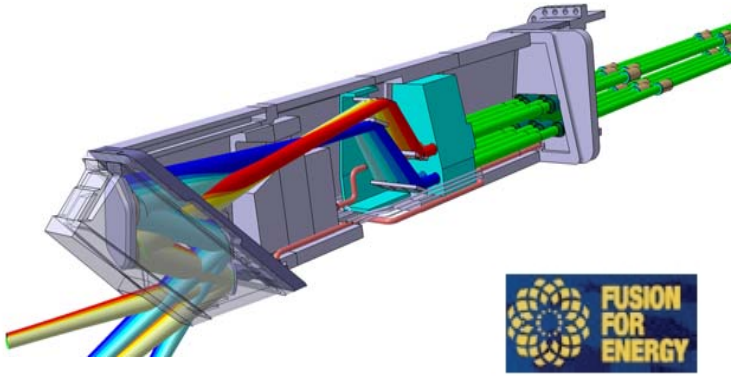


Equatorial launcher: Central heating & current drive

- 1 port with 24 entries.
- 3 steering mirrors in toroidal direction ($0<\rho_T<0.45$).

Upper launcher: Control of MHD activity

- 4 ports with 32 entries in total.
- 2 steering mirrors in poloidal direction ($0.3<\rho_T<0.95$).



- Both at or beyond preliminary design, no show stoppers in design, final design 2013.
- Prototype tests on critical components are on going (steering mechanism, BSM, sections of port plug structure.

ICH&CD system

Scope: Provide 20 MW of plasma heating during any phase of the discharge in differe conditions (Second harmonic tritium, 3He minority heating, D minority heating):

–Flexibility :

- •40 to 55 MHz corresponding to 3 main scenarios,
- •full control of phasing of the antenna to access current drive configuration
- •100% power modulation
- •Compatible with lower magnetic field if needed (to be checked for lower side of Freq. Band)

–Constraints : coupling is dependant of plasma configuration (geometry, density, shape, composition,ELMs, etc…)

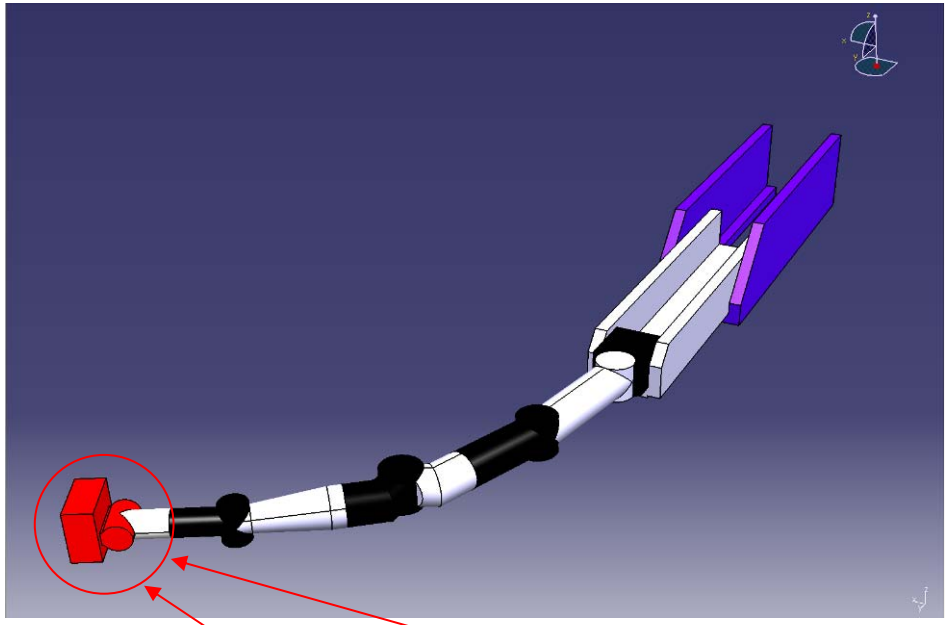
Upgrade possible by doubling the equipment to 40 MW

System is composed of:

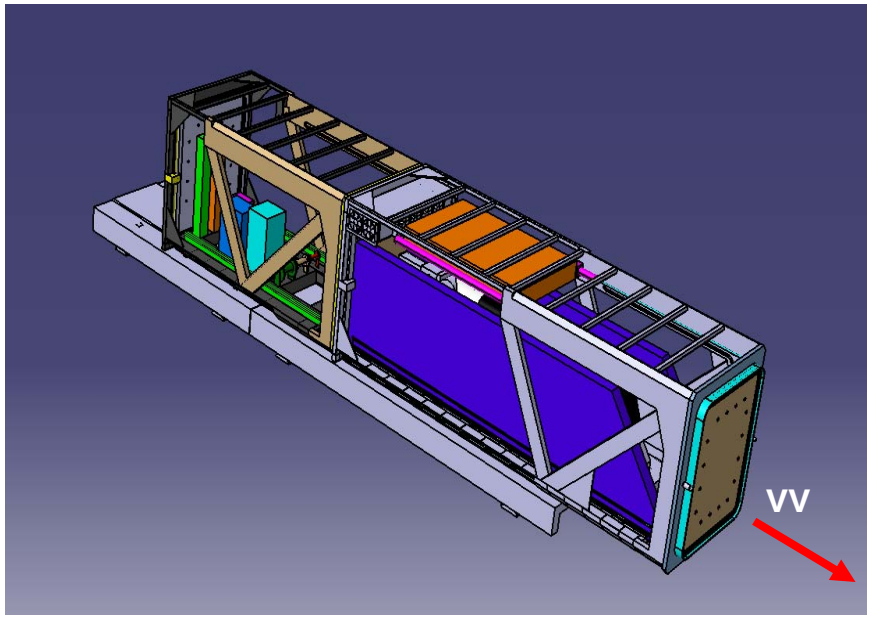
– AC/DC power supply system,	IN	(no R&D)	
– DC/RF converters system,	IN	(no R&D)	
– Transmission line system,		US	(little R&D)
– Antenna system	EU	(lot of R&D)	
+ control system interfaced with Tokamak	IO		

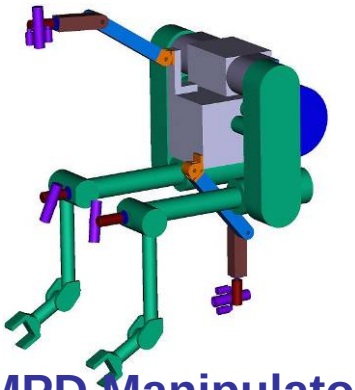
MPD System

MPD Transporter

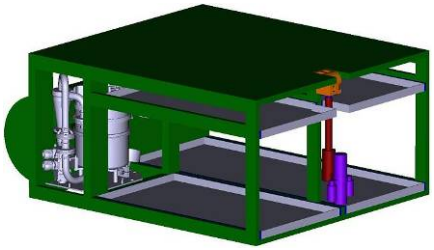


Transfer Cask System



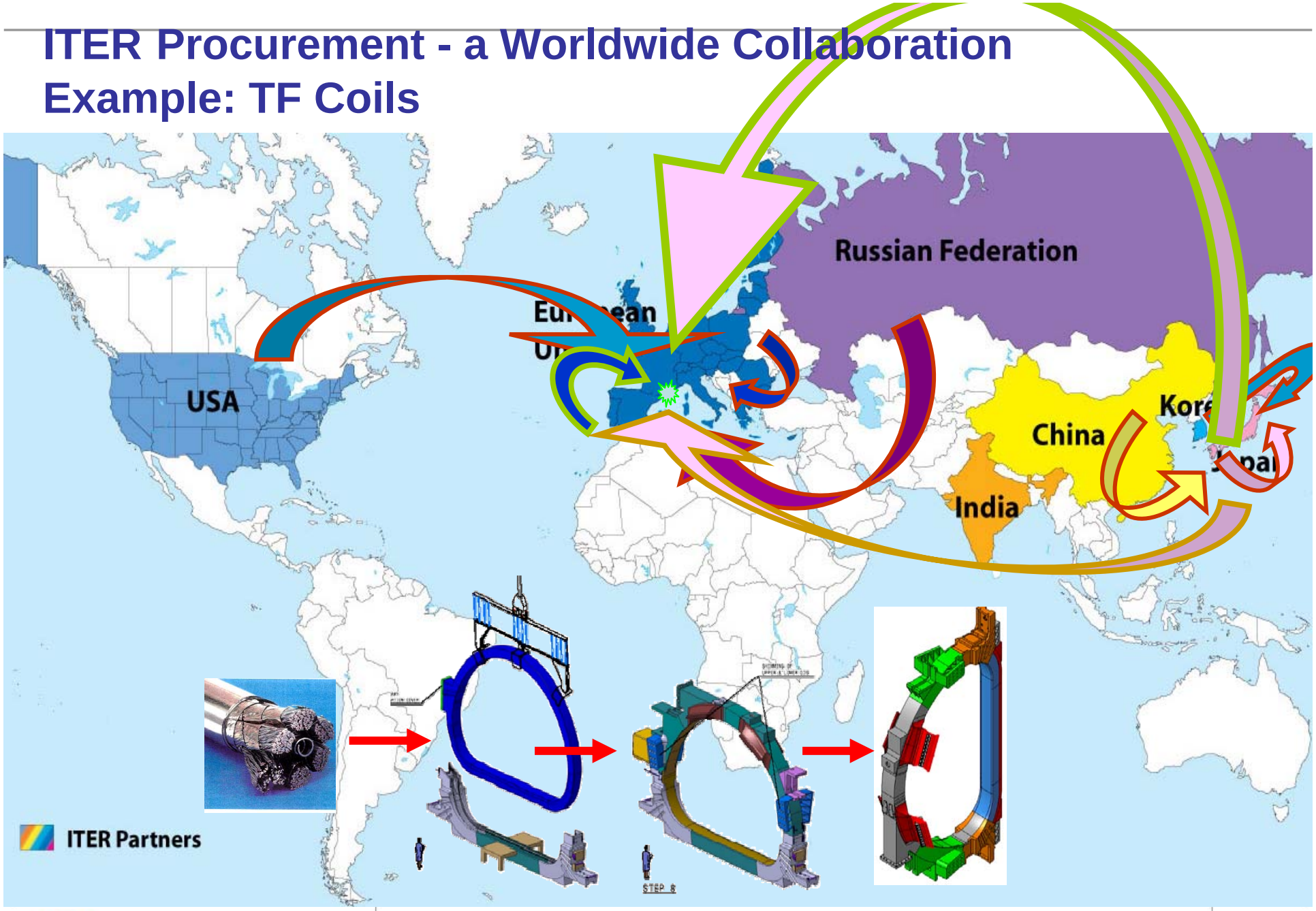


MPD Manipulator

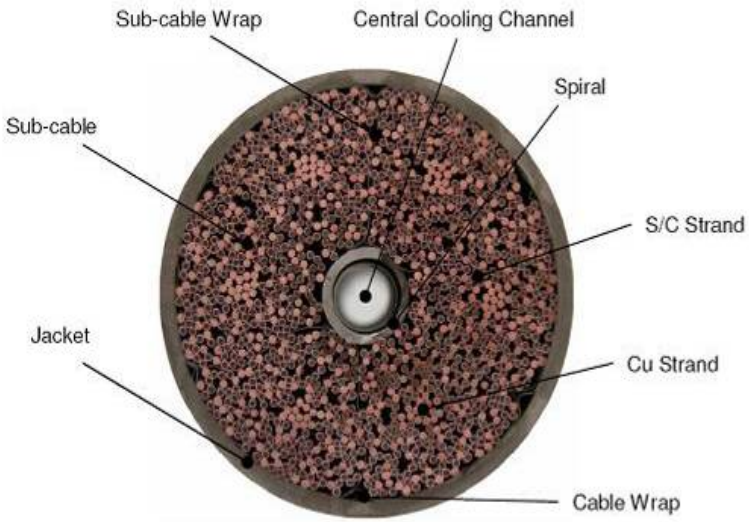


Task Module

ITER Procurement - a Worldwide Collaboration
Example: TF Coils



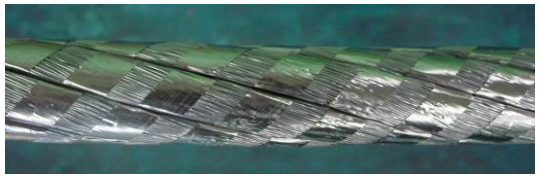
ITER Conductors



X-section of 70kA ITER TF Conductor (CEA)

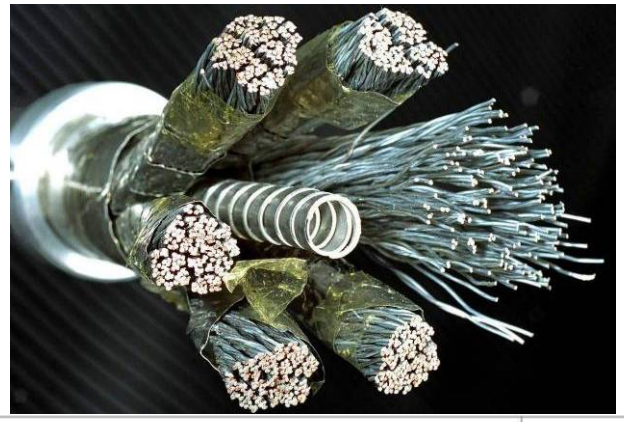
- ITER coils are wound from Cable-In-Conduit Conductors (CICC's), relying on superconducting multifilament composite strands mixed with pure Cu strands/cores.
- The strands are assembled in a multistage rope-type cable around an open central cooling spiral.
- The cable and its spiral are inserted inside a stainless steel conduit which provides helium confinement.

Cooling Spiral

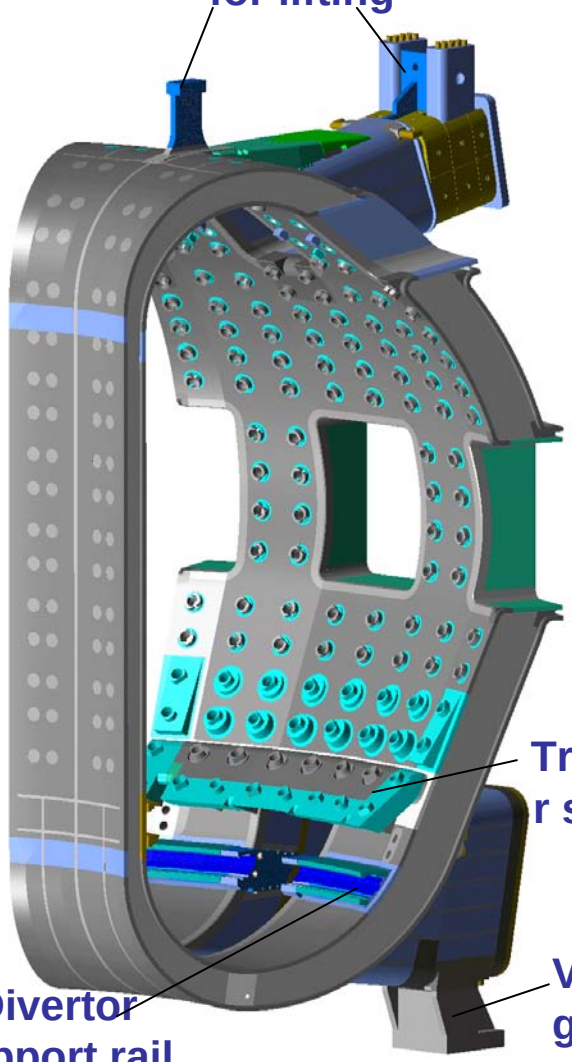


Final-Stage Cable (NFRI)

Stainless Steel Conduit (ASIPP)



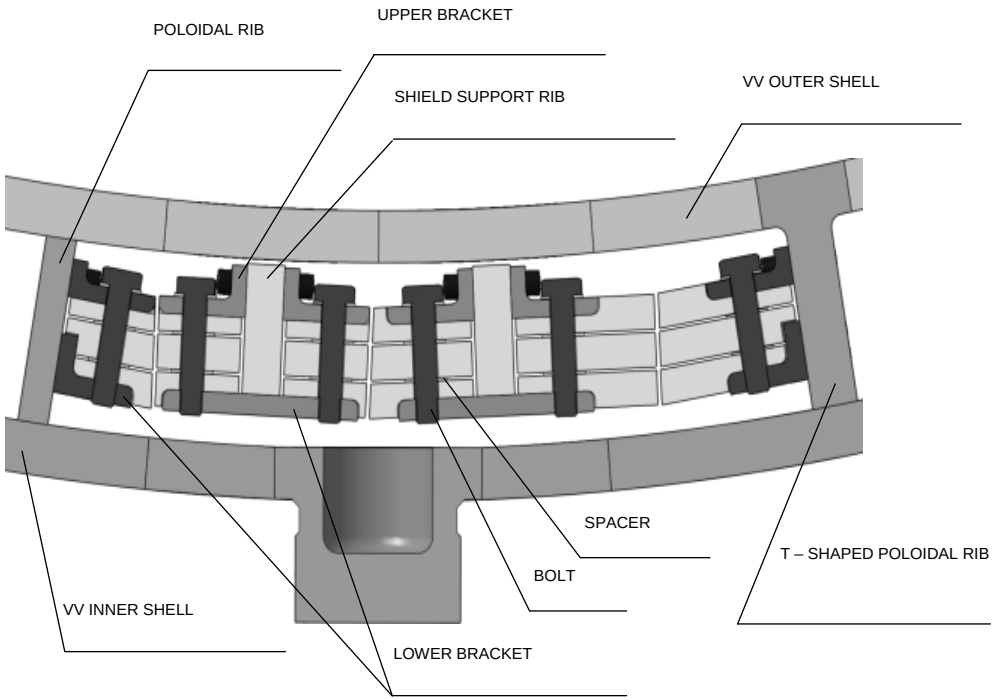
Main Parameters of the VV

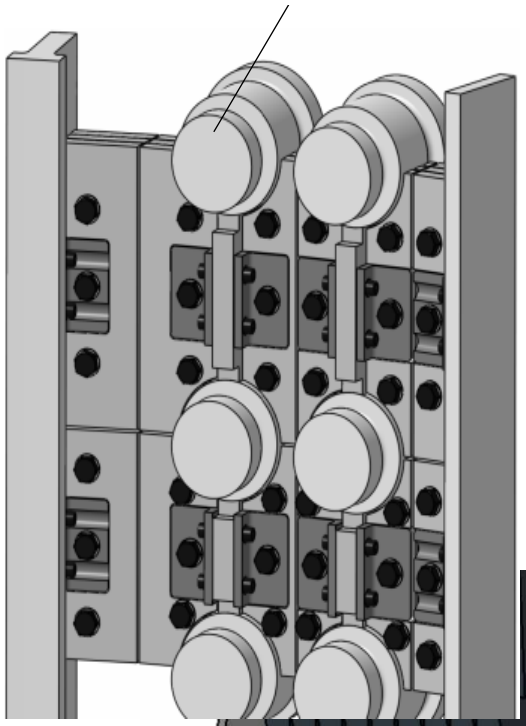


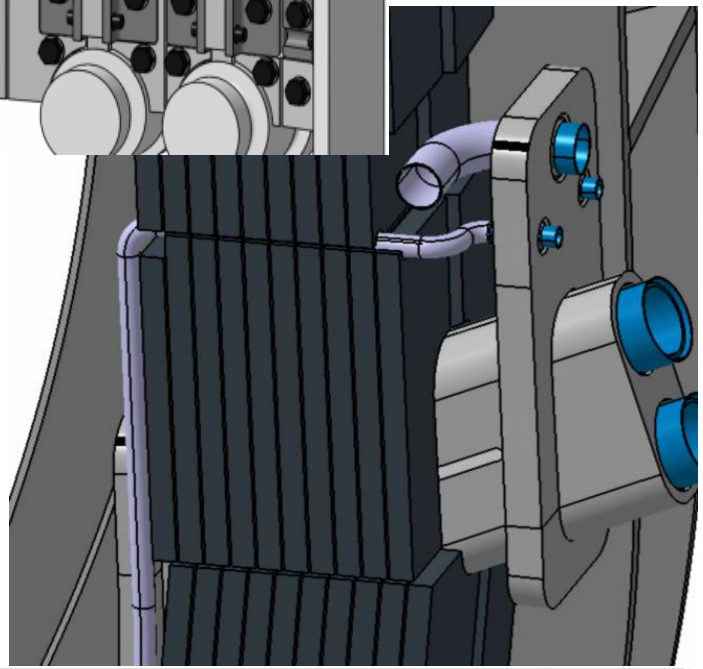
Surface temperature in operation	< 110 °C
Resistance - Toroidal - Poloidal	 7.9 μΩ 4.1 μΩ
Surface area / volume - Interior surface area - Interior volume excluding in-vessel components including in-vessel components	 ~850 m^2 ~1090 m^3 ~1600 m^3
Mass of the assembled vessel	5124 t
Main materials - Main vessel and port structures, double wall port components - Primary in-wall shielding (1) (2) - Ferromagnetic insert shielding - Single wall port components and connecting ducts	 SS 316L(N)-IG SS 304B7(1), SS 304B4(2) SS 430 SS 304
Allowable leak rate	10^{-7} Pa m^3s^{-1}

Note: (1) Inboard: Containing ~2 weight % boron
(2) Outboard: Containing ~1 weight % boron

Design of IWS (In-wall Shielding)







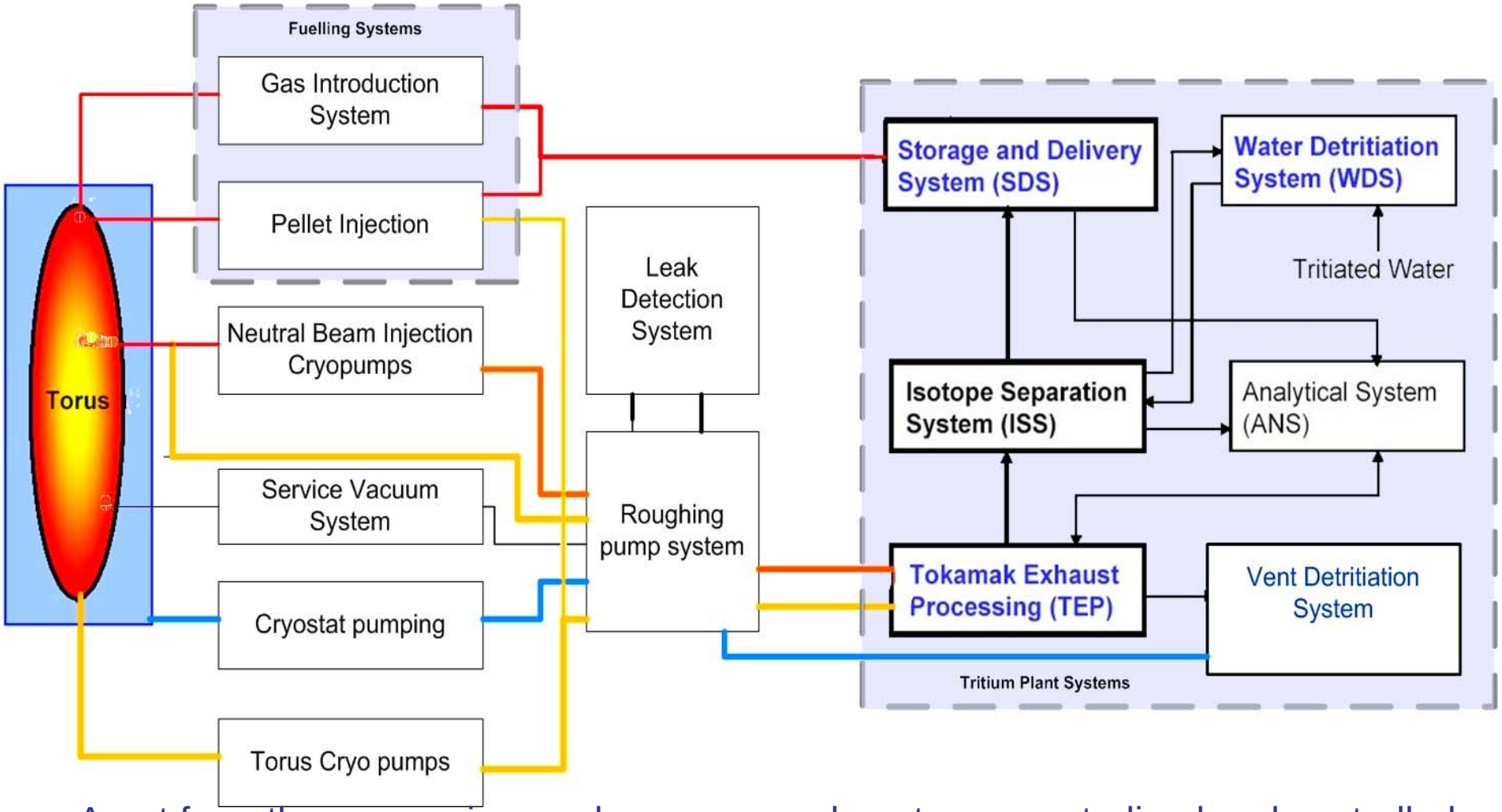
Design and Analysis on In-wall shielding (IWS)

Borated shielding plates are mounted inside the VV double wall structure

On the outer wall in special areas Ferro-magnetic plates are used for ripple reduction

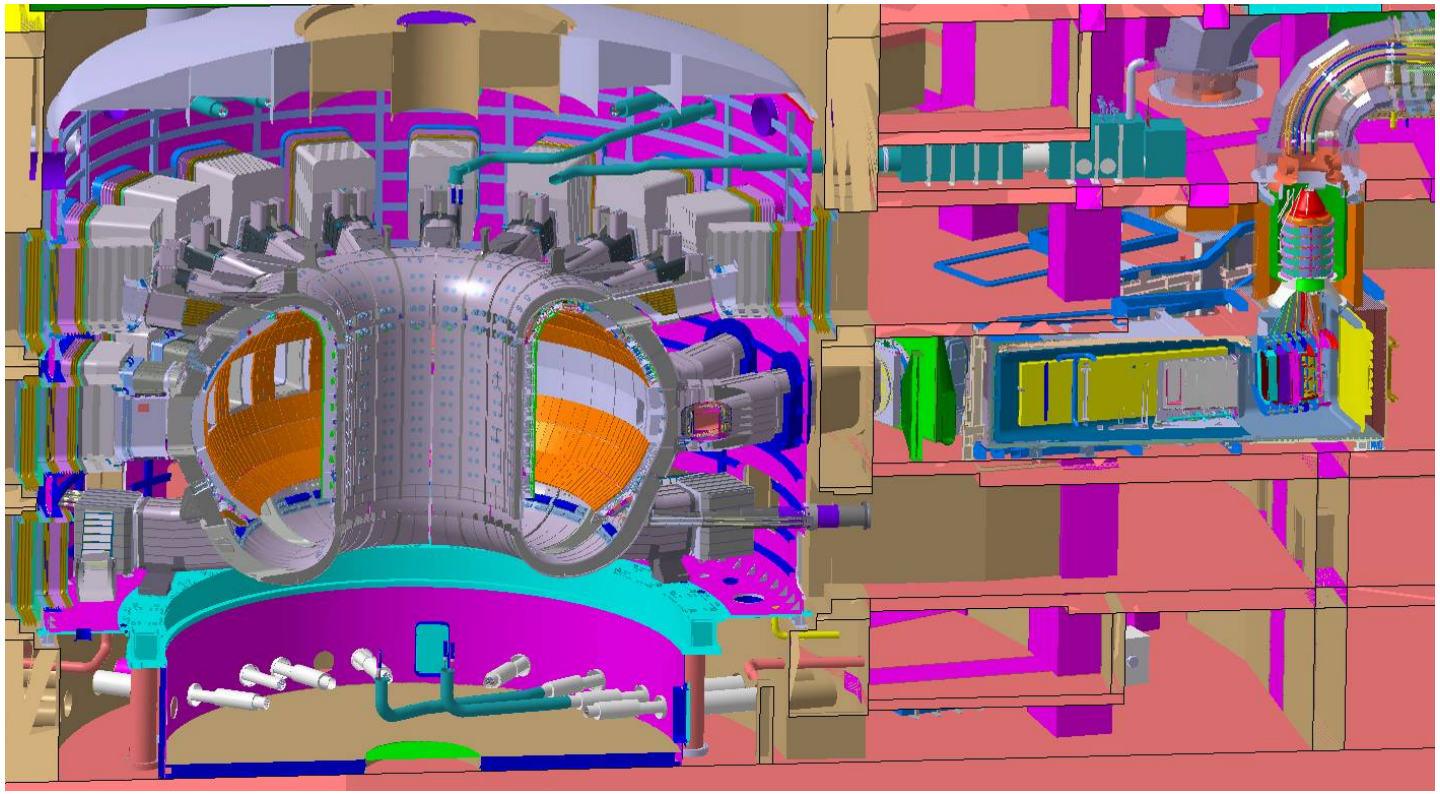
ITER Fuel Cycle

T-Plant handles all exhaust gases – release limits !!



Apart from the cryogenic guard vacuum – exhausts are centralized and controlled

ITER Vacuum Systems



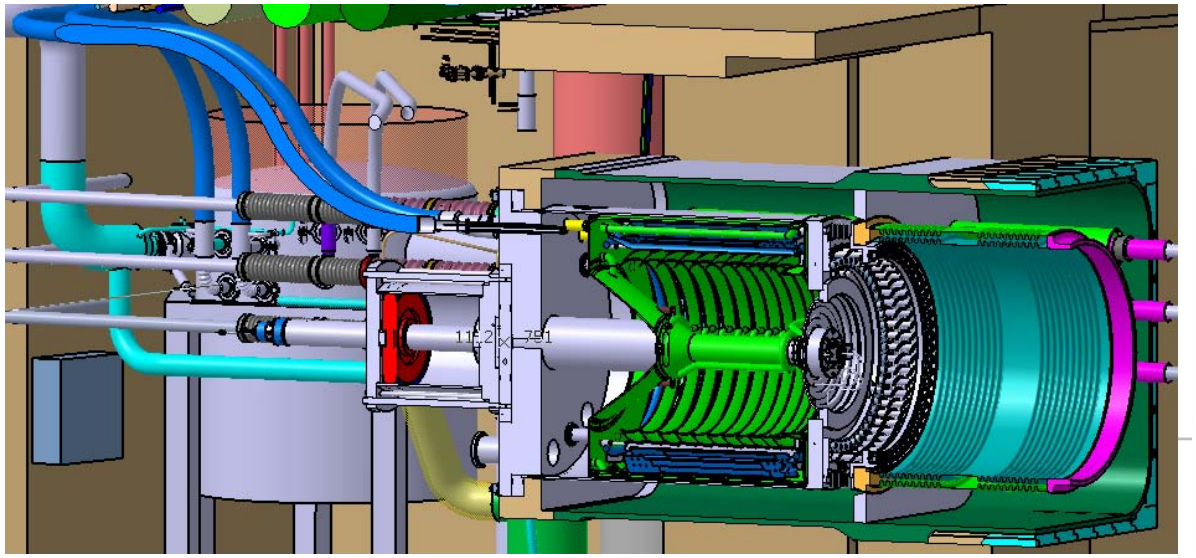
Cryostat vacuum(<10-4 Pa) 8500 m3

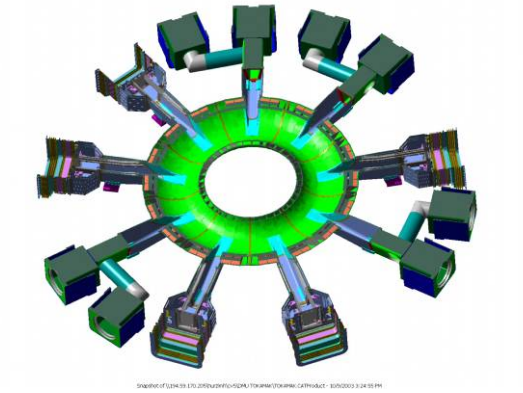
Torus vacuum(~10-6 Pa) 1400 m3

Neutral Beam vacuums(~10-7 Pa) 630 m3 (for 4)

Cryogenic Guard Vacuum

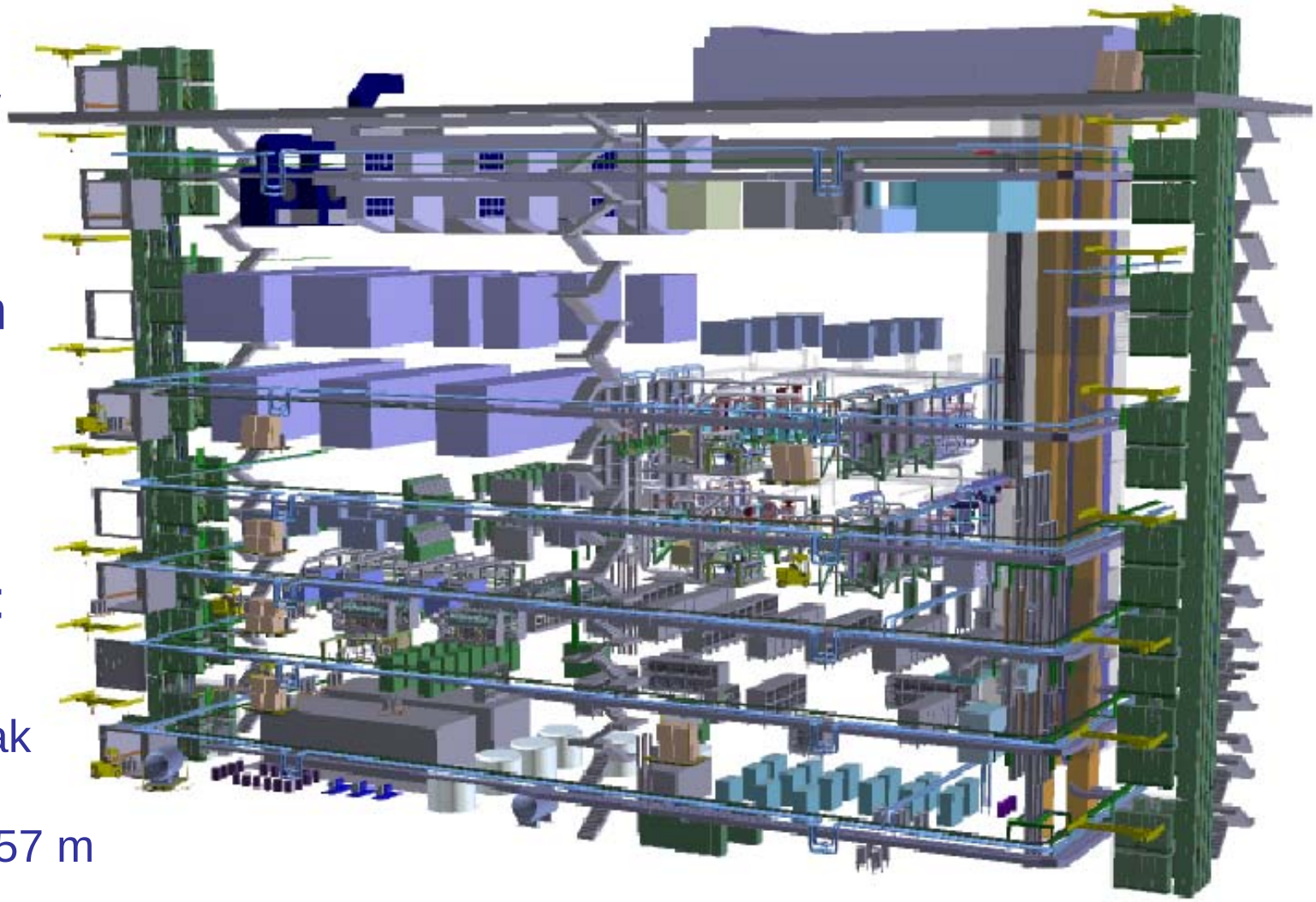
Service Vacuum System (Inc diagnostics)
ICRH and ECRH Vacuums





Tritium Plant Building Systems Layout

- 7 Floors
  - 2 below grade
- L = 80 m
- W = 25 m
- H = 35 m
- Release point elevation: 60 m
  - Tokamak building height: 57 m

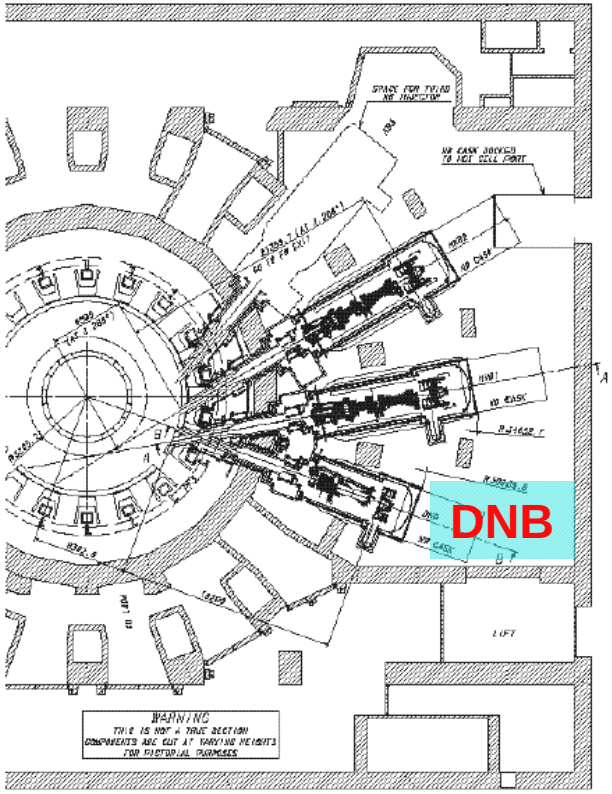


ITER Heating and Current Drive

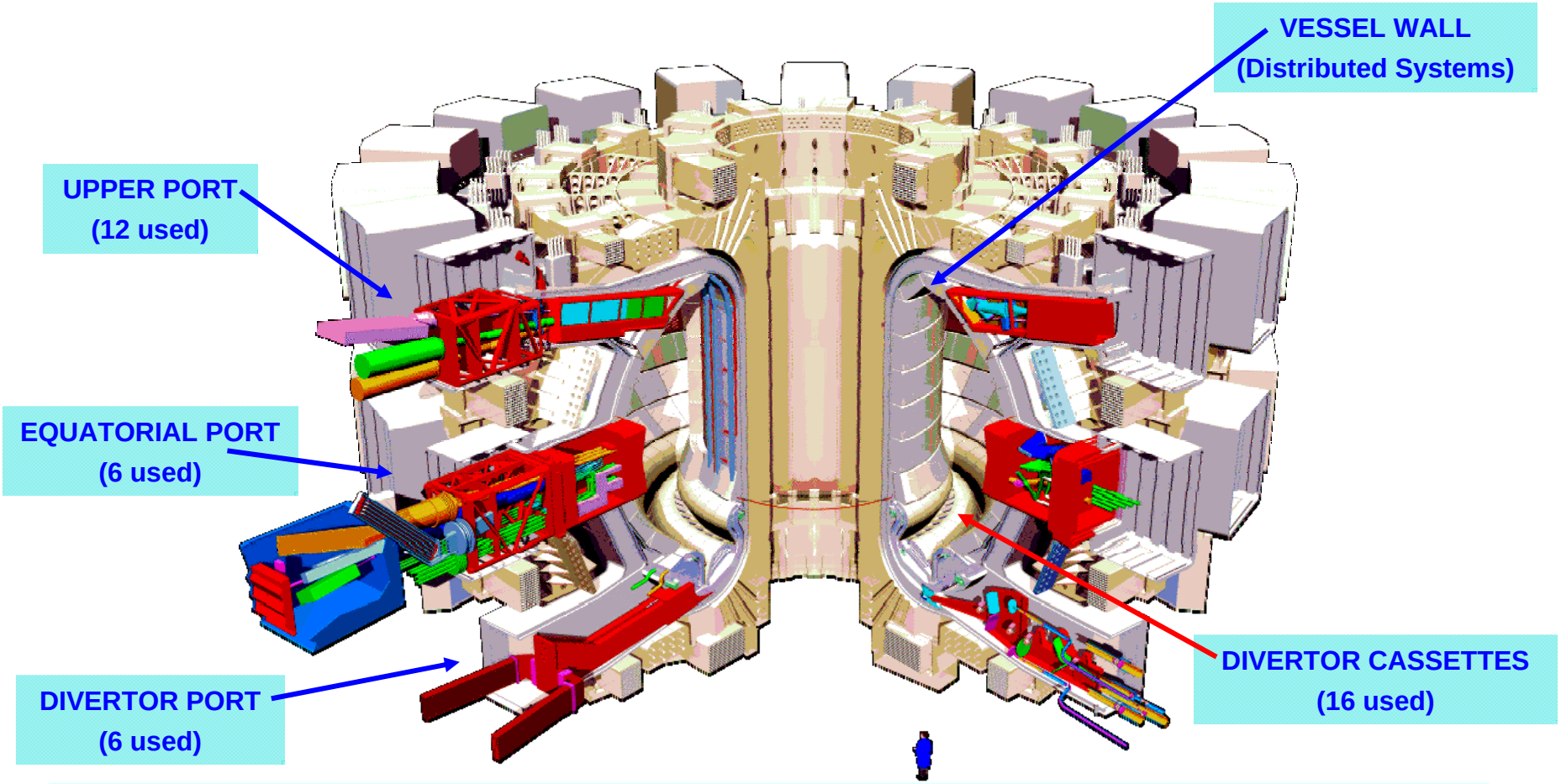
P_{aux} for Q=10 nominal scenario: 40-50MW

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		

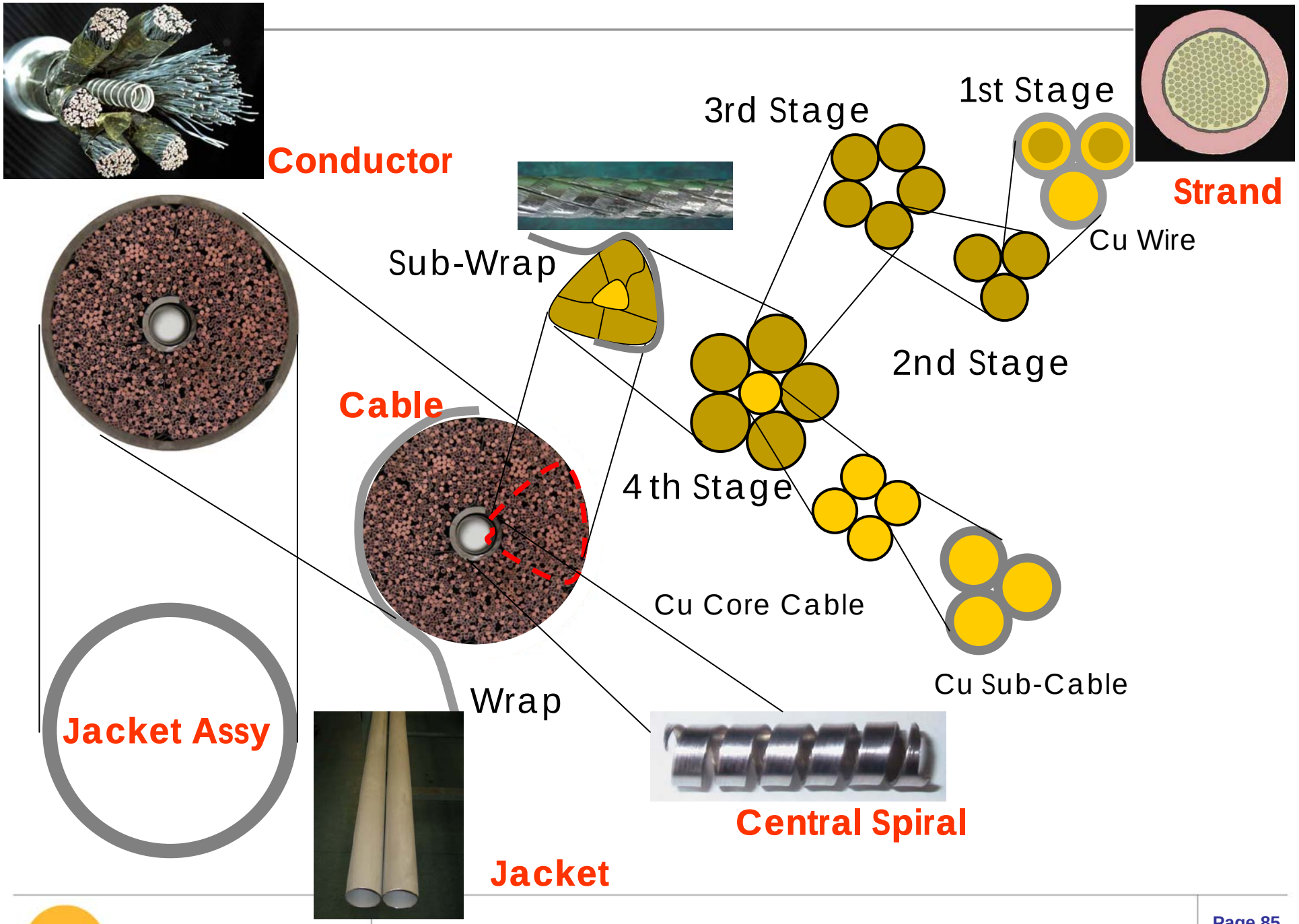
NBI Layout



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 ….)


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