Association
Euratom-CEA

3rd Karlsruhe International School on Fusion Technologies
August 31-September 11, 2009

JT-60SA

ITER Satellite Tokamak Program of JA-EU

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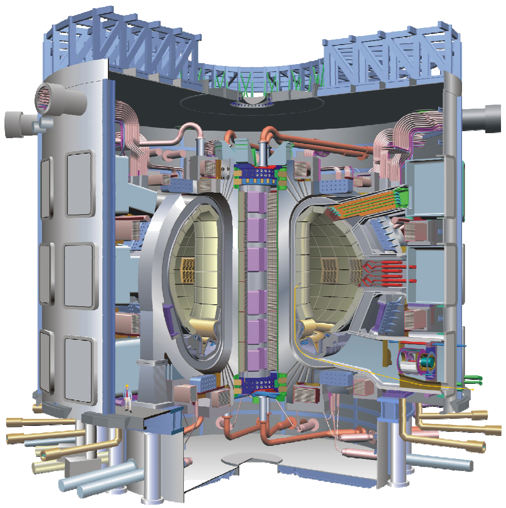
Plan

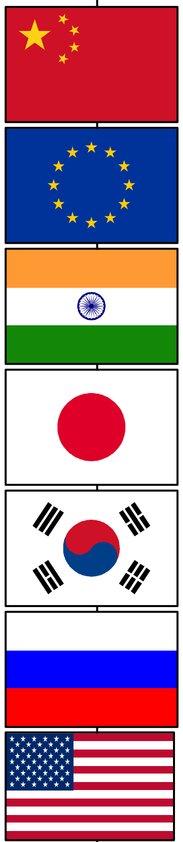
- The “Broader Approach” agreement
- Missions of JT60-SA
- Engineering design of JT60-SA
- Assembly and schedule
- Summary

The "Broader Approach" agreement

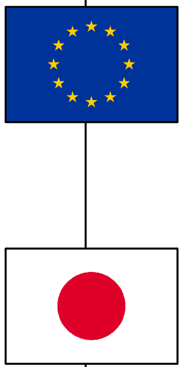
The “Broader Approach”

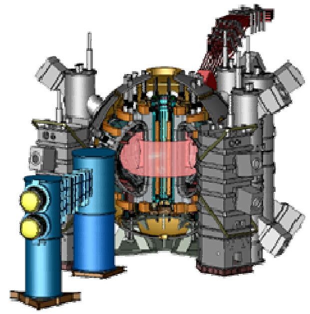
ITER





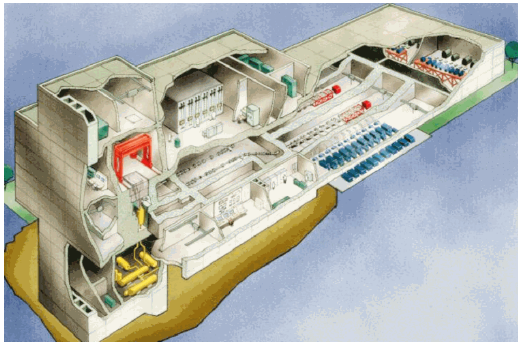
B.A.





JT-60SA

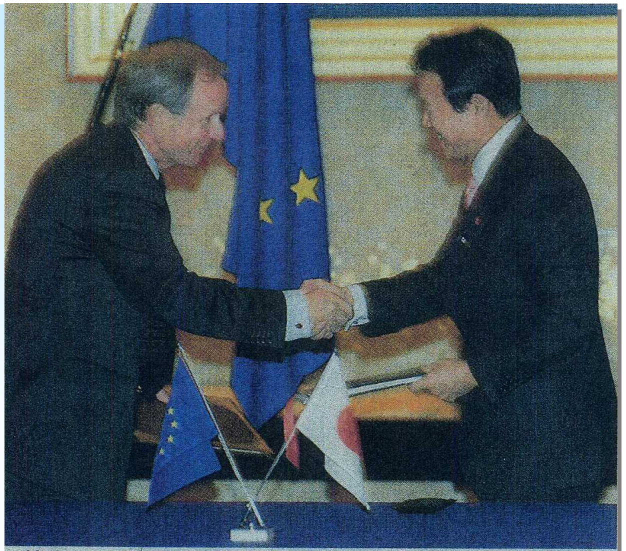
IFERC



IFMIF-EVEDA

The “Broader Approach”

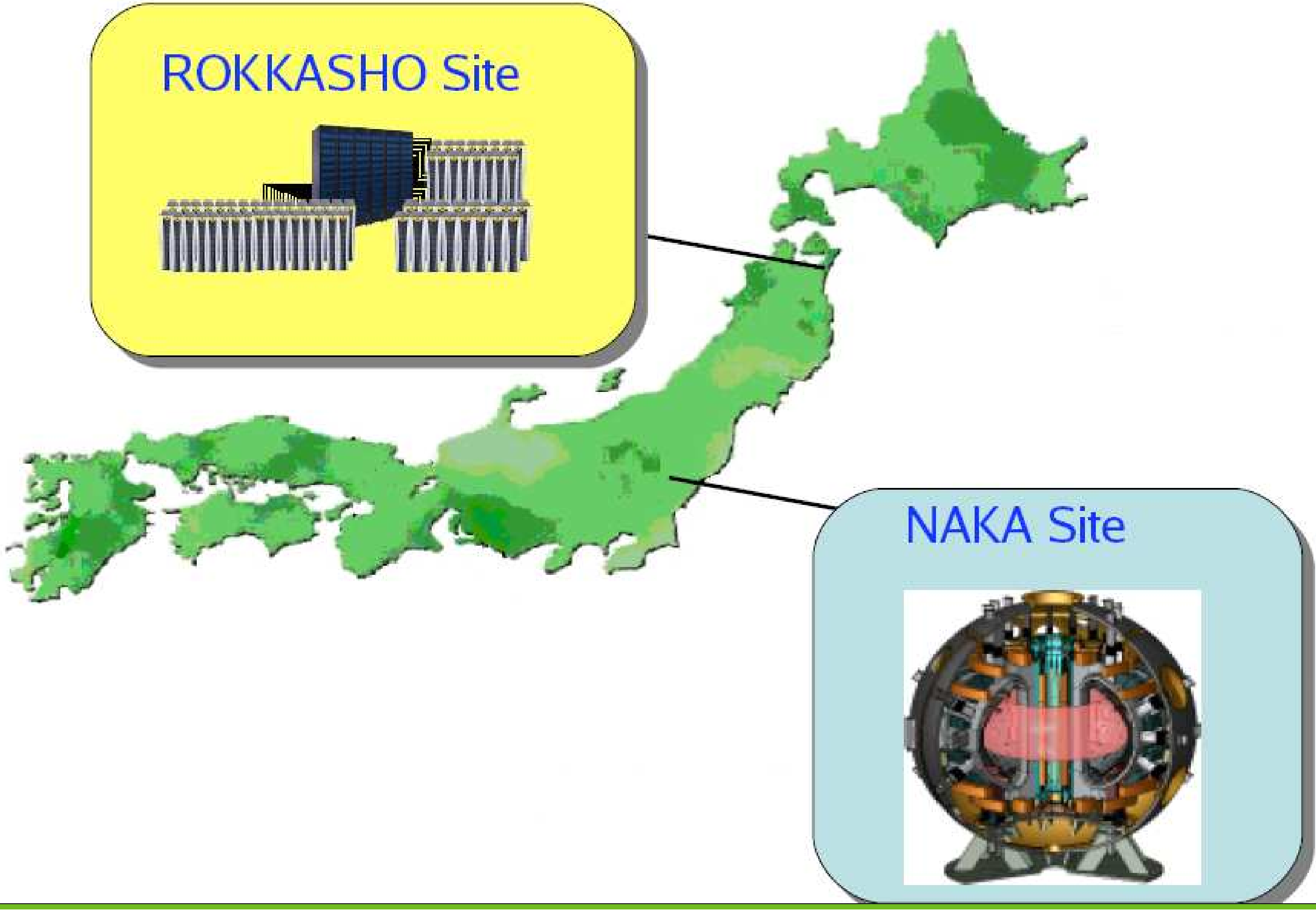
- **Signed in Tokyo on 5 Feb. 2007**
  - JT-60SA (Naka)
  - IFERC (Rokkasho)
  - IFMIF (Rokkasho)



協定への署名後、握手する麻生外相㊨とリチャードソン駐日欧州委員会代表部大使＝東京・麻布台の外務省飯倉公館

- **In kind procurements**
  - Balanced contribution on voluntary basis of Japan and 4 Member States (France, Italy, Germany and Spain), plus Switzerland
  - Pre-allocated sharing of contributions between partners
- **Project governance**
  - Supervision of the Agreement by a “Steering Committee”
  - Each project has a “Project Committee”
  - Domestic Agencies created for ITER ensure the legal implementation

Site location of the “Broader Approach” activities



Contributions to the “Broader Approach”

Projet	EU (%)	JA (%)	Total (%)
IFMIF-EVEDA	14.4	7.6	22.0
IFERC	12.0	18.7	30.7
Satellite Tokamak (JT-60 SA)	23.6	23.6	47.3
Total (%)	50.0	50.0	100.0

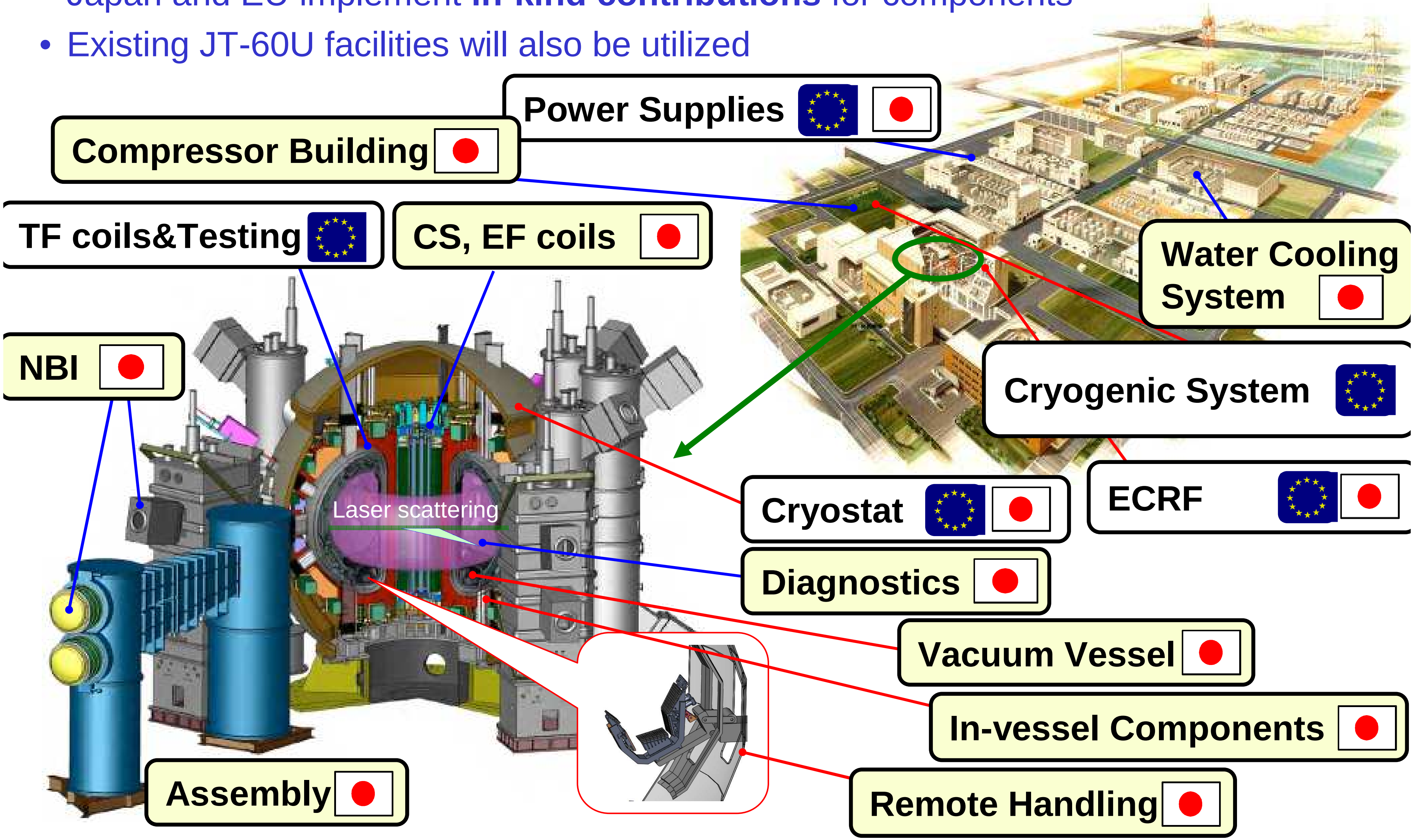
Contribution (value May 2005) of Europe : 339 M€
of Japan : 46 G¥

Mostly in kind

S. Matsuda, 21th IAEA, Oct. 2006, Chengdu, China

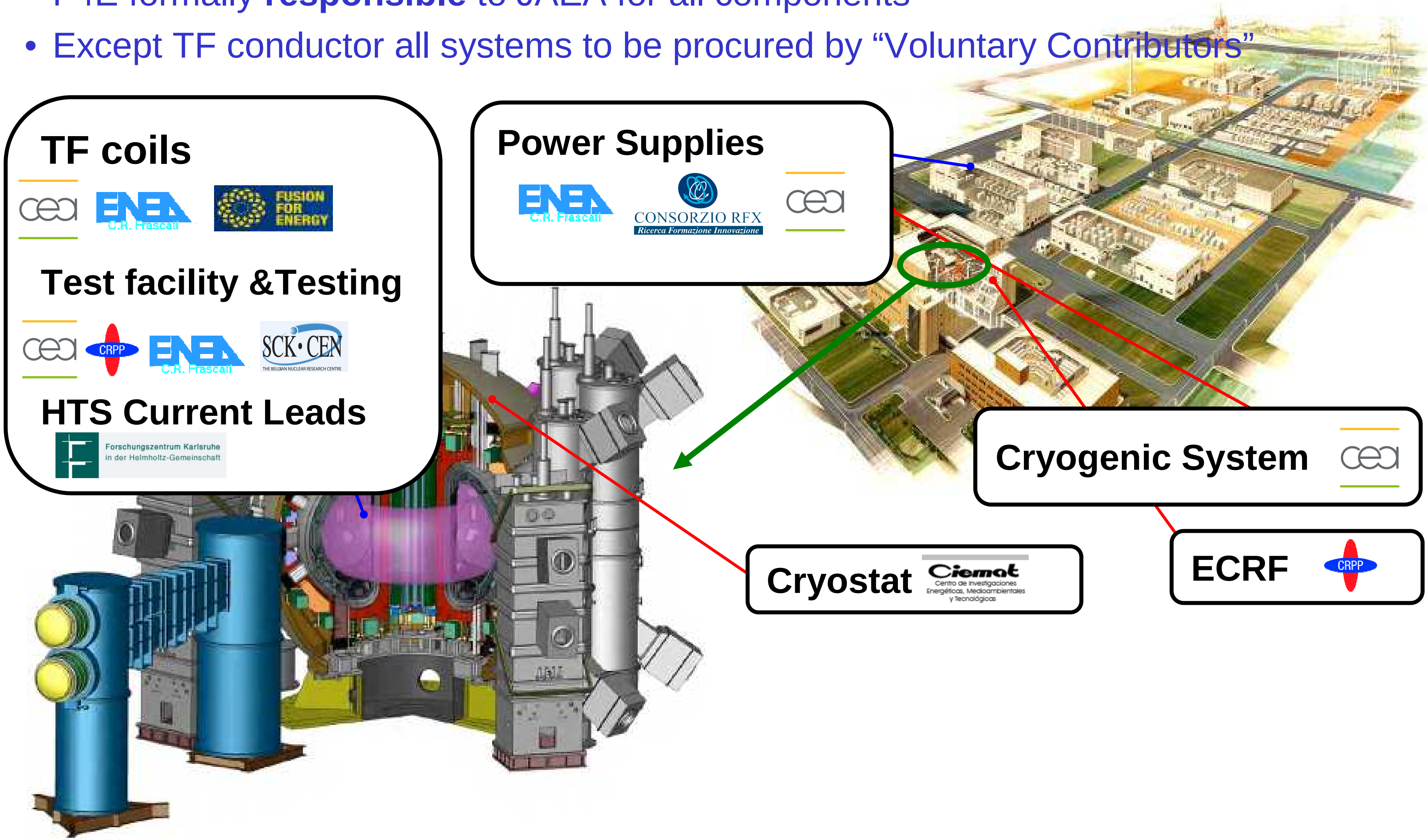
JT-60SA EU-JA Sharing

- Japan and EU implement **in-kind contributions** for components
- Existing JT-60U facilities will also be utilized



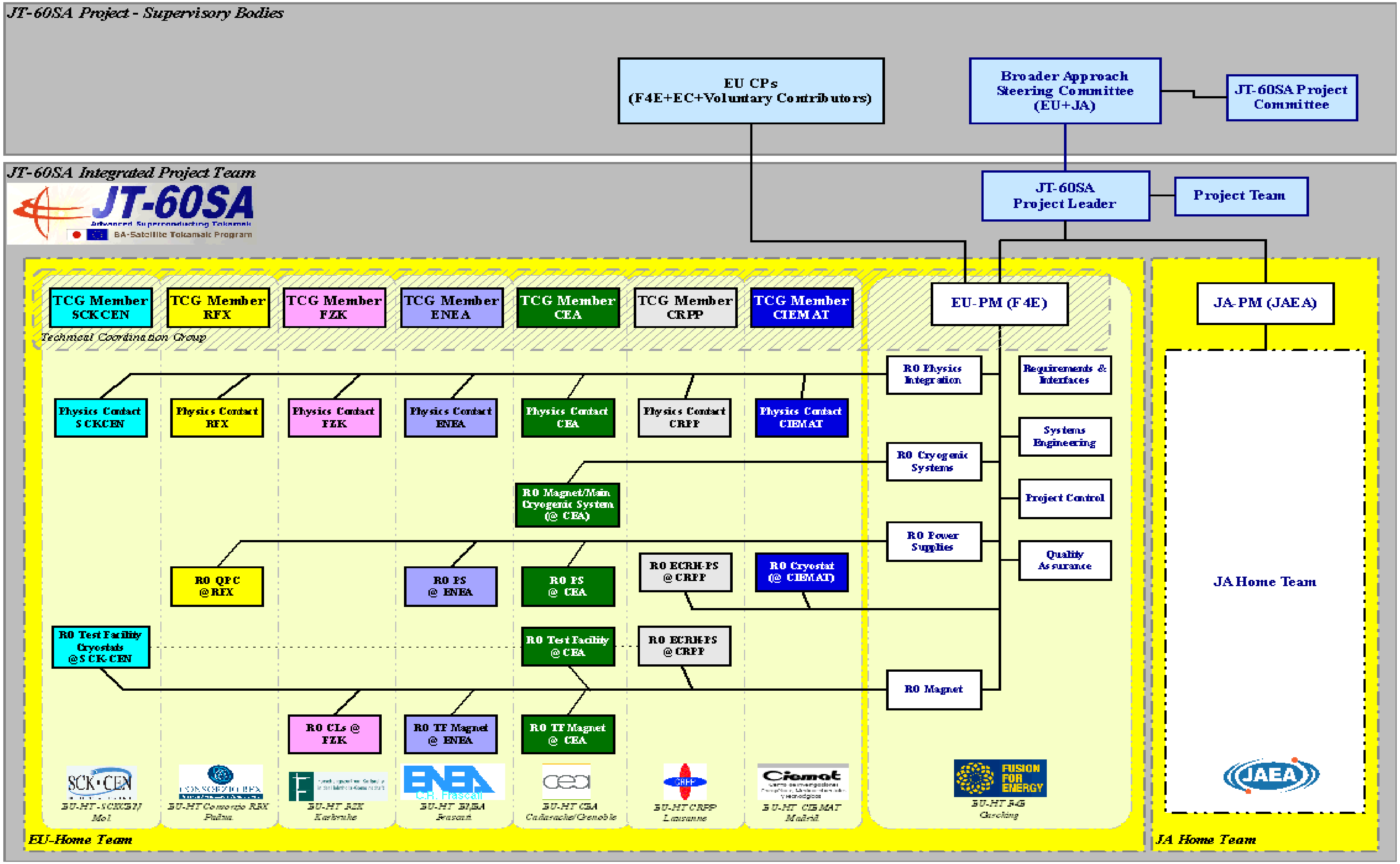
JT-60SA sharing within EU

- F4E formally **responsible** to JAEA for all components
- Except TF conductor all systems to be procured by “Voluntary Contributors”

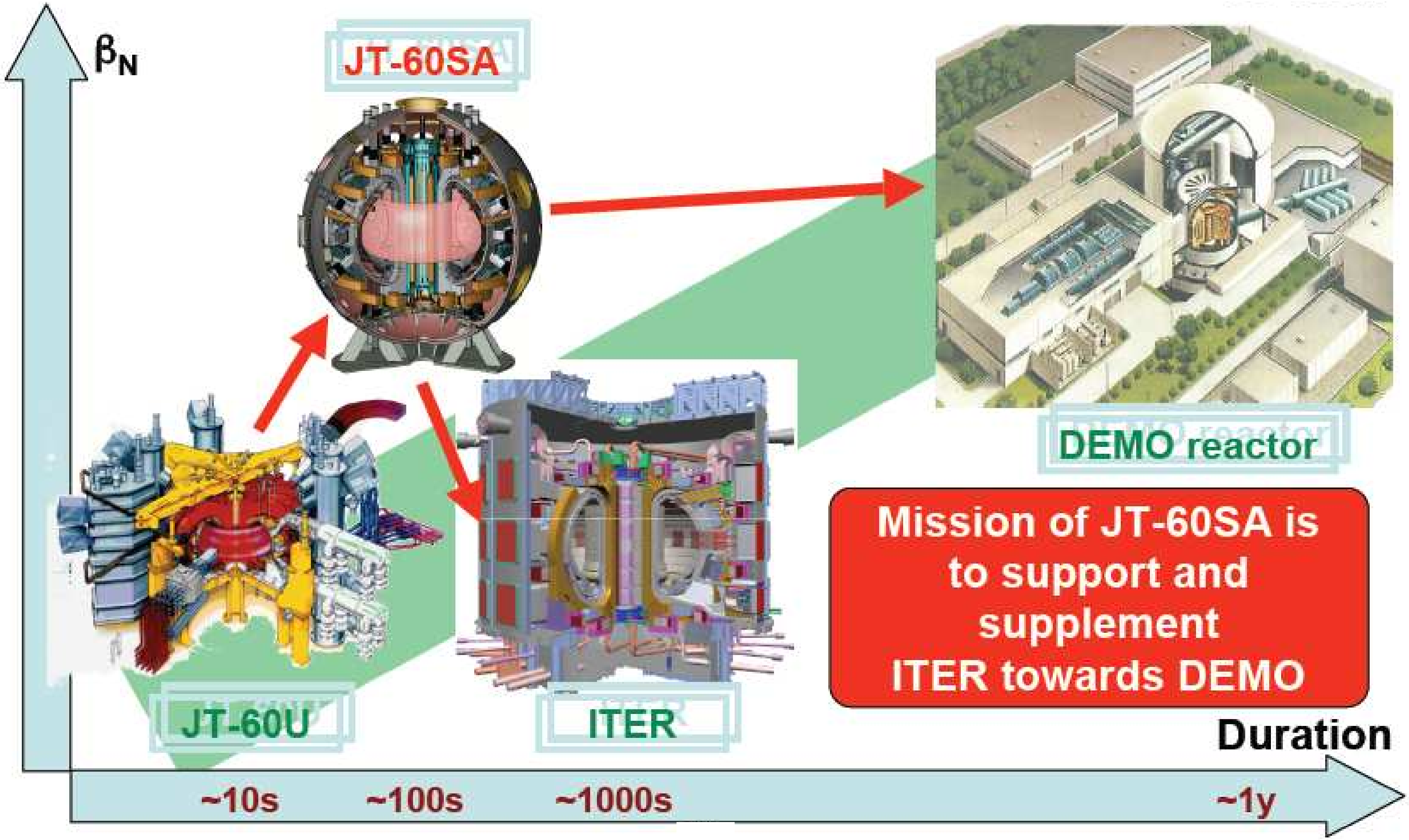


P. Barabaschi, Seminar, 2009, Cadarache, France

Organization



Missions of JT-60SA



S. Ide, 5th TM on SSO, May 2007, Daejeon, Korea

Missions of JT60-SA

Support to ITER

- Optimize ITER-relevant plasma scenarios and test new operating scenarios
- Test and optimize auxiliary systems which may find an application on ITER
- Advance the understanding of the ITER-relevant physics issues
- Test possible improvements and modifications of components and systems before their implementation on ITER
- Train, in an international environment, scientists, engineers and technicians

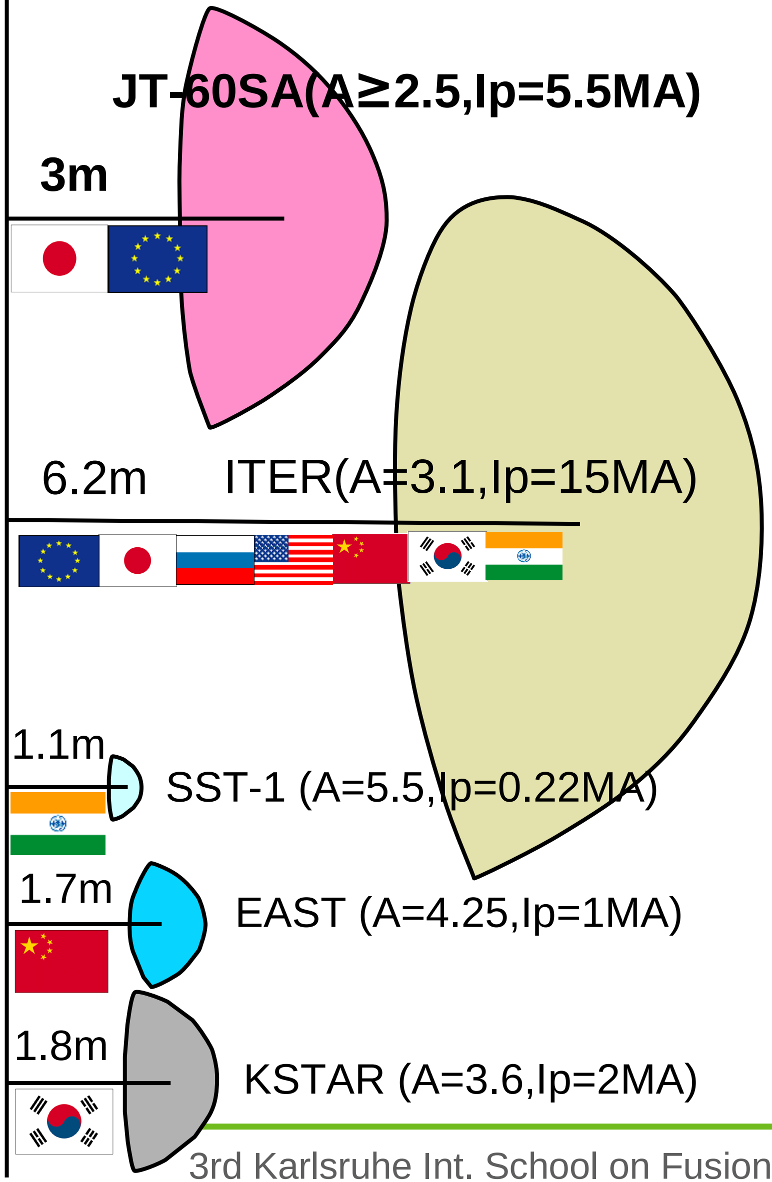
Complement ITER towards DEMO

- Demonstrate **steady state operation at high β_N (≥4.5) for 100s and more**
- Explore role of shaping and active stabilization on stability (RWM, NTM)
- Optimize non-inductive current drive for DEMO scenario
- Control of power fluxes to the walls in steady state operation regimes

Assessment of JT60-SA CDR, March 2007

Main parameters

Fully superconducting tokamaks



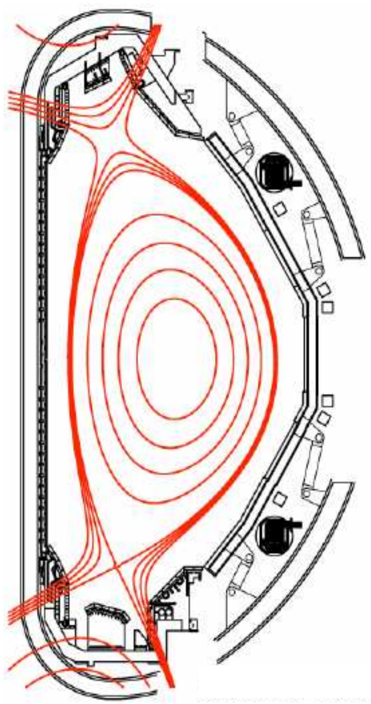
Parameter		JET
Plasma Current Ip (MA)	5.5	4
Toroidal Field Bt (T)	2.26	3.4
Major Radius (m)	2.95	3
Minor Radius (m)	1.18	0.9
Elongation, k95	1.94	1.7
Triangularity, d95	0.45	0.45
Aspect Ratio, A	2.50	3.3
Safety Factor q95	3	3
Plasma Volume (m^3)	~140	~80
Flattop Duration	**100 s** (8 hours)	
Heating & CD power	41 MW x 100 s	
NBI	34 MW	
ECRH	7 MW	
PFC wall load	15 MW/m^2	
Neutron (year)	4 x 10^{21}	

New IDR 2008

Support to ITER

ITER similar configuration

A=3.1, κ_{95}=1.7, δ_{95}=0.33, q_{95}=3.0

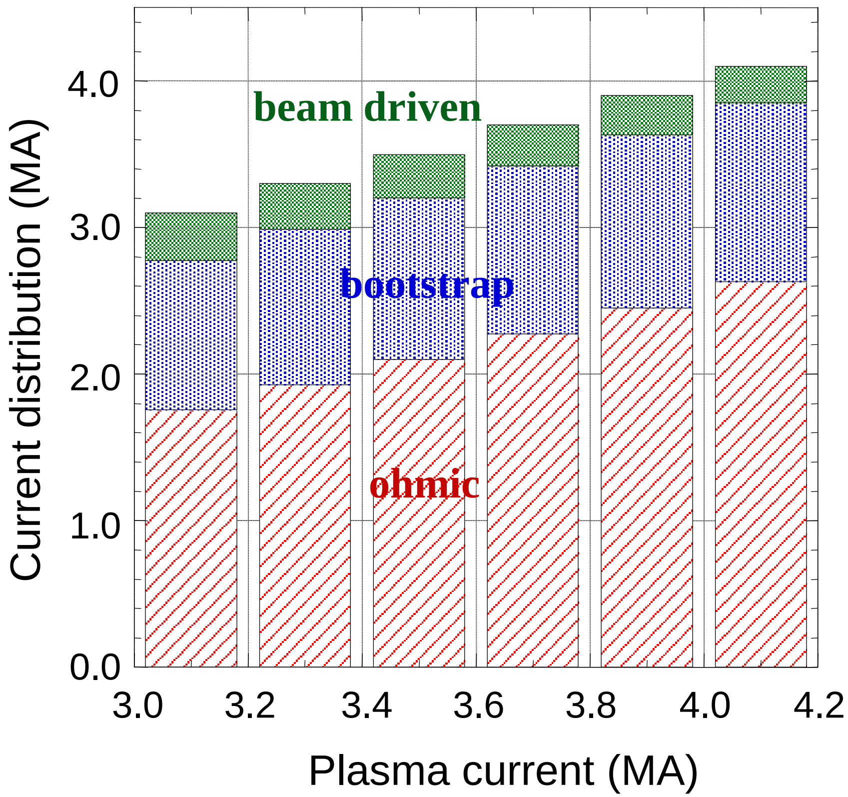


2007 design

	ITER	JT-60SA
I_p (MA)	15	3.5
B_T (T)	5.3	2.59
R (m)	6.2	3.16
a (m)	2.0	1.02
A	3.1	3.1
κ_{95}	1.7	1.7
δ_{95}	0.33	0.33
q_{95}	3.0	3.0
n_{GW} (m^{-3})	1.2×10^{20}	1.1×10^{20}

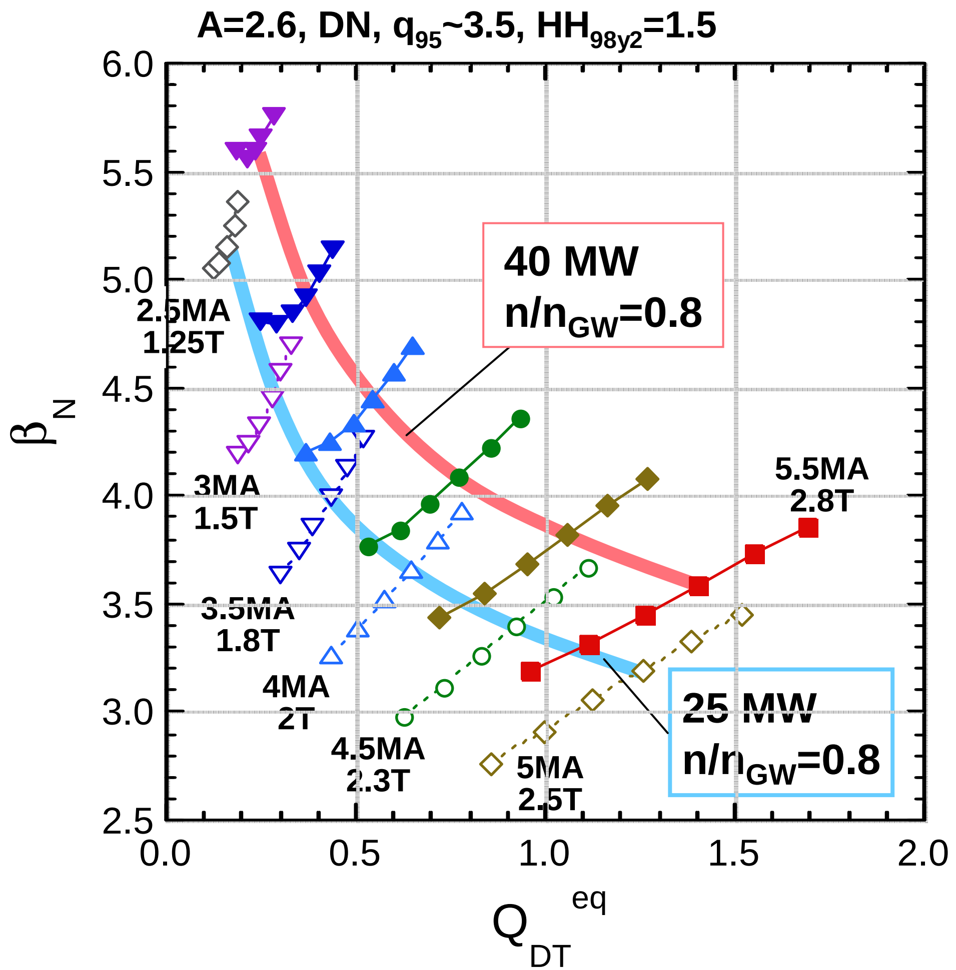
ACCOME-code analysis

f_{GW}=0.85, HH_{y2}=1.3, q_{95}=3.1, P_{in}=41MW



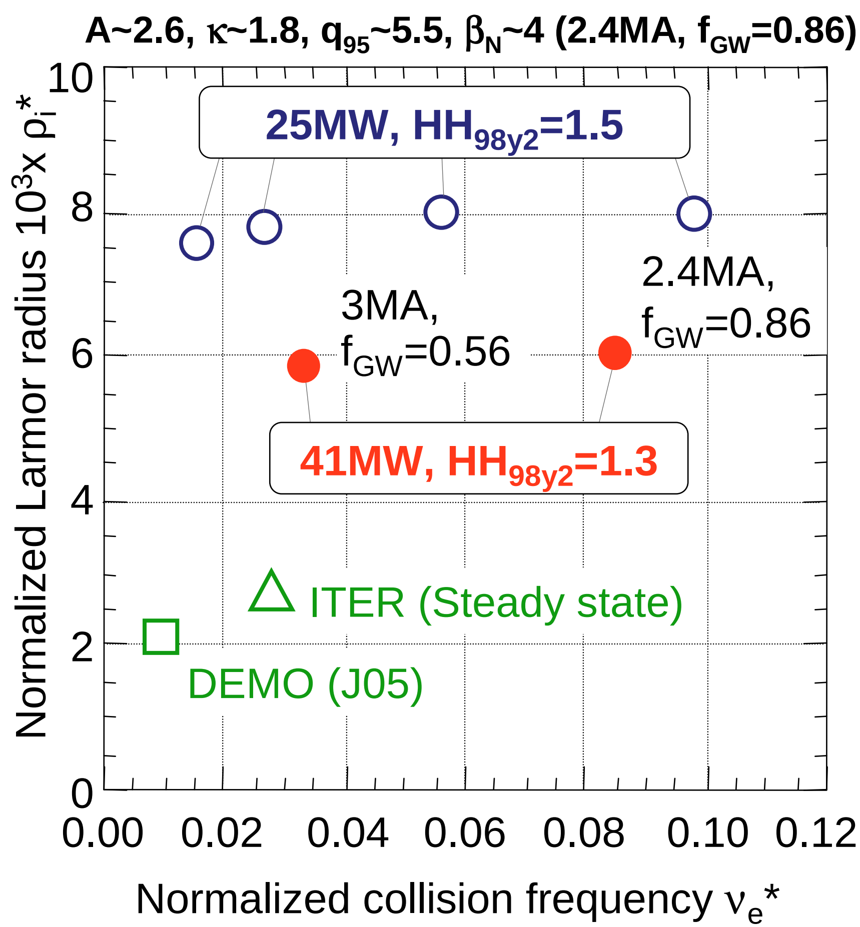
Hybrid operation up to 3.7MA for 100s available

Breakeven and high-β plasma



Accessibility for high Q_{DT} and high β_N with increased heating power

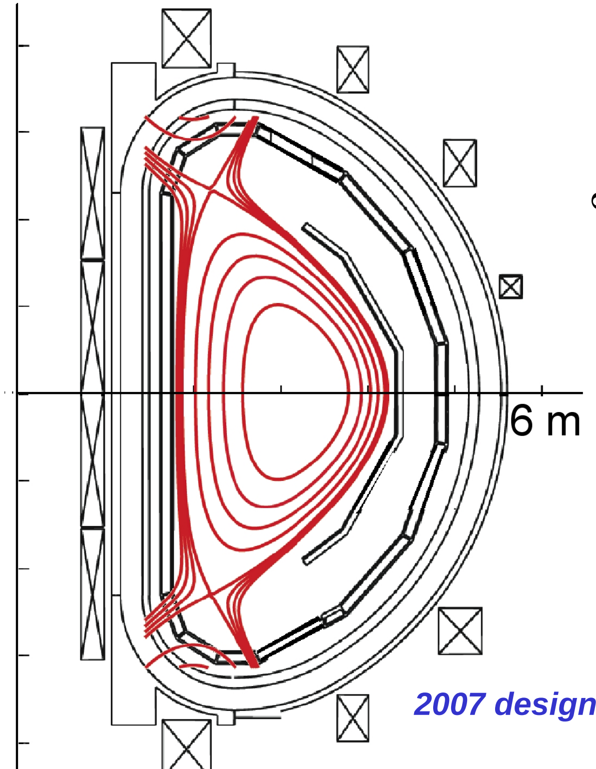
Non-dimensional parameters with ITER and DEMO relevant region are expected

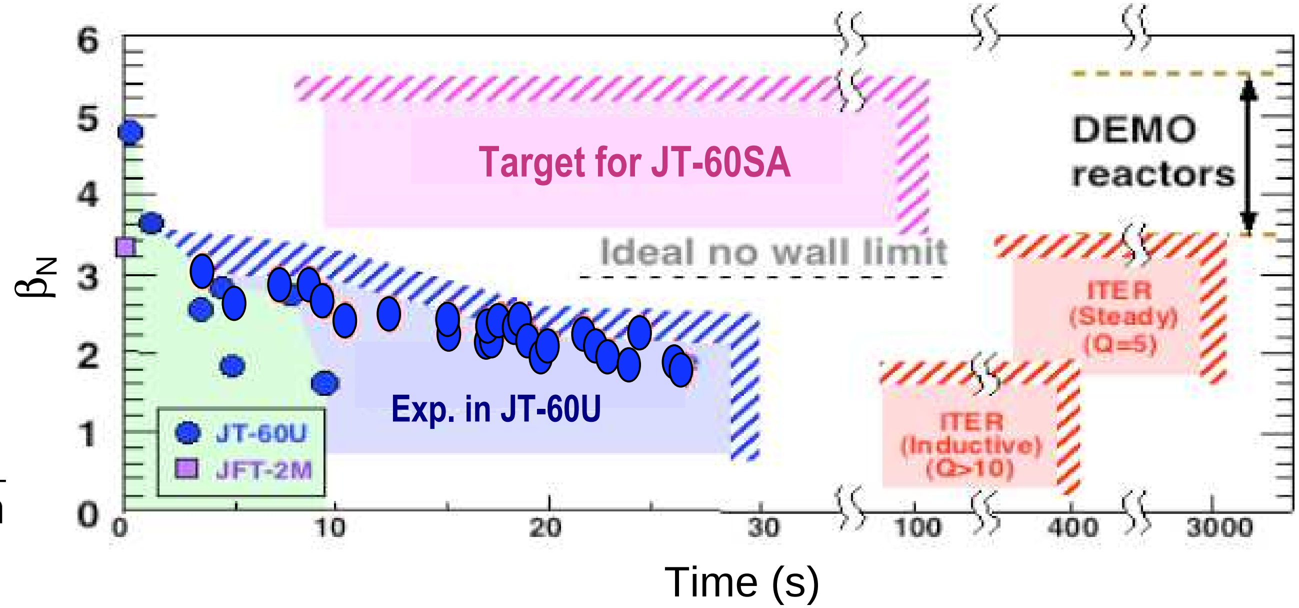


Preparation to DEMO

Sustain high beta (β_N=3.5-5.5) non-inductive CD plasma

- Explore high beta regime above no-wall limit
- Develop optimized integrated scenario for DEMO for shape, aspect ratio, SN/DN, current profile, MHD control, fuelling, pumping, divertor shape, …





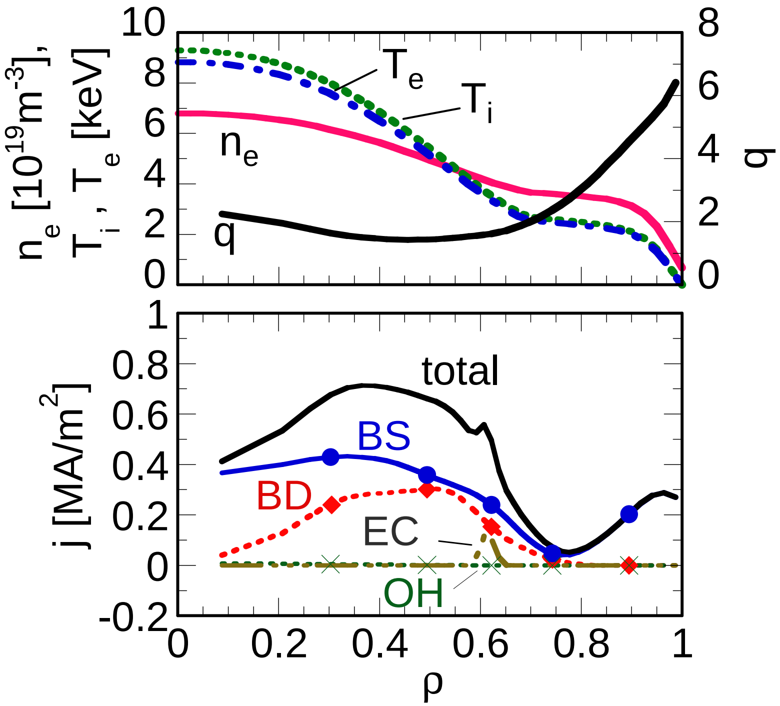
Test of Plasma Facing Component

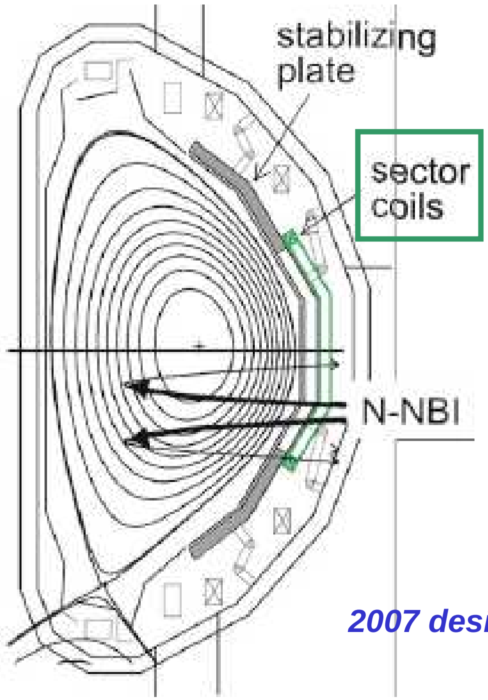
- Compatibility test of reduced activation ferritic steel
- Test candidate divertor modules
- Sample station for plasma-material research

high-κ, δ shape for high-beta operation

High-β full non-inductive CD scenario

- NNB shifted down by 0.6 m for off-axis CD to form a weak reversed shear q profile
- Normalized parameters are close to those required in DEMO
- For sustainment of high β_N, control of **Resistive Wall Mode** (RWM) is necessary as well as conducting shell (stabilizing plate)



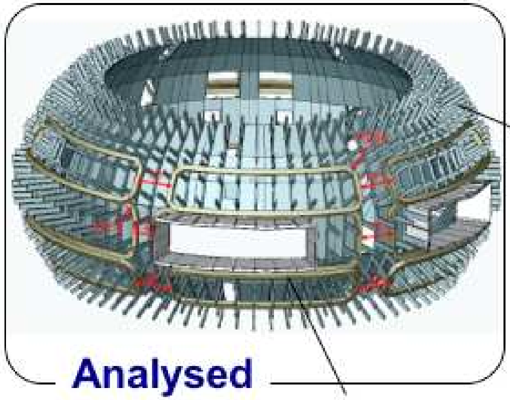


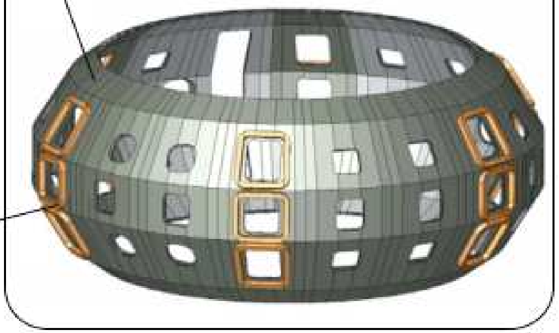
2007 design

- **2.4 MA full current drive is possible** with A = 2.65, β_N = 4.4, f_{GW} = 0.86, f_{BS} = 0.70 and H_{H98y2} = 1.3 with the total heating power of 41 MW

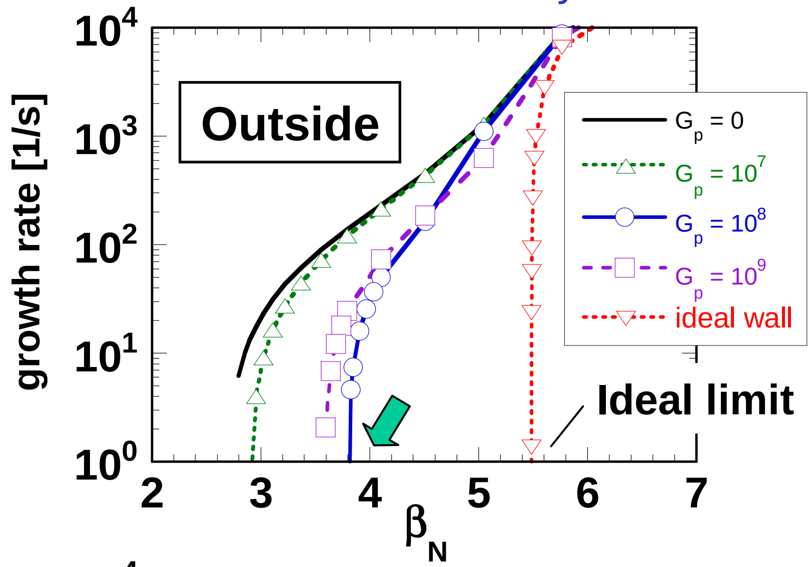
RWM stabilisation by feedback control of sector coils

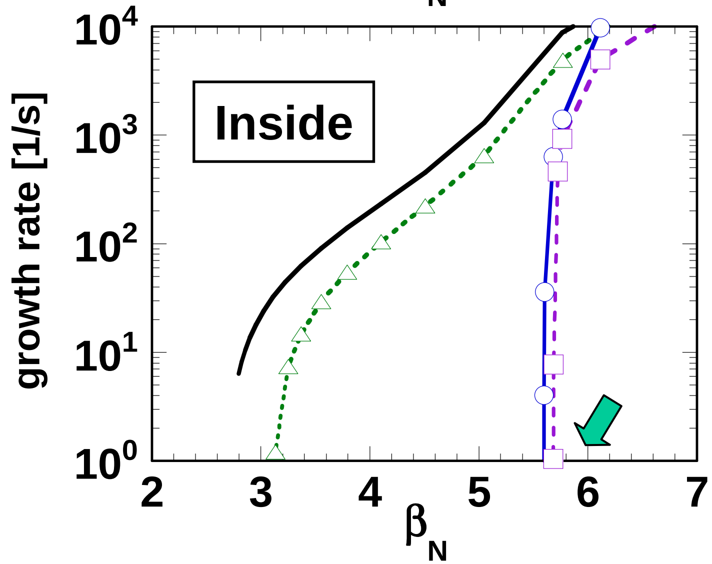
- Achievable β_N depends very much on the location of sector coil
  - outside stabilizing plates: β_N~3.8
  - inside stabilizing plates: β_N~5.6
- Sector coils are located on the port entrance in the present design (analysis ongoing)





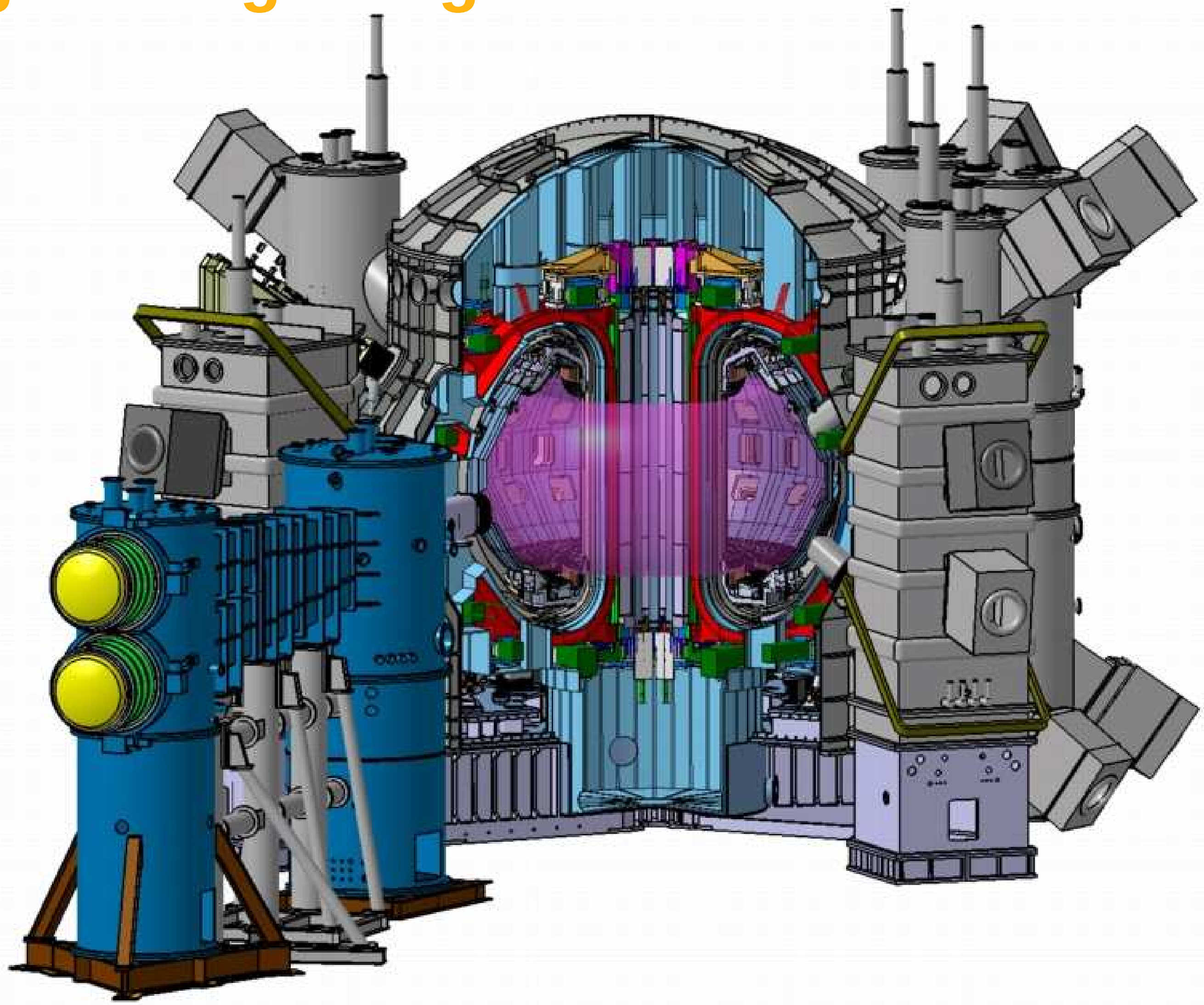
VALEN code analysis*



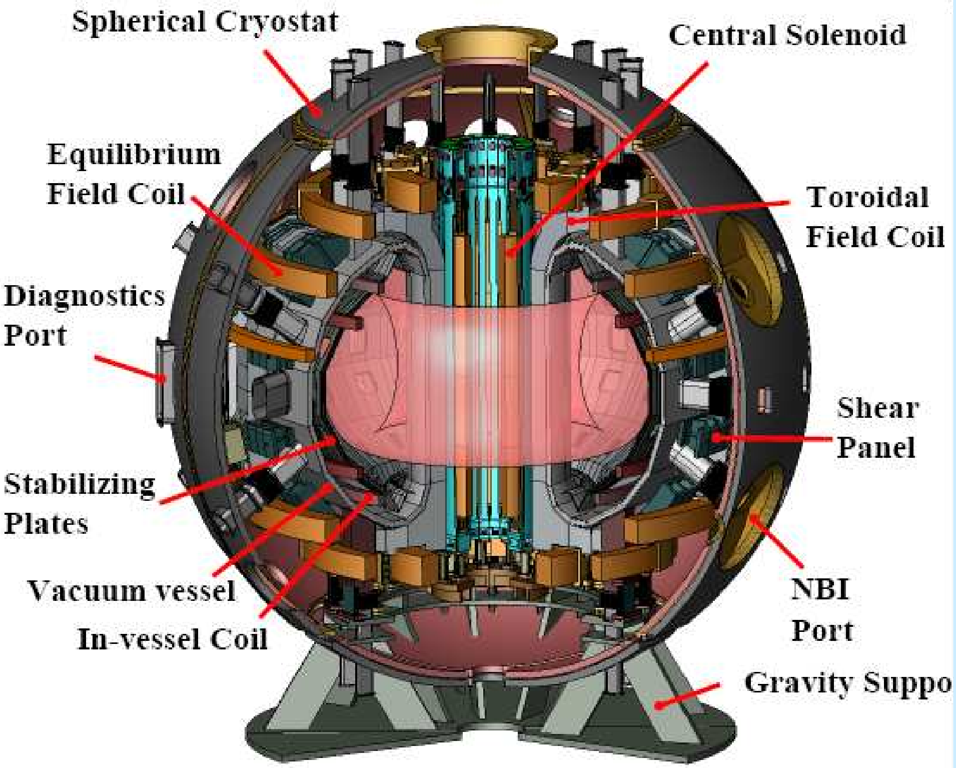


*G. Kurita, *et al.*, Nucl. Fusion 46 (2006) 383.

Engineering design



Overview of JT-60SA



2007 design

Fig. 1. Cut-set view of JT-60SA.

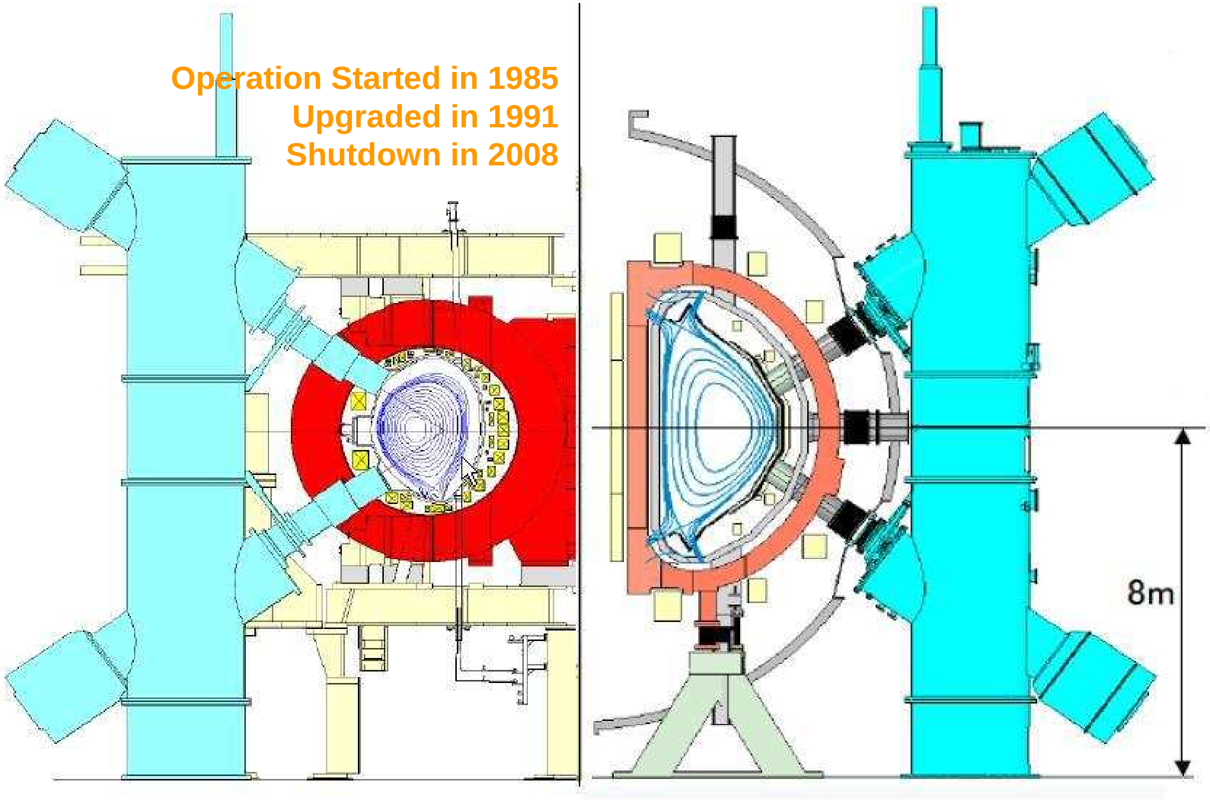
High performance, long pulse operation machine (& flexibility)

- **Superconducting tokamak**
- **Cooling of Plasma Facing Components**
- **Plasma control: stabilizing plates and in-vessel coils**
- **Shaping capability (DN)**
- **H&CD capability**
- **High n yield: neutron shielding and Remote Handling**

Magnet:~1300ton, VV:~600ton, Cryostat:~600ton, total:~2500ton

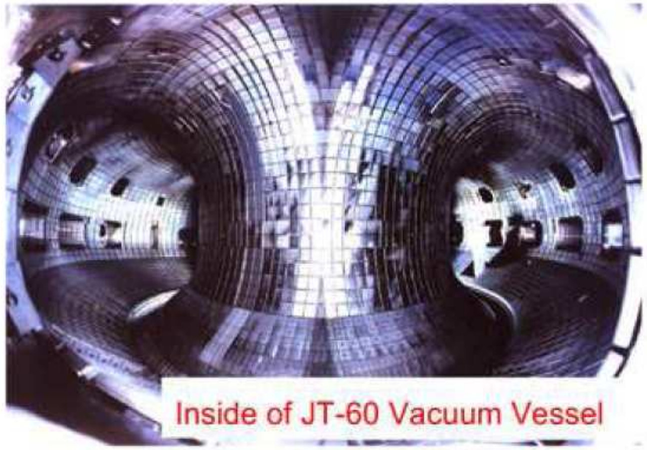
A major upgrade of the existing JT-60U

Operation Started in 1985
Upgraded in 1991
Shutdown in 2008



JT60-U

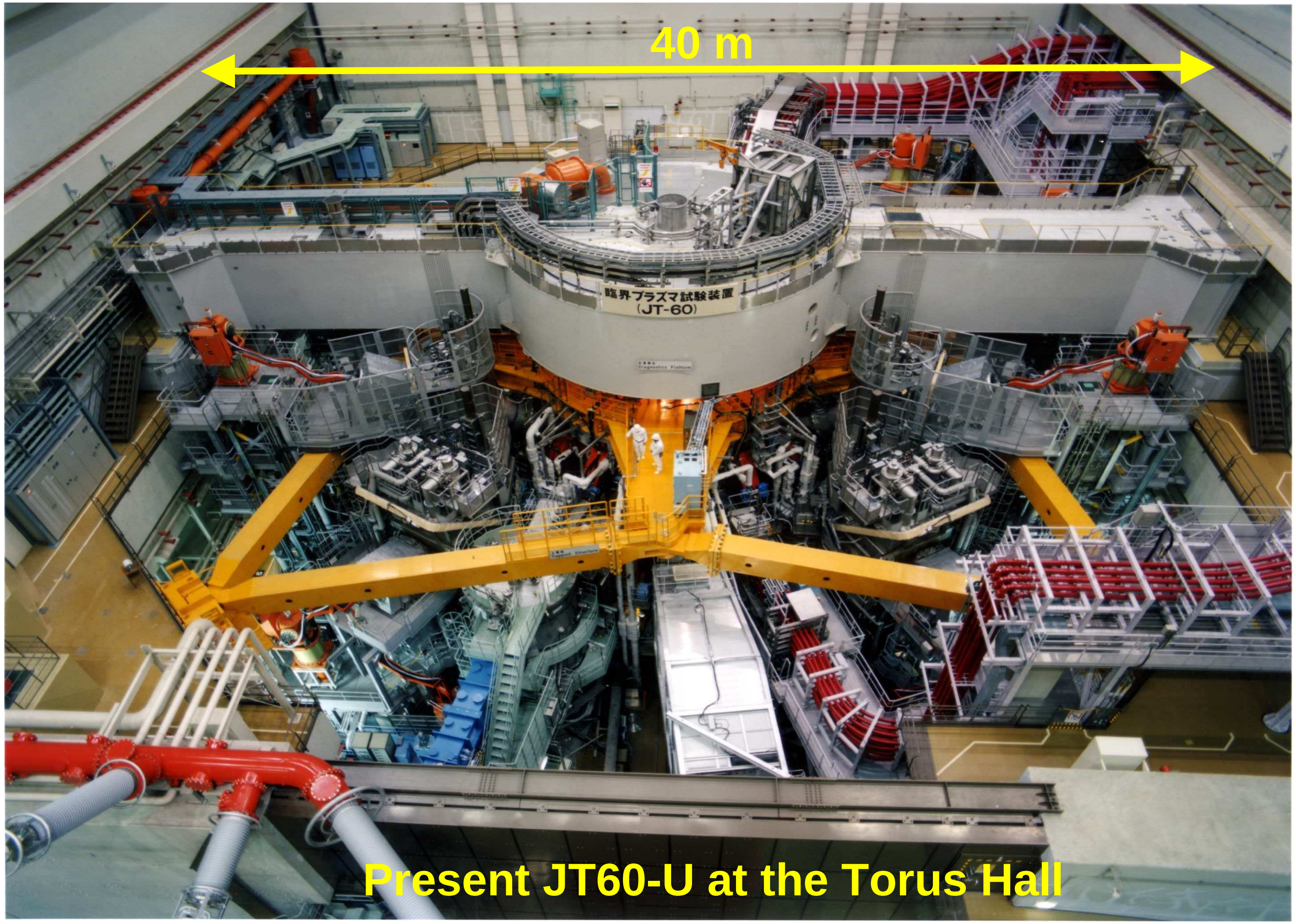
JT60-SA



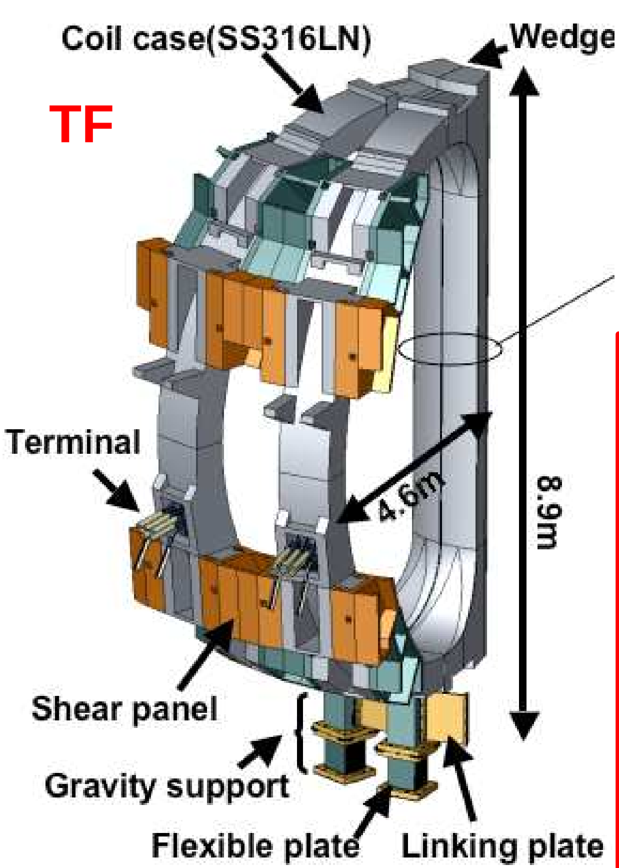
- Buildings
- Plasma H&CD systems
- Power supplies
- Diagnostics
- Cooling system
- Etc

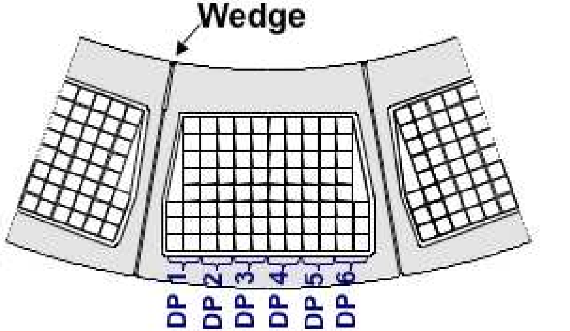
With maximum utilization of the existing facilities

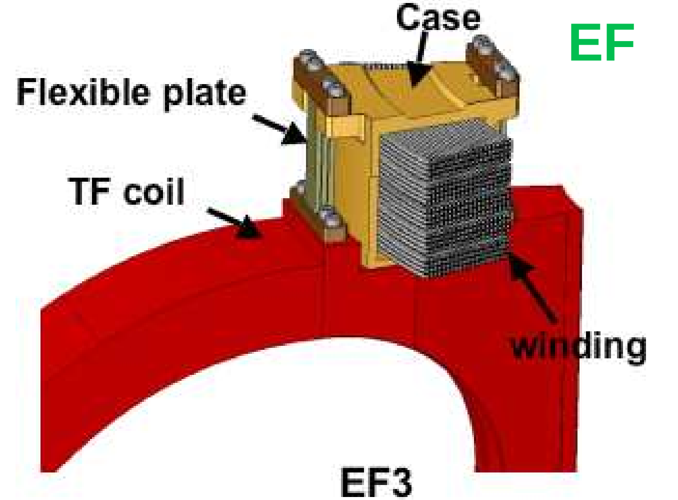
Layout of the Torus Hall

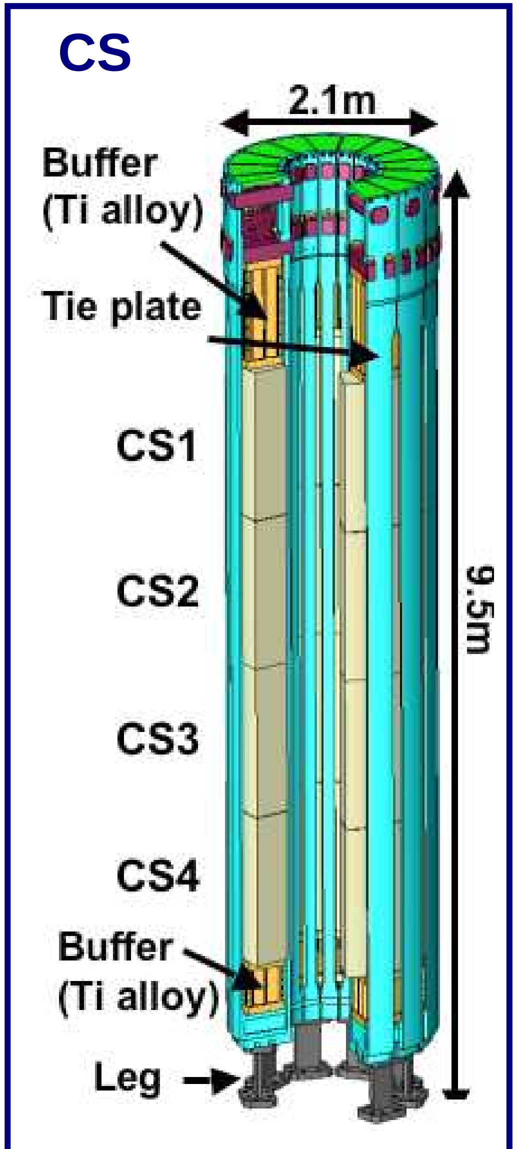


Superconducting Coils





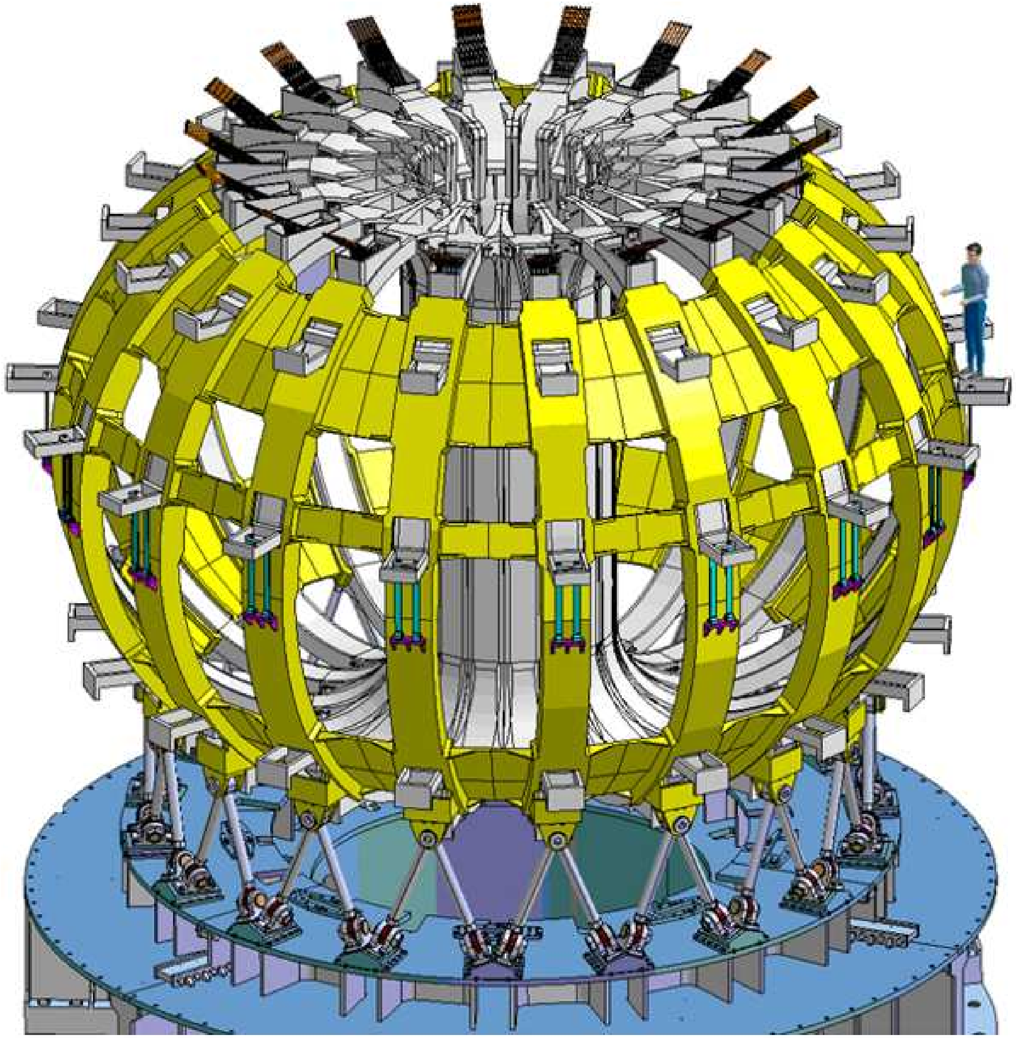




2007 design

	TF	CS	EF
strand	NbTi	Nb_3Sn	NbTi
conductor	cable-in-conduit		
B_{max} (T)	6.4	10	5.0
T_{op} (K)	4.6	5.0	4.8
I_{op} (kA)	25.7	20	20

Toroidal Field magnet



2008 design

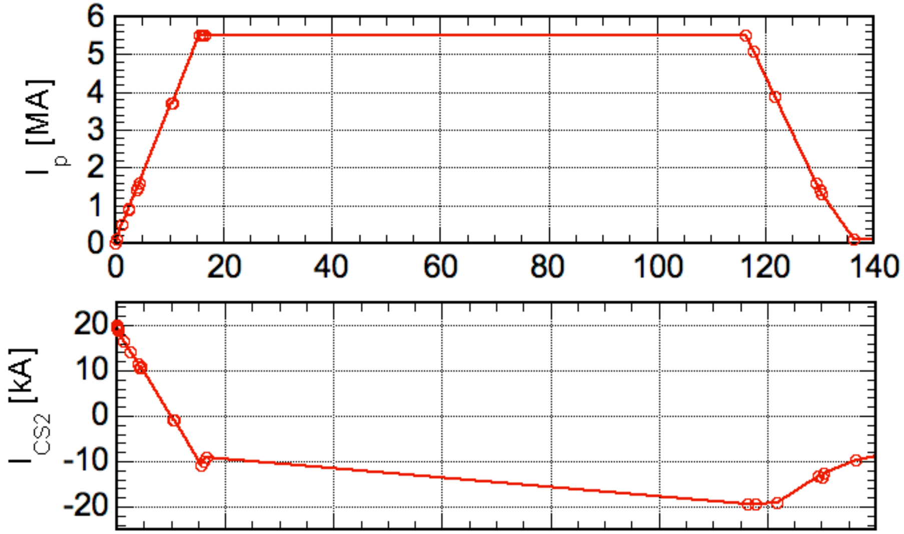
18 Toroidal Field superconducting coils

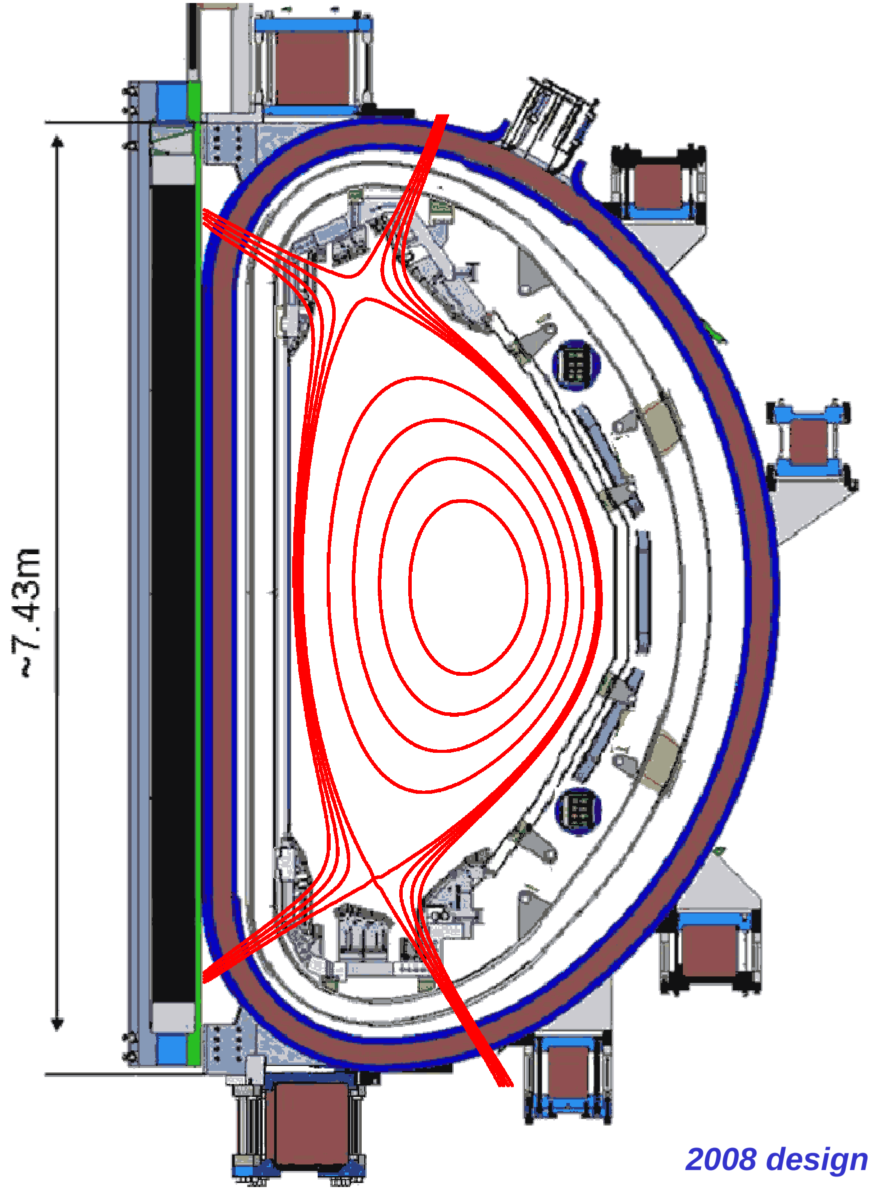
- 72 turns, 25.7kA each
- 6 double pancakes, 6 turns/pancake
- Helium inlets in high field side – joints in external low field side
- Electrically coupled
- Mechanically coupled
- Supports for EF system
- Intercoil structure to support out of plane loads

Weight: ~280 t (SC 33.4 t)

Poloidal field magnet

- **6 Poloidal Field** Superconducting coils
- **4 independent CS** modules, same number of power supplies
- Coil current < 20 kA.
- dIp/dt~0.35 MA/s during Ip ramp



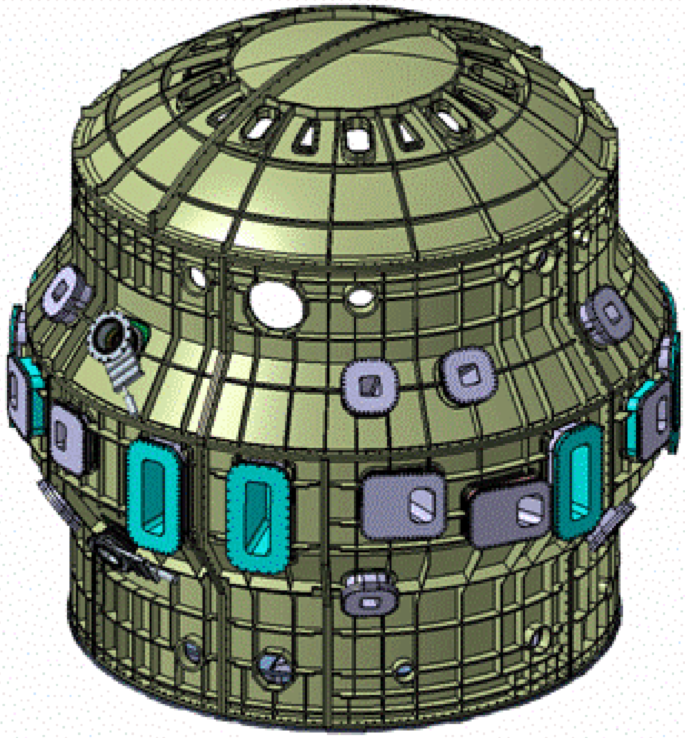


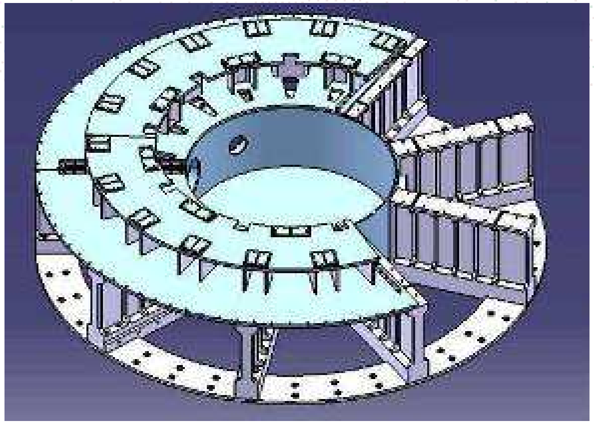
2008 design

Cryostat

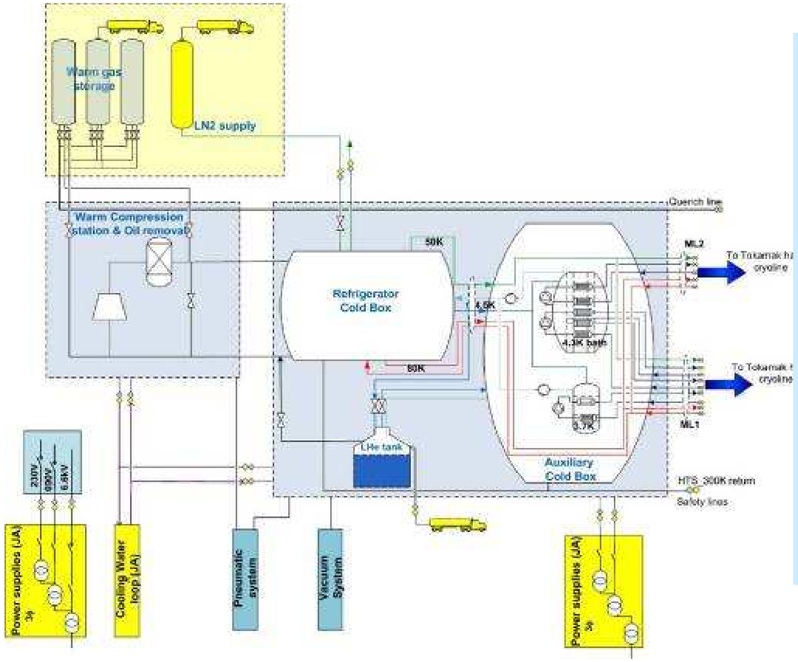
- Originally (2007)
  - spherical
  - double walled
  - with concrete shielding
- 2008 design
  - **Faceted**
  - **Single wall**
  - **No concrete**
- Two parts
  - Main machine support
  - Cylindrical and lid

Weight: ~650 t





Cryogenic Plant



Users

- Magnet system
  - Winding loops (4.3K + pump)
  - Structure loop (4.3K + pump)
  - HTS current leads (supply: 50K, return: 300K)
  - Thermal Shield for Coil Terminal Box (80K)
- Thermal Shield in Cryostat (80K-100K)
- Cryo-pump in VV (4.2K + pump)
- Pellet Injection System (Liquid Helium)

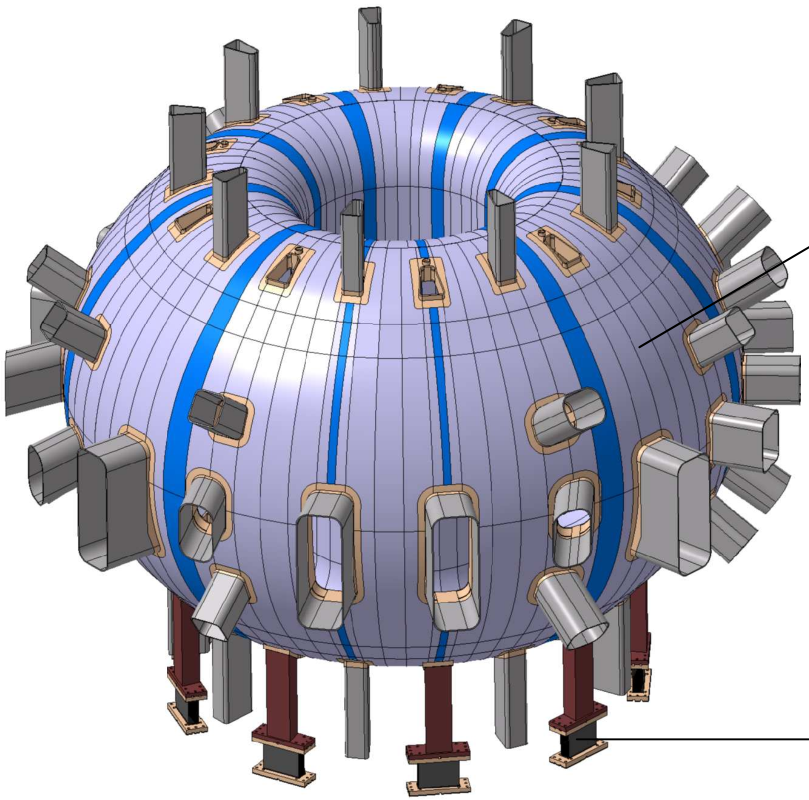
Tokamak operating mode

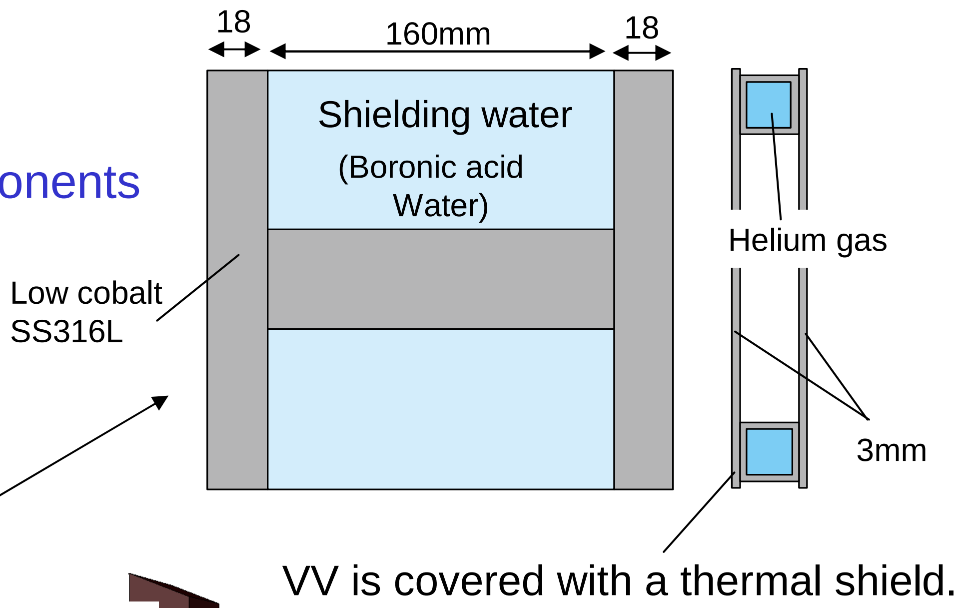
- Yearly exploitation: 6 months per year (**6/12 m**)
- 1 week/month for baking and conditioning: 3 weeks/month of ops **(3/4 w)**
- Operation 5 days each week, with a shut-down during week-end (**5/7 d**)
- Day operation about 12 hours (**12/24 h**; stand by duration: 12h)

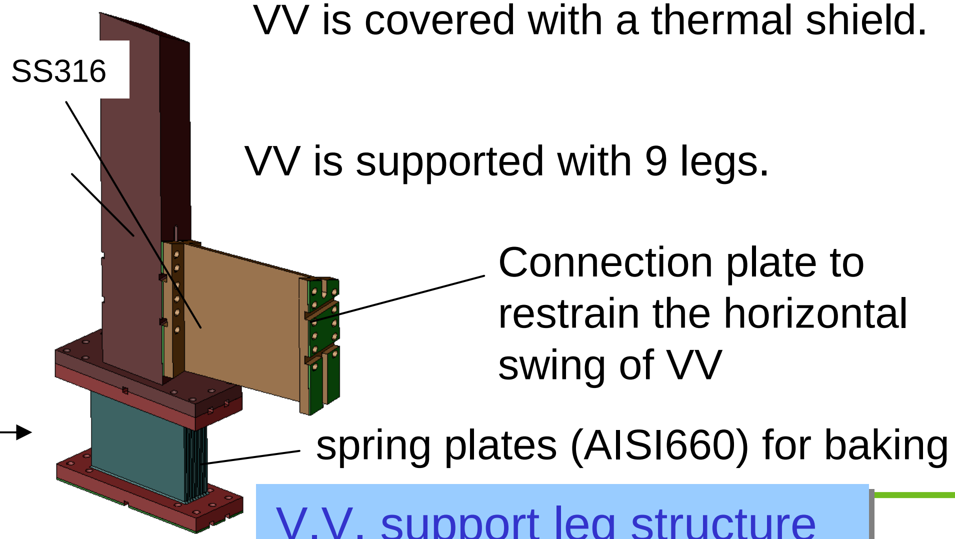
TOTAL: ~ **10 kW at 4.5 K** + 80 K TS + margins

Vacuum Vessel

- **Double wall**
- Baking temp. ~200°C
- One turn resistance ~15μΩ
- Weight ~300 t without in-vessel components



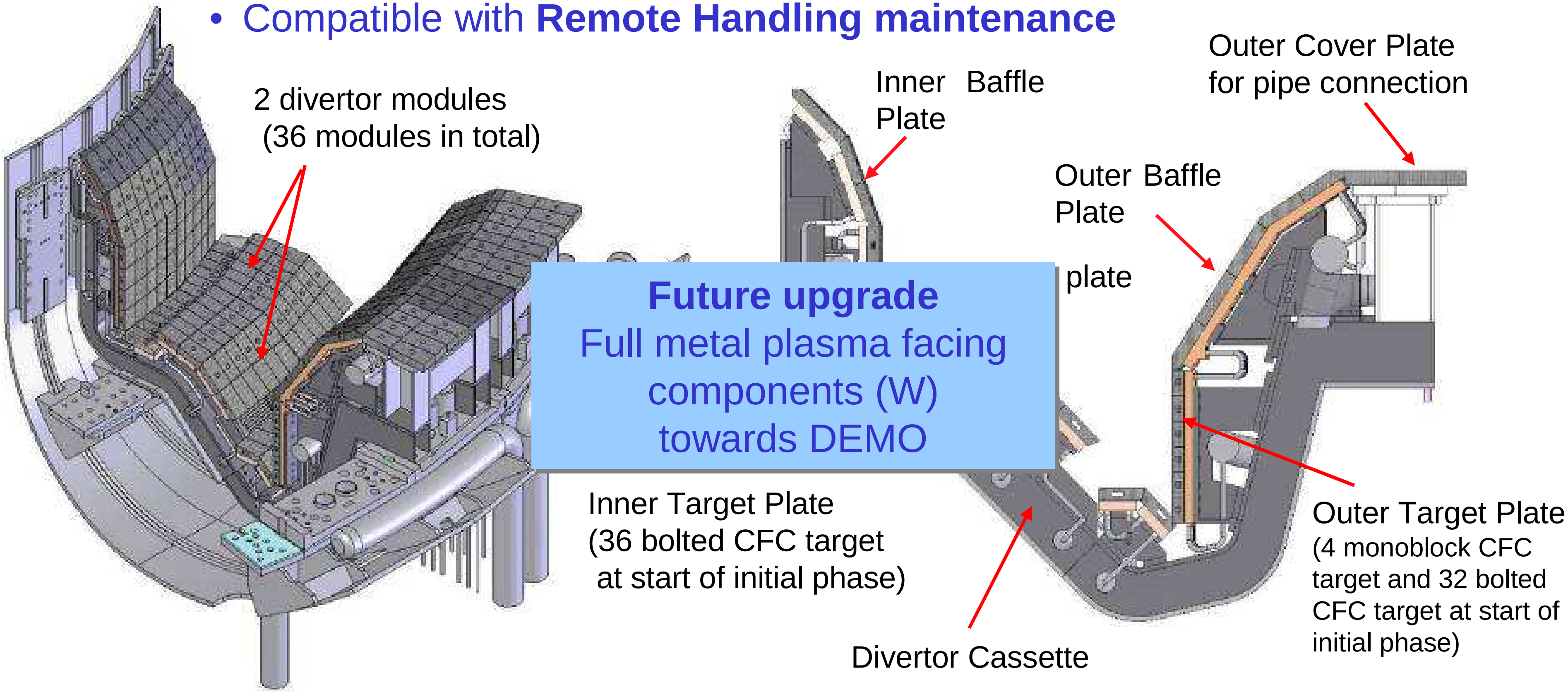




V.V. support leg structure

Plasma Facing Components

- Design optimized for a high triangularity (δx~0.5) in LSN
- Divertor vertical targets, with a V-shaped corner in LF Side
- Initially **bolted CFC** (+partial monoblock) ➔ Full monoblock
- Cryopanels beneath the cassette for pumping
- **All plasma-facing-components will be water-cooled** (@ 40℃)
- Compatible with **Remote Handling maintenance**

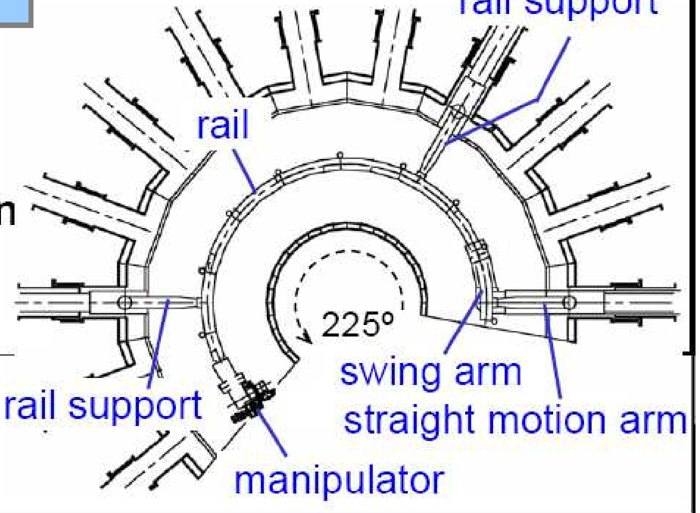


Future upgrade
Full metal plasma facing components (W) towards DEMO

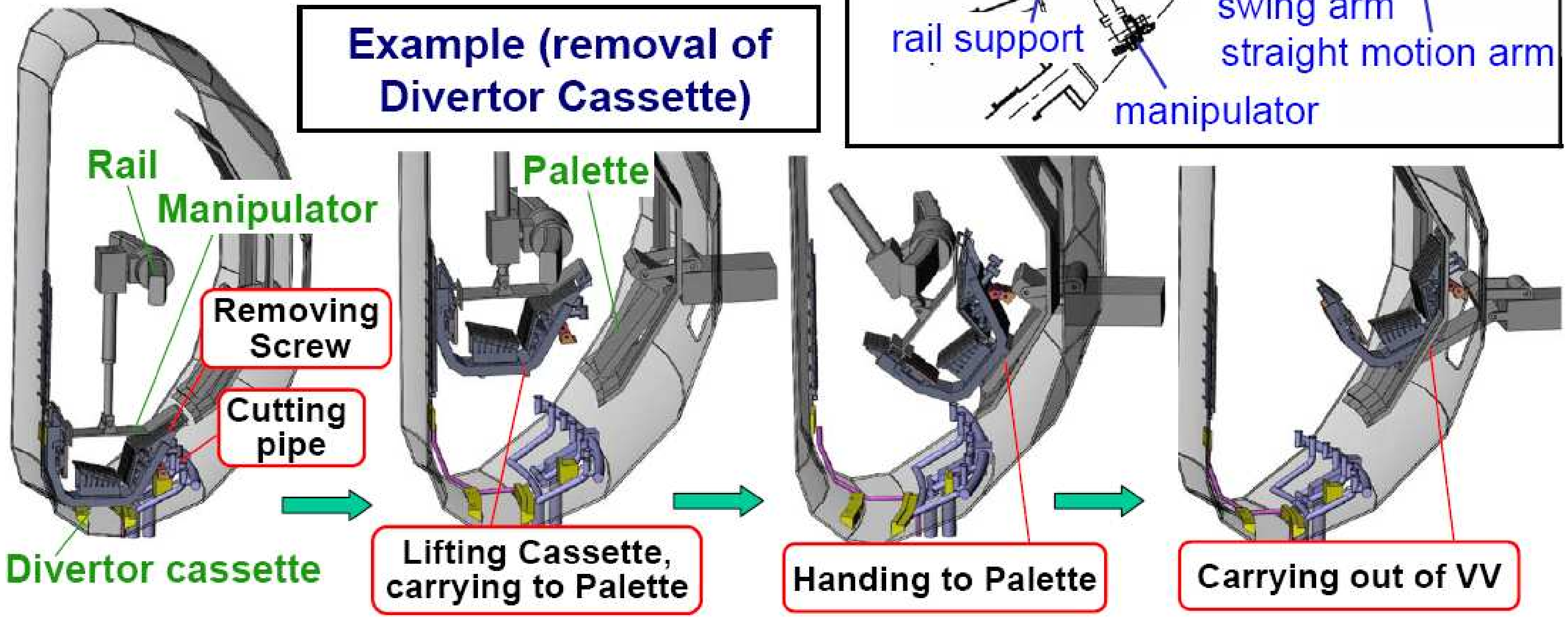
Remote Handling System

Vehicle-type system (adopted in ITER)

- purpose: maintenance and repair of in-vessel components
- capable weight ≤ 500 kg
- rail expansion: 225° in toroidal direction
- tooling function: inspection, holding, cutting, welding, screwing, lifting

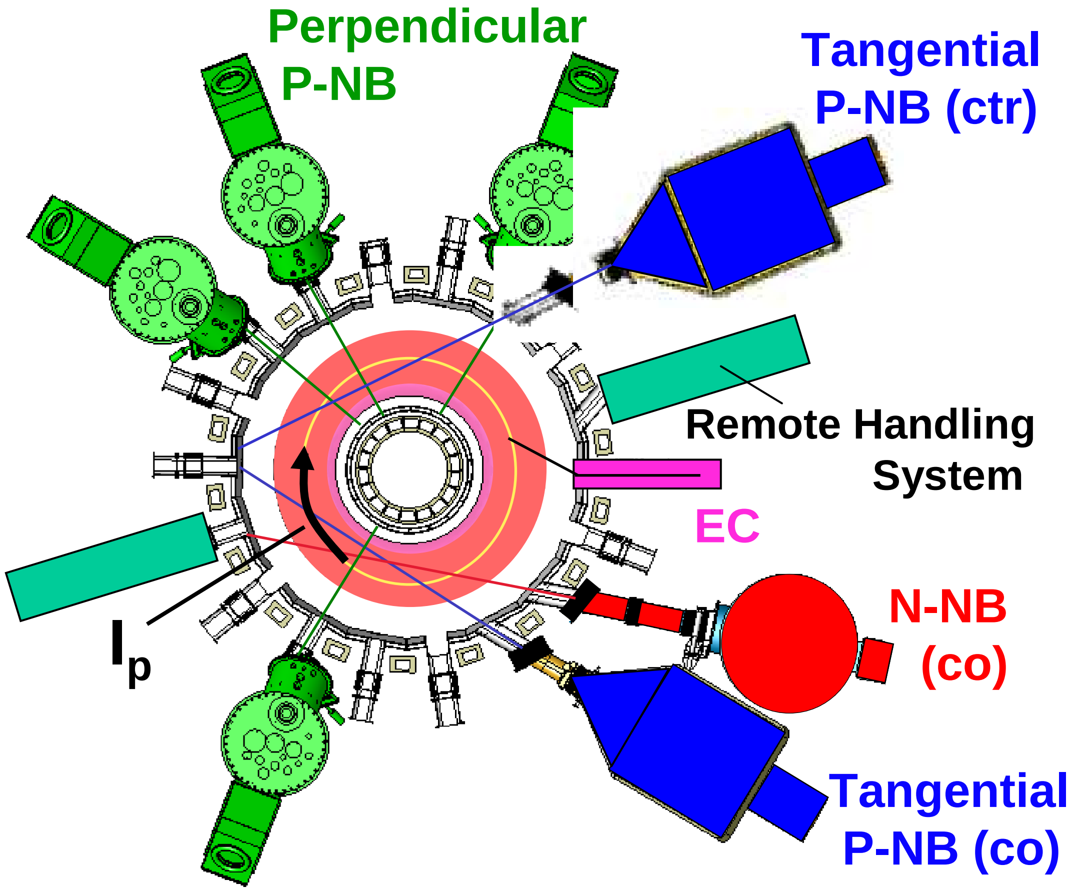


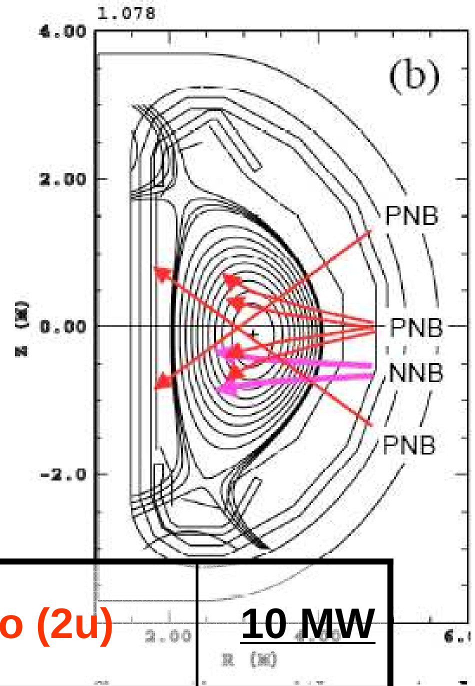
Example (removal of Divertor Cassette)



Heating & Current Drive systems

- P-NB: **balanced** injection for toroidal rotation control
- EC: **two-frequency** system for flexible control of CD, MHD…

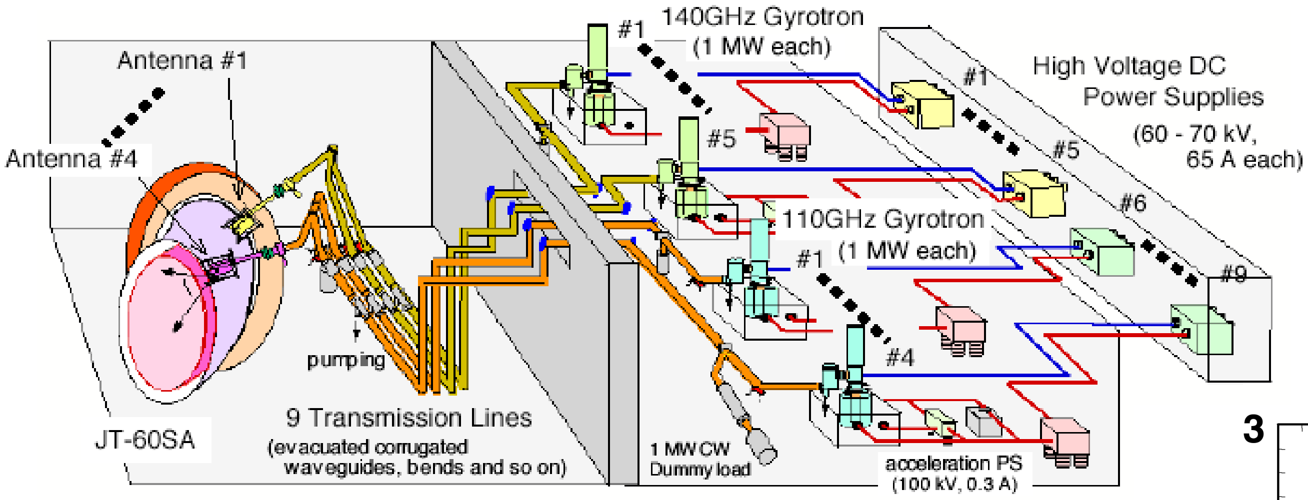




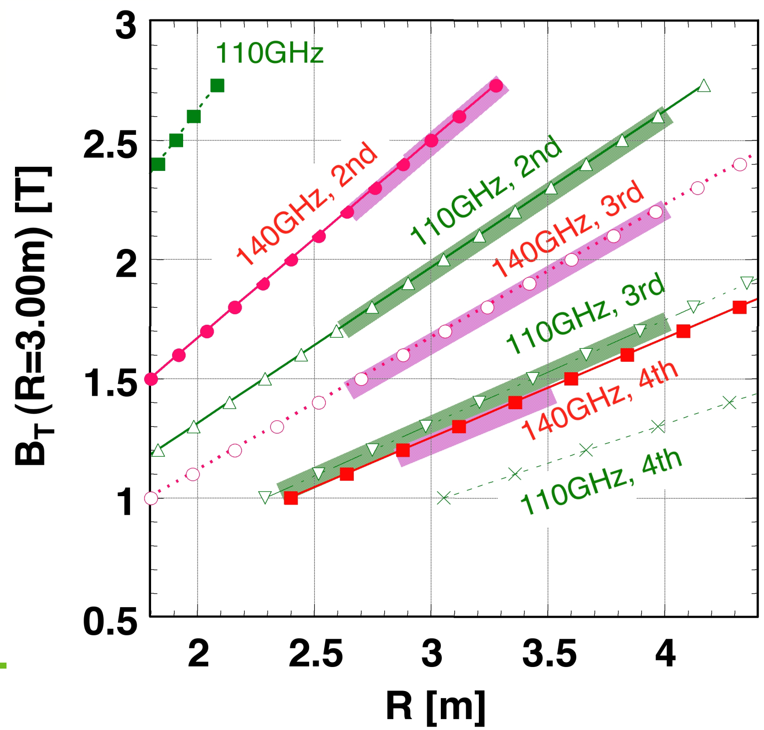
for 100s

N-NB (500 keV)	co (2u)	10 MW
P-NB (85 keV)	co (2u)	4 MW
	ctr (2u)	4 MW
	perp (8u)	16 MW
EC	110 GHz	3 MW
	140 GHz	4 MW
total		41 MW

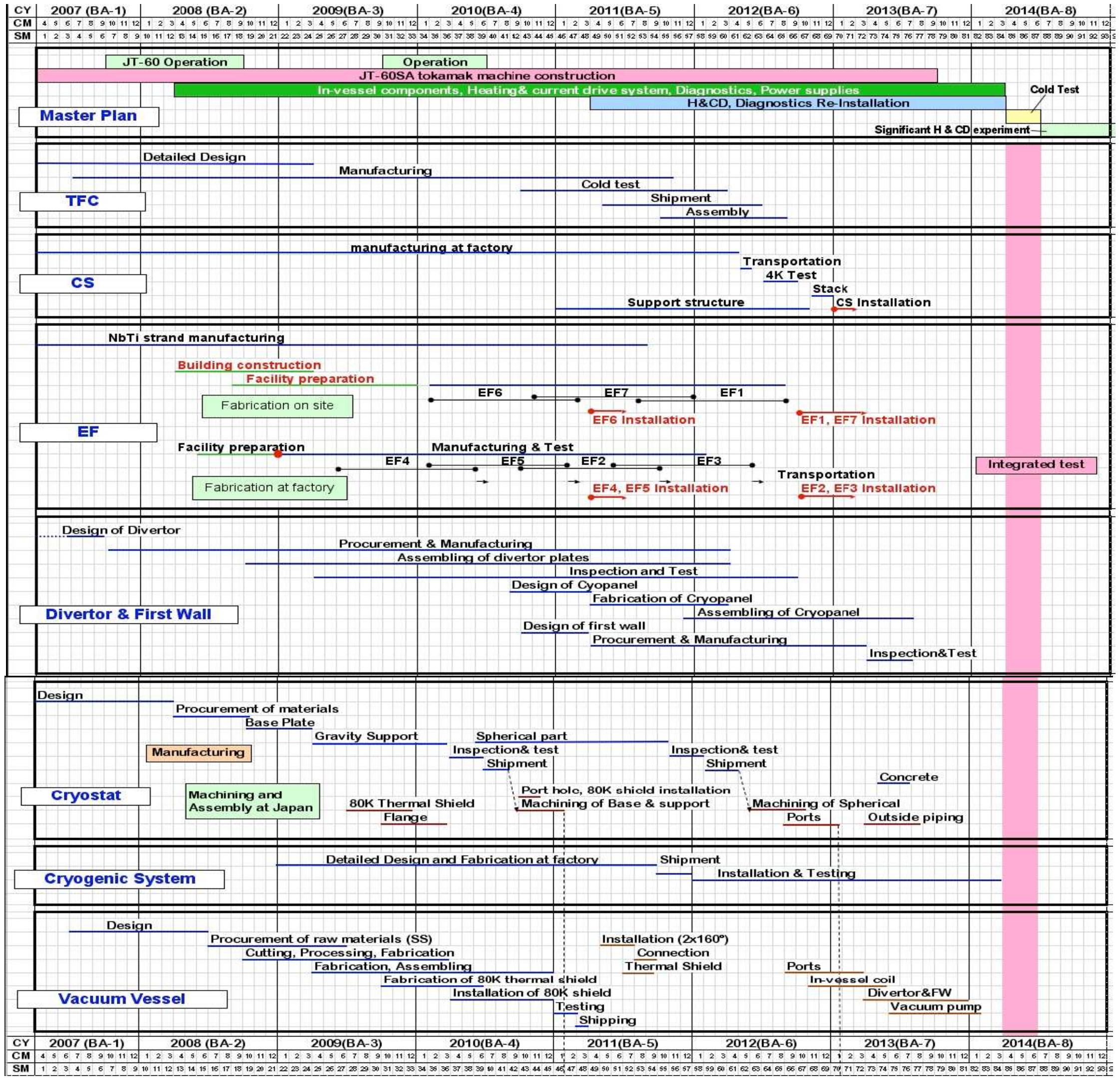
Heating & Current Drive systems



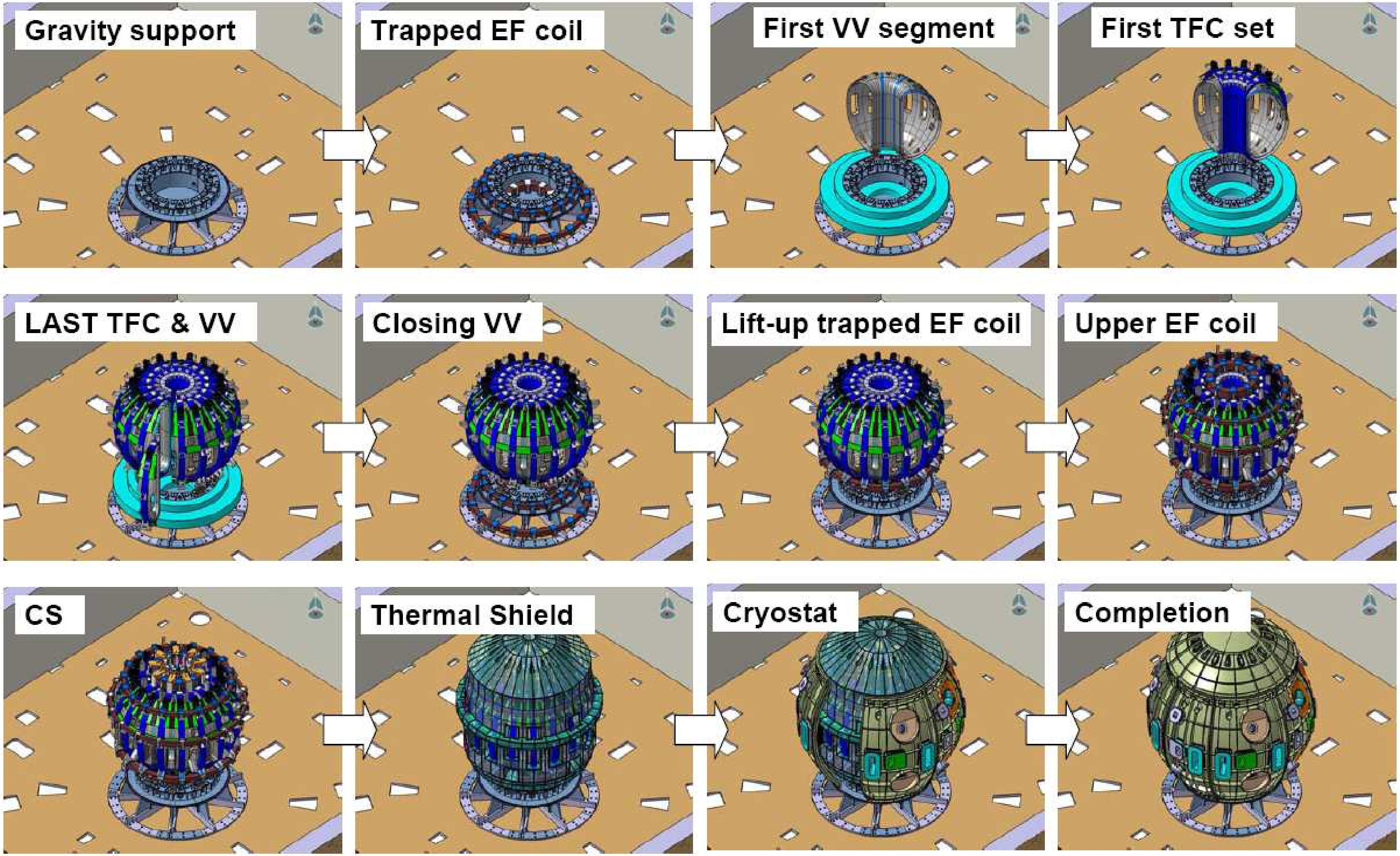
Resonance layer of EC with two-frequency system



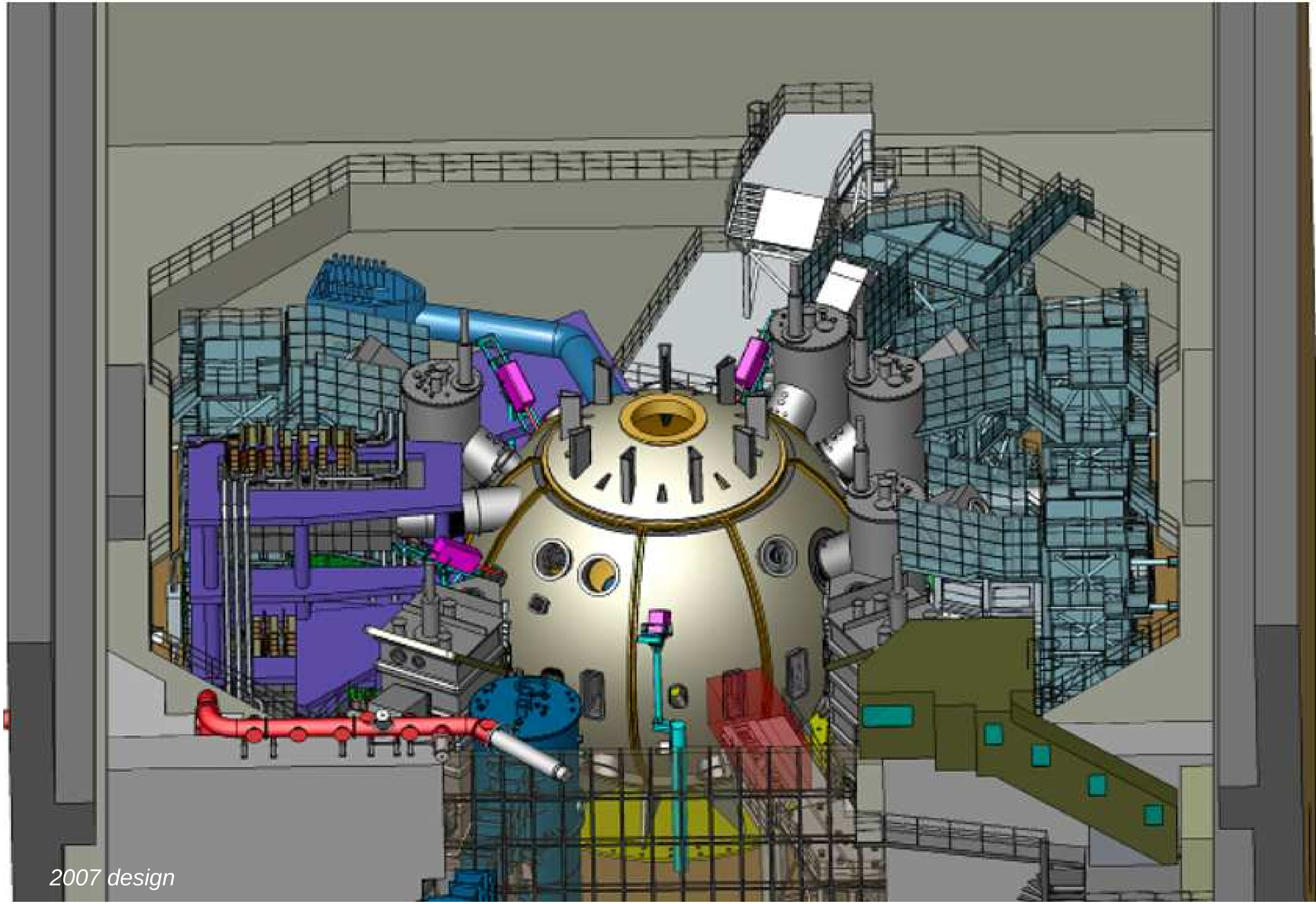
Assembly and Schedule



Assembly

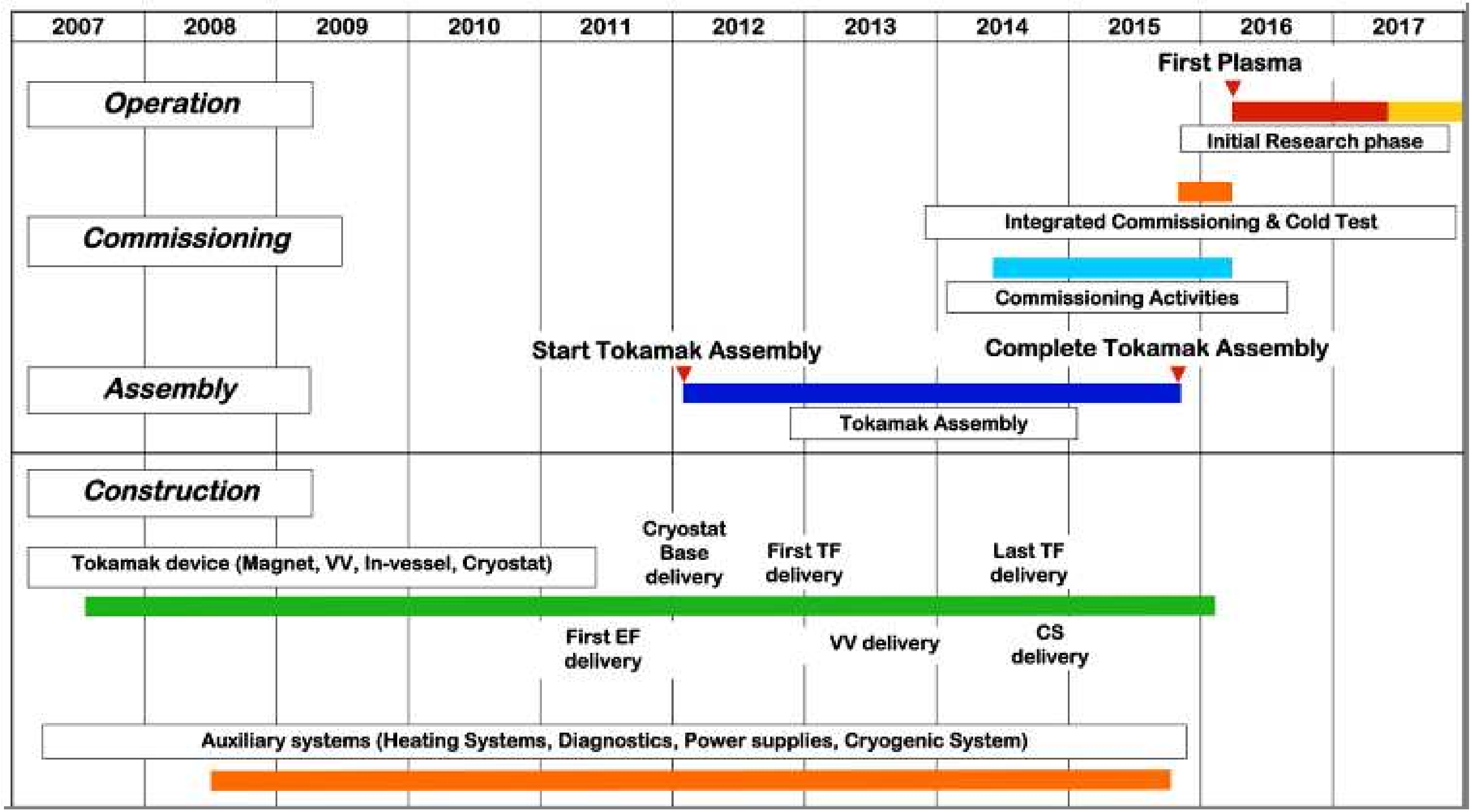

Gravity support
Trapped EF coil
First VV segment
First TFC set
LAST TFC & VV
Closing VV
Lift-up trapped EF coil
Upper EF coil
CS
Thermal Shield
Cryostat
Completion

JT-60U to JT-60SA



Baseline Schedule

- **Start of Tokamak Assembly**: February 2012
- **Completion of Tokamak Assembly**: October 2015
- **First Plasma**: March 2016



Phased Exploitation Plan

- Exploitation within the BA period will aim at the initial research phase
- Principles of "**Joint Exploitation**" later phases now agreed with JA:
  - without finite duration
  - taking into fair account hardware contributions in case of 3rd party later accession

<table>
<tr><th></th><th>Phase</th><th>Expected Duration</th><th></th><th>Annual Neutron Limit</th><th>Remote Handling</th><th>Divertor</th><th>P-NB</th><th>N-NB</th><th>ECRF</th><th>Max Power</th><th>Power x Time</th></tr>
<tr><td rowspan="2">Initial Research Phase</td><td>phase I</td><td>1-2 y</td><td>H</td><td>-</td><td rowspan="3">R&D</td><td rowspan="2">LSN partial monoblock</td><td>10MW</td><td rowspan="5">10MW</td><td rowspan="2">1.5MW x100s
+
1.5MW x5s</td><td>23MW</td><td rowspan="4">NB: 20MW x 100s
30MW x 60s
duty = 1/30

ECRF: 100s</td></tr>
<tr><td>phase II</td><td>2-3y</td><td>D</td><td>4E19</td><td rowspan="3">Perp.
13MW

Tang.
7MW</td><td>33MW</td></tr>
<tr><td rowspan="2">Integrated Research Phase</td><td>phase I</td><td>2-3y</td><td>D</td><td>4E20</td><td rowspan="2">LSN full-monoblock</td><td rowspan="3">7MW</td><td rowspan="2">37MW</td></tr>
<tr><td>phase II</td><td>>2y</td><td>D</td><td>1E21</td><td rowspan="2">Use</td></tr>
<tr><td>Extended Research Phase</td><td></td><td>>5y</td><td>D</td><td>1.5E21</td><td>DN</td><td>24MW</td><td>41MW</td><td>41MW x 100s</td></tr>
</table>

Manufacturing Activities

- Six Procurement Arrangements (PAs) between EU-IA and JA-IA already entered into force by **February 2009**
  - (1) PF conductor, (2) Vacuum Vessel, (3) Raw material for In-vessel component, (4) PF coil manufacturing buildings, (5) PF Coils manufacturing, (6) Divertor components
- **Contracts** with the manufacturers were awarded
- Buildings for **PF coil manufacturing** are completed at the Naka site

Dummy copper conductor

Welding test for Vacuum Vessel

A building for winding EF coils.

630 m long line for jacketing superconducting cables

A meeting of JT-60SA Team (TCM-5) at Naka

Summary

- **One of the three projects of the "Broader Approach"**
- **"Fast Track" approach**
  - provide the international community with an additional experiment on the path to DEMO
  - satellite tokamak to ITER
- **The second largest tokamak**
  - about 1/3 of the plasma current capability of ITER and half its major radius
  - significant heating and current drive capability and configuration flexibility
- **Joint exploitation of the machine by EU and JA teams**
  - will allow experimentation addressing both the European and Japanese approaches to DEMO
  - should allow the European and Japanese fusion programs to make significant advances in the field of tokamak physics

- **Reference documents for preparing the presentation**
  - *Draft report of the assessment of the JT60-SA CDR by AHG appointed by the EFDA STAC under request of CCE-FU (March 2007)*
  - *Conceptual Design Report documents (draft, Feb. 2007)*
  - *M. Kikuchi, H. Tamai and M. Matsukawa et al. presentations at the 24th SOFTconference, Sep. 2006, Warsaw, (Poland) and the 21st IAEA conference, 2006, Chengdu, (China)*
  - *Report of JA-EU Satellite Tokamak Working Group (March 2006)*
  - *P. Bayetti, Seminar on JT-60SA, 2007, Cadarache (France)*
  - *P. Barabaschi, Seminar "The JT-60SA Project", 2009, Cadarache (France)*