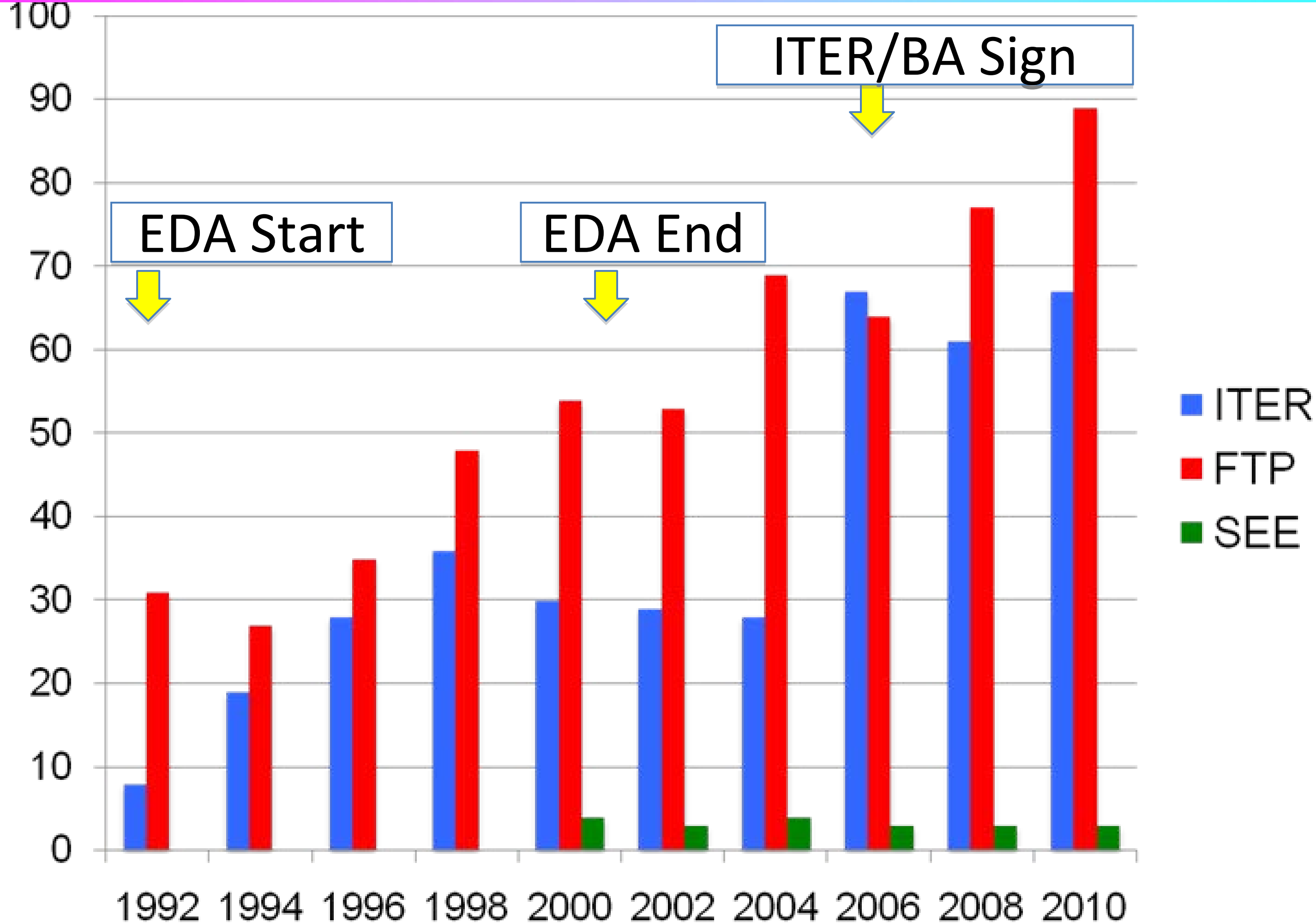
S/1-5

Summary on ITR, FTP and SEE

Hideyuki Takatsu
JAEA

Special Thanks to:
D. Campbell IO
K. Sakamoto JAEA

Evolution of the number of FTP/ITR/SEE Papers in the past and present IAEA-FECs

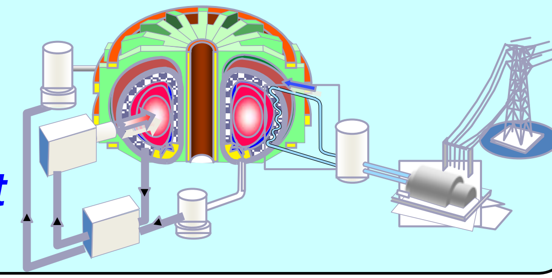


ITER papers increased with ITER/BA progress.
FT papers are increasing constantly.

Roadmap to DEMO

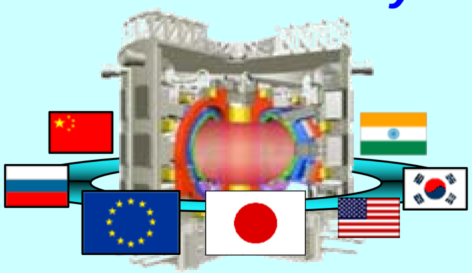
DEMO

Demonstration of Fusion Power Plant



ITER

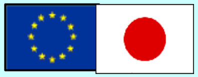
Demonstration of Scientific and Technol. Feasibility of Fusion Energy



Q =10
DT Burning
300-500s
TBM

Complementary Activities

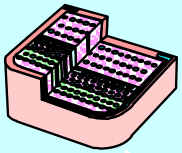
- Broader Approach Activities
  - JT-60SA
  - IFMIF-EVEDA
  - IFERC



- Long-term Technology R&D
  - Materials
  - Blanket
- Near-term DT Facilities
  - CTF, FAST, FNSF, etc.

Large Tokamaks

Ex: JT-60
Q = 1.25
Ti(0) = 45keV



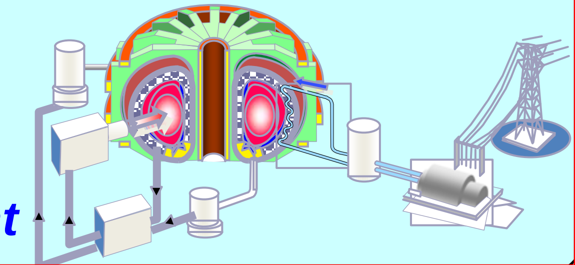
Fusion Technology
Material
Blanket
R&D (Coils, VV, Heating)

Road Map to DEMO

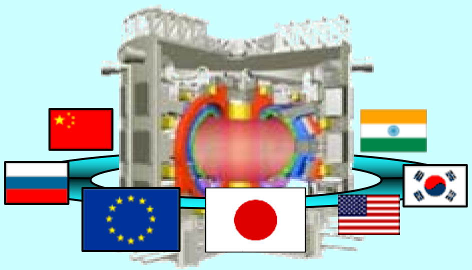
Contributions in ITR, FTP and SEE

DEMO

Demonstration of Fusion Power Plant



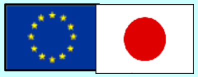
ITER : Demonstration of Scientific and Technological Feasibility of Fusion Energy



Q =10
DT Burning
300-500s
TBM

Complementary Activities

-Broader Approach Activities
- IFMIF-EVEDA
- IFERC
- JT-60SA

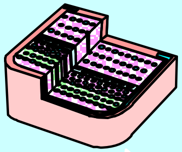


-Long-term Technologies R&D
- Materials
- Blacket

-Mitigating risk to DEMO
- CTF
- FAST, etc.

Large Tokamaks

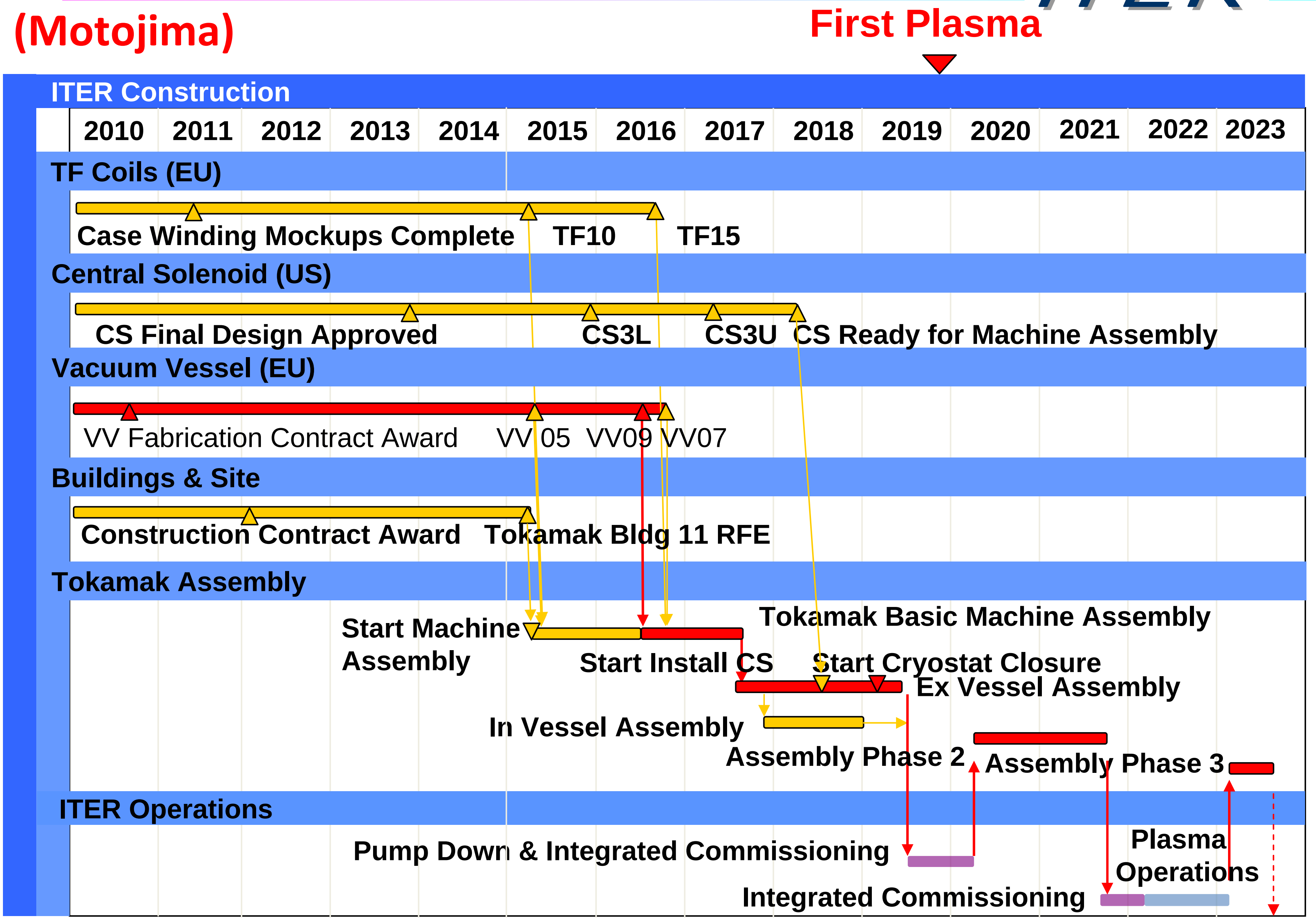
Ex: JT-60
Q = 1.25
Ti(0) = 45keV



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

ITER Master Schedule Established

(Motojima)



Evacuation/Construction at ITER site started

ITER

Leveling

PF Building

HQ building (Annex build.)
Tokamak building complex.
PF building

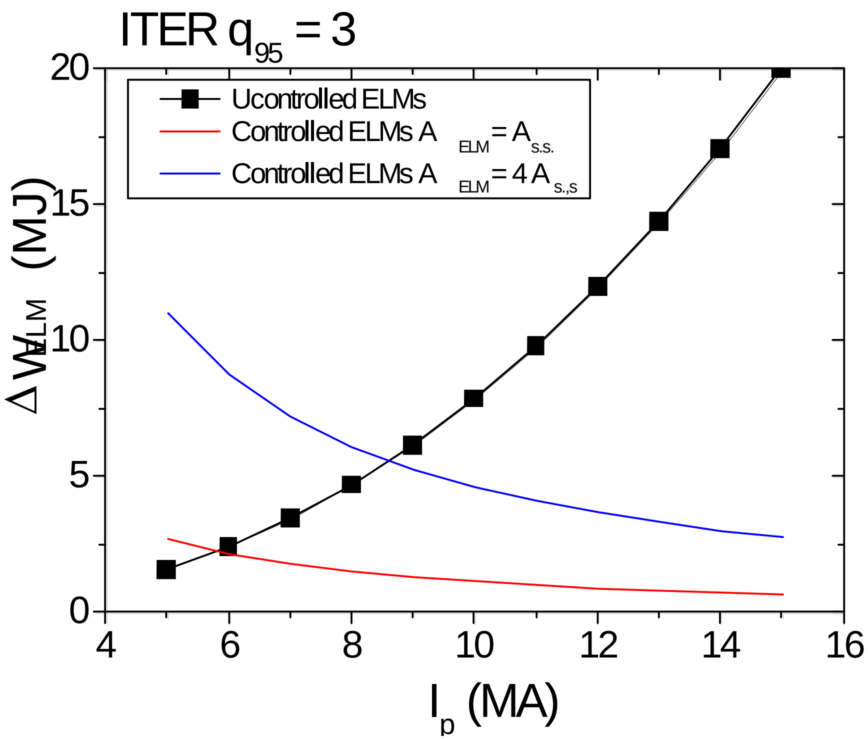
(Sep. 2010)

(Motojima)

ELM Control is Essential in ITER
Uncontrolled ELMs - Operation limited to $I_p \lesssim 6 - 9$ MA

- $\Delta W_{ELM}^{uncontrolled}$ determined by ELM physics
- Material damage avoidance + ELM physics → required $\Delta W_{ELM}^{controlled}$

0.5 MJm^{-2} → $\Delta W_{ELM}^{controlled}$ ~ 0.7 MJ (15 MA, Q_{DT} = 10, $A_{ELM} = A_{s.s.}$)



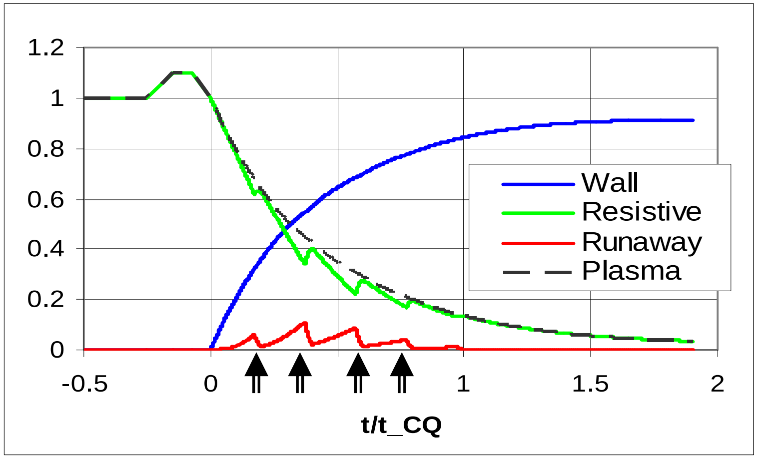
(Loarte)

Uncontrolled ELM operation with low erosion up to I_p = 6.0–9.0 MA depending on $A_{ELM}(\Delta W_{ELM})$

→ No ELM damage for initial H-mode operation in ITER

Runaway electrons must be suppressed in ITER

- Massive runaway electrons can be produced during Current Quench of plasma disruptions in ITER. They must be suppressed by Disruption Mitigation System.



(Putvinski)

Modeling of CQ with repetitive gas injection show suppression of RE current at ~1 MA

- A new scheme based on injection of dense gas jets in Current Quench plasmas could allow reduction of RE current to a tolerable level at a reduced amount of gas.

ITER H&CD Analysis - Q=10 Scenario

ITER

Tools, assumptions, results:

JETTO with GLF-23 transport
$\Delta_{barrier}$: 6 cm

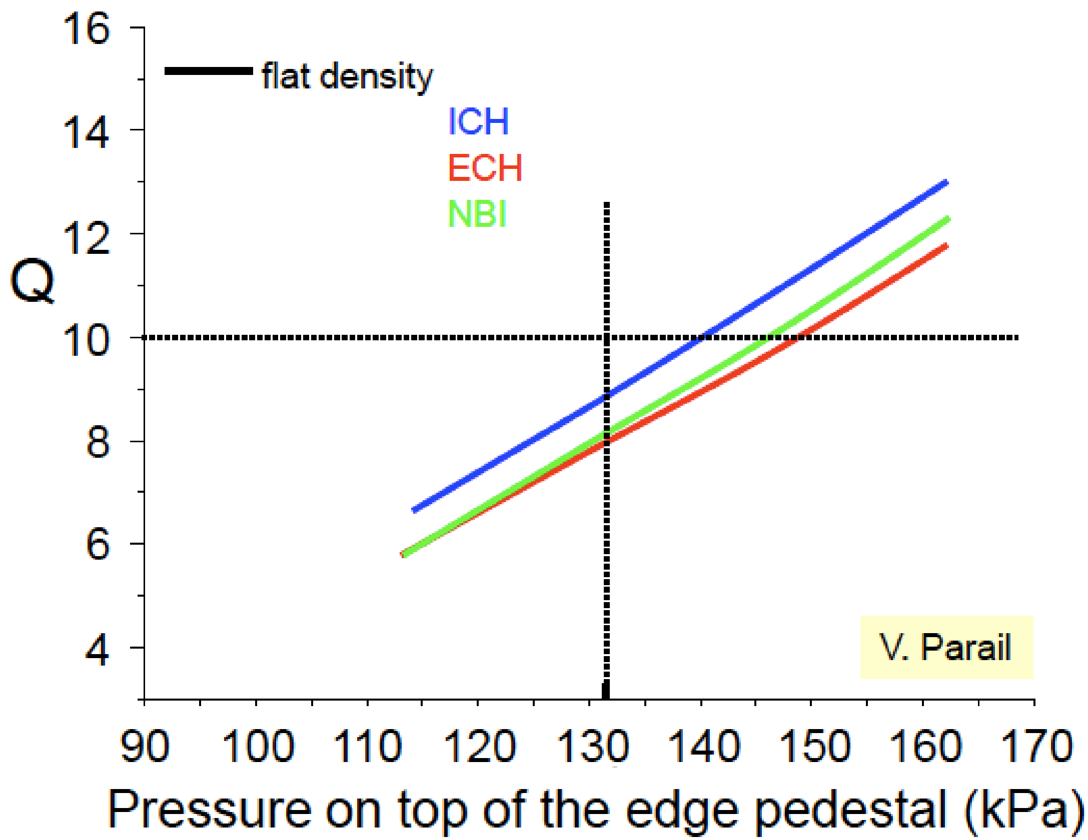
2 cases considered:
flat and peaked n_e

Each heating system separately considered:

When P_α developed
P_{ext} -> 40 MW

Inductive scenario:
$f_{bs} = I_{bs}/I_{pl} = 0.2$
$f_{CD} = I_{CD}/I_p = 0.07$

Q on the pedestal pressure (H-mode)



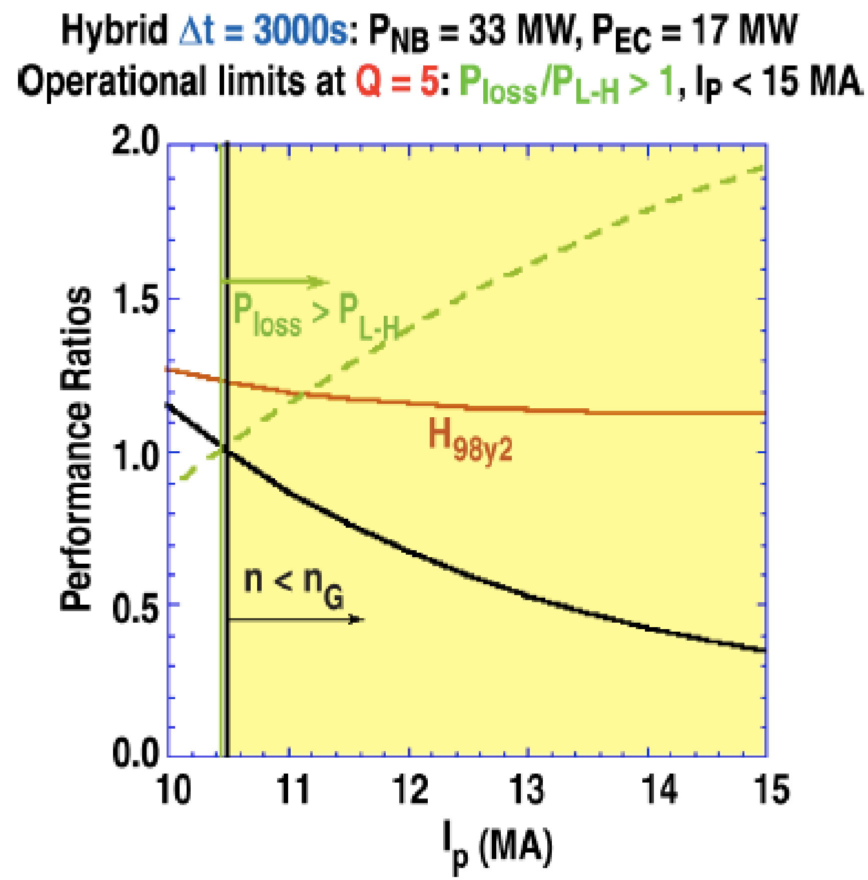
Discussion: ICRH ion heating pays off: $\Delta Q > 1$

(Wagner)

Extrapolation Backward From ITER Shows Required Conditions Exist in Present Experiments

ITER

- **Desired pulse length, auxiliary power, and gain are specified**
- **Operational limits define the parameters consistent with the specifications**
  - Density limit and necessity for H mode require operation with I>10.5 MA
  - Required H_{98y2} lies between 1.1 and 1.3
  - Divertor power load and required β_N are reasonable
- **Conditions needed for ITER operation at Q=5 for almost 1 hour are consistent with present experience**

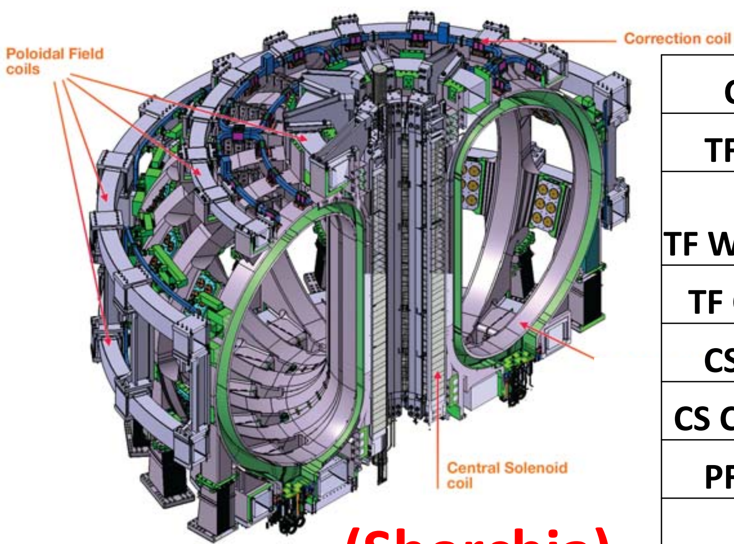


(Luce)

Superconducting Magnet (1/2)

ITER

Most of the Procurement Arrangements have been signed and an extensive progress has been made to meet the 2019 1st plasma.

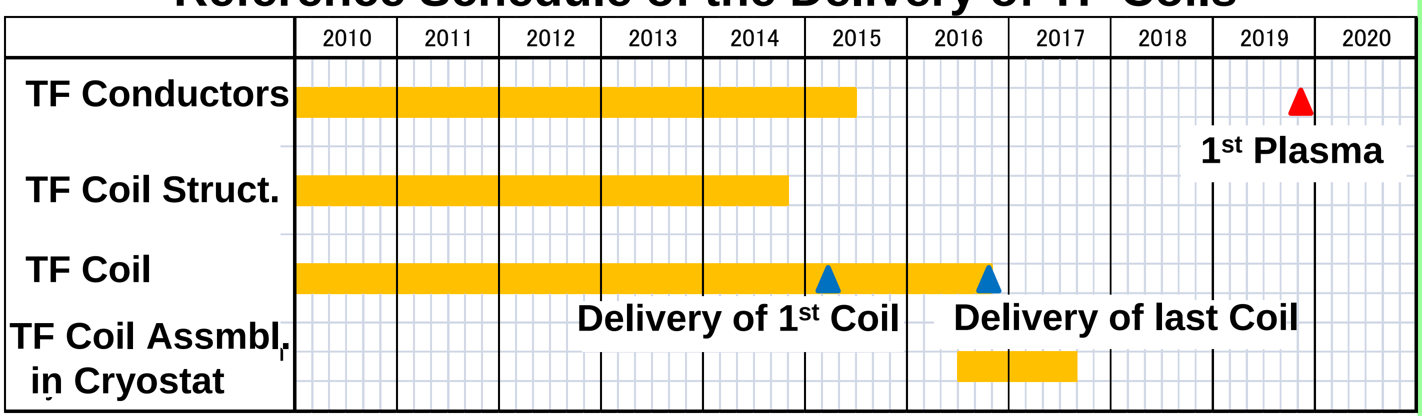


(Sborchia)

Sharing of ITER magnet procurement among DAs

Component	IO	CN	EU	KO	JA	RF	US
TF Conductors		7%	20%	20%	25%	20%	8%
TF Windings+Insert.			10 coils		9 coils		
TF Case Sections					100%		
CS Conductors					100%		
CS Coils+Structure							7 coils
PF Conductors		65%	21%			14%	
PF Coils			5 coils			1 (PF1)	
TF, CS Supports		100%					

Reference Schedule of the Delivery of TF Coils



Major milestones

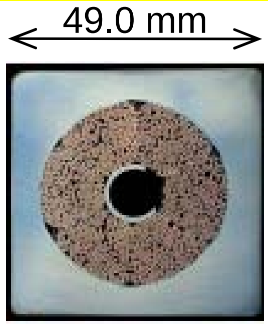
- **Delivery of 1st TF conductor in 2010**
- **Start of assembly of 1st TF coils in 2016**
- **Delivery of the last PF coil and the CS coils in 2017**

Superconducting Magnet (2/2)

ITER

Large scale production of superconductors (strands, cables and jacketing) has started. (Takahashi, Sborchia)

TF conductor (Nb_3Sn)

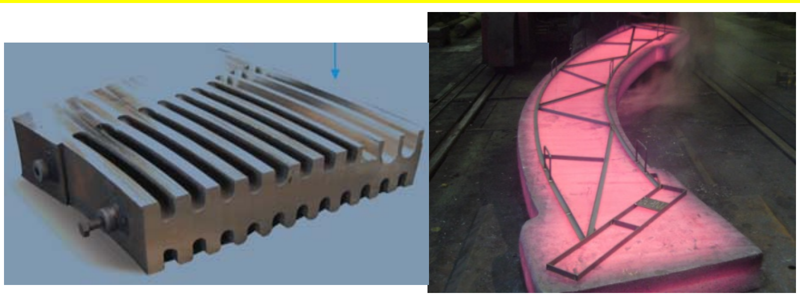


PF conductor (NbTi) and CS conductor (Nb_3Sn)

Jacketing facility is in operation in JA and RF, and is being set up in CN, EU and US.

First TF conductor (JA)

Demonstration of manufacturing technology has started. (Li, Wei, Sborchia)



Radial plate mock-ups for TF coil produced by HIP (left) and forging (right) (EU)

Prototype of side plate for TF coil case (JA)

Tooling for 1/3 scale dummy winding (JA)

Studies of radiation effect on the TF coil insulation (Weber) and R&D on 52kA HTS current lead (Zhou) support the ITER magnet design.

Vacuum Vessel

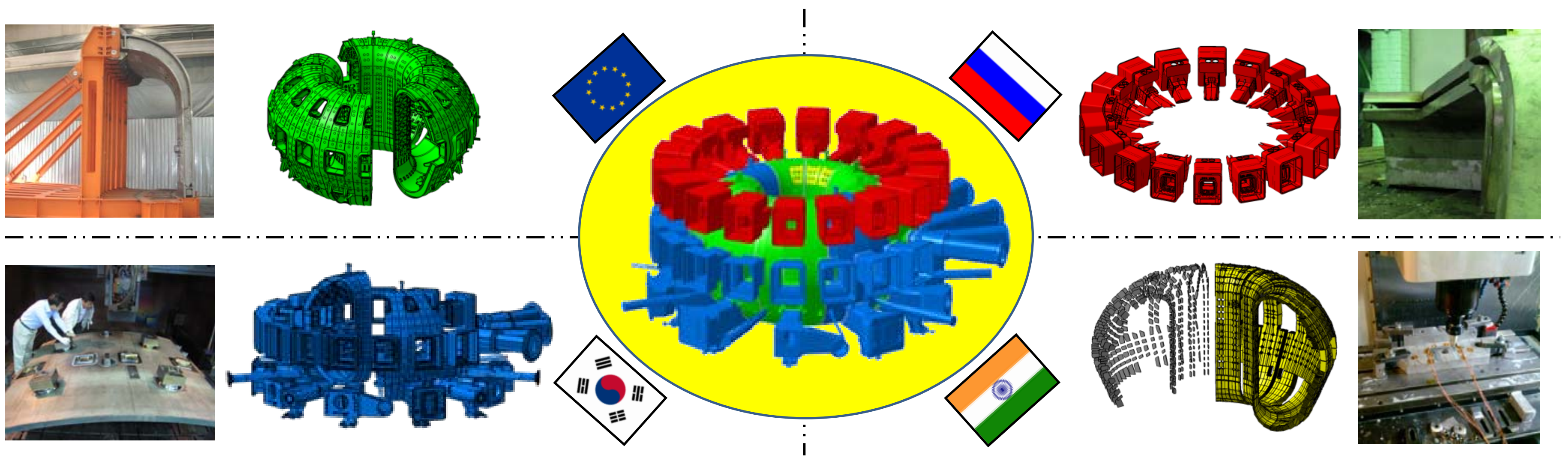
Characteristics of Vacuum Vessel

- **A torus shaped double wall structure**
- **First containment barrier and highest safety importance**
- **Tight overall profile tolerances**

DA	Procurement Item	kIUA
EU	Main vessel (7 sectors)	92.06
KO	Main vessel (2 sectors)	26.20
	Equatorial & lower ports	57.86
IN	In-wall shields	37.30
RF	Upper ports	20.86

DA	Activity	Milestone
EU	PA signature	19 Nov 2009
	Contract award	18 Oct 2010
	1st sector delivery (#5)	05 May 2015
KO	PA signature	19 Nov 2008
	Contract award	15 Jan 2010
	1st sector delivery (#6)	18 Mar 2015
RF	PA signature	09 Jun 2009
	Contract award	09 Jun 2009
IN	PA signature	24 Sep 2009
	Contract award	01 Sep 2010

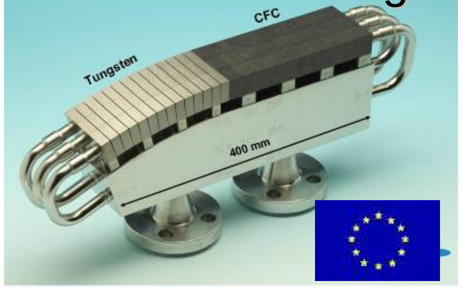
(Bak)

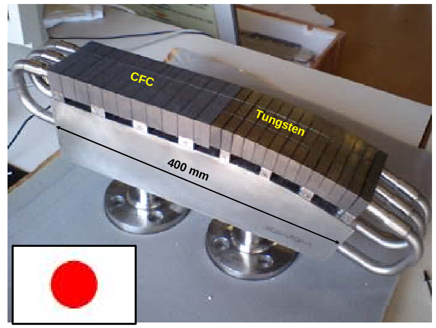


Divertor

ITER

Inner Vertical Target



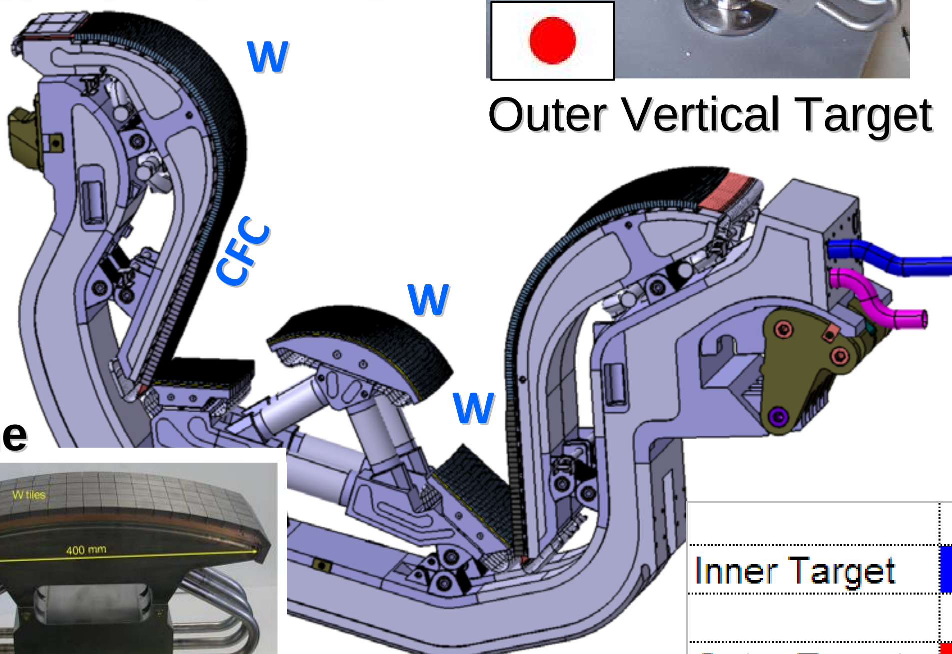


Outer Vertical Target

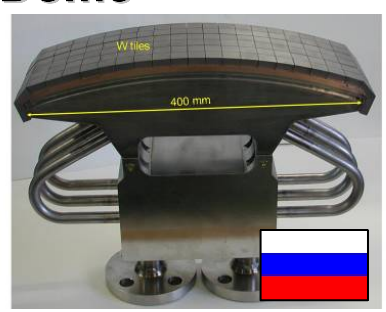
Status and Plan

- Pre-qualific. mock-up's testing successful (JA/EU/RF) by 2009.
- After successful completion of Prototypes testing (final qualification), each DA will start procurement, to be completed in 2019.

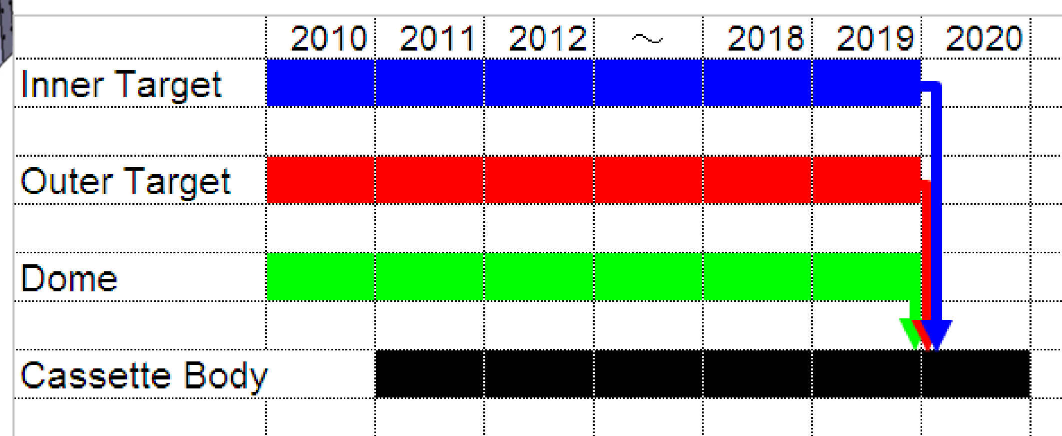
(Merola)



Dome

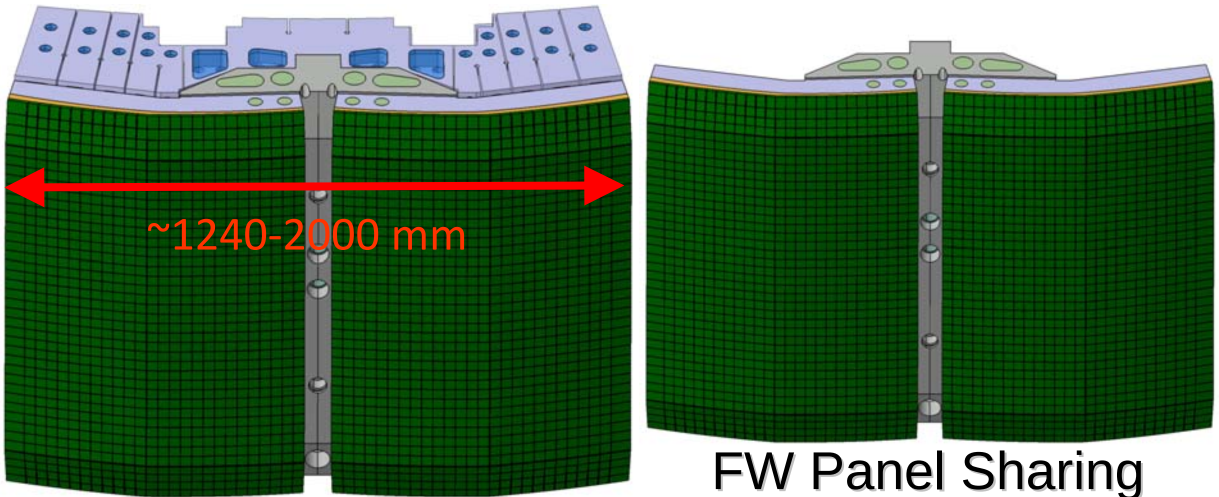


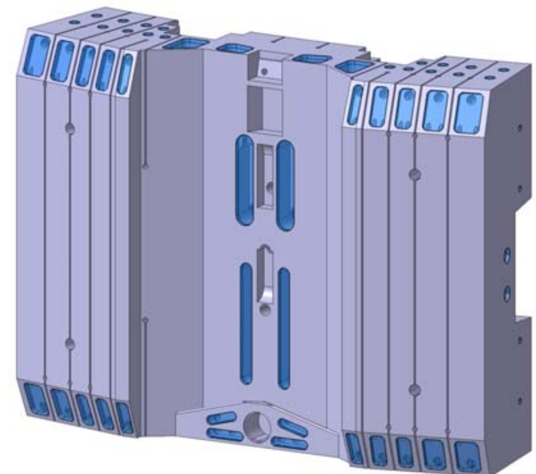
Procurement schedule



Procurement sharing and Qualification Prototypes

First Wall and Blanket





FW Panel Sharing

50%

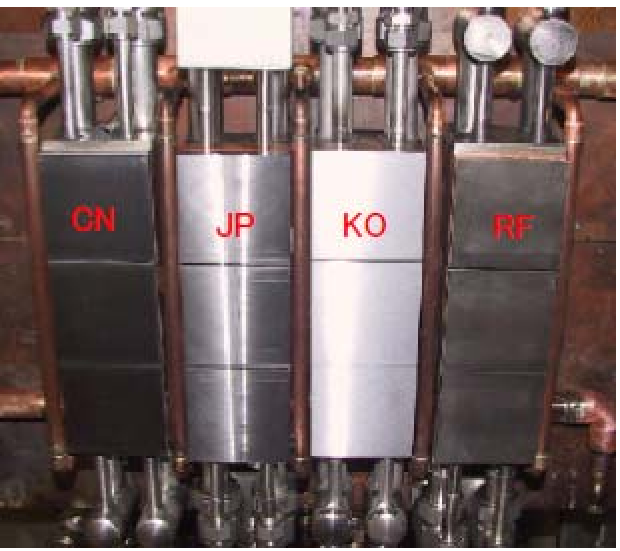
40%

10%

Shield Block Sharing

50%

50%



First wall qualification test
(at Sandia National Lab.)

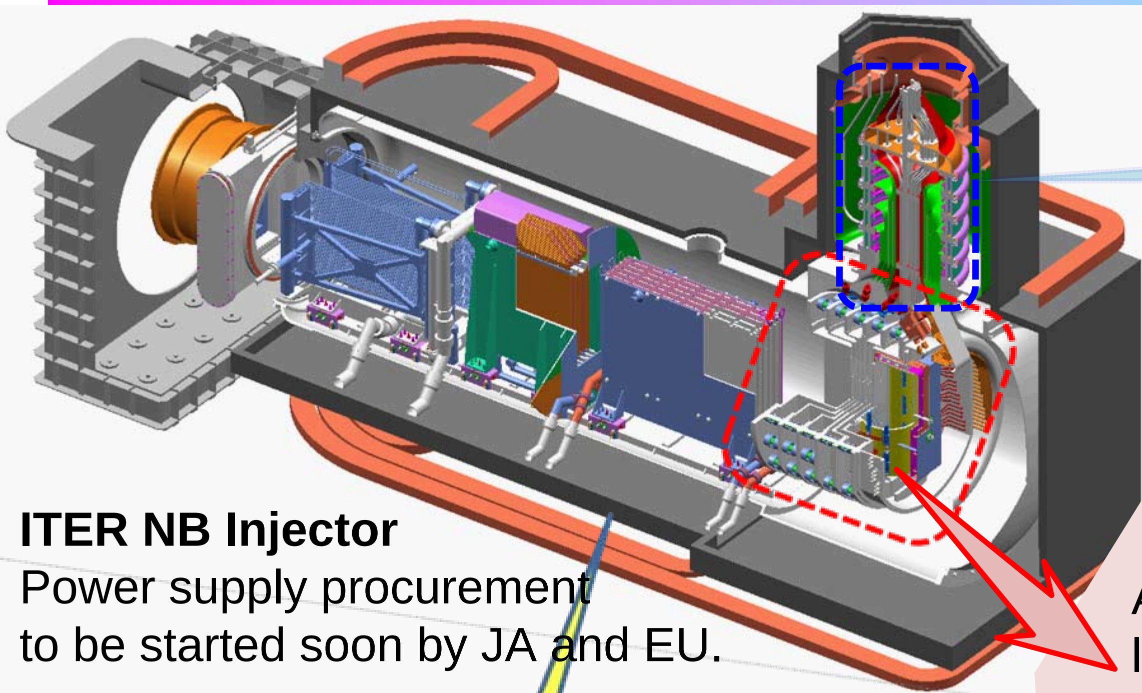
Procurement Schedule

February 2010 → Conceptual Design Review
Late 2011 → Preliminary Design Review
Late 2012 → Final Design Review
End-2012 → Start procurement
End-2019 → Last Delivery on Site

(Merola)

Neutral Beam H&CD

ITER

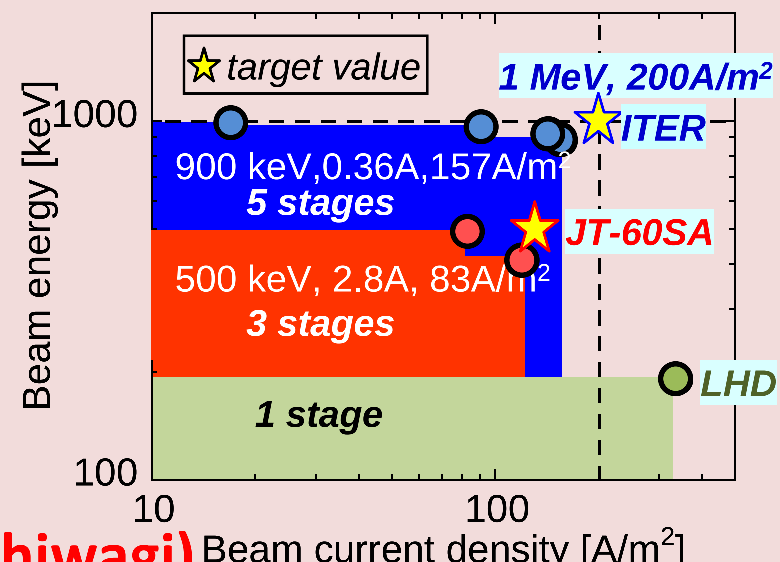


ITER NB Injector
Power supply procurement
to be started soon by JA and EU.

Accelerator voltage holding
led to beam parameter improvement.

NBTF design at Consorzio RFX, Padua
To be operational ~ 2017.

(Sonato)

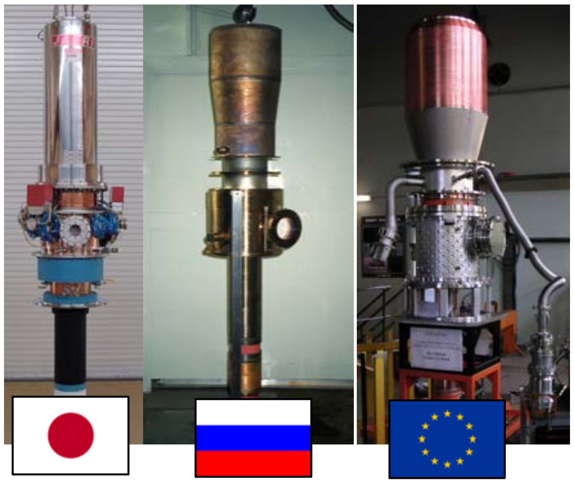


(Kojima, Kashiwagi)

Gyrotron for ECH&CD

ITER

ITER Gyrotron development

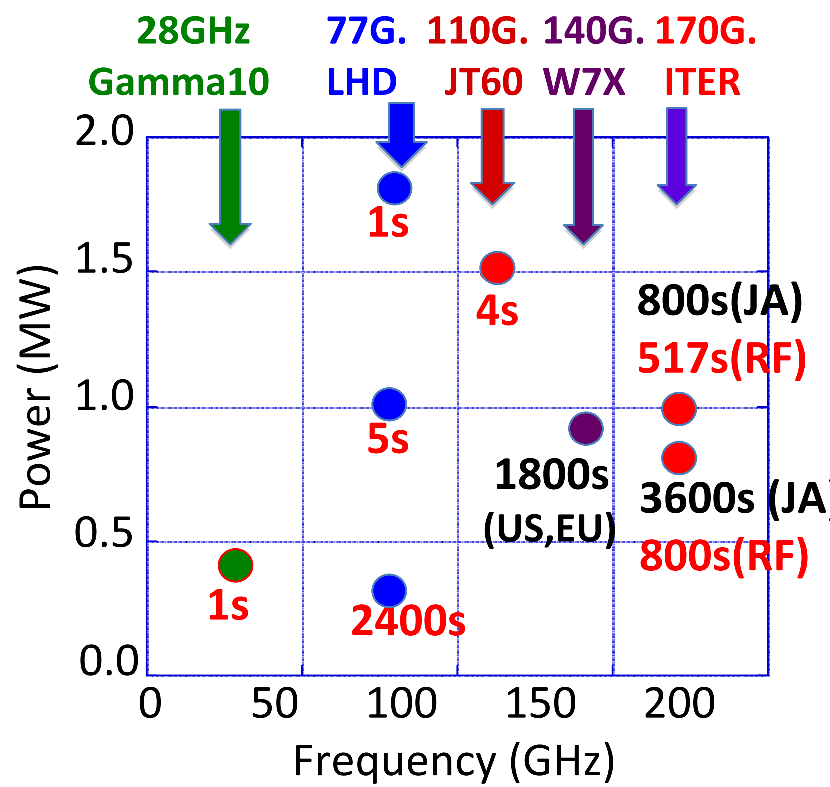


New results on 170GHz gyrotrons

- 1MWx570s at Russian gyrotron **(RF)**
- 2.2MW (5ms) on coaxial gyrotron **(KIT)**
- Repetitive operation of 0.8MWx600s with every 30 min for 8 days **(JAEA)**
- 5kHz-1.1MW-CW power modulation was proved for NTM suppression **(JAEA)**
- 1.3MW outputs at 170GHz and 136GHz with dual frequency gyrotron **(JAEA)**

Gyrotron powers attained

(Red: New data after 2008, >1s)

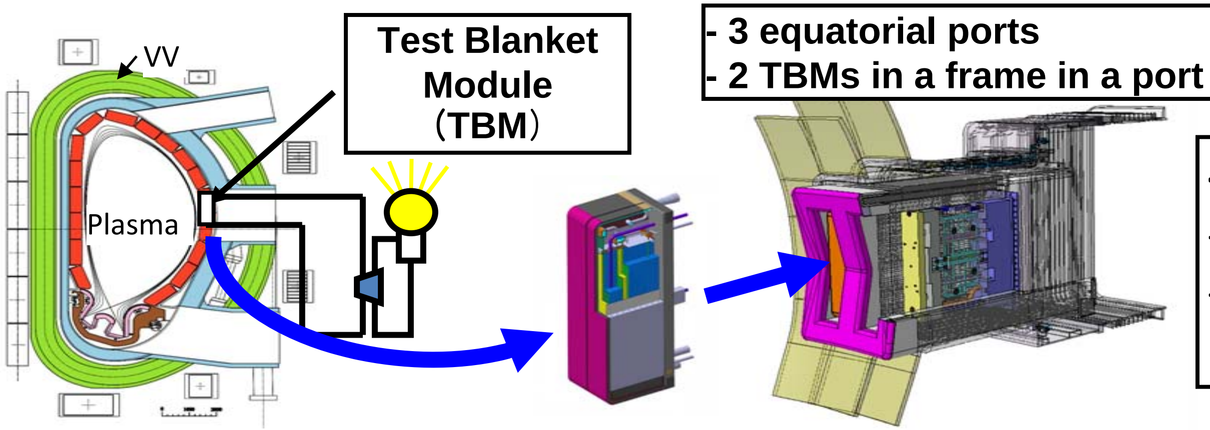


- 1.8 MWx1s for LHD **(Imai)**
- 1.5 MWx4s for JT-60SA **(Kobayashi)**

(Litvak, Sakamoto, Gantenbein)

ITER Test Blanket Module (TBM) Program

Unique testing to evaluate blanket functions of prototypical modules of DEMO Blankets in the real fusion environment of ITER.



- Production of tritium
- Extraction of energy
- Soundness of structure

- **ITER Council approved TBM Program be undertaken within ITER framework.**
- **ITER Organization will prepare infra-structure and components needed for TBM testing and provide space for testing.**
- **Proposed is to test initial TBM in 2020 and to test DT phase TBM in 2027.**

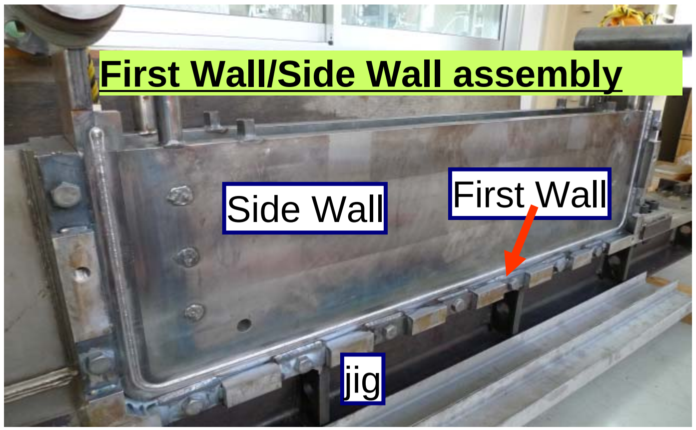
Present status of the selection of the six TBM Systems to be installed in ITER

Port No. and PM	TBM Concept	TBM Concept
16 (PM : EU)	HCLL (TL : EU)	HCPB (TL : EU)
18 (PM : JA)	WCCB (TL : JA)	DCLL (InCo : US (KO))*
2 (PM : CN)	HCCB (TL : CN)	LLCB (TL : IN)

(*InCo=Interfaces Coordinator (=TBM delivery not committed))
HCLL : Helium-cooled Lithium Lead, **HCPB** : He-cooled Pebble Beds (Ceramic/Beryllium)
WCCB : Water-cooled Ceramic Breeder (+Be), **DCLL** : Dual Coolant (He & LiPb) Lithium Lead
HCCB : He-cooled Ceramic Breeder (+Be), **LLCB** : Lithium-Lead Ceramic Breeder (DC type, He & LiPb)

R&Ds on TBM - Highlights of this Conference

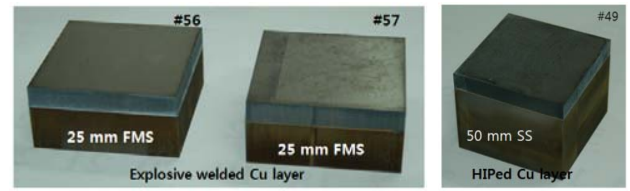
- Full-scaled TBM mock-ups successfully fabricated from Reduced Activation Ferritic/Martensitic (RAF/M) steel, and their functions confirmed. (JA: Tanigawa)



- Tritium recovery ratio of 1.05± 0.08 from the ceramic breeder measured at 873 K under DT neutrons for the first time in the world. (JA: Ochiai)

DT neutron irradiation mock-up

- For joining Be to RAF/M, HIP(hot isostatic pressing) technology applied, and performances verified by thermal fatigue test. (KO: Lee)



Mockups

- A 500kg of RAFM (CLF-1)s teel was recently produced by vacuum induction melting and electroslag remelting method. Be pebbles and the Breeder pebbles (Li_2TiO_3, Li_4SiO_4) successfully fabricated. (CN: Feng)

RAFM(CLF-1)steel

Be Pebbles

Simulated ITER TBM Error Field Experiments Showed Effects to be Small and Probably Correctable

ITER

RESULTS

Small Effects on:

- Plasma startup
- L-mode confinement
- L-to-H transition
- ELMs
- RMP ELM suppression
- Fast ion power loss
- Divertor splitting

Of Concern if Scaling is too Unfavorable:

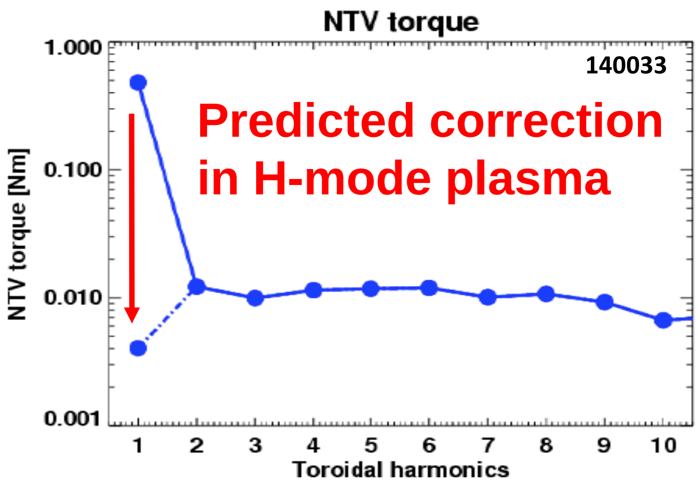
- H-mode confinement and plasma braking at high ß

- **Confinement loss correlates with flow braking**

THEORY says most TBM braking is NTV from a few n=1 harmonics

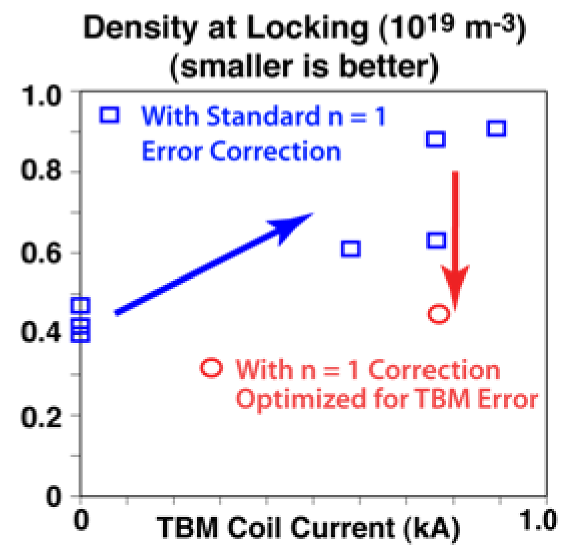
- Plasma amplifies n=1

IPEC predicts correction in DIII-D plasma



EXPERIMENT demonstrated n=1 compensation of TBM effect on locked modes

- Despite uncorrected n>1

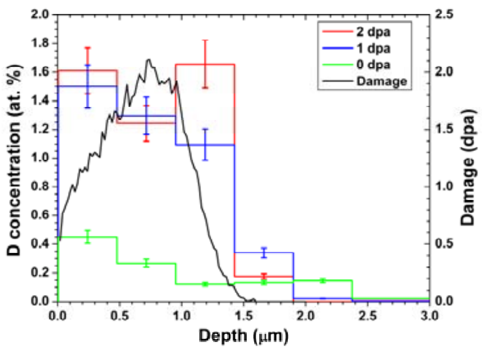


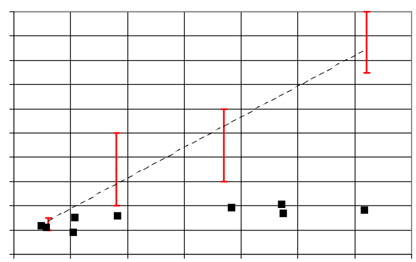
(Schaffer)

D retention in irradiated W-targets

Fusion Technology

Simulation of neutron irradiation by 12.3 MeV W^{4+} ions and subsequent exposure to ITER divertor like ion fluxes in Pilot-PSI (10^{24} $m^{-2}s^{-1}$, Te~1 eV)

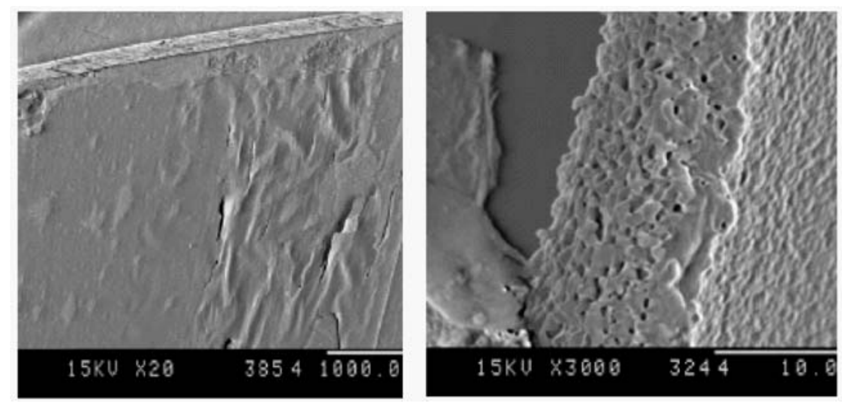




- Pronounced increase of D retention for damage levels of 0.5 dpa and higher
- Relative enhancement of D-retention is highest at high target temperature

(Rapp)

Simulation of neutron irradiation by 3-4 MeV $^4He^{2+}$ ions and subsequent exposure to ITER first wall like ion fluxes in Lenta (E_i=250 eV)



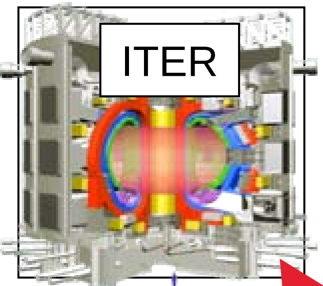
- Irradiation by $^4He^{2+}$ ions led to large voids (Δ=2µm) and nano-structures in the material
- D-retention was highest in those voids

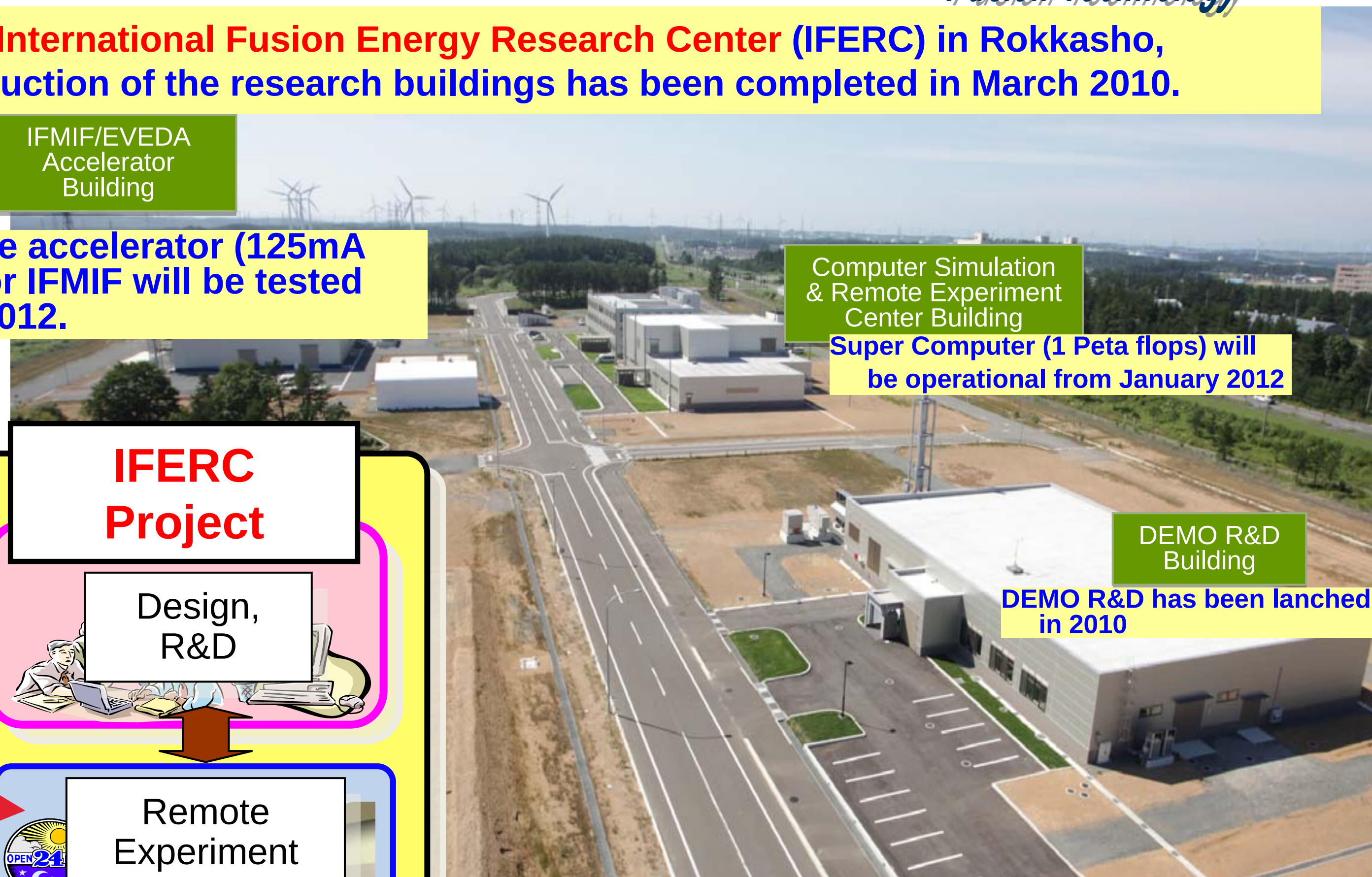
(Koidan)

Broader Approach (BA) Activities

Fusion Technology

■In the **International Fusion Energy Research Center (IFERC) in Rokkasho, construction of the research buildings has been completed in March 2010.**



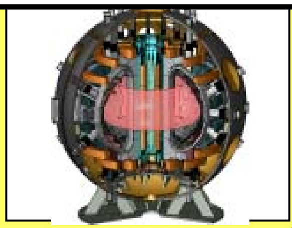


Prototype accelerator (125mA CW) for IFMIF will be tested from 2012.

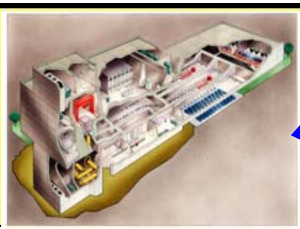
Super Computer (1 Peta flops) will be operational from January 2012

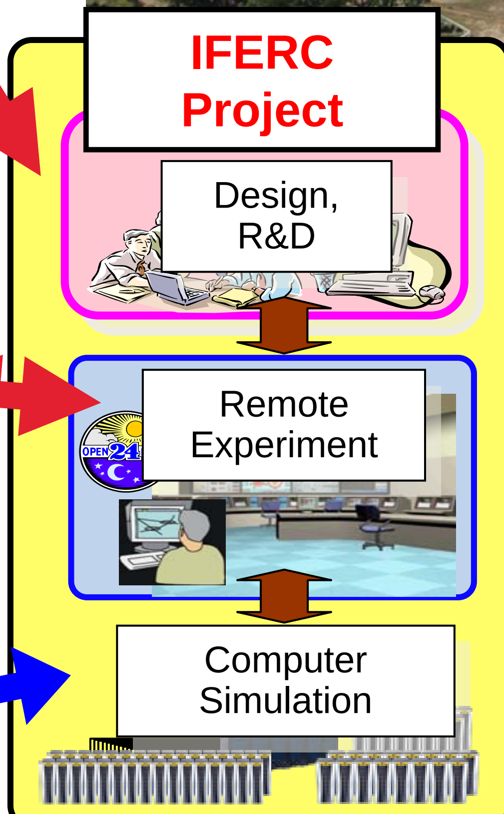
DEMO R&D has been lanched in 2010

Satellite Tokamak Project



IFMIF/EVEDA Project





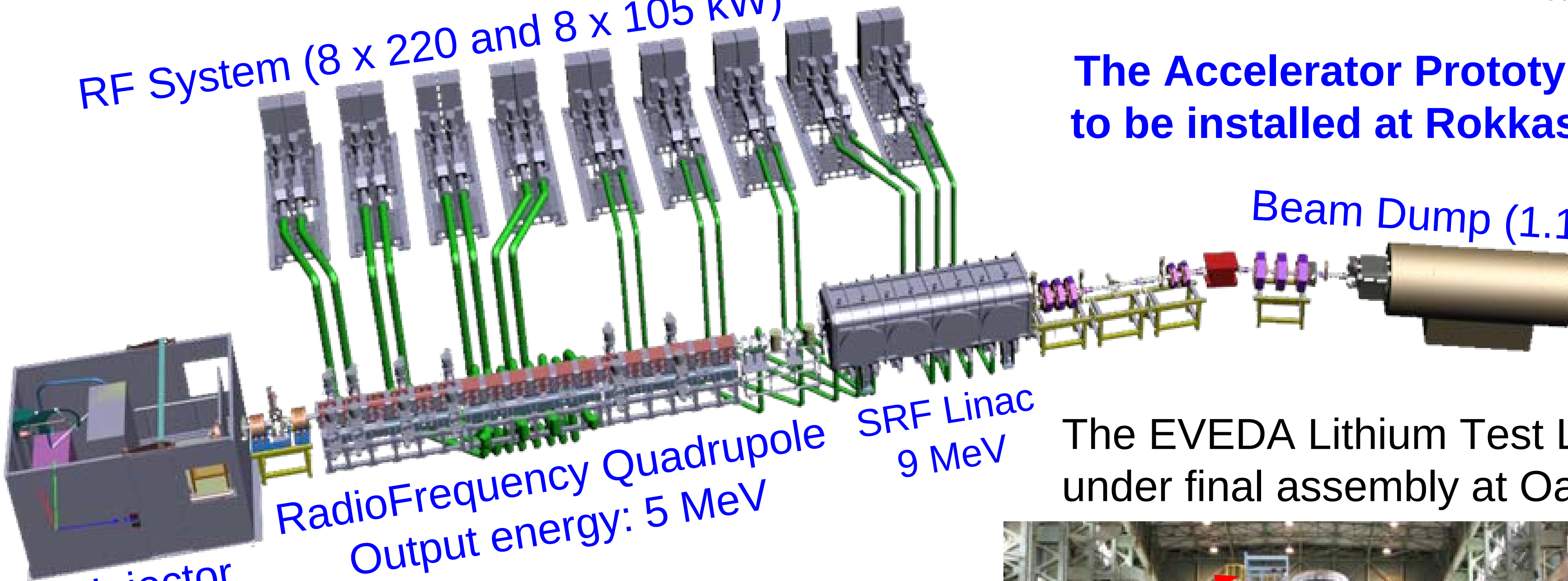
■**Five potential R&D for DEMO R&D (Yamanishi)**

- **SiC/SiC Composites**
- **Tritium Technology**
- **Reduced Activation Ferritic/Martensitic Steels**
- **Advanced Neutron Multiplier**
- **Advanced Tritium Breeders**

F82H Slab

IFMIF/EVEDA Status

Fusion Technology



The Accelerator Prototype, to be installed at Rokkasho

The EVEDA Lithium Test Loop, under final assembly at Oarai

Vessel containing the Target Assembly

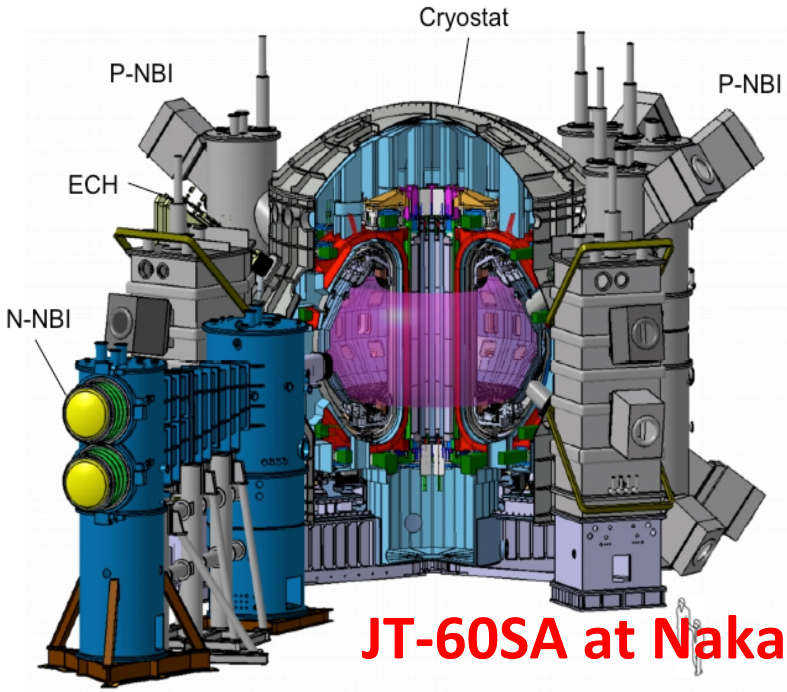
- Manufacturing of the Accelerator Prototype has started.
- Assembly of the EVEDA Lithium Test Loop is almost completed.
- IFMIF Engineering Design has started, with the goal to deliver the Engineering Design Report by mid 2013.

(Garin)

JT-60SA is being constructed

Fusion Technology

(Barabaschi, Ishida, Kamada)

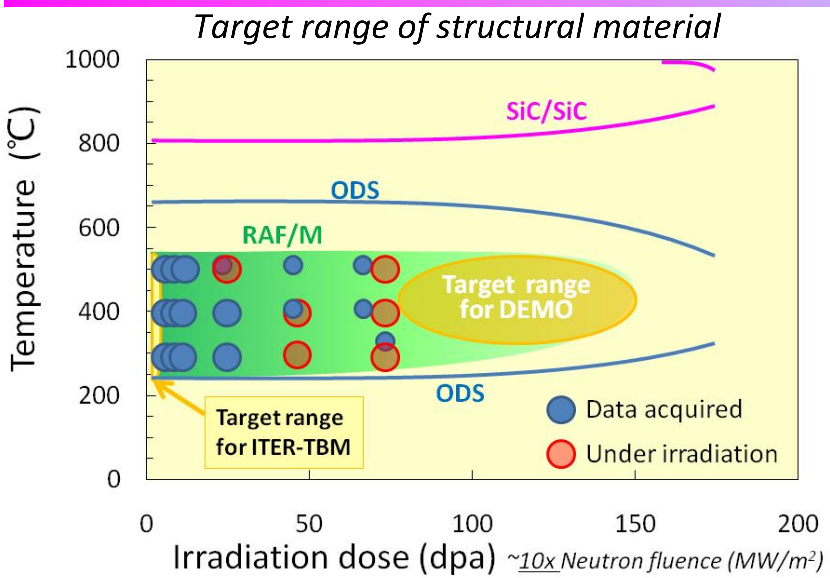


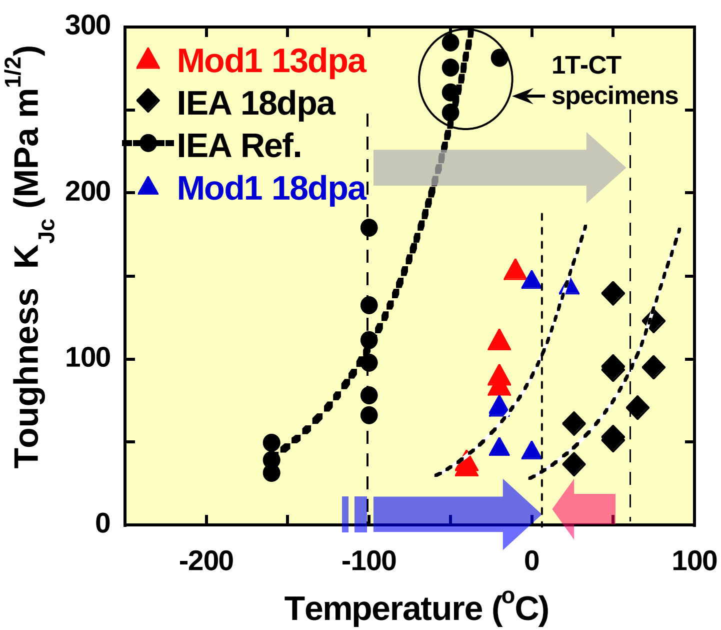
- **To explore high beta steady state and ITER-relevant regimes with high performance and high shaping capability for ITER and DEMO.**
- **International project for construction and exploitation contributed by EU/JA.**
- **Machine design completed in 2008.**
- **Procurement activities started for TF and PF magnets, vacuum vessel, divertor, first wall materials, cryostat and power supply.**
- **PF magnet and vacuum vessel are being manufactured.**

I_p = 5.5 MA, B_t = 2.25 T
R = 2.97 m, a = 1.18 m, A ~2.5
Shape: κ_x ~ 2, δ_x ~ 0.6, S ~ 7
Fully superconducting magnets
Heating power: 41 MW (D^0 into $D^{+)}$ with
N-NBI(500 keV), P-NBI and ECRF
Duration: 100 sec
In-vessel: divertor cassette, control coils

- **Disassembly of JT-60 facilities proceeds.**
- **Start of tokamak assembly and first plasma are planned in 2012 and 2016, respectively.**
- **JT-60SA research plan development started.**

Development of Reduced-activation Structural Materials





Candidate materials:

- Ferritic/martensitic (RAF/M) steels as a leading candidate (F82H, EUROFER)
- ODS, V-alloys and SiC/SiC composite as advanced candidates

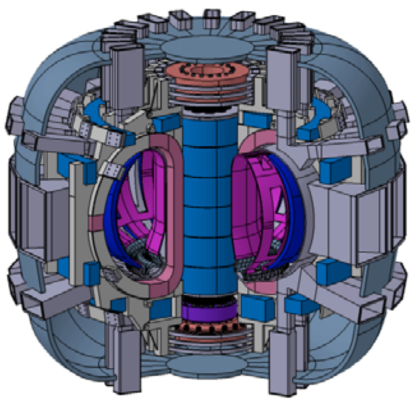
Evaluation of RAF/M steels:

- On-going with irradiation database toward the design window
- Suppression of irradiation-induced hardening and embrittlement possible (F82H) by applying appropriate heat treatment **(Ohkubo)**
- Low cycle fatigue lifetime after 70dpa irradiation comparable to that of unirradiated (EUROFER97) **(Gaganidze)**
- China(CLAM) and Russia (RUSFER) initiated development of RAF/M **(Chernov)**

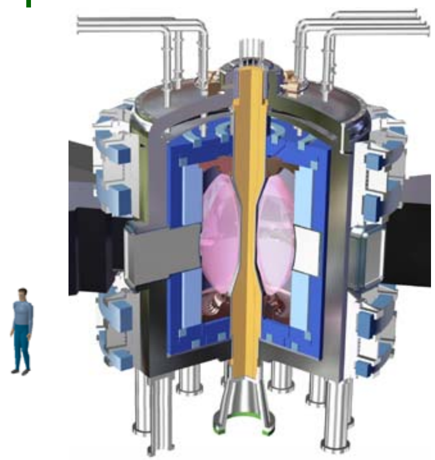
Designs / Concepts for Next-Term D-T Facilities

Fusion Technology

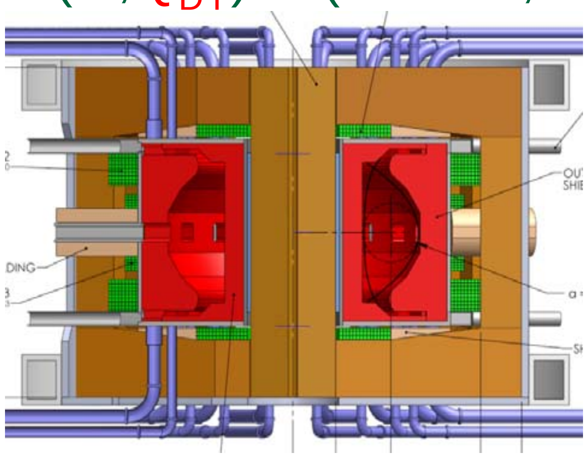
- FAST (ENEA), FNSF-ST (ORNL), FDF / FNSF-AT (GA)
- R = 1.3m – 2.7m; Aspect ratio = 1.6 – 4; Q_{DT} = 0.1 – 7
- Support or complement ITER: ITER: (R;Q_{DT}) = (6.21m;5-10)



FAST (1.85m;<1.5)

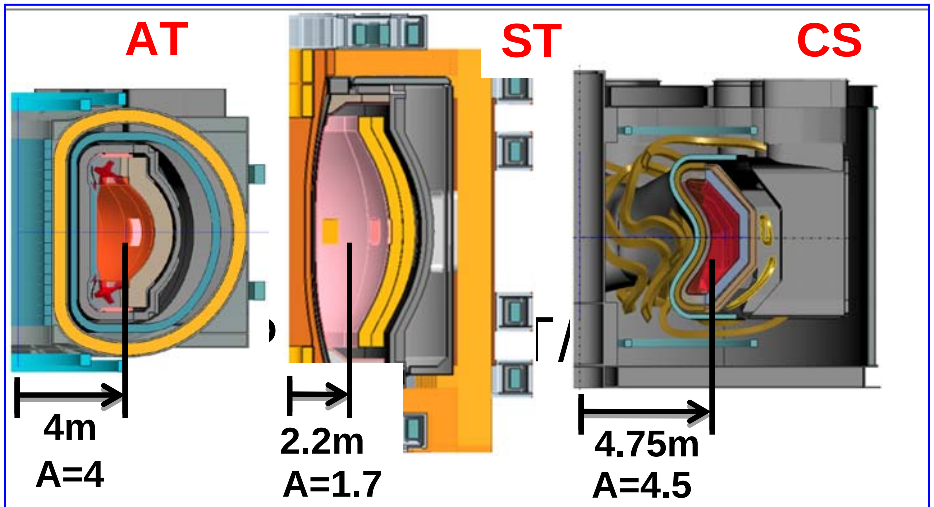


FNSF-ST (1.3m;<3)



FDF / FNSF-AT (2.7m;<7)

(Peng, Chan, Crisanti)



Pilot Plant (AT/ST/CS)

(Menard)

Concluding Remarks (1/2)

- In the sessions of ITR, FTP and SEE, 159 contributions were presented in total, showing remarkable progress of the ITER Project and good progress in the areas of a variety of complementary activities to DEMO, including BA activities and long-term fusion technology.

- ITER Baseline has been established, and procurement activities have been started in the member countries as planned under the leadership of IO. In particular, those for the long lead-time components are now in a serious manufacturing phase with a target to realizing the first plasma in 2019.

- ITER physics basis is sound. Operation scenarios and operational issues (ELM, RE, etc.) have been extensively studied in close collaboration with ITPA. Further efforts are strongly encouraged with a focus on some of the key operational issues.

Concluding Remarks (2/2)

- **Test Blanket Module program has been incorporated in the ITER Program, and extensive R&Ds has been on-going in the member countries with a view to delivering their own TBMs in a timely manner according to the ITER master schedule.**

- **Broader Approach Activities (EU-JA collaboration) are now at a full swing. Dismantling of JT-60 and manufacturing of key components are on going in JT-60SA Project, and engineering validation activities by prototypical accelerator and Li loop has started in IFMIF/EVEDA Project.**

- **Development of reduced-activation structural materials is one of the most critical, long-term R&D items toward DEMO, and very promising progresses were reported in this conference.**

- **Also presented and discussed in this conference were interesting concepts of near-term DT facilities with a mission to mitigate physics and/or technology risks from ITER to DEMO, which are subject to further discussions in the fusion community.**