Status of JT-60SA Project and Rokkasho Broader Approach activities

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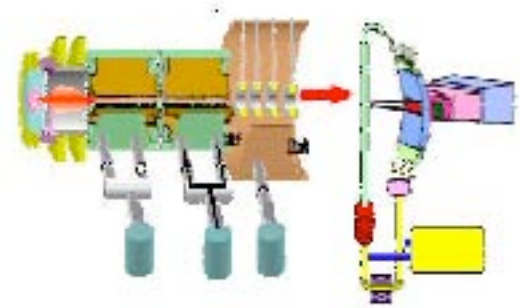
1. Broader Approach
2. Status of JT-60SA Project
3. Status of BA activities at Rokkasho

Broader Approach (BA) comprises three Projects

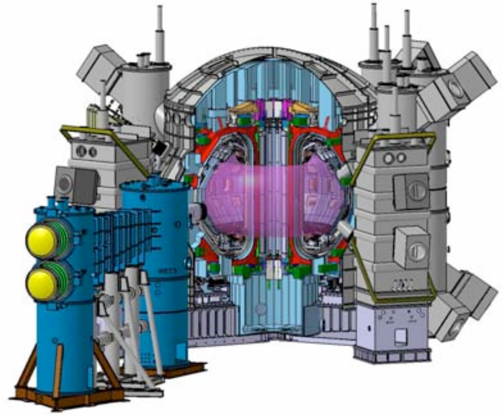
1) **Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA)**



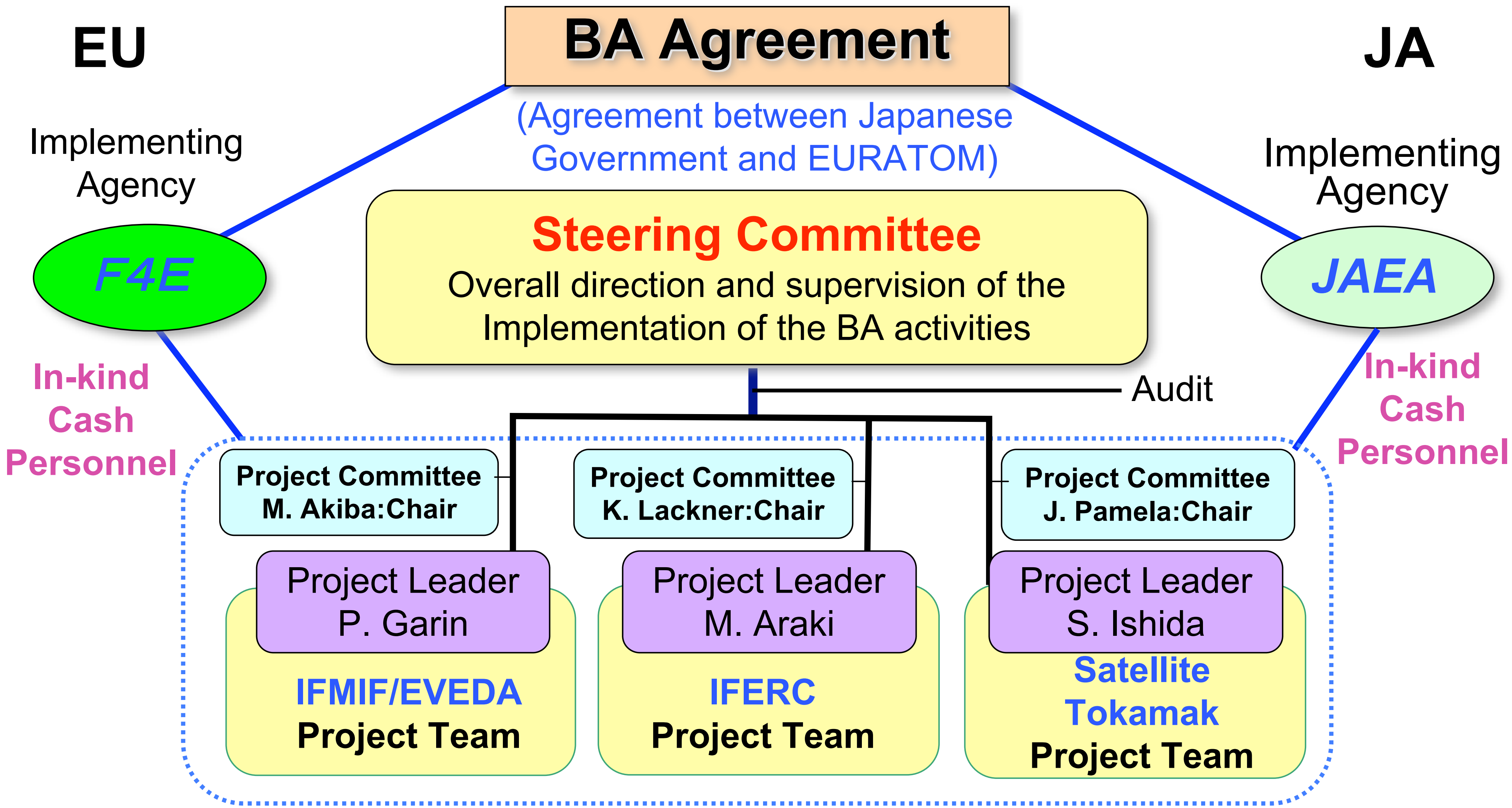
2) **International Fusion Energy Research Center (IFERC),**
   - a) **DEMO Design and R&D coordination Center**
   - b) **Computational Simulation Center**
   - c) **ITER Remote Experimentation Center**

3) **Satellite Tokamak Programme**

Participation to upgrade of JT-60 Tokamak to JT-60SA and its exploitation.



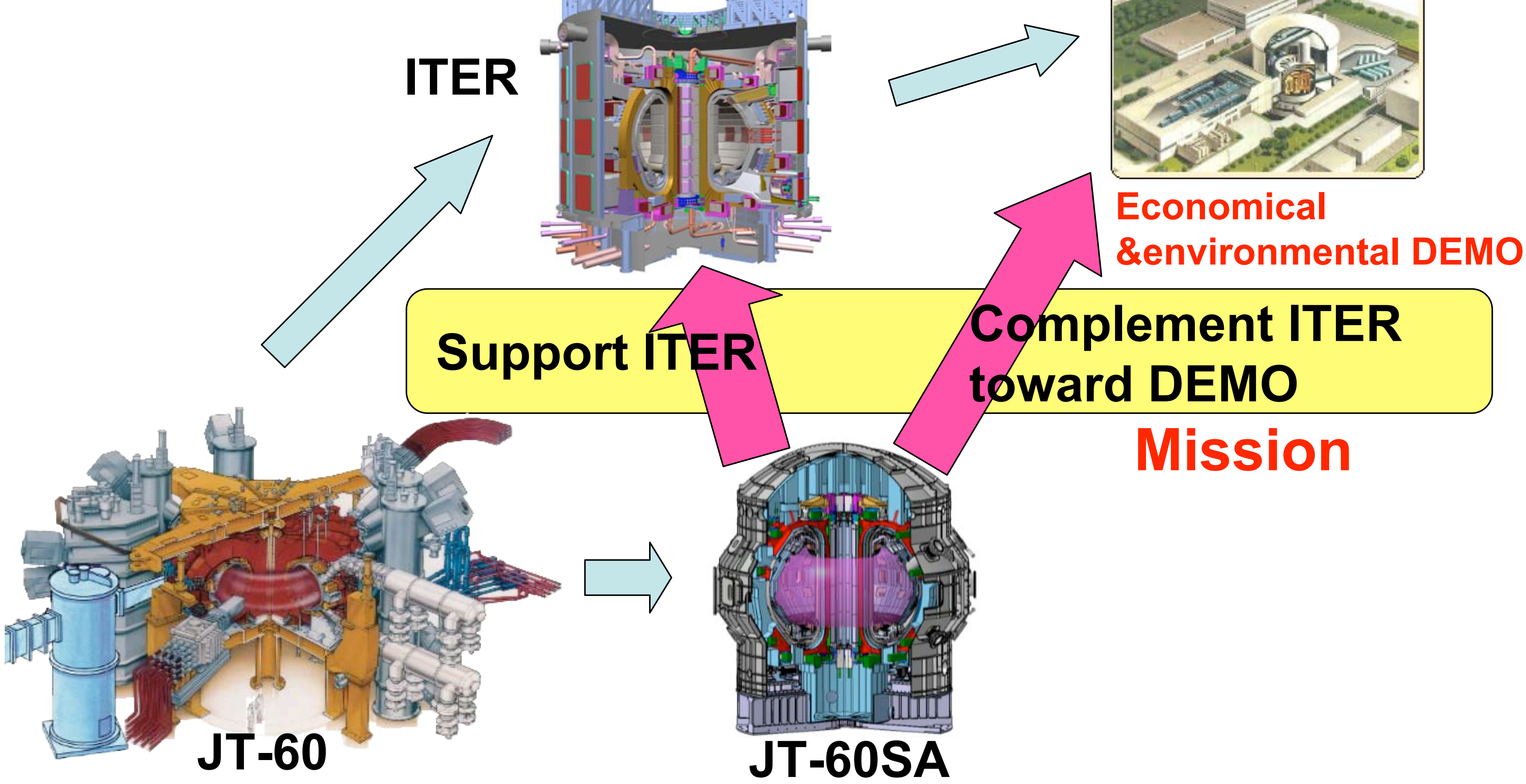
Management Structure for Broader Approach



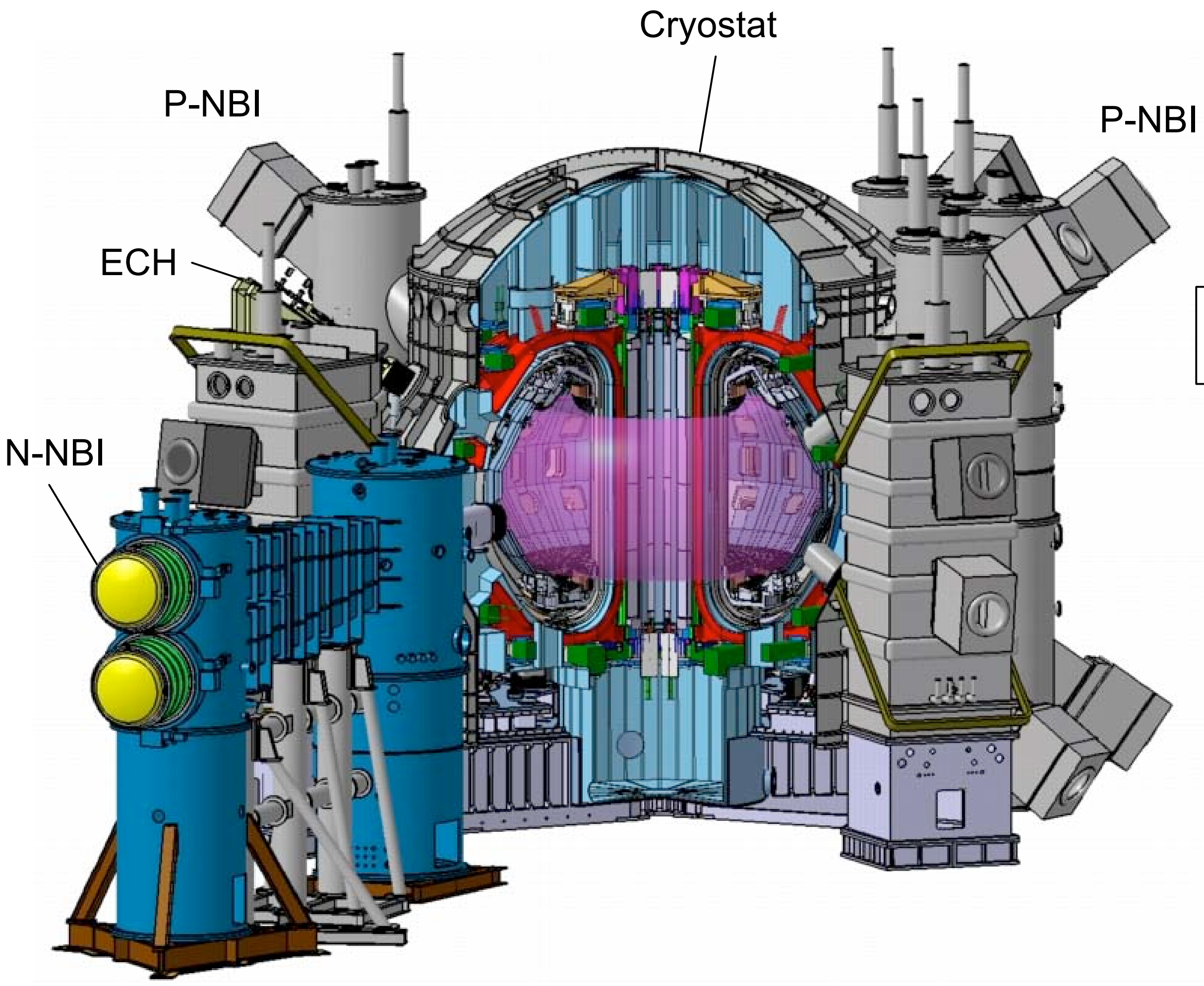
Status of JT-60SA Project

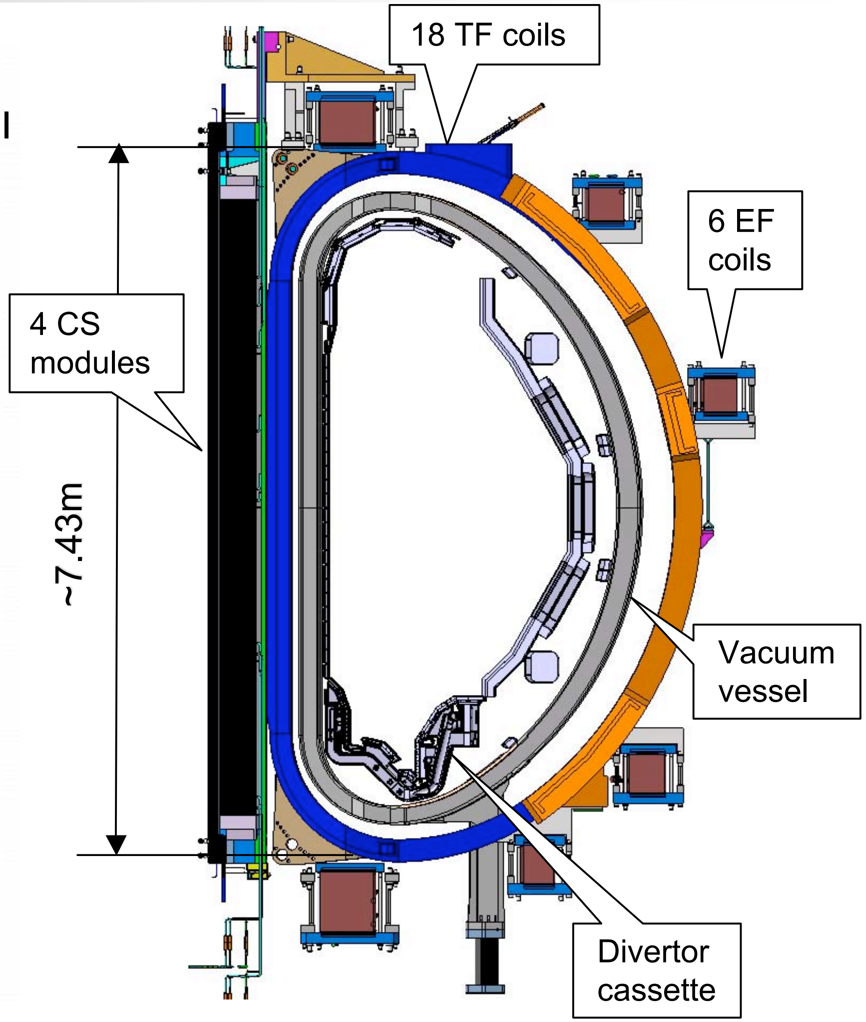
JT-60SA (Super Advanced) project

- A combined project of the ITER Satellite Tokamak Programme of EU-JA Broader Approach and the Japanese national program.
- Contribute to the early realization of fusion energy by addressing key physics issues in ITER and DEMO.



JT-60SA tokamak overview

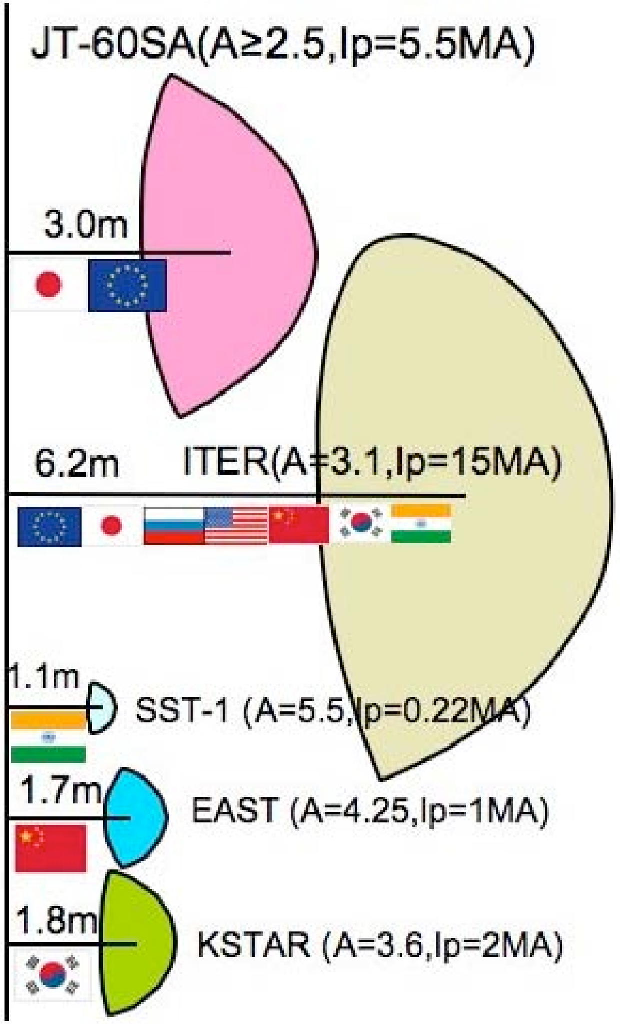


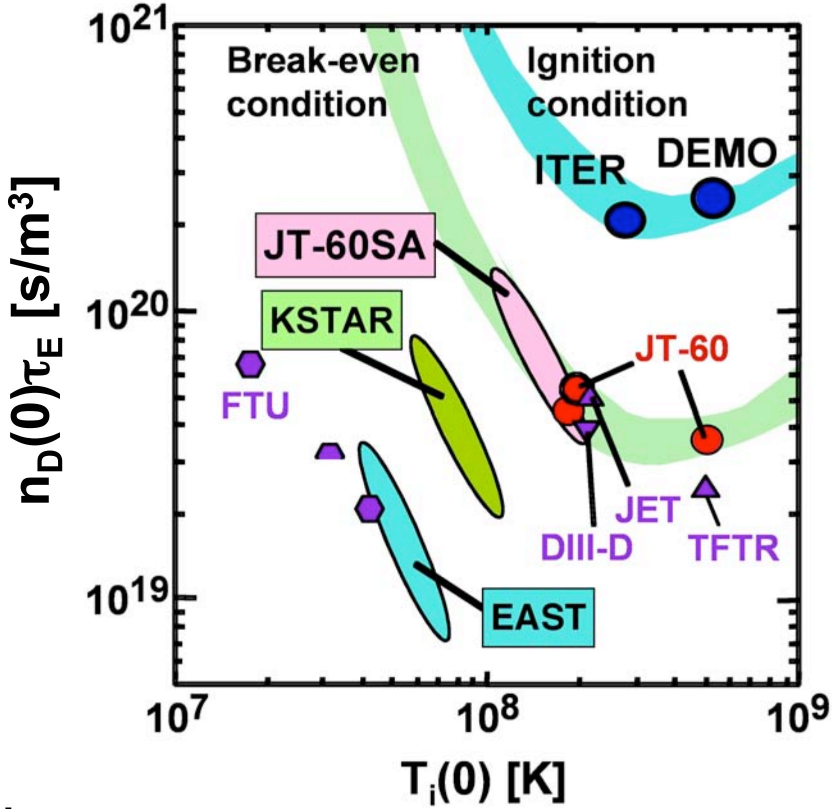


- **Superconducting TF and PF (CS&EF) coils.**
- **Low aspect ratio (A=2.5), Ip = 5.5 MA, Bt = 2.25 T.**
- **All plasma-facing-components will be water-cooled (@40°C).**
- **Compatible with Remote Handling maintenance (divertor cassette).**

JT-60SA Plasma Regime

- A unique superconducting tokamak (except for ITER) capable of operating in the equivalent break-even regime.





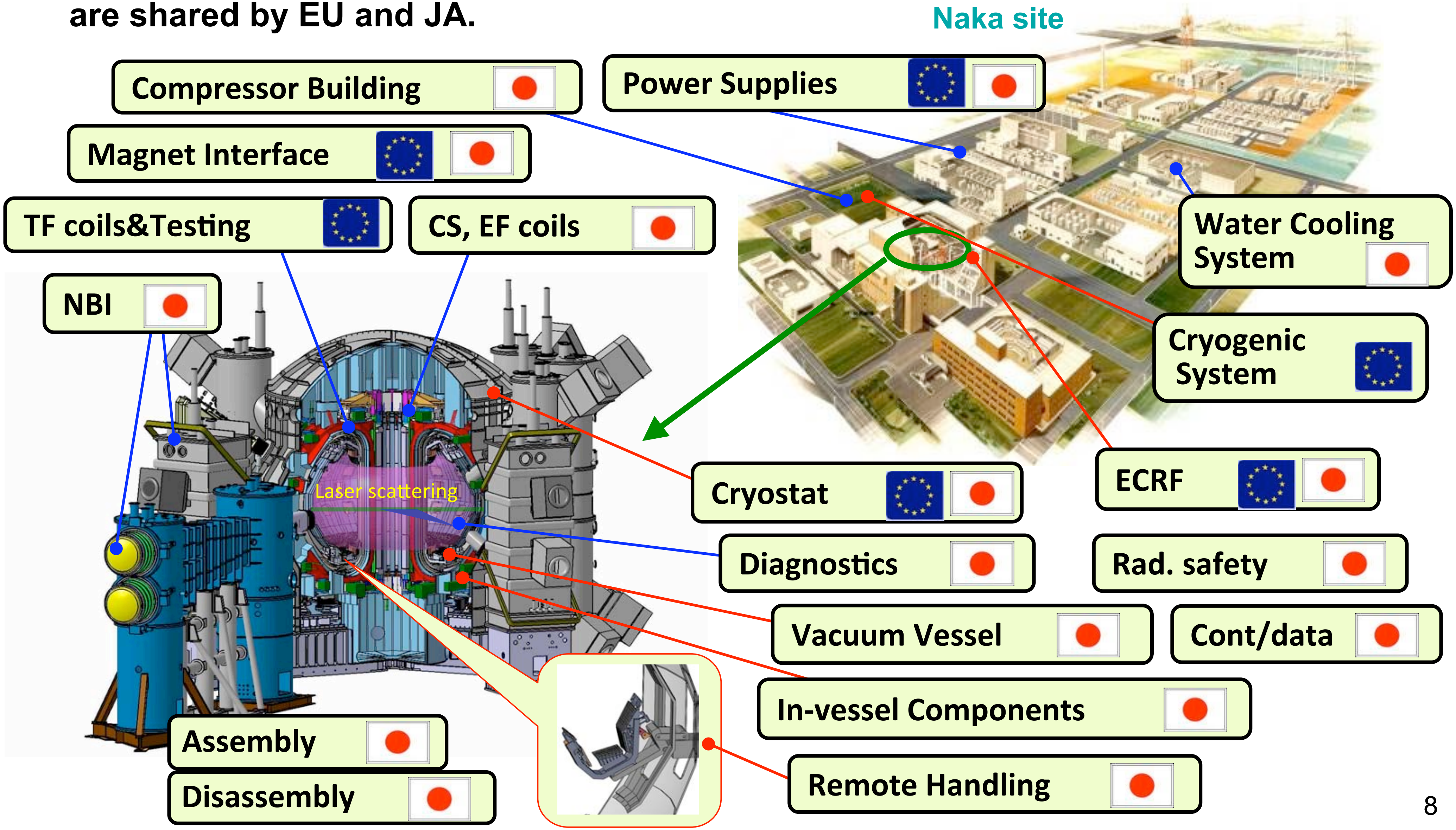
Conditions:

H_{H98y2}=1.3, n_e/n_{GW}=0.4-1, $T_e=T_i$, Z_{eff}=2 (carbon)
$n_e(r)=n_e(0)(1-\rho^2)^{an}$, a_n=0.5,
$T_e(r)=T_e(0)(1-\rho^2)^{aT}$, a_T=1.5,
P_{heat} = 41 MW(JT-60SA), 16 MW(KSTAR), 7 MW(EAST)

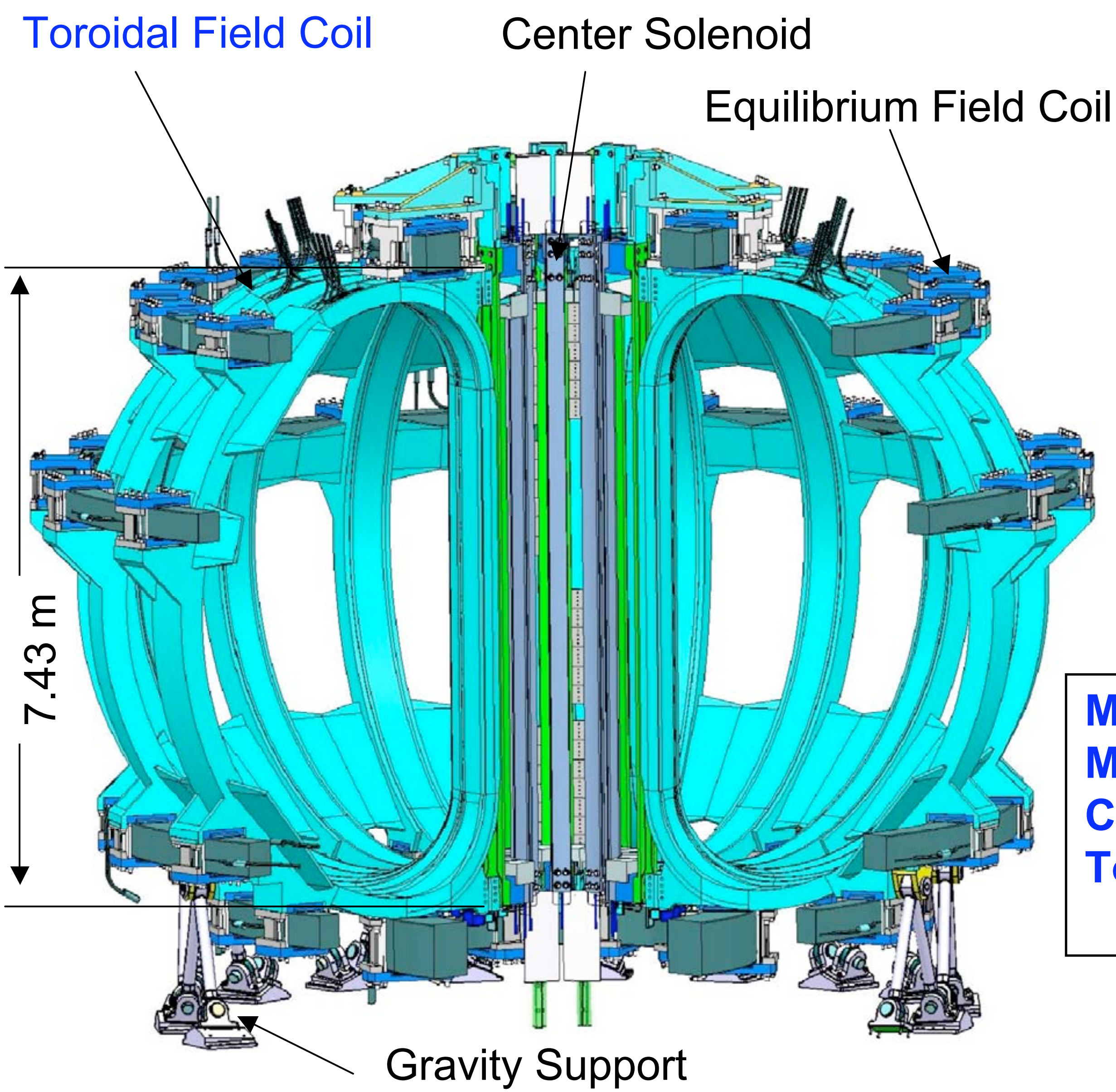
JT-60SA Advanced Superconducting Tokamak BA-Satellite Tokamak Program

EU-JA sharing of components

- In-kind contributions for construction and financial contributions for exploitation are shared by EU and JA.



Superconducting Magnet System



- **18 TF coils, a CS with 4 modules, and 6 EF coils.**
- **Conductors are cooled by a forced-flow of supercritical helium.**
- **High-Temperature-Superconducting current leads will be used for all SC magnets to reduce cryogenic loads.**

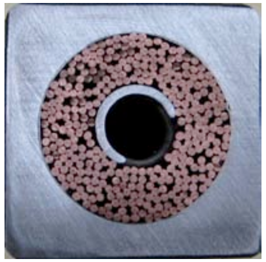
Magnetic energy in TF coils: 1.5 GJ
Maximum field in TF coils: 5.8 T
CS peak field: 8.9 T
Total weight of magnet system ~ 700 tons (4K)

Superconducting Conductors

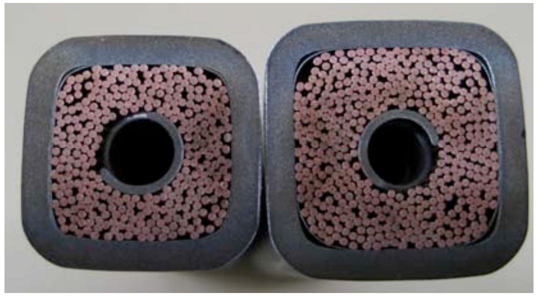
Coil	TF	CS
Type of strands	NbTi	Nb3Sn
Operating current (kA)	25.7	20
Nominal peak field (T)	5.65	8.9
Operating temperature (K)	4.9	5.1
Number of SC strands/Cu strands	324 / 162	216 / 108
Local void fraction (%)	32	34
Cable dimensions (mm)	18.0 x 22.0	Φ21.0
Central hole (id x od) (mm)	non	7 x 9
Conductor ext. dimensions (mm)	22.0 x 26.0	27.9 x 27.9
Jacket material	SUS316L	SUS316LN

Conductor type	EF-H	EF-L
No. of coils	EF3, 4	EF1, 2, 5, 6
Type of strand	NbTi	←
Operating current (kA)	20.0	←
Nominal peak field (T)	6.2	4.8
Operating temperature (K)	5.0	4.8
Number of SC/Cu strands	450 / 0	216 / 108
Local void fraction (%)	34	34
Cable dimensions (mm)	21.8	19.1
Central hole (id x od) (mm)	7 x 9	←
Conductor ex. dimensions (mm)	27.7	25.0
Jacket material	SUS316L	←

TFC conductor



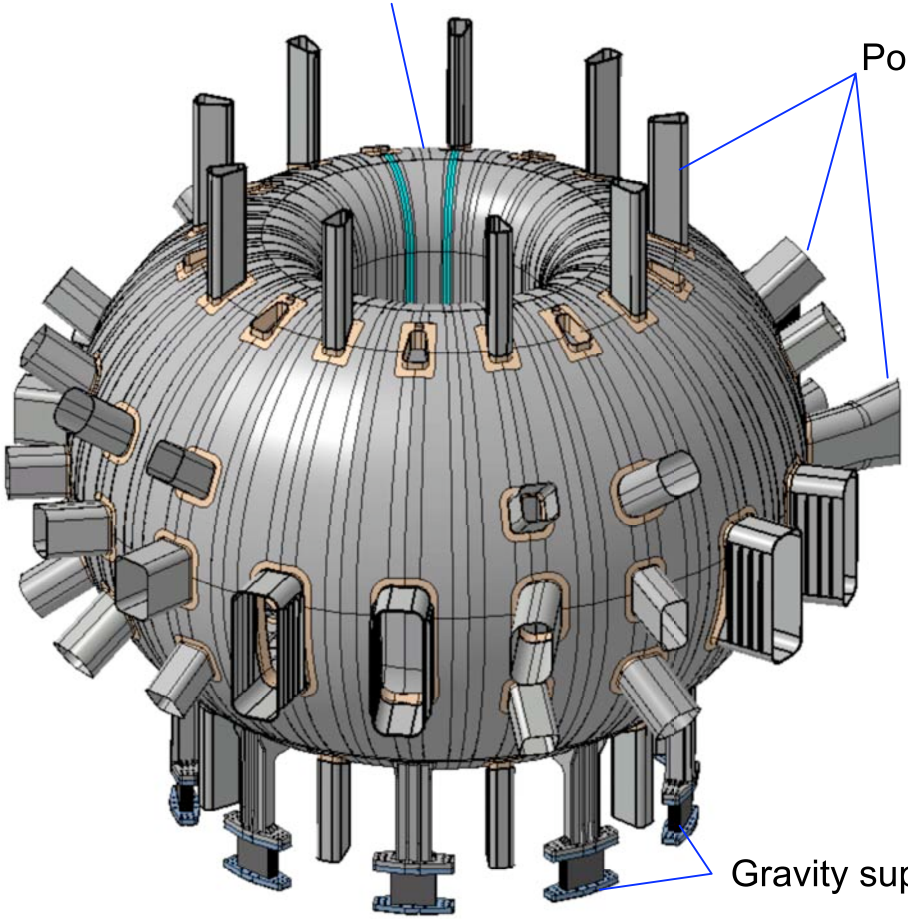
CS conductor



EF-L&H conductor

Vacuum Vessel

Torus outside diameter	9.95 m
Torus inside diameter	2.86 m
Torus height	6.63 m
Inner/outer shell thickness	18 mm
Main vessel body weight	~150 ton
One turn resistance	~19 μΩ

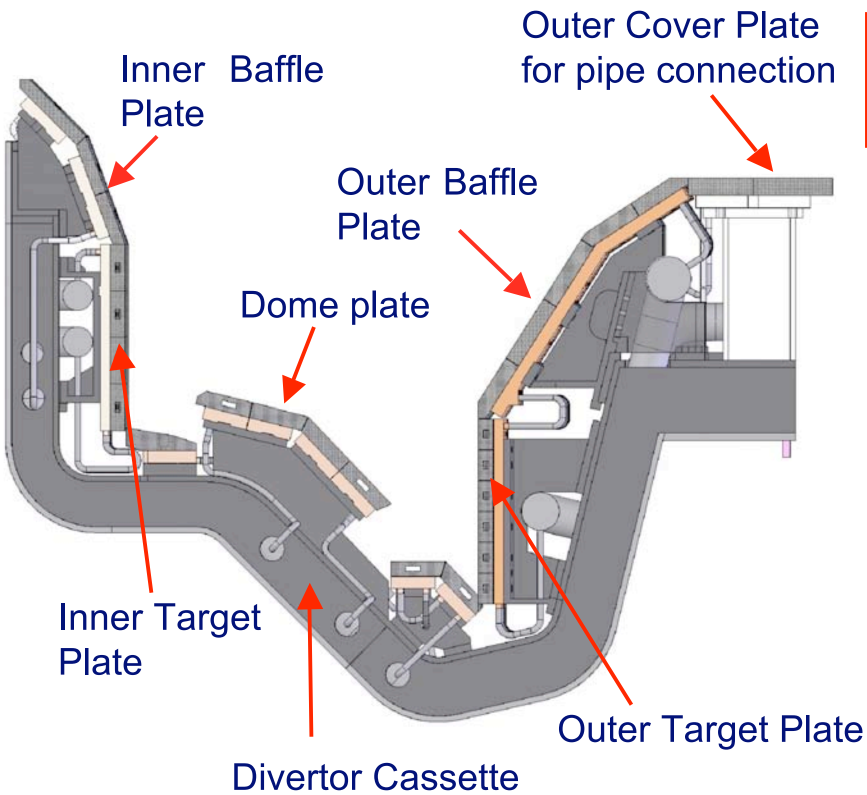


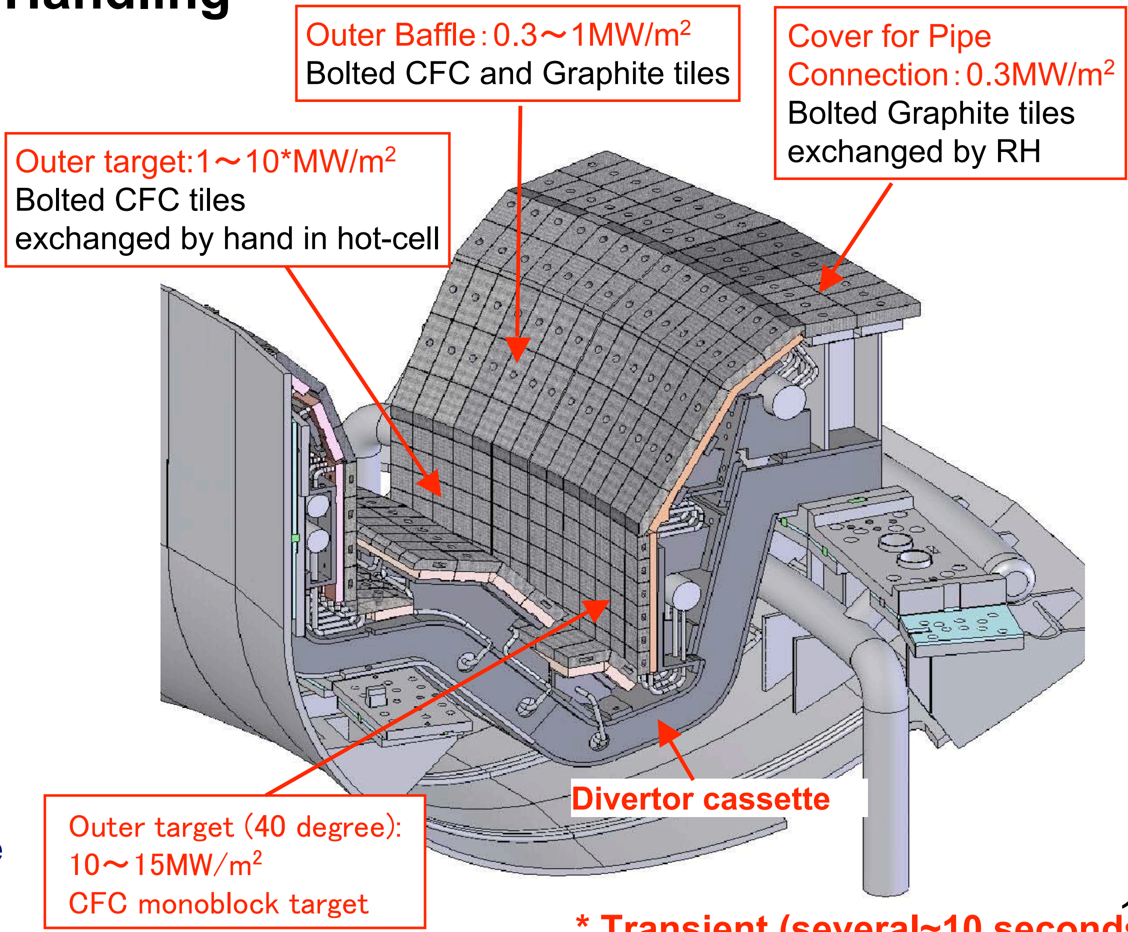
Bird's view of Vacuum Vessel

- **VV : 18 toroidal sectors of SS316L with low Co to reduce activation levels.**
- **Boric acid water between shells is used for neutron shielding.**
- **The vacuum vessel can be baked up to 200°C using nitrogen gas. The temp. of the vacuum vessel in normal operation is kept at ~50°C.**

Lower Divertor

- **The design is optimized for a higher triangularity (δ_x~0.5) in LSN.**
- **Vertical targets, with a V-shaped corner for the LFS one.**
- **Initially bolted CFC (+partial monoblock) => Full monoblock.**
- **Cryopanels beneath the cassette for pumping.**
- **Compatible with future Remote Handling maintenance.**





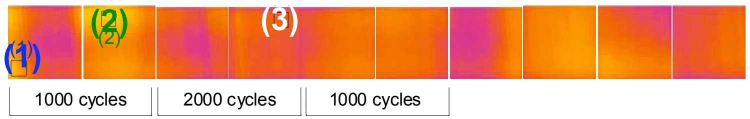
* Transient (several~10 seconds)

R&D : CFC monoblock

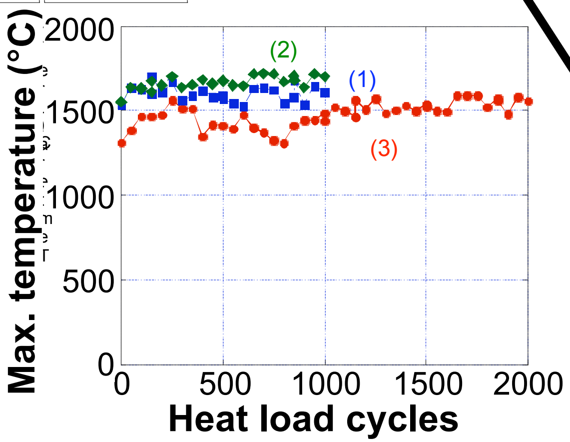
12 full-size mock-ups produced in one furnace

- **Full-size mock-ups of CFC monoblock target with 10 CFC blocks (30x30x30mm)**

Qualified target survived 2000 heat load cycles.



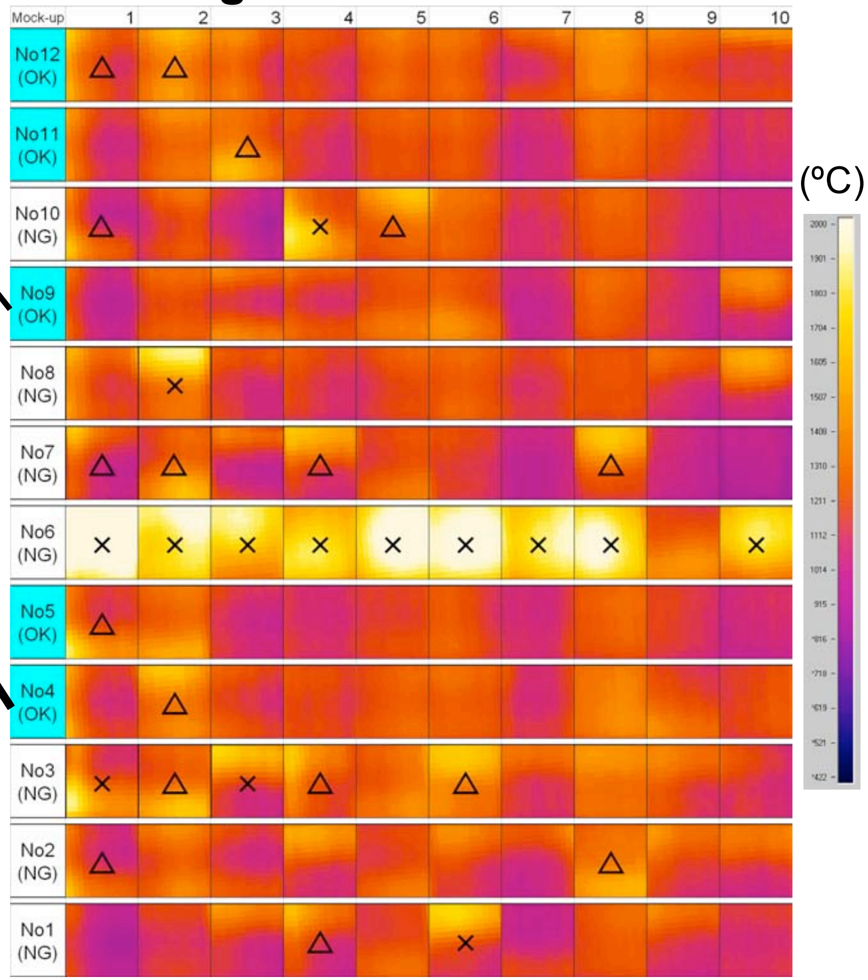
(1): existing the crack in the circumferential direction in CFC block
(2): the maximum temperature
(3): the representative at the monoblock receiving 2000 heat cycles



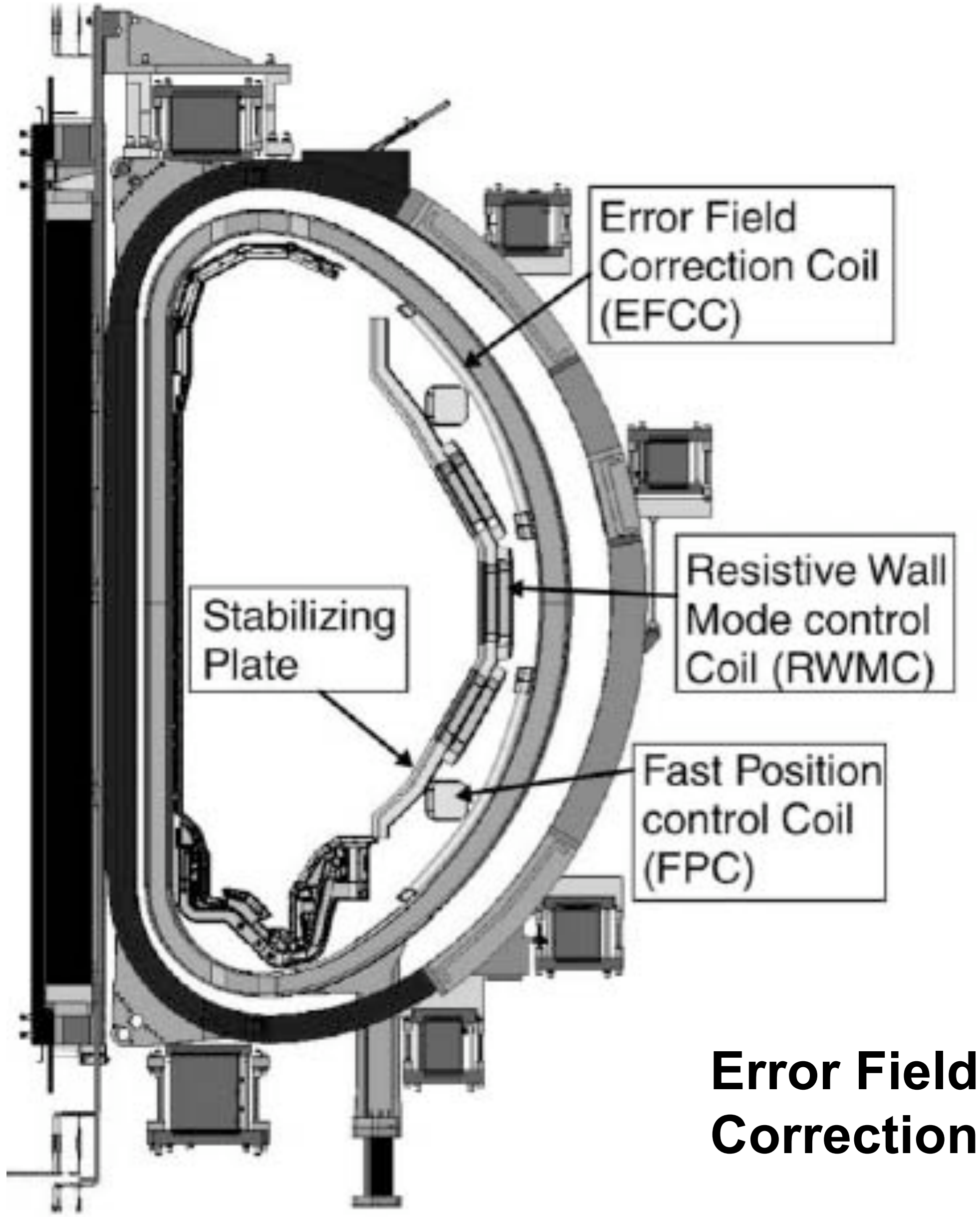
Test at JEBIS up to 15MW/m²

About half of mock-ups satisfy the performance

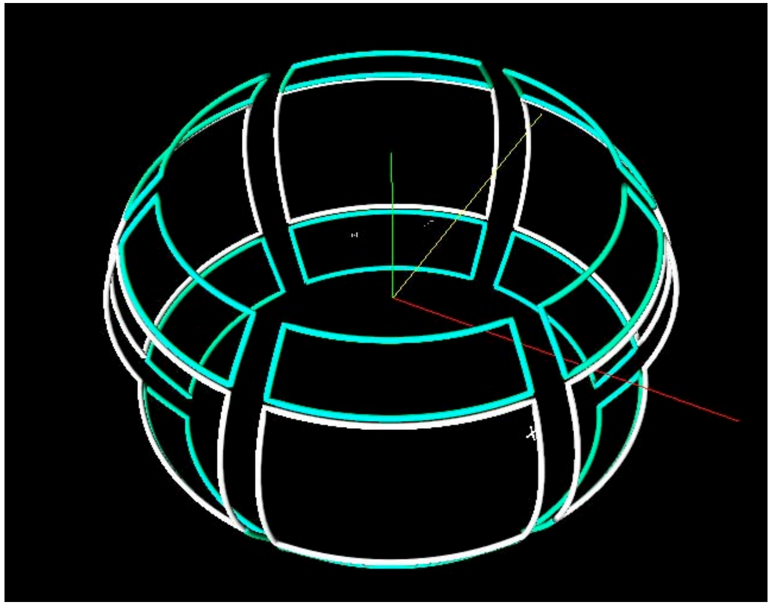
IRTV image at ~15MW/m² of heat load



In-vessel coils



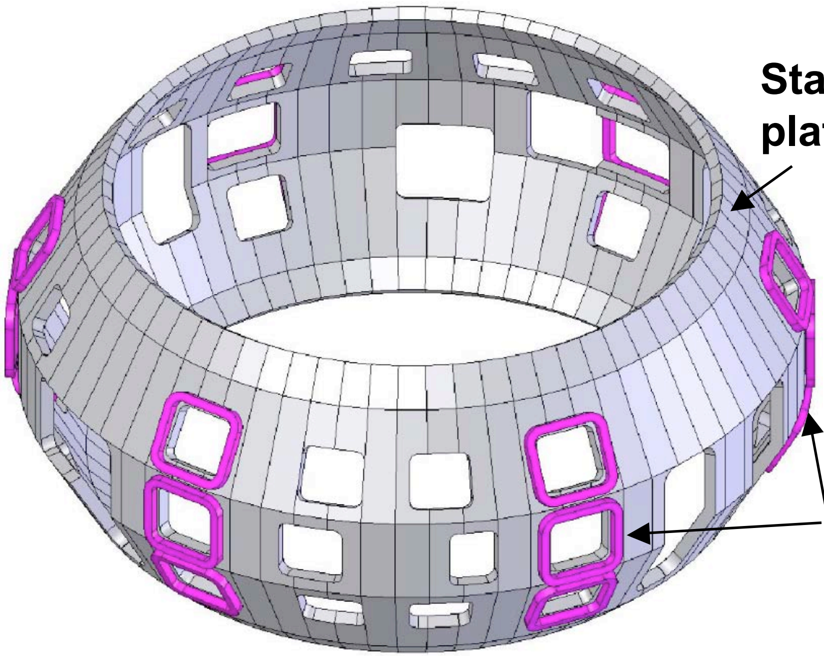
- **Fast Position Control coil: vertical and horizontal position control.**
- **Error Field Correction coil: compensate non-axisymmetric field (incl. Resonant Magnetic Perturbation). Slow response.**
- **RWM Control coil: for fast feedback control of RWM; 3 (poloidal)x6 (toroidal) = 18 coils.**

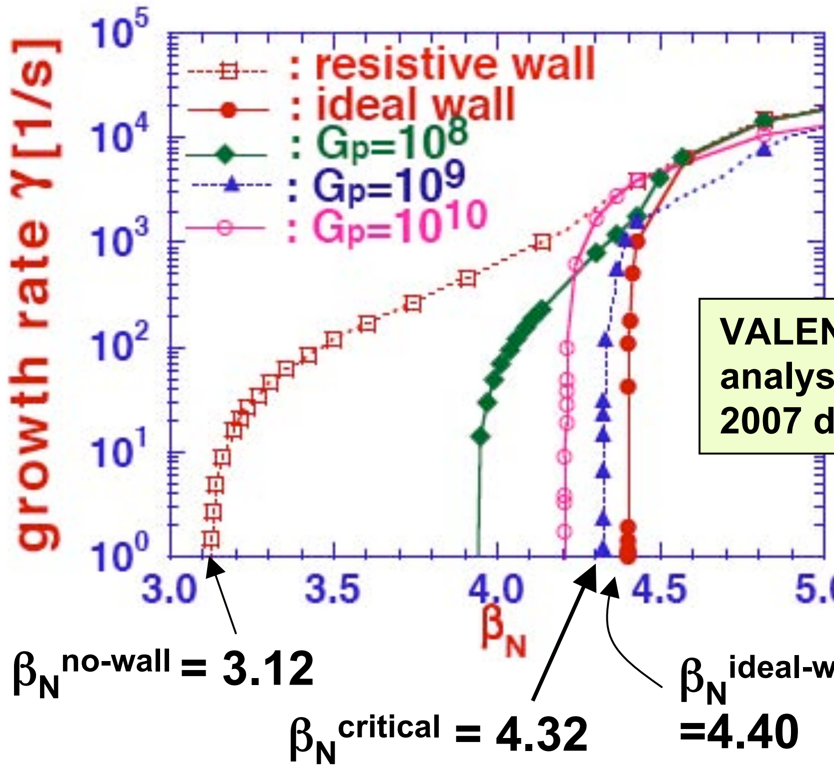


Error Field Correction coil

RWM control coils

- Sustainment of high β_N (>~3.5), above the no-wall limit, is one of major targets of JT-60SA, and requires control of Resistive Wall Mode (RWM) as well as conducting shell (stabilizing plate).
- Efficient stabilization of RWM is expected with present design.
- Using co and counter NBI, stabilization of RWM by plasma rotation will also be studied.





VALEN code analysis on 2007 design

Heating and Current Drive systems

Variety of heating/current-drive/ momentum-input combinations

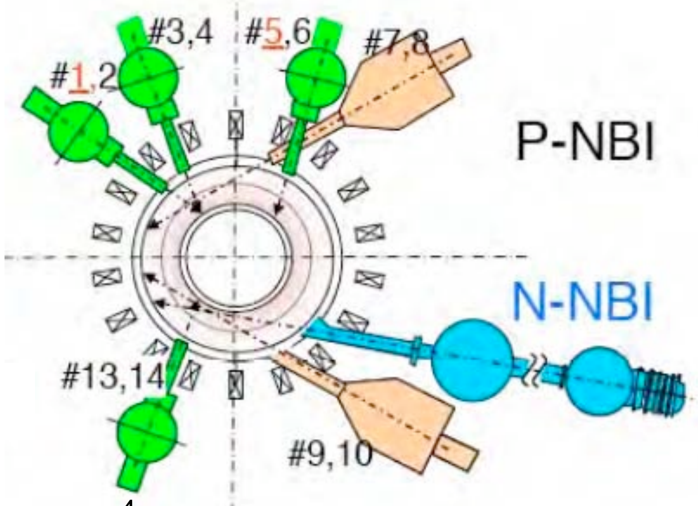
NB: 34MWx100s

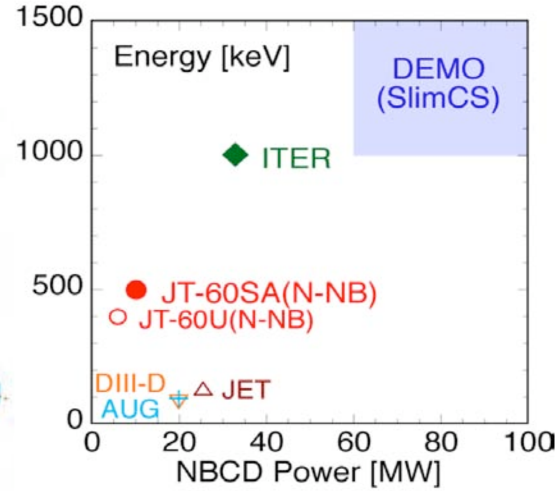
Positive-ion-source NB
85keV
12units x 2MW=24MW
COx2u, 4MW
CTRx2u, 4MW
Perpx8u, 16MW

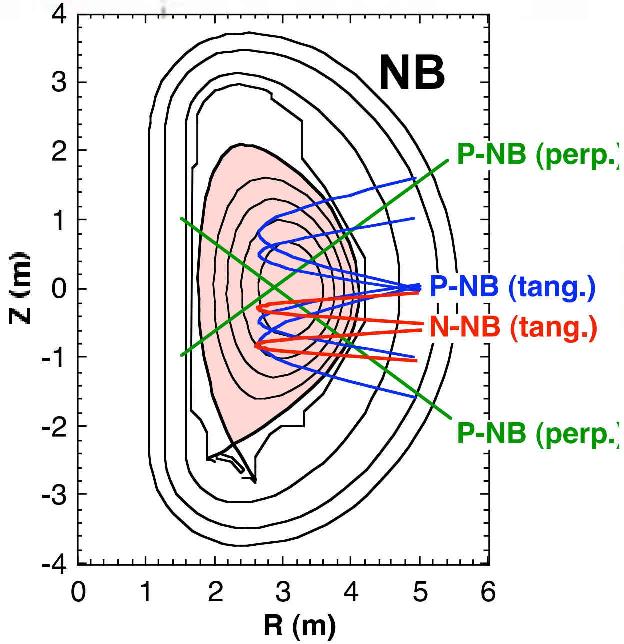
Negative-ion-source NB
500keV, 10MW
Off-axis for NBCD

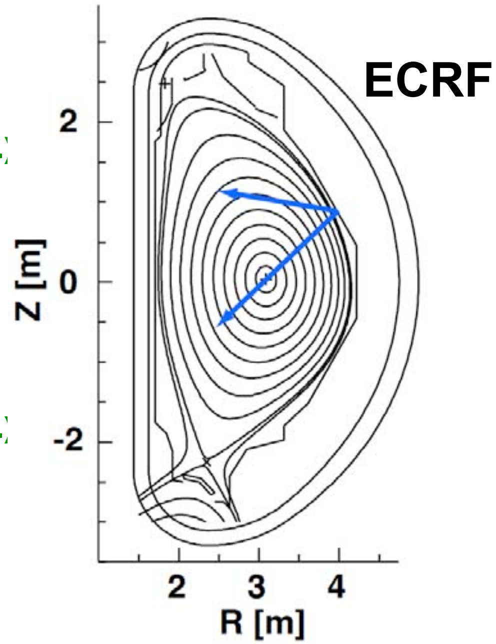
ECRF: 110GHz, 7MW x 100s

- **9 Gyrotrons,**
- **4 Launchers with movable mirror**
- **>5kHz modulation**





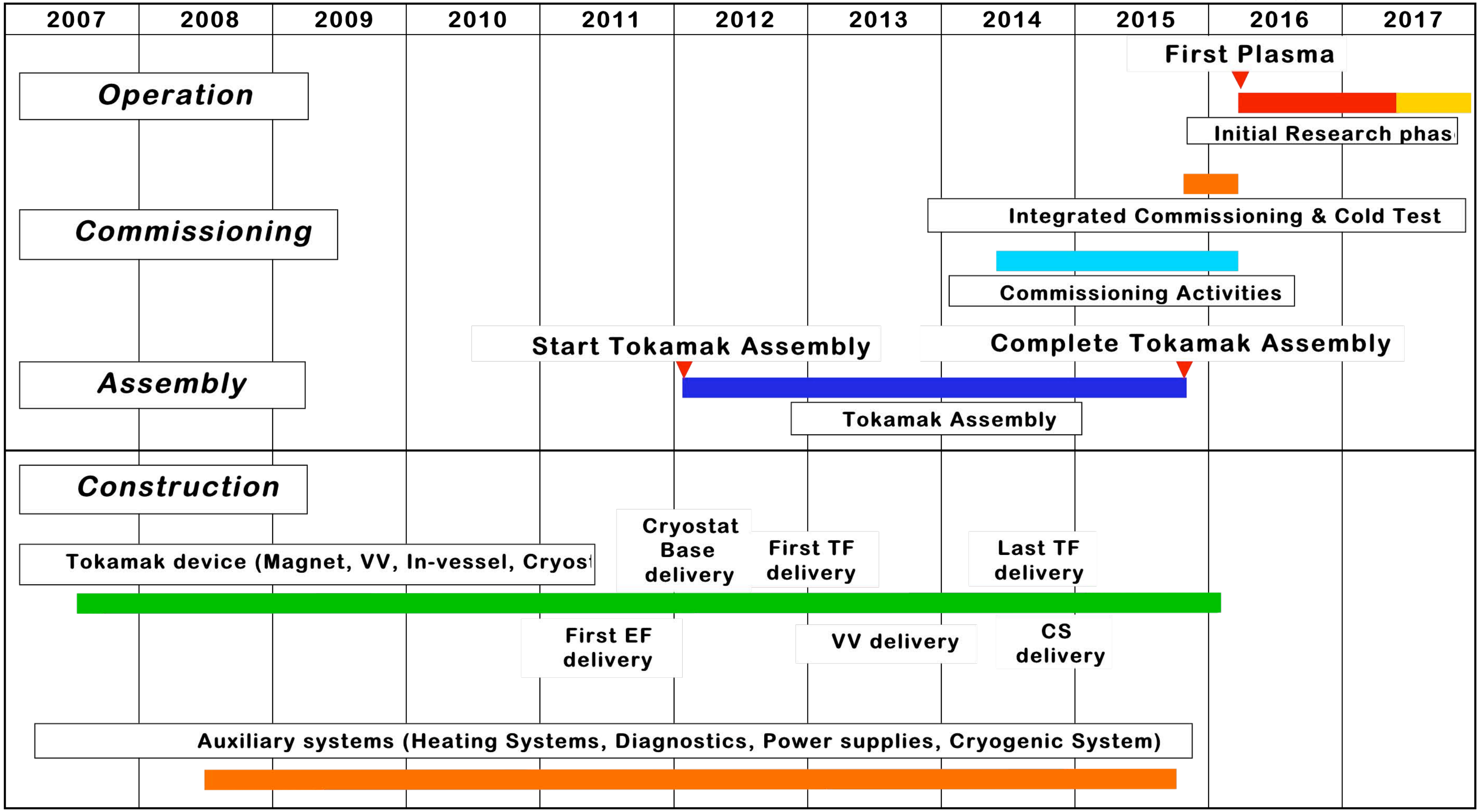




Project Schedule

- **Tokamak assembly will start in 2012 on the JAEA Naka site.**
- **The first plasma is foreseen in 2016.**

Baseline Project Schedule V.2.0



Exploitation plan

JT-60SA
Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

- **JT-60SA is planned to be upgraded according to the phased equipment plan.**
  - Divertor, ECRF, P-NB, Remote Handling
- **Exploitation within the BA period will aim at the initial research phase**
- **Physics experiment to be defined in the *JT-60SA Research Plan*.**

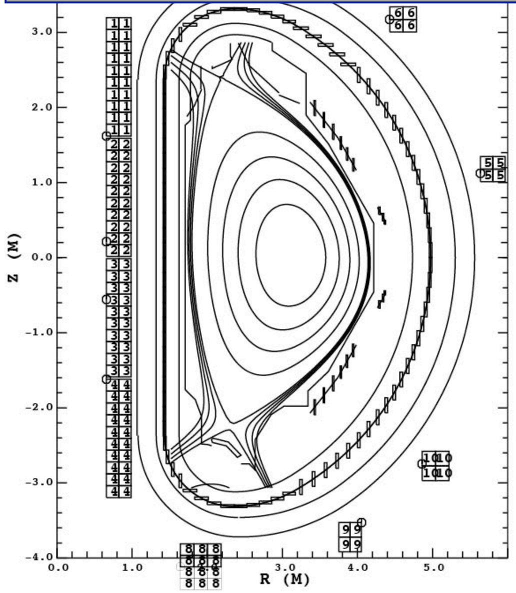
<table>
<tr><th></th><th>Phase</th><th>Expected Duration</th><th></th><th>Annual Neutron Limit</th><th>Remote Handling</th><th>Divertor</th><th>P-NB</th><th>N-NB</th><th>ECRF</th><th>Max Power</th><th>Power x Time</th></tr>
<tr><td rowspan="2">Initial Research Phase</td><td>phase I</td><td>1-2 y</td><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

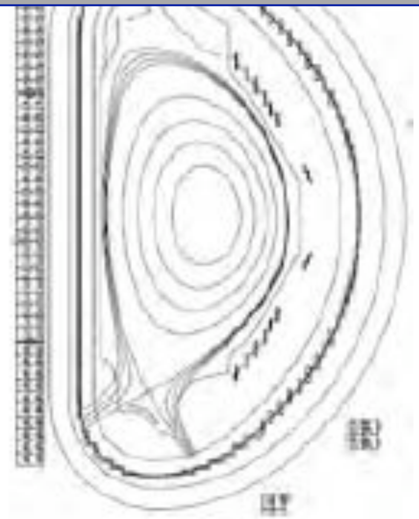
Tang. 7MW</td><td>33MW</td></tr>
<tr><td rowspan="2">Integrated Research Phase</td><td>phase I</td><td>2-3y</td><td>D</td><td>4E20</td><td rowspan="2">LSN full-monoblock</td><td rowspan="3">7MW</td><td rowspan="2">37MW</td></tr>
<tr><td>phase II</td><td>>2y</td><td>D</td><td>1E21</td><td rowspan="2">Use</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>

Typical plasma parameters

Ip=5.5MA, Double Null



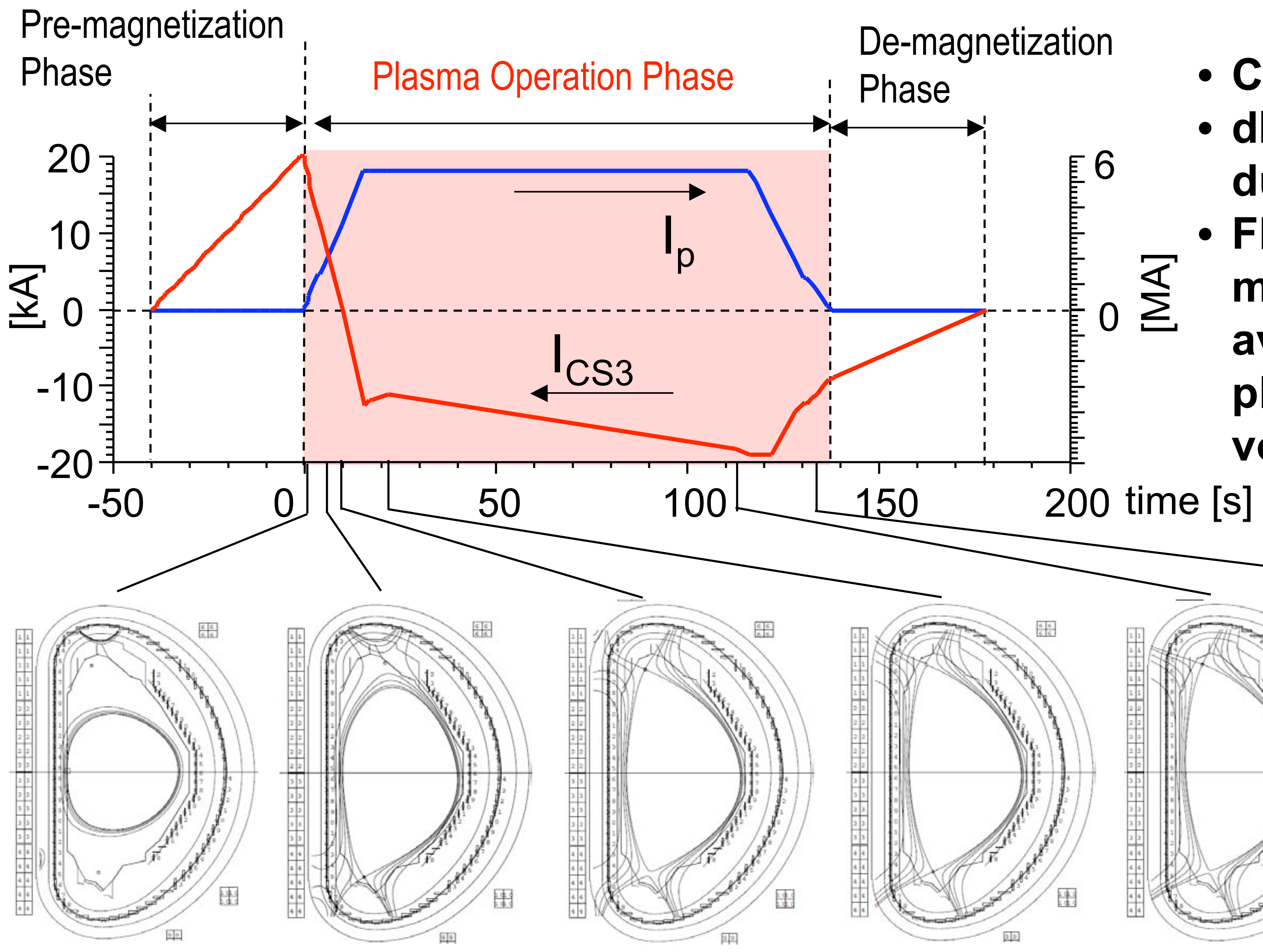
Ip=4.6MA ITER-shape



Parameter	DN Low A	ITER-shape	High-β_N full-CD
Plasma Major Radius R (m)	2.96	2.93	2.97
Plasma Minor Radius a (m)	1.18	1.14	1.11
Plasma Current I_p (MA)	5.5	4.6	2.3
Toroidal Field B_o (T)	2.25	2.28	1.71
Plasma Aspect Ratio A	2.5	2.6	2.7
Plasma Elongation κ_x , κ_{95}	1.95, 1.77	1.81, 1.70	1.92, 1.83
Plasma Triangularity δ_x , δ_{95}	0.53, 0.42	0.43, 0.33	0.51, 0.41
Shape Parameter S	6.7	5.7	6.9
Safety Factor q_{95}	3.2	3.2	5.7
Plasma Volume (m^3)	132	122	124
Heating Power (MW)	41	34	37
Assumed HH-factor	1.3	1.1	1.3
Normalized Beta β_N	3.1	2.8	4.3
Thermal Energy Confinement Time τ_E (s)	0.54	0.52	0.26
Electron Density n_e ($10^{20}/m^3$)	0.63	0.91	0.50
Greenwald Density $n_{Greenwald}$ ($10^{20}/m^3$)	1.3	1.1	0.59
Normalized Plasma Density $n_e/n_{Greenwald}$	0.5	0.8	0.86
Flattop Flux (Vs) (li=0.73-0.75)	~9	~17	- (full CD)
Bootstrap current fraction	0.29	0.30	0.66
Discharge flattop duration (s)	100	100	100

ITER-shape: same κ and δ but lower A than ITER.

Operation scenario for 5.5 MA DN



(i) 0.9s (ii) 5.7s (iii) 9.8s (iv) 21.6s (v) 112.4s (vi) 132.4s

- Coil current < 20 kA.
- dI_p/dt~0.35 MA/s during I_p ramp.
- Flat top duration may depend on available flux and plasma loop voltage.

Plasma parameters in design scenarios

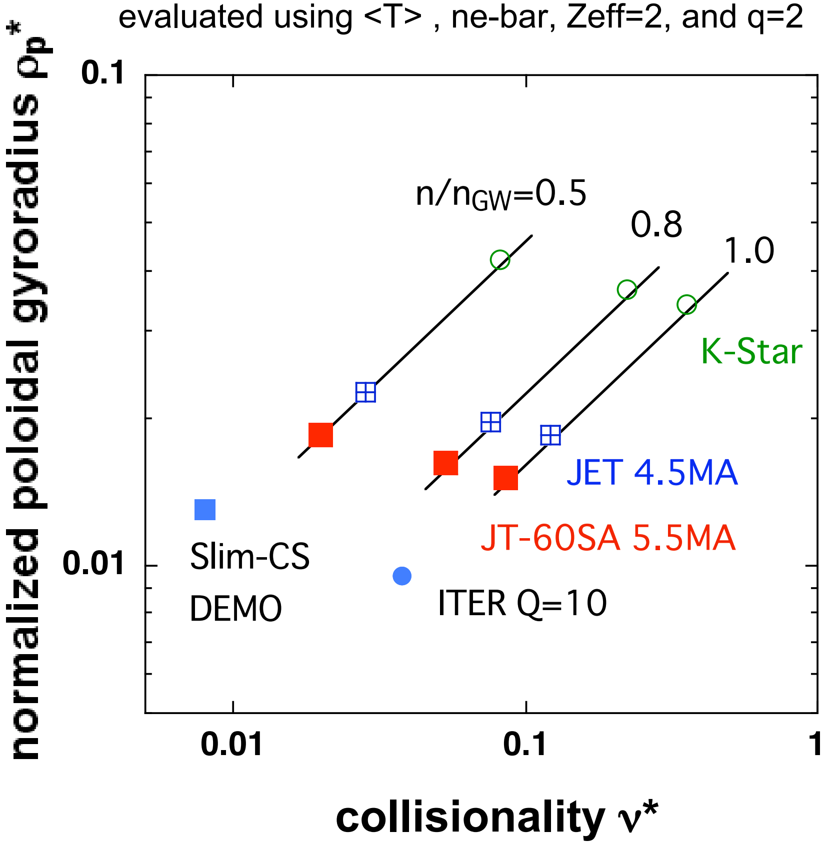
Scenario	#1	#2	#3	#4	#5	#6 (note)
	Full Current Inductive DN, 41MW	Full Current Inductive SN, 41MW	Full Current Inductive SN,30MW High density	ITER like Inductive	High β_N full-CD	High β_N 300s
Plasma current, I_p (MA)	5.5	5.5	5.5	4.6	2.3	2.0
Toroidal field, B_t (T)	2.25	2.25	2.25	2.28	1.71	1.41
q_{95}	~3	~3	~3	~3	~5.7	~4
R/a (m/m)	2.96/1.18	2.96/1.18	2.96/1.18	2.93/1.14	2.97/1.11	2.97/1.11
Aspect ratio A	2.5	2.5	2.5	2.6	2.7	2.7
Elongation, κ_x	1.95	1.87	1.86	1.81	1.92	1.91
Triangularity, δ_x	0.53	0.50	0.50	0.41	0.51	0.51
Normalised beta, β_N	3.1	3.1	2.6	2.8	4.3	3.0
Electron density, $\overline{n_e}$ ($10^{19}m^{-3}$)	6.3	6.3	10.	9.1	5.0	2.0
P_{add} (MW) (N-NB/P-NB/EC)	41 (10/24/7)	41 (10/24/7)	30 (10/20/0)	34 (10/24/0)	37 (10/20/7)	13.2 (3.2/6/4)
Thermal confinement time, $\tau_{E,th}$ (s)	0.54	0.54	0.68	0.52	0.23	0.3
$H_{H98\,(v.2)}$	1.3	1.3	1.1	1.1	1.3	1.3
V_l (V)	0.06	0.06	0.15	0.12	0	0.02
Available flux at flat-top (Wb)	<~9	<~9	<~9	<~17	-	>~8
Neutron production rate, S_n (n/s)	1.3×10^{17}	1.3×10^{17}	6.5×10^{16}	6.6×10^{16}	4.5×10^{16}	1.2×10^{16}

NOTE: Scenario 6 is, for the time being, to be considered a "to be assessed" scenario whereby the verification that it can be executed, within the limits set by the requirements from scenarios 1-5, is performed and that no extra requirements to the initial facility installation is required.

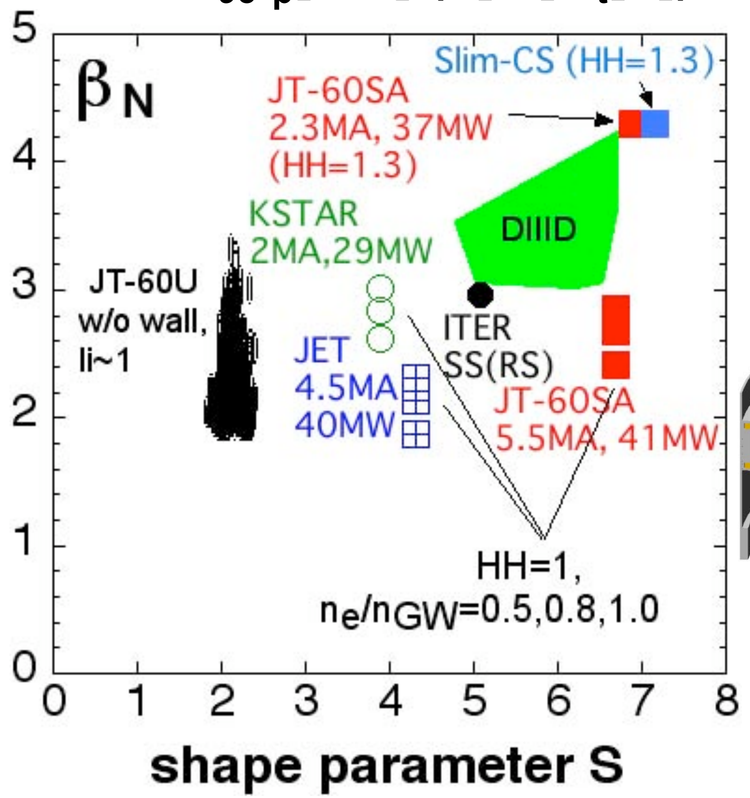
β, ν*, ρ* of JT-60SA

- ITER- and DEMO- relevant plasma regimes in terms of β_N, ρ_p* and ν*.
- High β_N with highly shaped configurations (S~7).

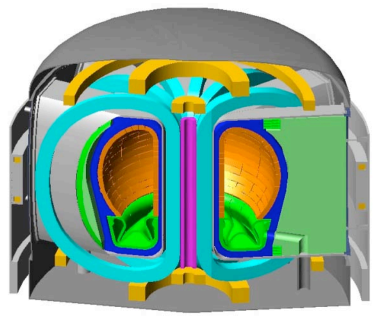
HH=1, (SlimCS:H=1.3)
Ti=Te,
n(r)&T(r)=paraboric shape with α_n=0,5, α_T=1.5
evaluated using <T> , ne-bar, Zeff=2, and q=2



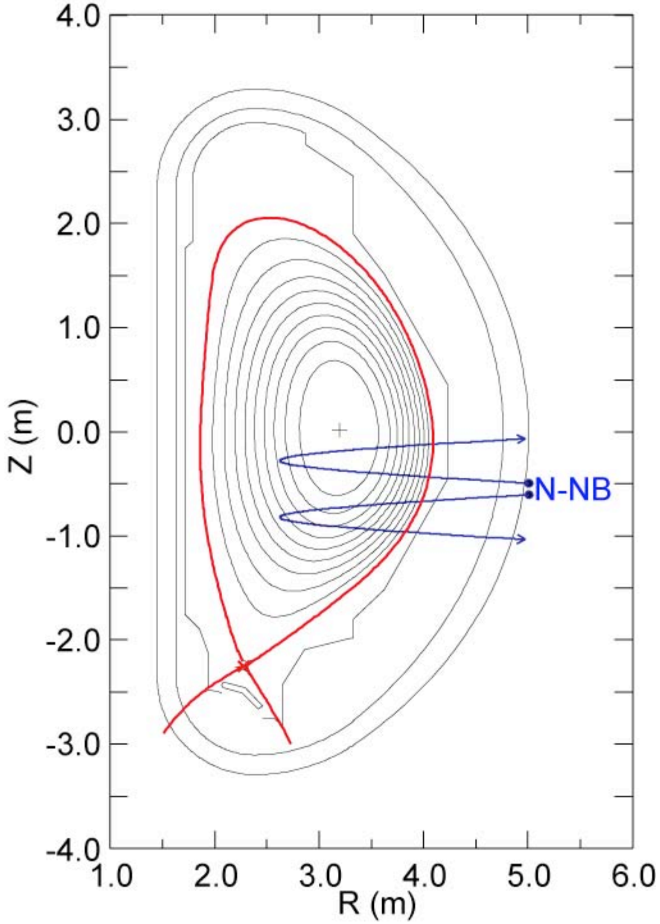
S = $q_{95}I_p$[MA]/(a[m]B_t[T])

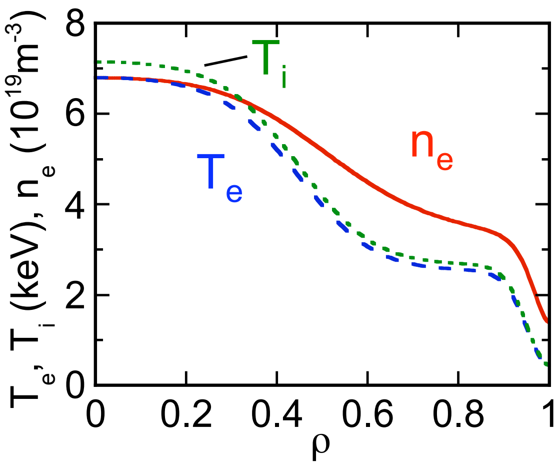


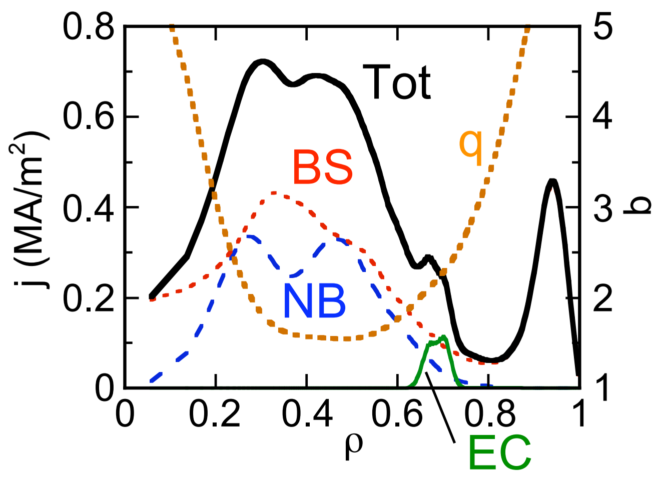
SlimCS



High β_N steady-state operation

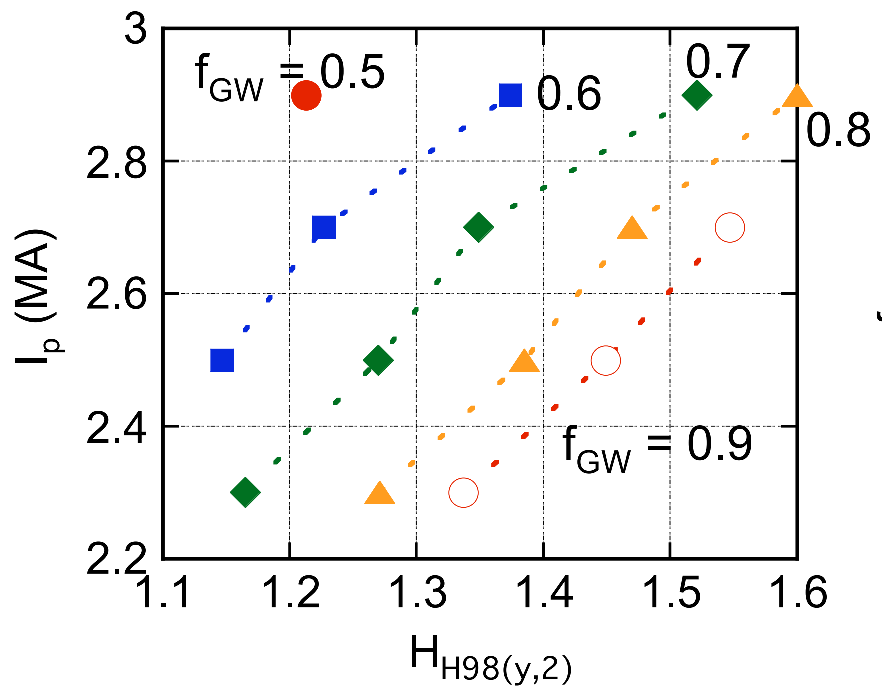


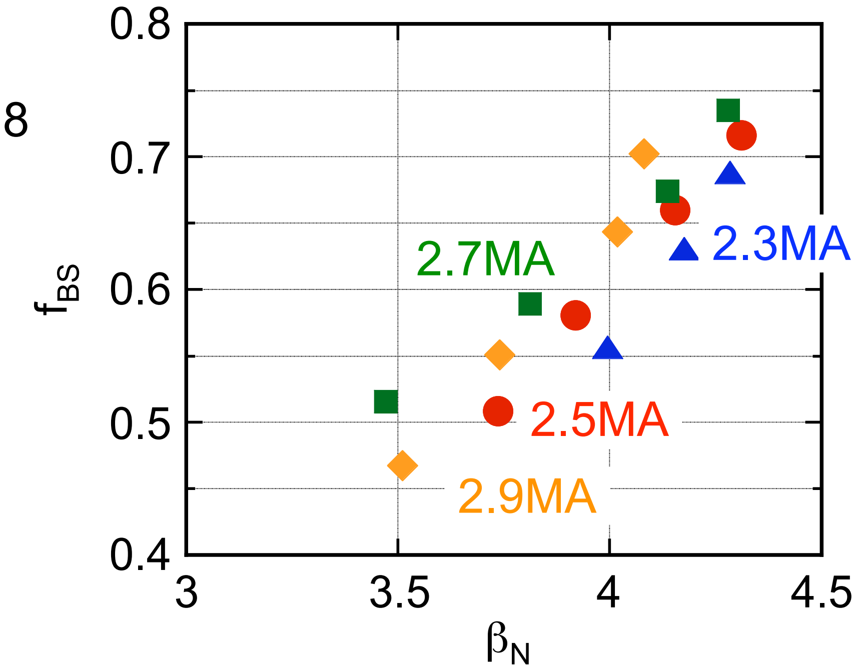




- **Current profile analysis by ACCOME, with assumed density/temperature profiles.**
- **Shown here is an example of full-CD.**
  - **I_p/B_t=2.3MA/1.7T, q_{95}=5.6, f_{GW}=0.85, f_{BS}=0.66, β_N=4.3, H_H=1.3**
  - **I_{BS}=1.53MA, I_{NB}=0.661MA, I_{EC}=0.069MA**
  - **P_{PNB}=20MW, P_{NNB}=10MW, P_{EC}=7MW**
- **Off-axis NBCD with N-NB→Reversed shear with q_{min}~1.6 at r/a~0.5.**

High β_N steady state operational space





- **Assuming profiles, full-CD (I_{OH} =0MA) solutions are evaluated by ACCOME with varying I_p and f_{GW}. Full power injection is assumed.**
- **Full CD at 2.3 MA (with f_{GW} ~0.85) to 2.9 MA (with f_{GW} ~0.55) can be expected with moderate H_H of 1.3.**
- **Here q_{95} is around 5.5, q_{min} ~1.6 ρ_{min} ~0.5 – 0.55.**
- **I_p = 2.9 MA at B_t ~2.16T.**
- **f_{BS} up to >~70% is expected with DEMO relevant β_N.**

ITER & DEMO-relevant heating condition / scan

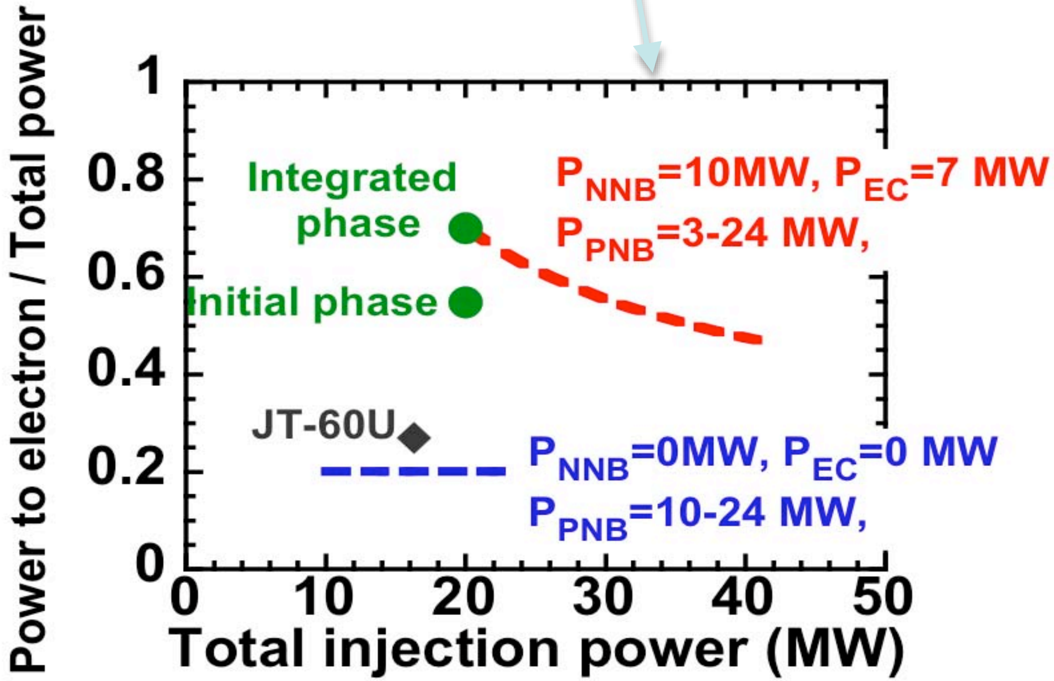
JT-60SA allows

- dominant electron heating, scan of power ratio to electron
- high power heating with low central fueling
- high power heating with low external torque input
  (incl. scan of rotation)

ECRF (110GHz, 7MW)
N-NB (500keV, 10MW)
=> Electron Heating dominant
Low Particle input
Low Torque input

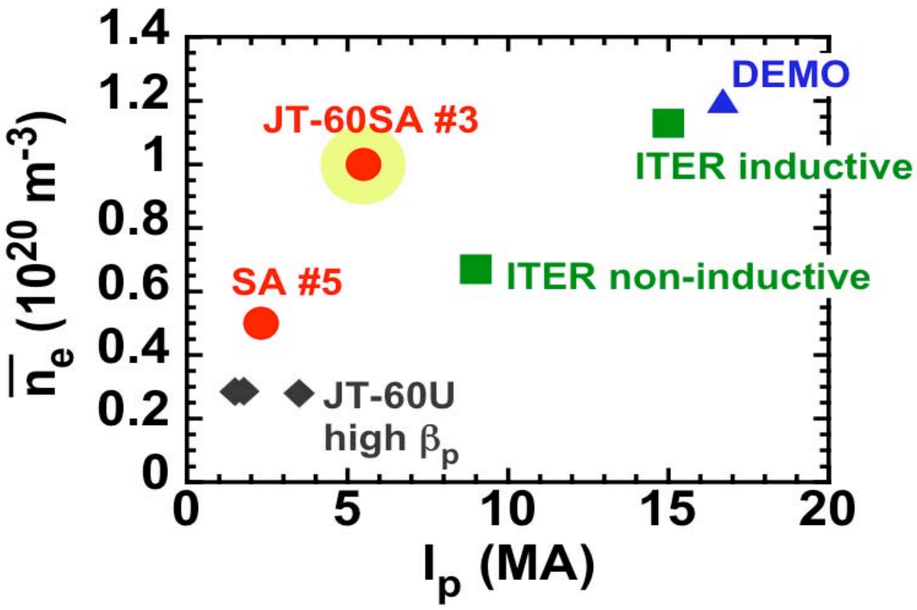
P-NB (85keV, 24 MW)
=> Ion Heating dominant

Perp-NB & balanced CO/CTR-NB
=> low torque input
(torque input scan)

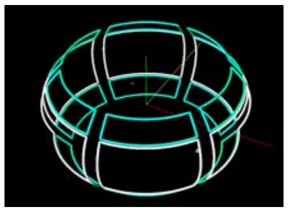


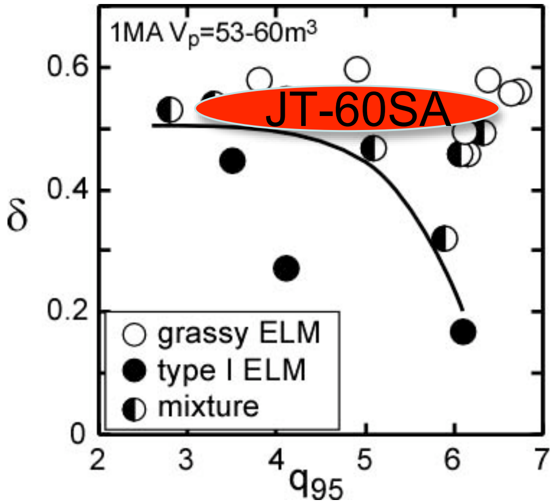
H-mode and ELMs

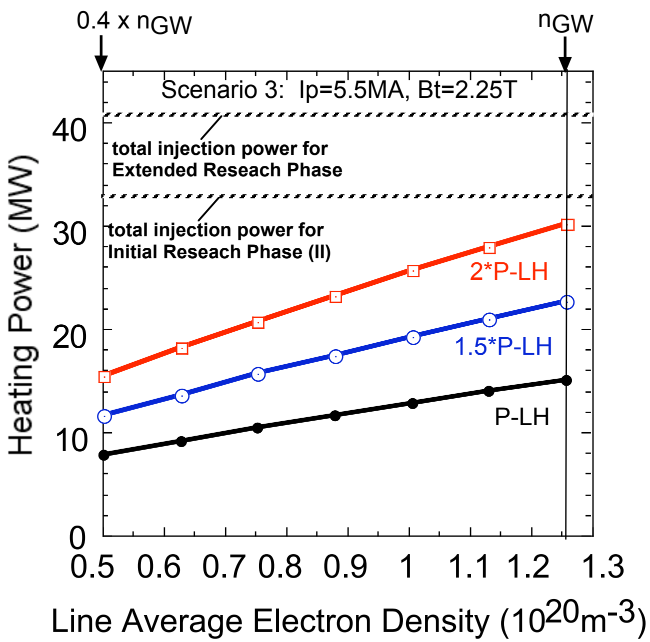
- ITER-relevant high density plasma regimes well above the H-mode power threshold is possible
- Will contribute to ITER H-mode operations towards Q=10, w.r.t. L-H transition, Pedestal Structure and H-mode confinement (incl. compatibility with radiative divertor, RMP, etc.)



- ELM mitigation will be studied by RMP, pellet and high δ operation.



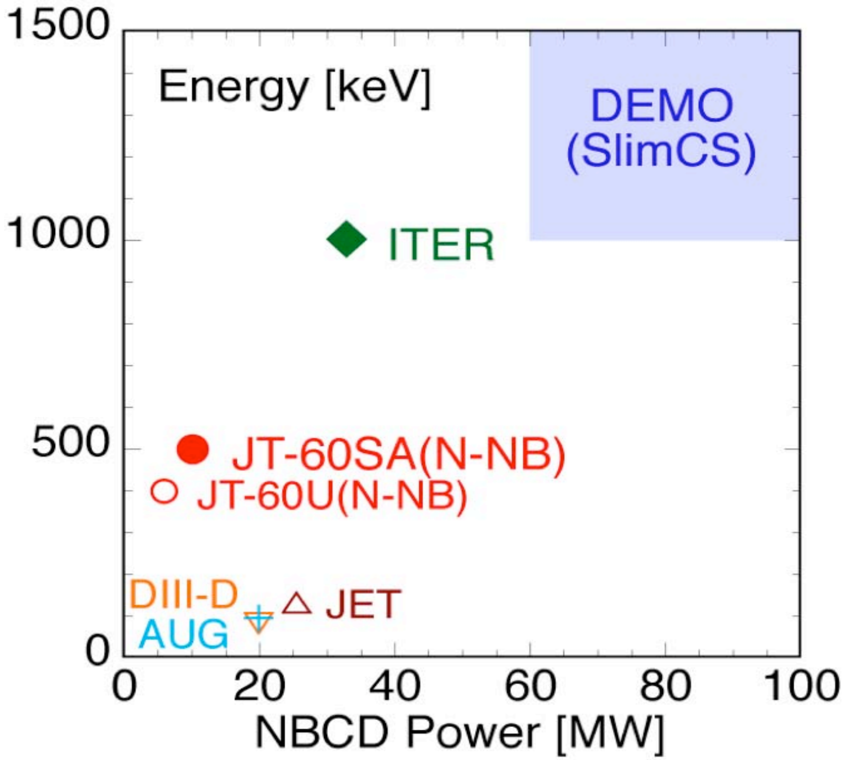


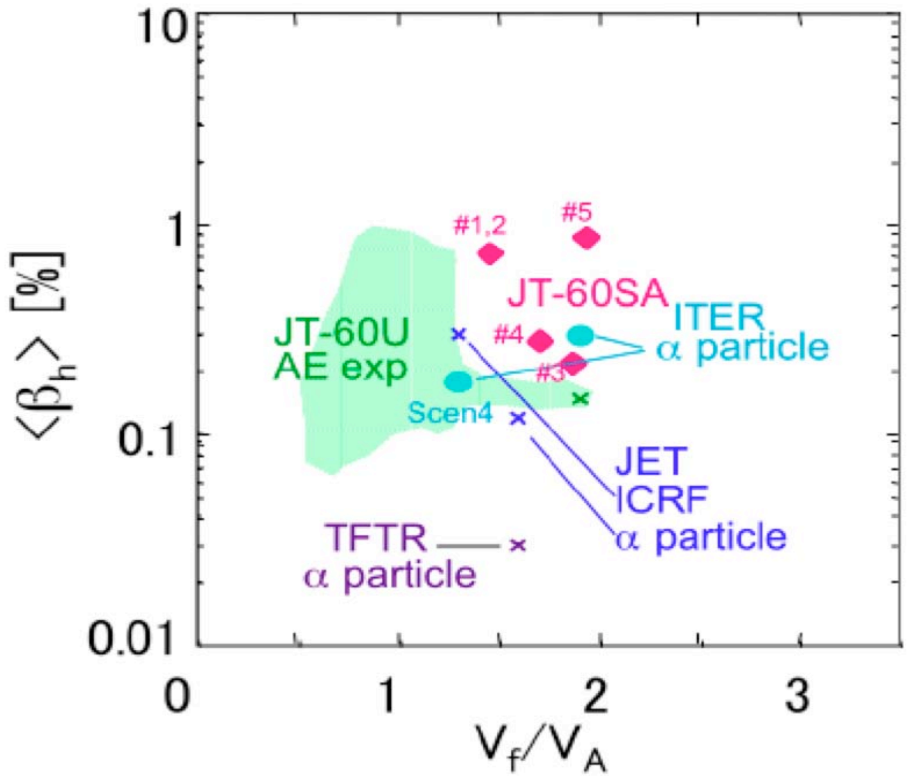


High Energy Particle Studies

JT-60SA allows exploitations of
- **NB Current Drive studies (incl. off-axis NBCD),**
- **AE mode stability & effects on fast-ion transport,**
- **Interactions between high energy ions and MHD instabilities**

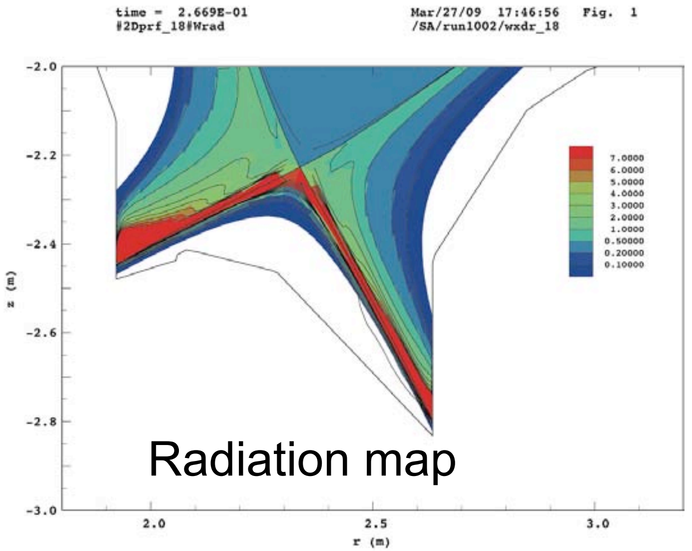
with 10MW high energy (500keV) N-NB.

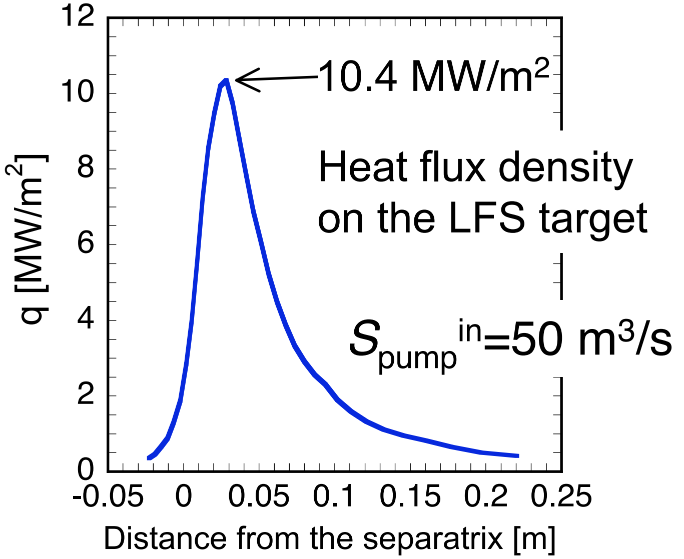




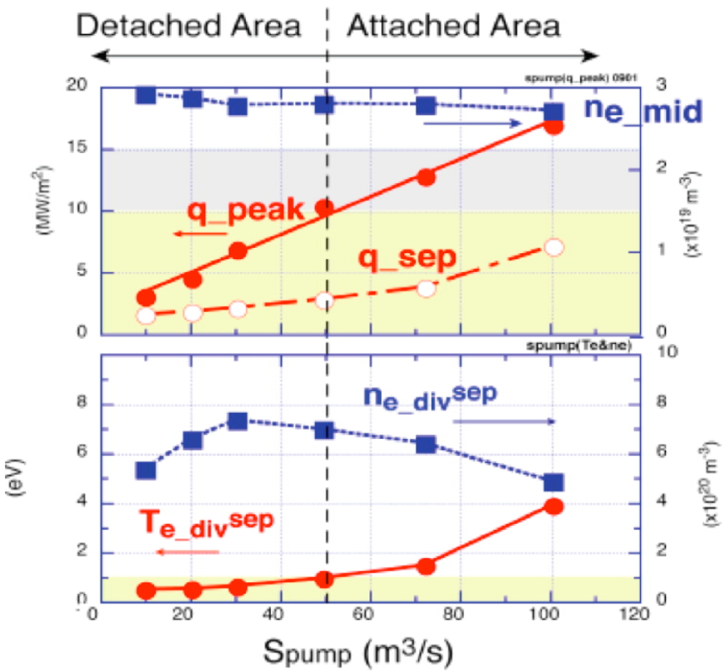
Heat and particle control with divertor

== SONIC code simulation ==





- **The peak heat flux can be suppressed within the mono block capability (15 MW/m²) by gas puffing for the maximum heating power (41 MW).**
- **$n_{e,sep}$ = 2.8x10^{19} m^{-3} is acceptable in a 5.5MA operation ($n_{e,ave}$ ~1x10^{20} m^{-3} at f_{GW}=0.8).**
- **A lower $n_{e,sep}$ of 1.7x10^{19} m^{-3} (q_{peak} = 8.6 MW/m²), compatible with lower I_p plasmas, is obtained with impurity seeding in the divertor region.**



Divertor condition can be controlled from attached to detached conditions with constant main plasma density with changing pumping speed (0-100 m³/s) by 8 steps.

Divertor & Wall Material Research for DEMO

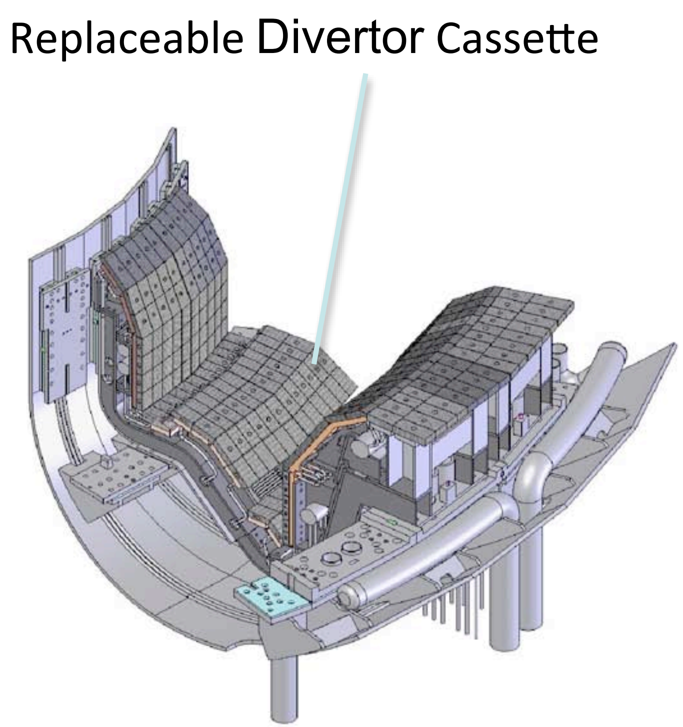
Extended Research Phase:

Installation of the metallic divertor targets and first wall together with an advanced shape divertor will be conducted based on progress of the research in the world tokamaks including ITER.

Integrated Research Phase:

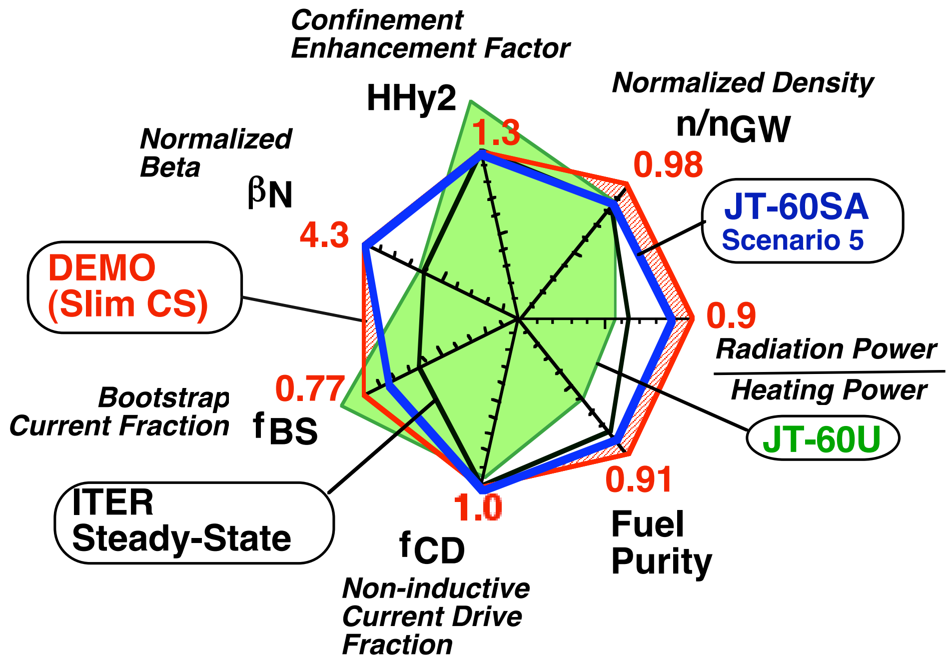
The material of the divertor target and the first wall is now considered to be carbon before achievement of the JT-60SA's main mission of the high-β steady-state.

However, possibility of replacement to metallic materials will be discussed based on the results in JET and ASDEX-U.

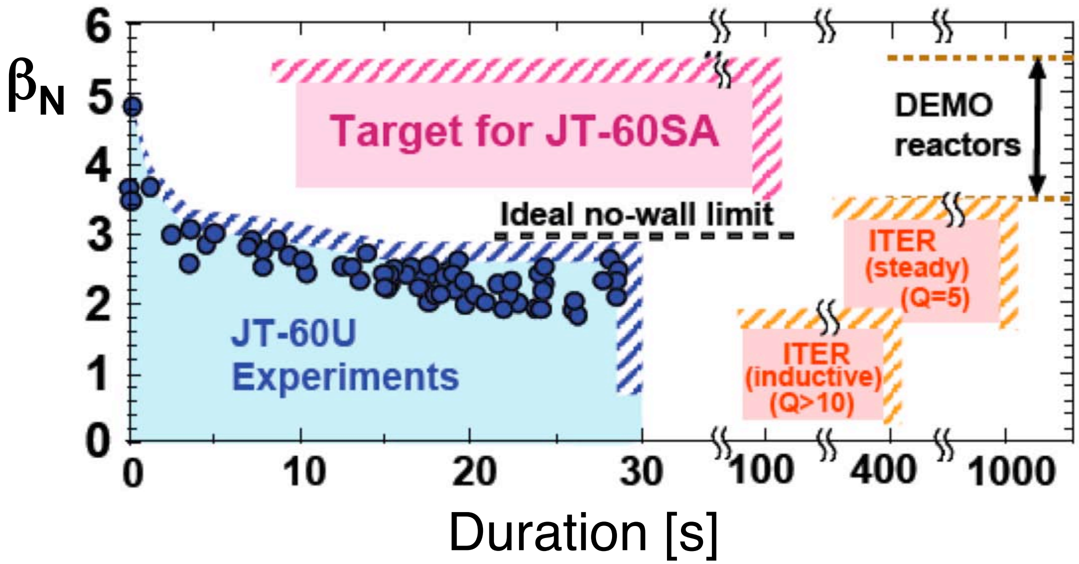


High Integrated Performance for DEMO

'Steady-state sustainment of integrated performance required for DEMO' has not been achieved yet.
=>
the goal of JT-60SA



Key points:
Understanding of highly self-regulating system (linked p(r),j(r), Vt(r)) and establishment of control scenarios with minimum actuators.



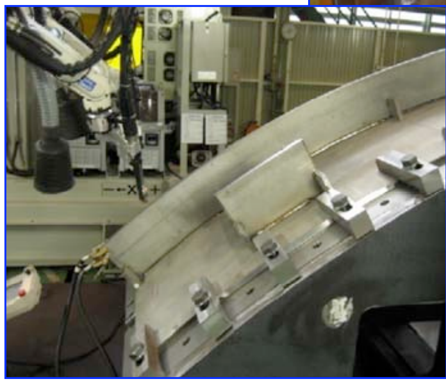
JT-60SA
Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

Manufacturing activities

Naka Fusion Institute

PF coil manufacturing building

PF conductor manufacturing building



Prototype of VV and welding test at manufacturing factory

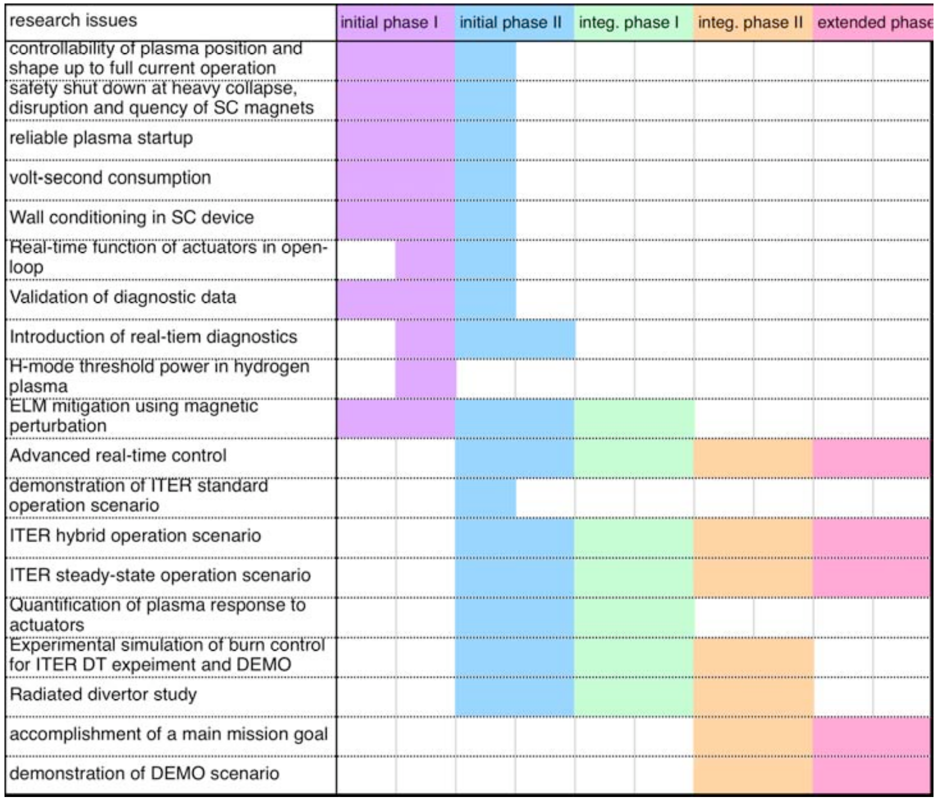
- **Manufacturing activities have commenced with contracts according to the PAs.**

JT-60SA Research plan

- **The JT-60SA research plan is under development to define research objectives and strategy, to be consistent with the phased equipment plan.**
- **Needs to plasma actuators and diagnostics would be taken into account in the detailed design.**
- **Joint work between JA and EU has just started, based on the draft research plan developed by JAEA and JA universities.**

Contents of JT-60SA Research Paln draft (v2.0)

Contents



A plan for operation scenario development

Summary of JT-60SA

- JT-60SA is characterized by
  - High I_p (5.5MA), highly shaped (κ_x~1.95, δ_x~0.53) and low A (~2.5).
  - High heating power (41 MW including 10 MW of NNBI) for 100 s.
  - All plasma-facing-components with water-cooled, including CFC monoblock divertor target.

- JT-60SA will contribute to resolving key physics issues in ITER and DEMO. In particular, high β_N (> no-wall limit) full non-inductive steady-state operation is one of the major targets.

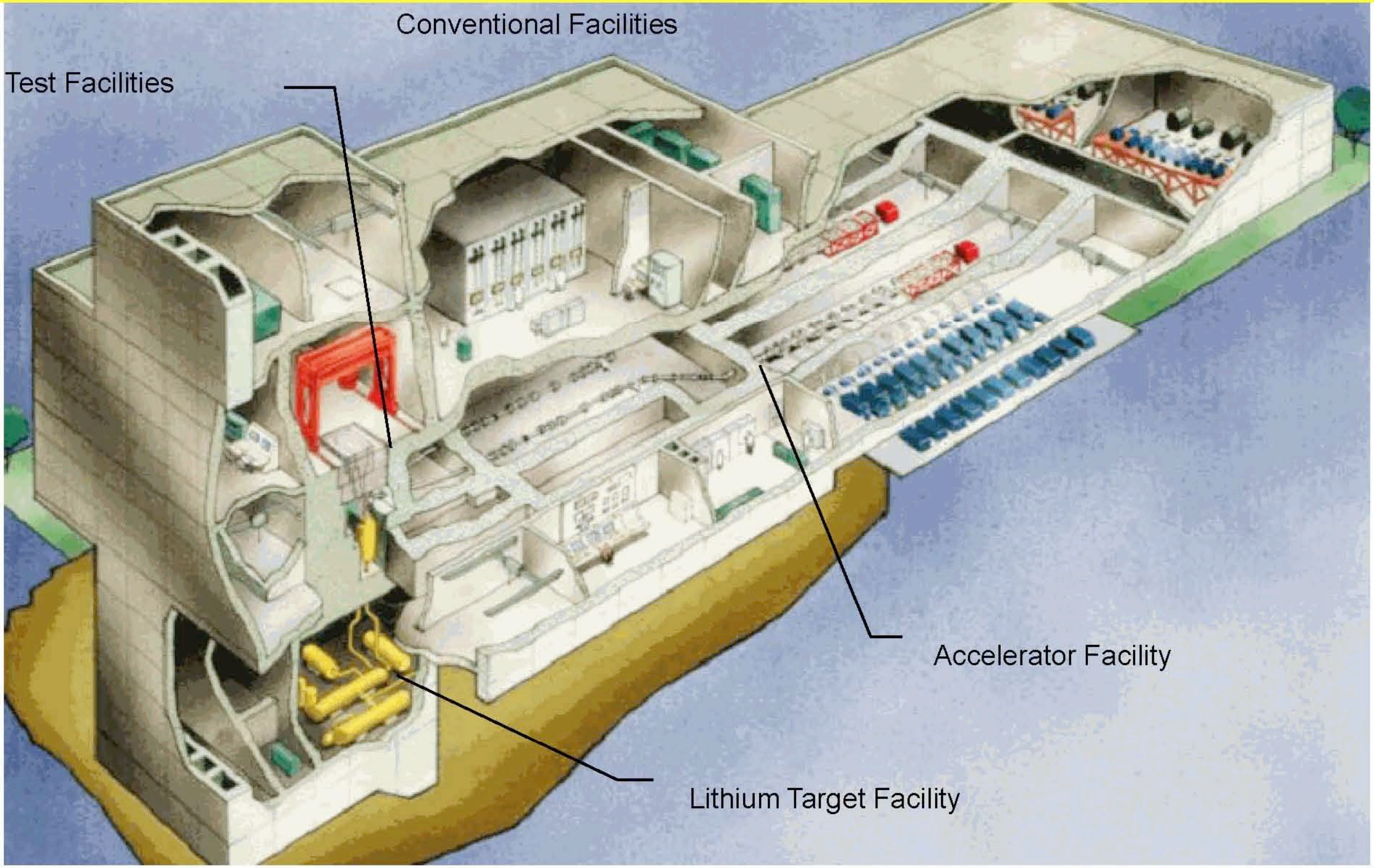
- Construction of JT-60SA has been started, toward the first plasma in 2016

- Development of the JT-60SA Research Plan has been started jointly by EU and JA physicists.

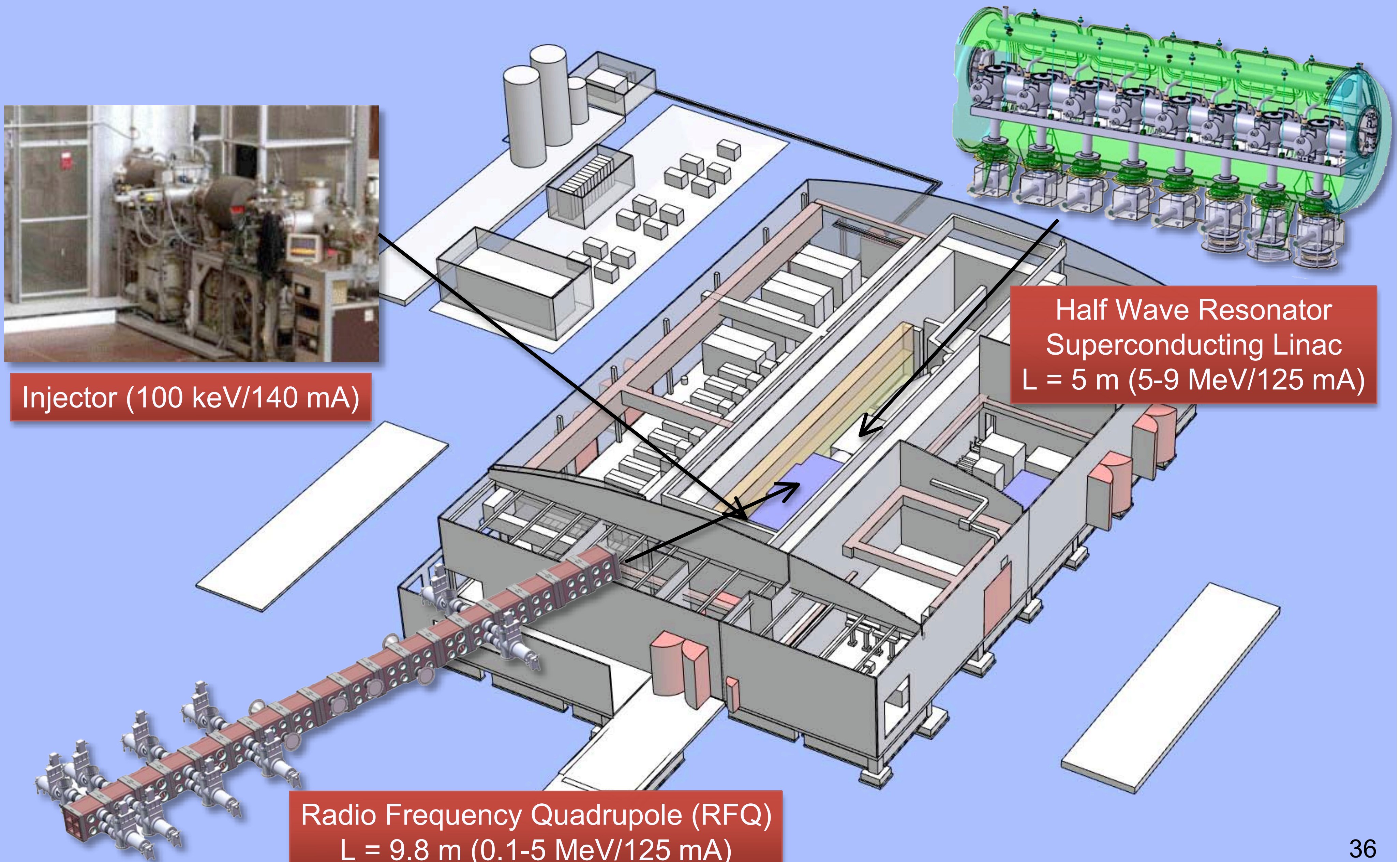
Status of BA activities at Rokkasho
~ IFMIF/EVEDA and IFERC ~

International Fusion Material Irradiation Facility (IFMIF)

To characterize the fusion materials under the 14MeV neutron irradiation necessary for DEMO design and licensing



IFMIF/EVEDA Project – Accelerator Development

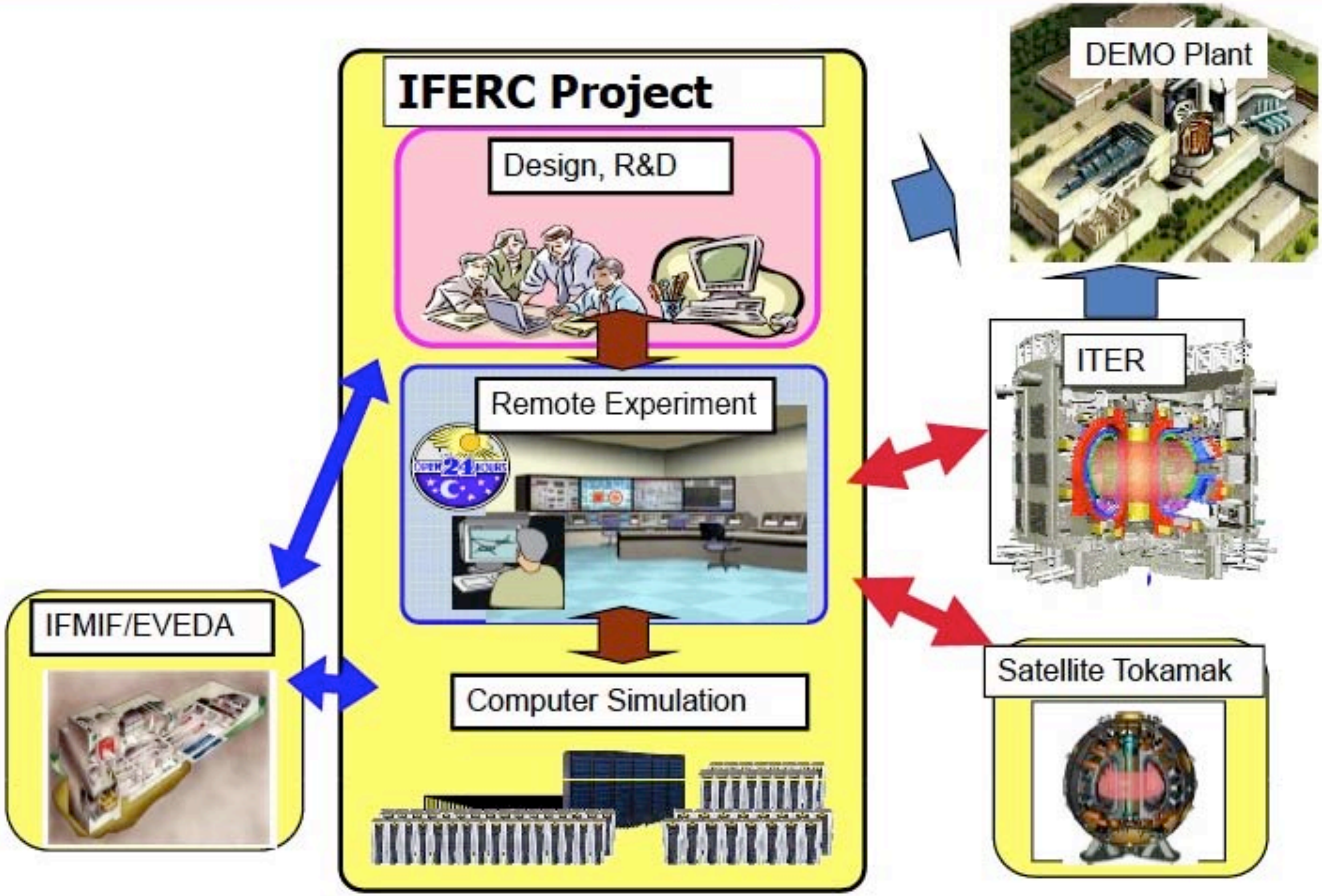


Injector (100 keV/140 mA)

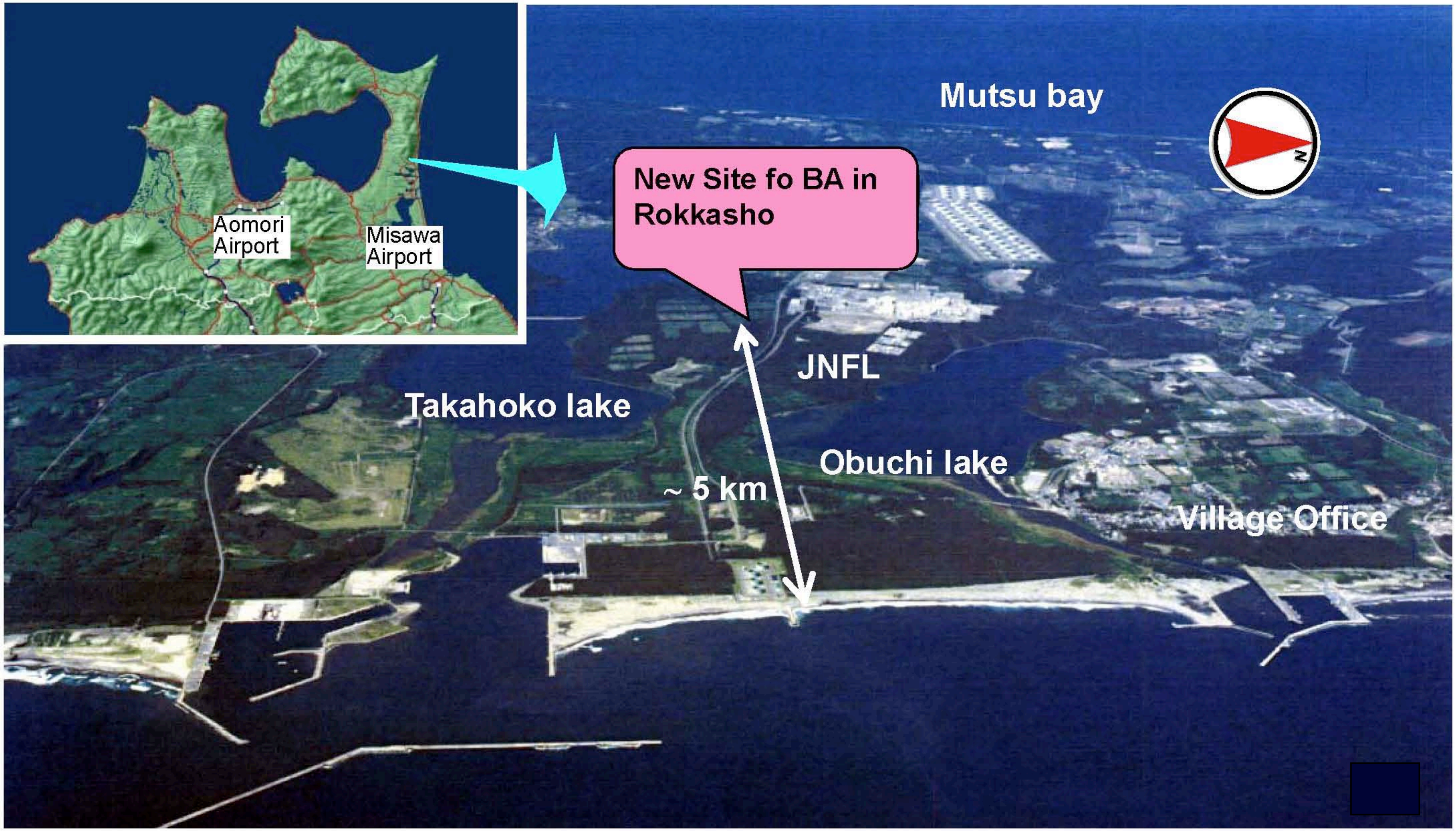
Half Wave Resonator Superconducting Linac
L = 5 m (5-9 MeV/125 mA)

Radio Frequency Quadrupole (RFQ)
L = 9.8 m (0.1-5 MeV/125 mA)

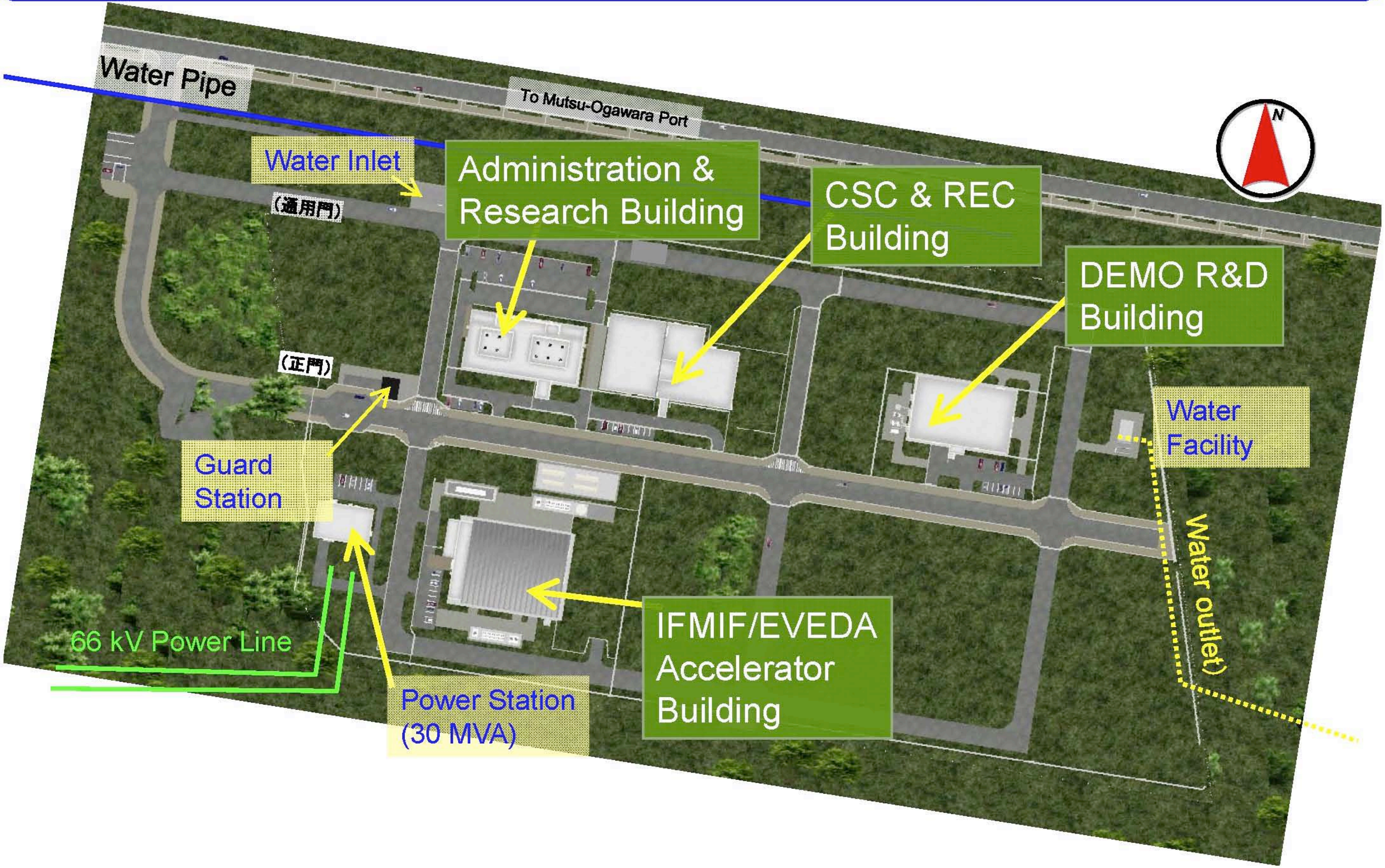
IFERC Project



Rokkasho from the sky

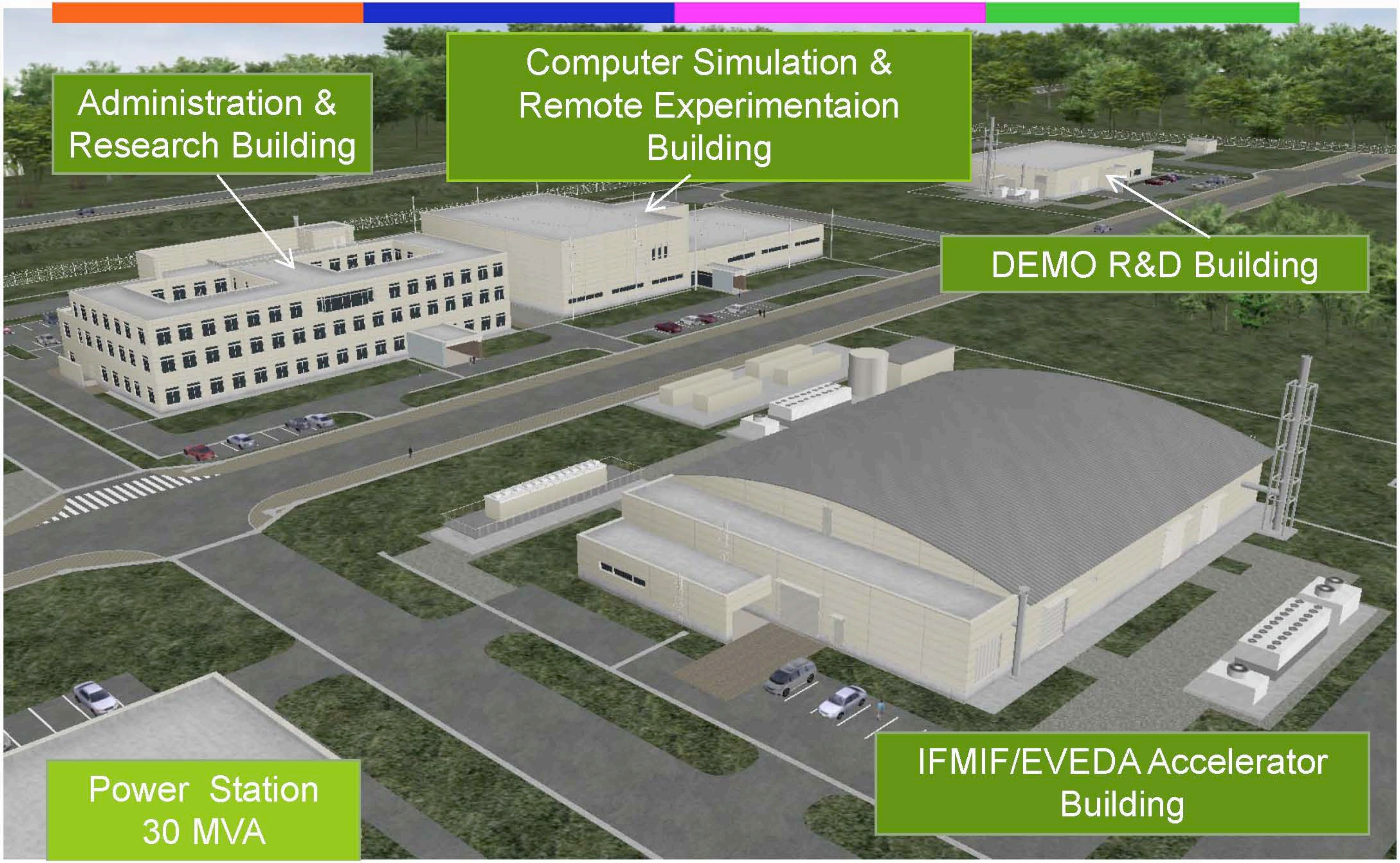


New Research Center in Rokkasho (IFERC)



International Fusion Energy Research Centre

International Fusion Energy Research Centre

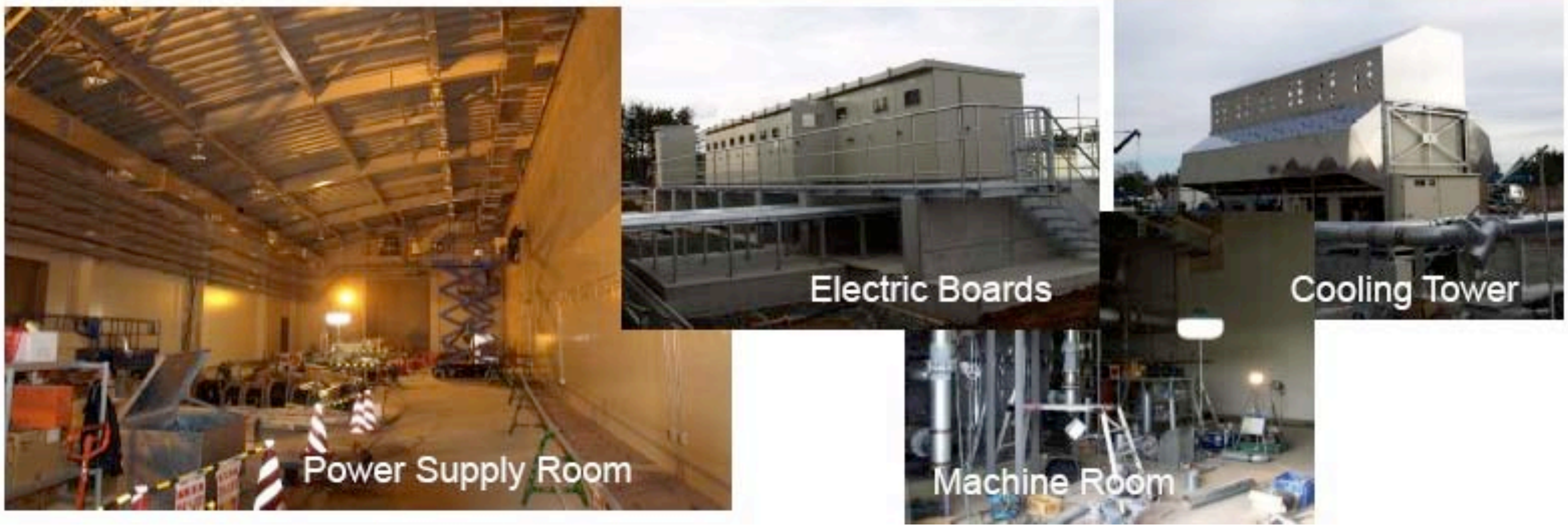


International Fusion Energy Research Centre

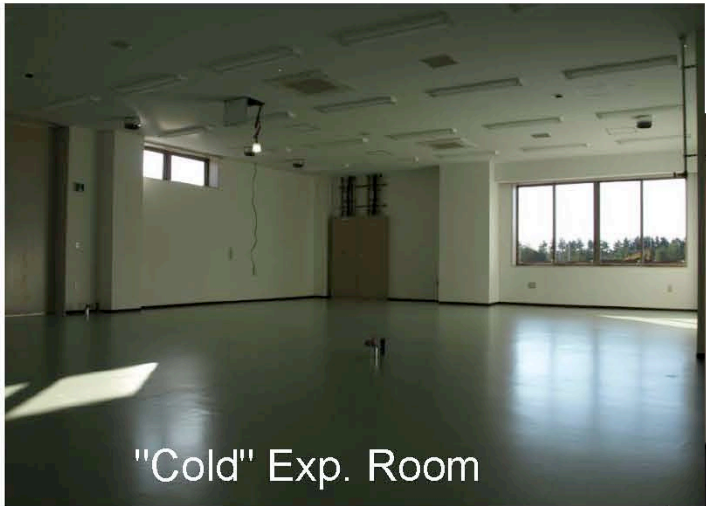
International Fusion Energy Research Centre

Computer Simulation & Remote Exp. Center Bldg.

IFMIF/EVEDA Accelerator Bldg.




DEMO R&D Building
December 1st, 2009


"Cold" Exp. Room


Resercher's Room


"Hot" Exp. Room

International Fusion Energy Research Centre

Project team members and JAEA staffs have moved to International Fusion Energy Research Centre on 30th March 2009.

At present, 68 people including 10 reseachers from EU are working in IFERC.