Engineering Feature in the Design of JT-60SA

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JA-EU satellite tokamak working group and the JT60-SA design team

Abstract

This paper intends to clarify the latest design option of the JT-60SA.

(1) JT-60SA Project is one of the ITER Broader Approach.
(2) JT-60SA is a combined program of ITER satellite tokamak and National Centralized Tokamak in Japan.
(3) JT-60SA is aiming at to contribute DEMO reactor design as well as ITER experiments.
(4) Wide range of plasma shaping capability (aspect ratio A=2.6-3.1) is ensured.
(5) The NbTi superconductor is adopted to generate the central magnetic field of 2.7 T at R=3.0m.
(6) Plasma heating power of 41 MW, 100s is being planned.
(7) An optimization of neutron and radiation shielding is made on the vacuum vessel and cryostat structures for the neutron yield of about $2x10^{19}$/shot.
(8) Existing power supplies, heating & CD system and cooling system are utilized as much as possible.
(9) ITER type remote handling system will be introduced.

Contributors

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Outline of JT-60SA Device

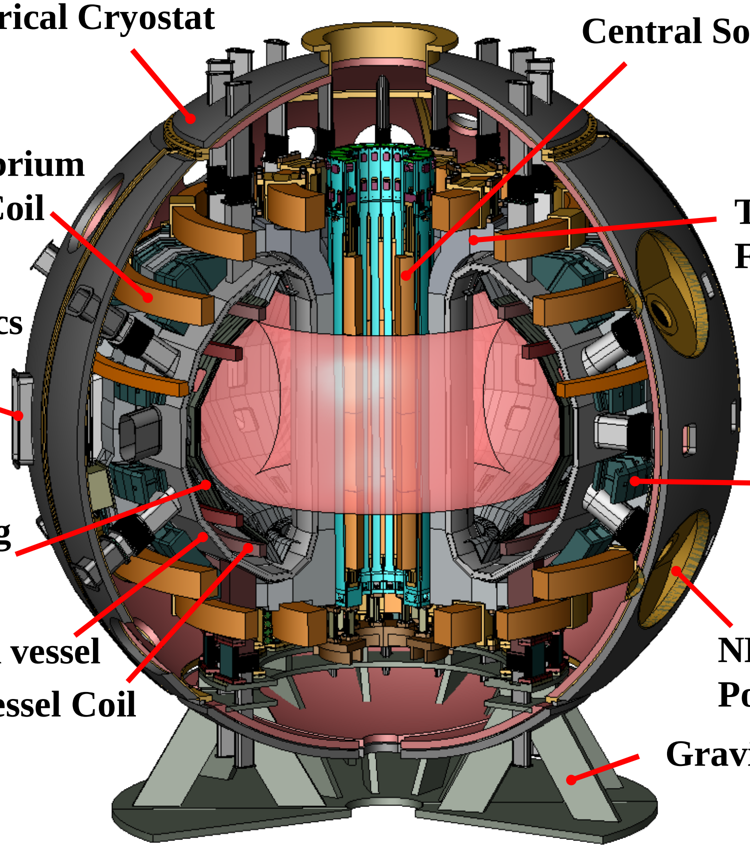


Fig. 1. Cut-set view of JT-60SA.

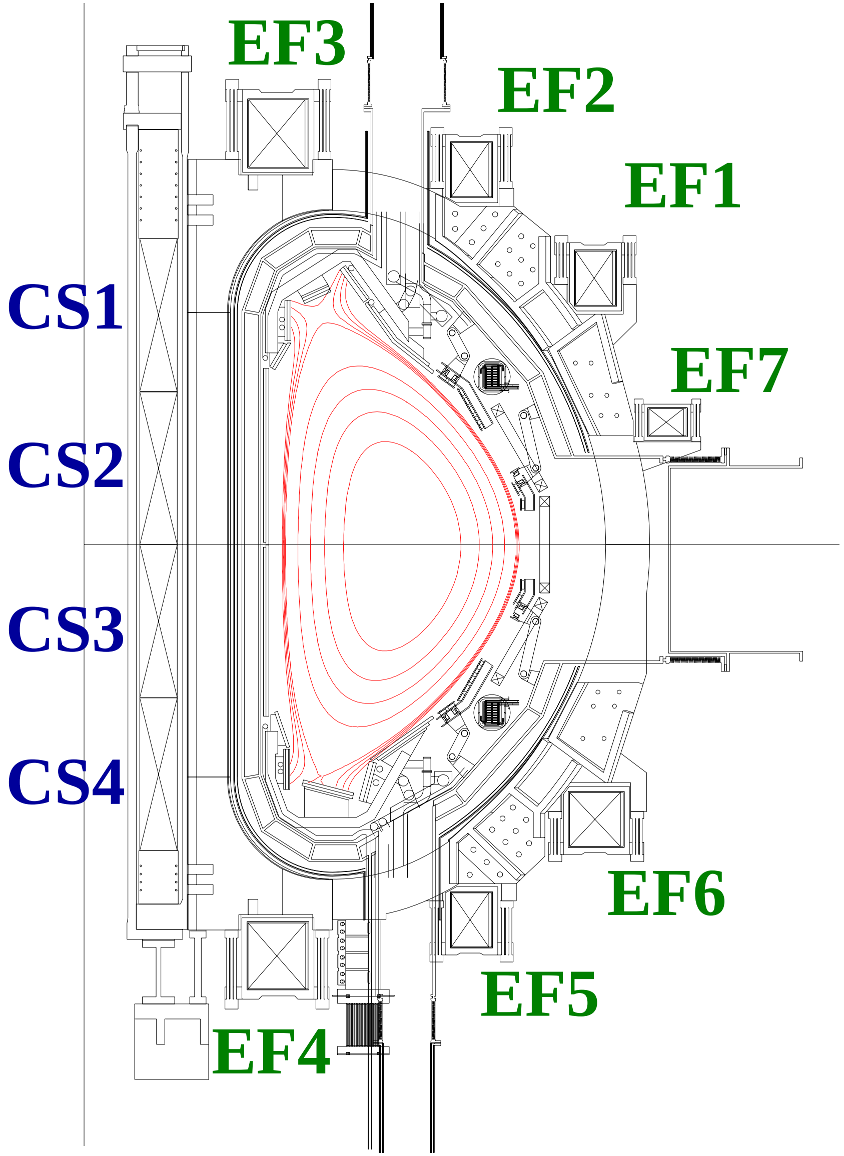
TABLE I: BASIC PARAMETERS OF JT-60SA.

Parameter	Large Plasma (DN)	ITER Similar (SN)
Plasma Current Ip (MA)	5.5	3.5
Toroidal Field Bt (T)	2.72	2.59
Major Radius (m)	3.01	3.16
Minor Radius (m)	1.14	1.02
Elongation, k_{95}	1. 83	1.7
Triangularity, d_{95}	0. 57	0.33
Aspect Ratio, A	2.64	3.10
Shape Parameter, S	6.7	4.0
Safety Factor q_{95}	3.77	3.0
Flattop Duration	100 s (8 hours)	
Heating & CD power	41 MW x 100 s	
N-NBI	34 MW	
ECRH	7 MW	
PFC wall load	10 MW/m^2	
Neutron (year)	4 x 10^{21}	

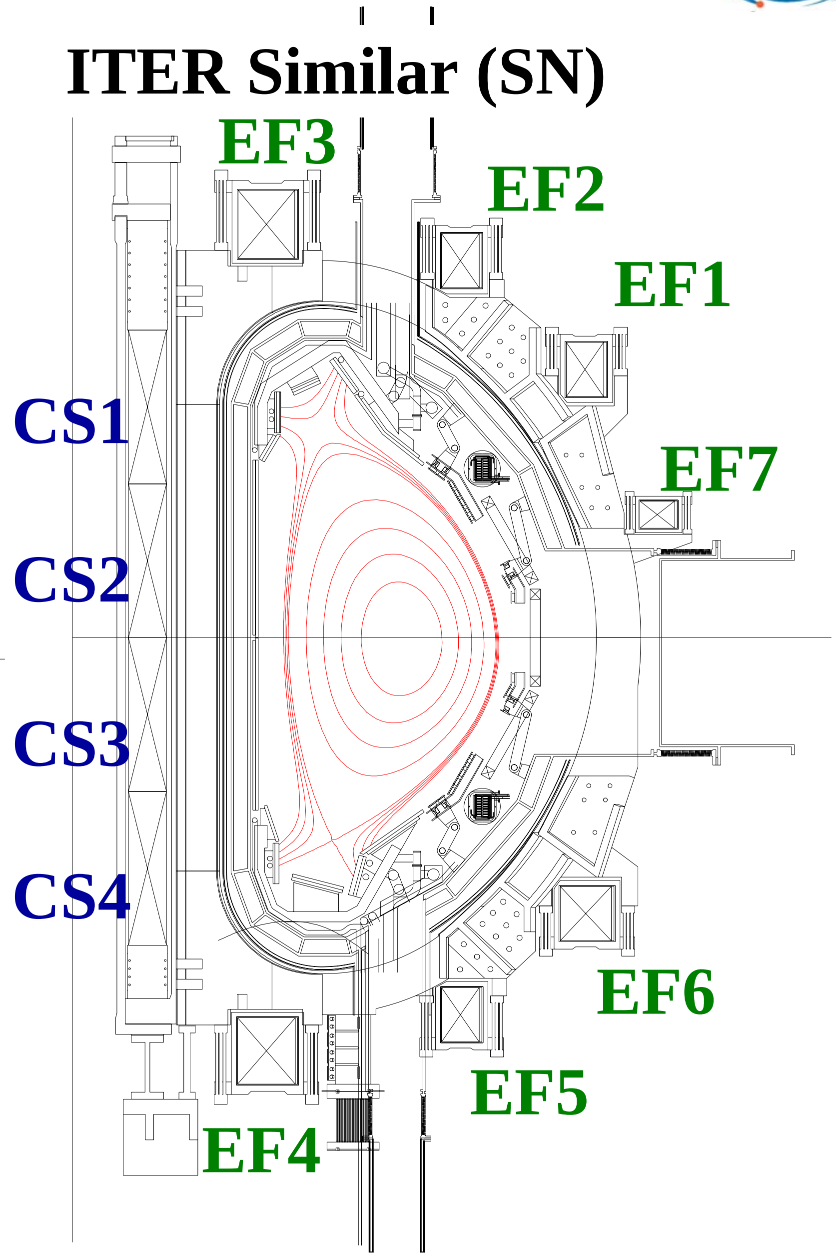
Magnet:~1300ton, VV:~600ton, Cryostat:~600ton, total:~2500ton

Typical Plasma Configuration

Large Plasma (DN)



ITER Similar (SN)



Layout of Torus hall

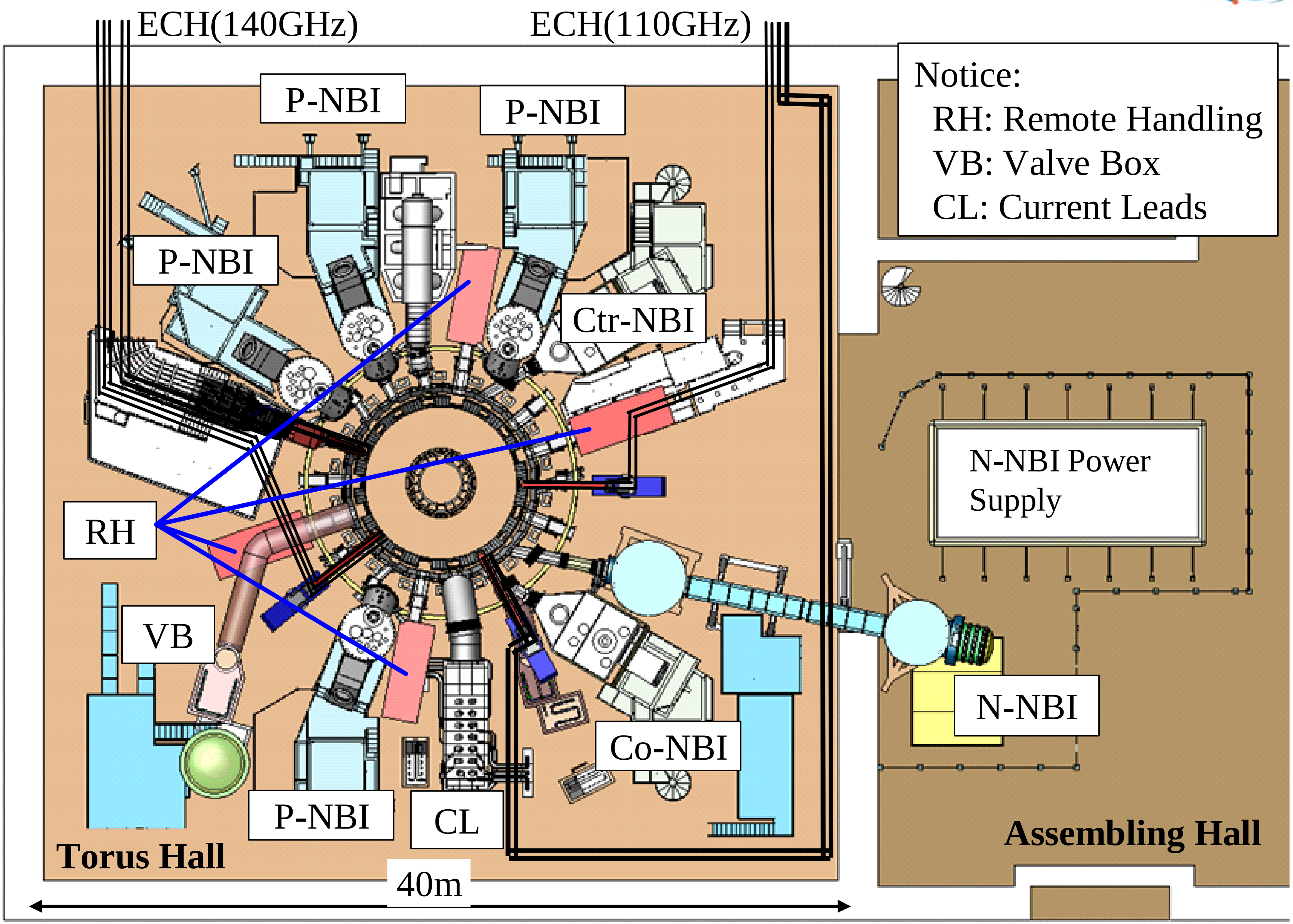
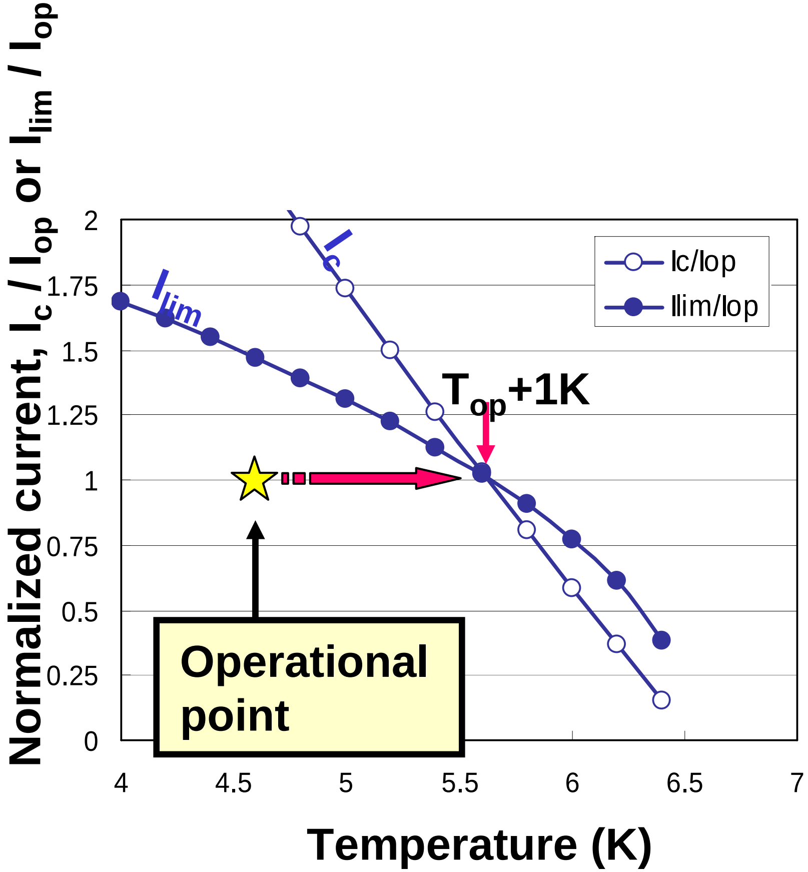


Fig. 2. Layout plan of the JT-60SA torus hall.

Toroidal Field Coil

TABLE II: TF CONDUCTOR DESIGN.

Parameter	JAEA Criterion
Operating field Bop	6.4 T
Operating current Iop	26.5 kA
Strand diameter d	0.712 mm
Operating temperature Top	4.6 K
Cu/non-Cu ratio	7.0
Critical Current Density	>2900 A/mm^2
Number of SC strands	720
Cabling pattern	3 x 3 x 4 x 4 x 5
Conduit material	SS316LN
Inner diameter of conduit	22 x 22 mm
Temperature Margin	Top= Tcs-Tmargin Tmargin > 1.0 K
Limiting Current criterion	Ilim (Bop, Top+1K)/Iop>1
Critical Current	Ic / Iop > 1



Steckly Criteria is satisfied.

TF coil case, winding pack, inuslation

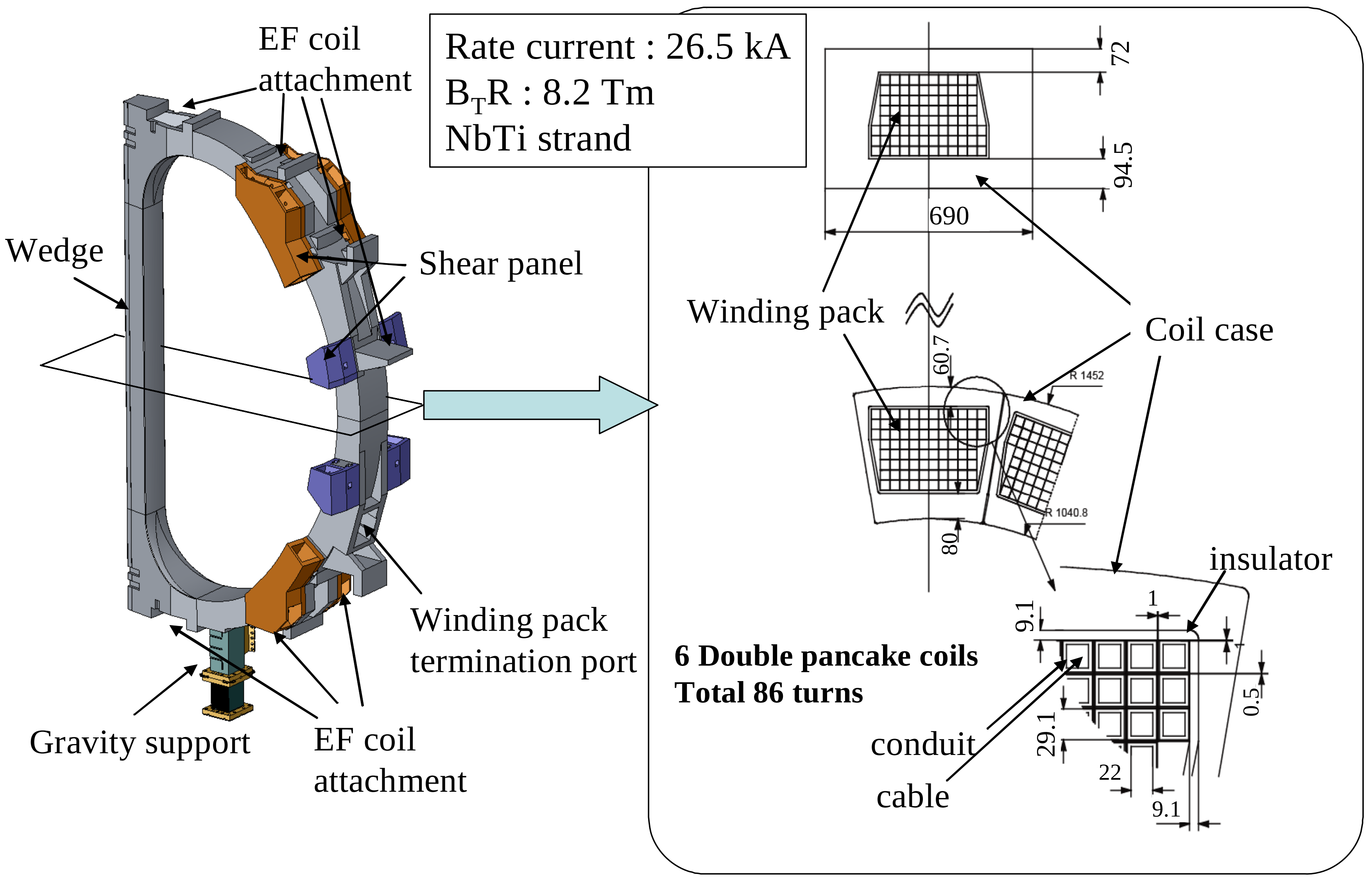
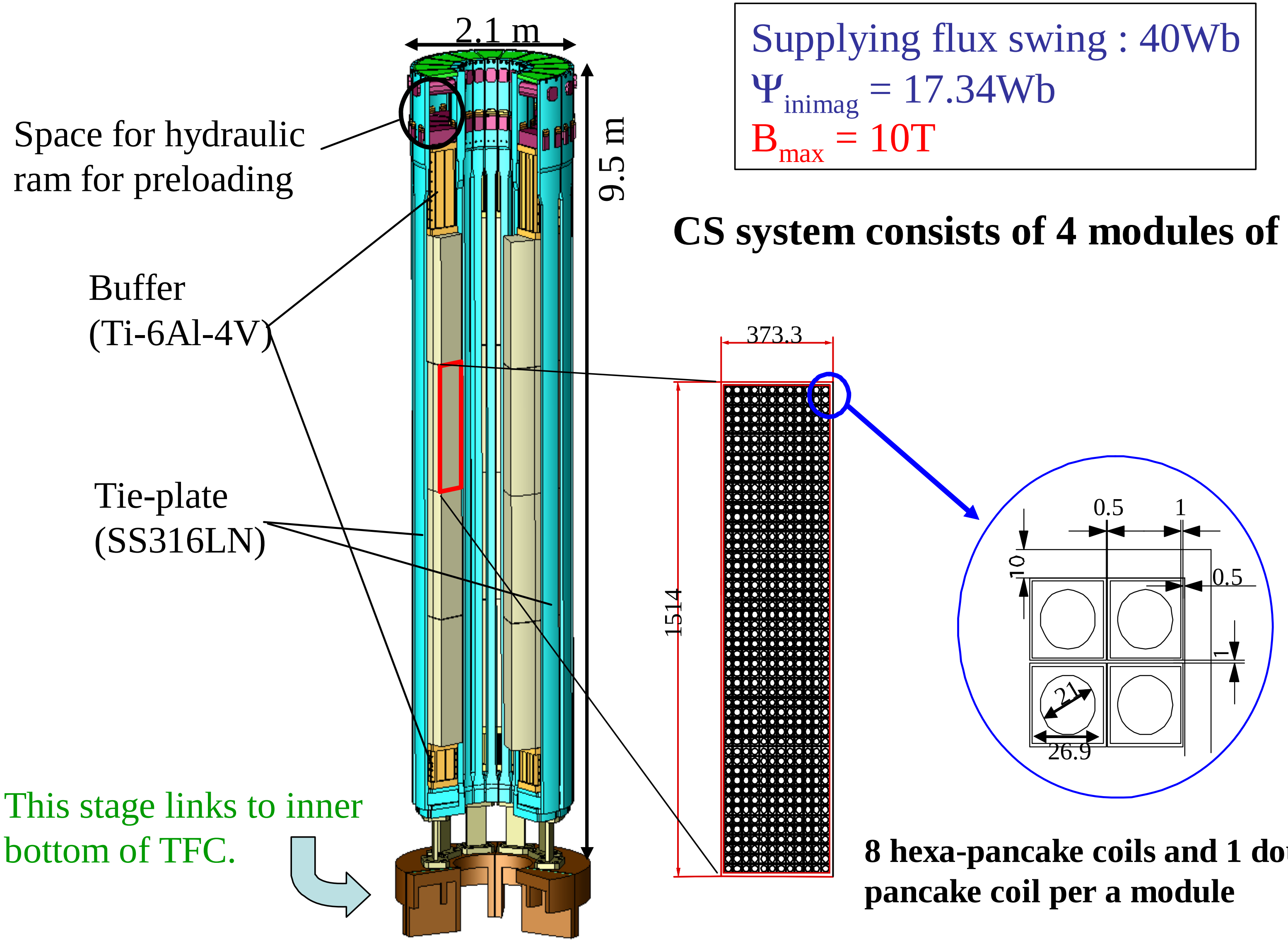


Fig. 3. TF coil structure including coil case, shear panel and winding pack.

Central Solenoid (CS)

Supplying flux swing : 40Wb
Ψ_{inimag} = 17.34Wb
B_{max} = 10T

CS system consists of 4 modules of solenoid.



8 hexa-pancake coils and 1 double pancake coil per a module

Fig. 5. Outline of CS and the supporting structure.

Radial Build

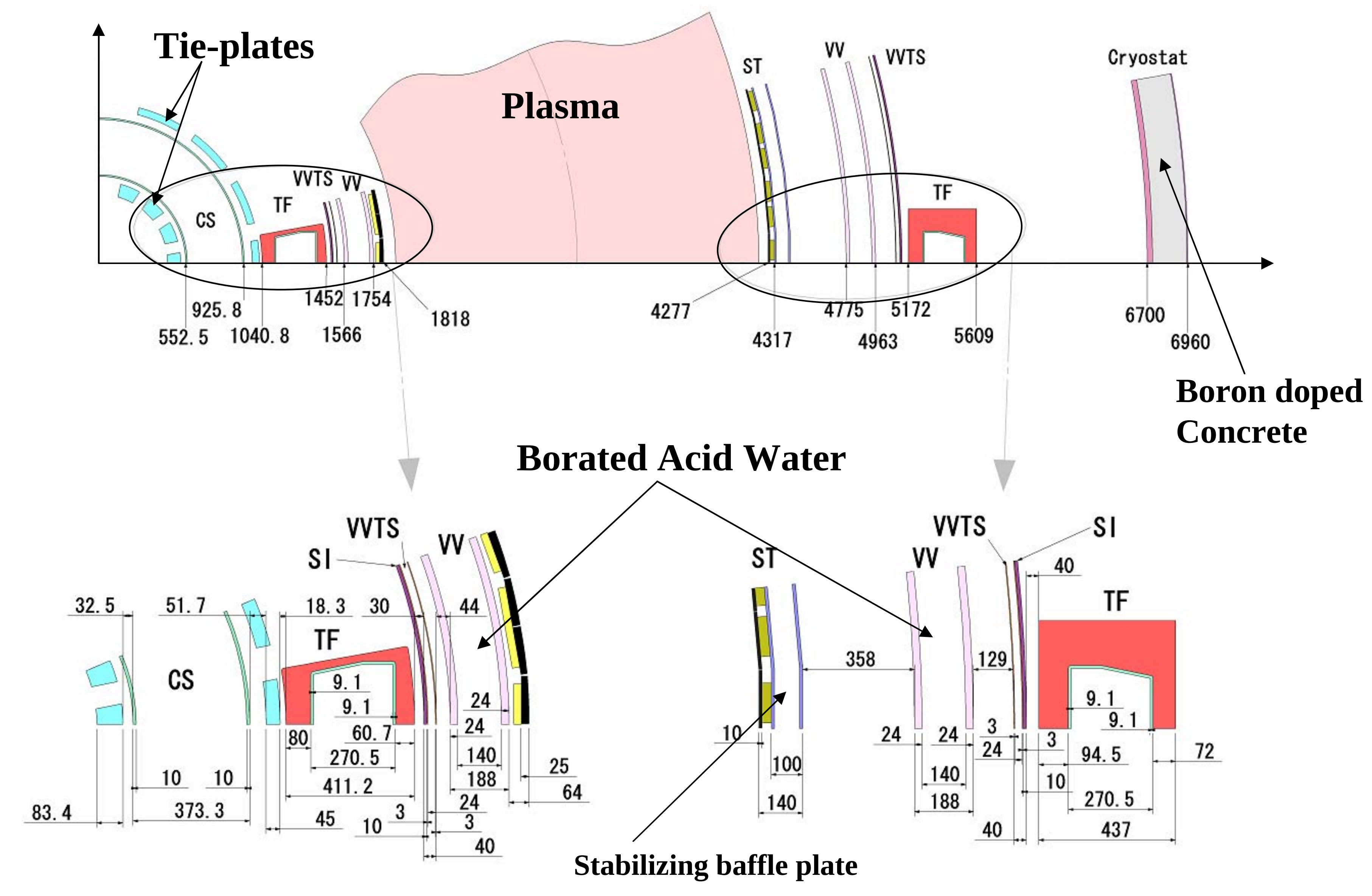
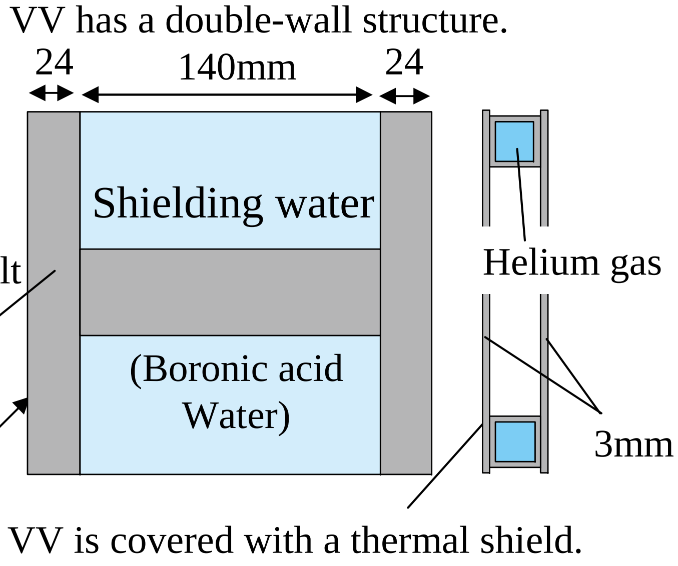


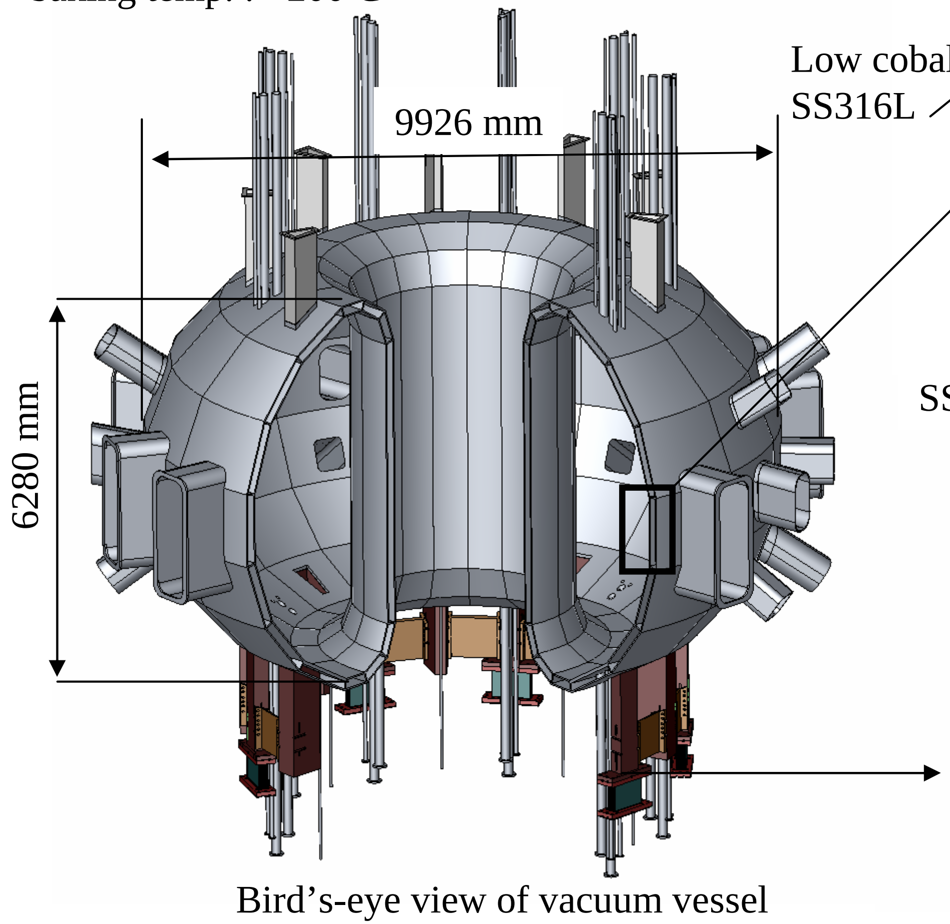
Fig. 6. Radial build of JT-60SA.

Vacuum vessel

consists of 18 sections

cylindrical: toroidally, polygonal:poloidally
weight: ~300 ton without in-vessel components
one turn resistance: ~15μΩ
baking temp. : <200°C





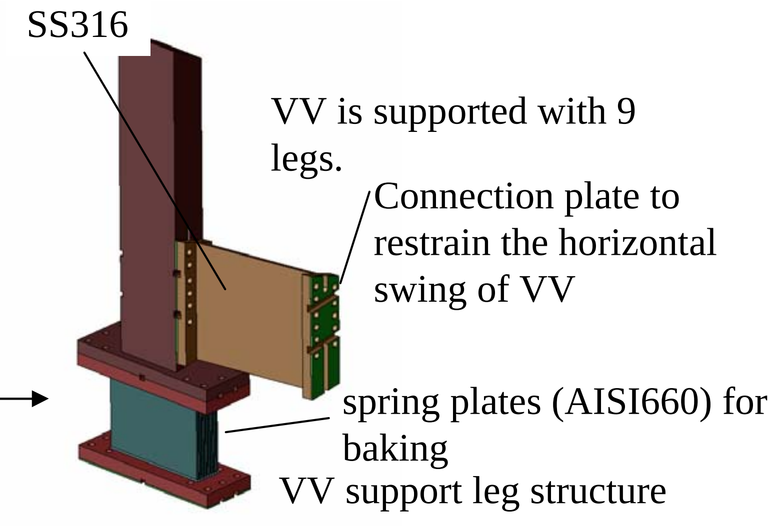
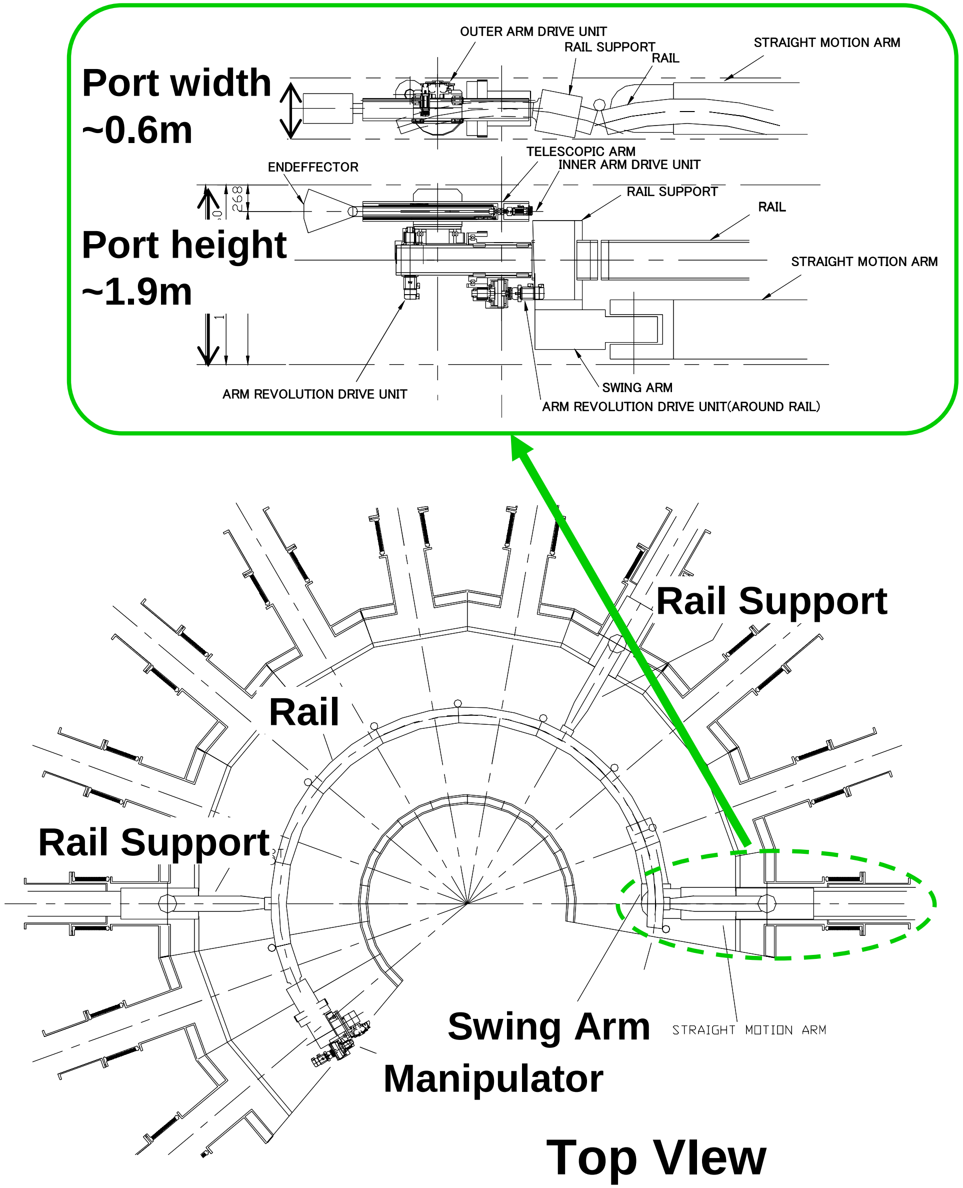


Fig. 7. Structure of vacuum vessel.

Concept of RH System for JT-60SA

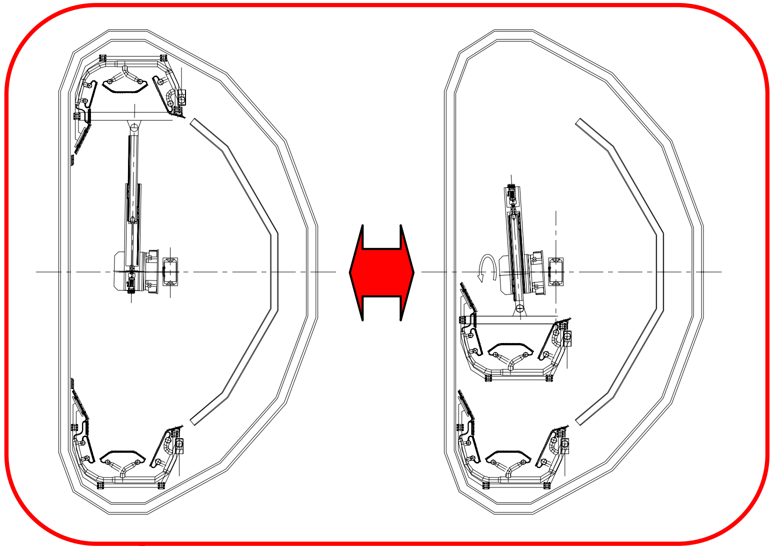
- **Bolted armor tiles (>10000 pieces)** at first wall, dome and baffles are exchanged for
  - PMI research (10-100 pieces / year)
  - metal wall for DEMO (~All / once)
  - => Vehicle type can exchange many tiles quickly.
- **Large and heavy components** are exchanged for
  - repairing (once*? in lifetime)
  - modification (once* in lifetime)
  - *lifetime of divertor targets might be shorter than that of machine.
  - => Boom type can handled large components in narrow space.

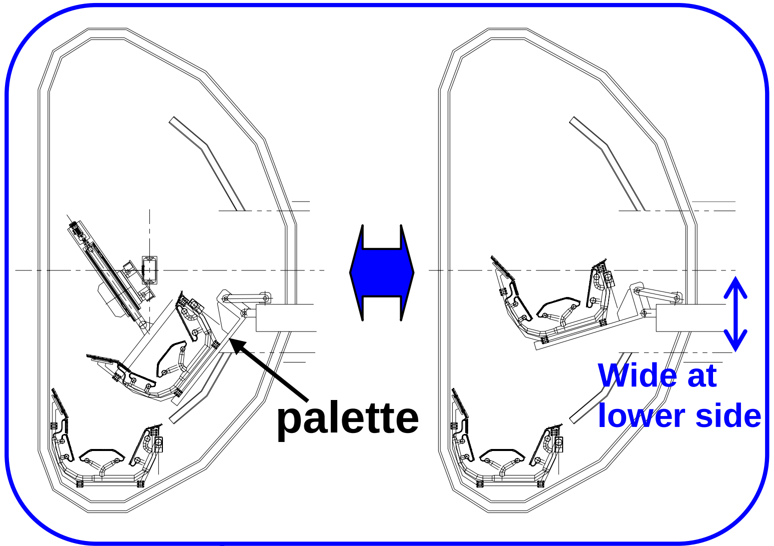
Hybrid type is most promising candidate.



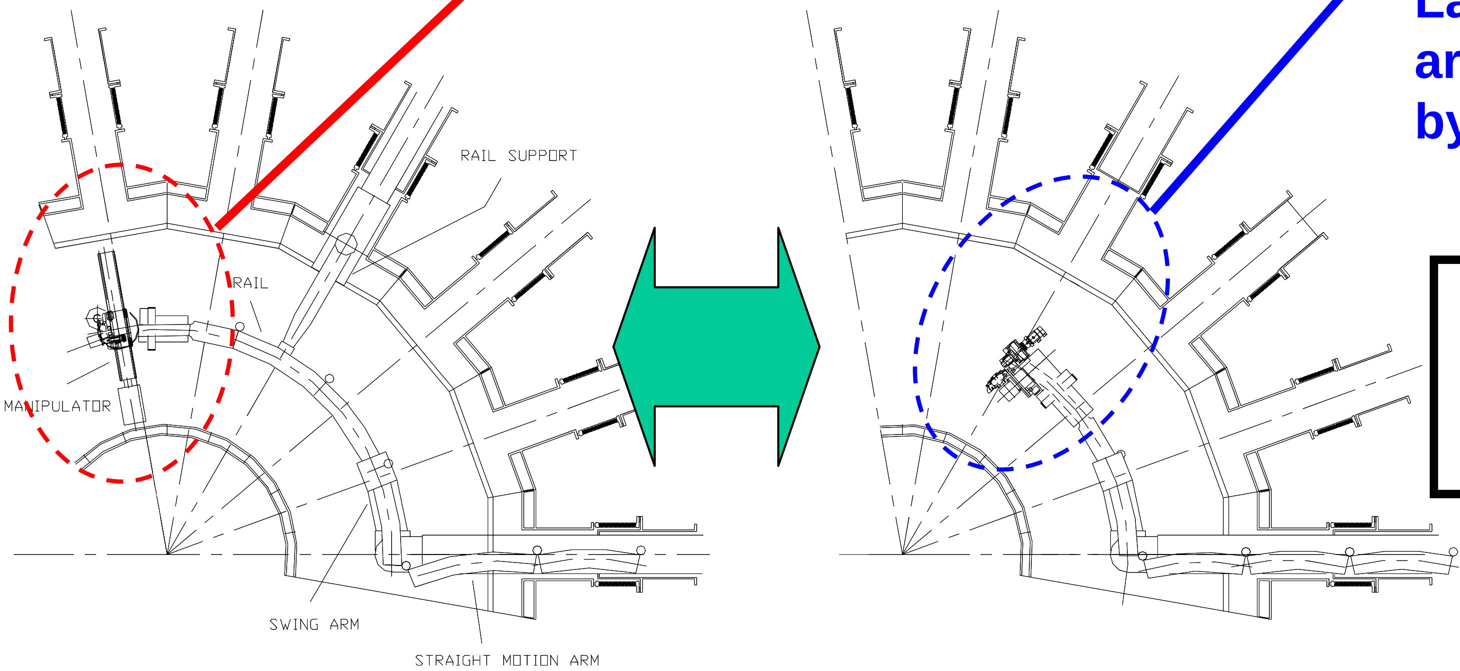
Large and Heavy Weight Manipulator

Upper-side components are turn over to lower side



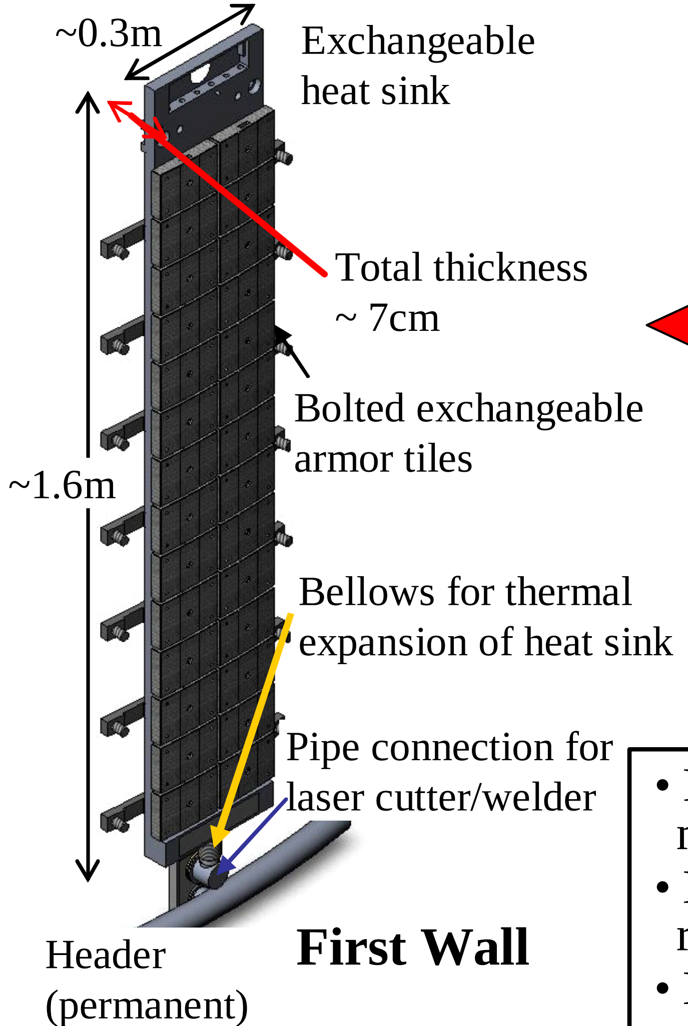


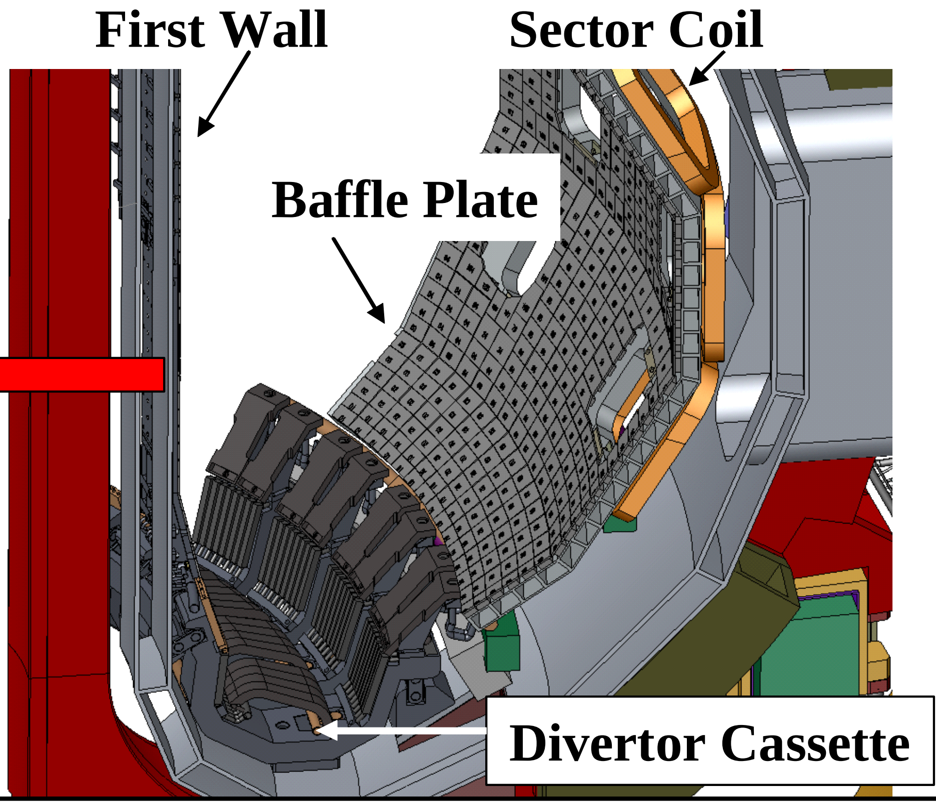
Large components are brought in/out by palette



Max. weight 500kg
Max width 0.6m
Max height ~1m

In-vessel components

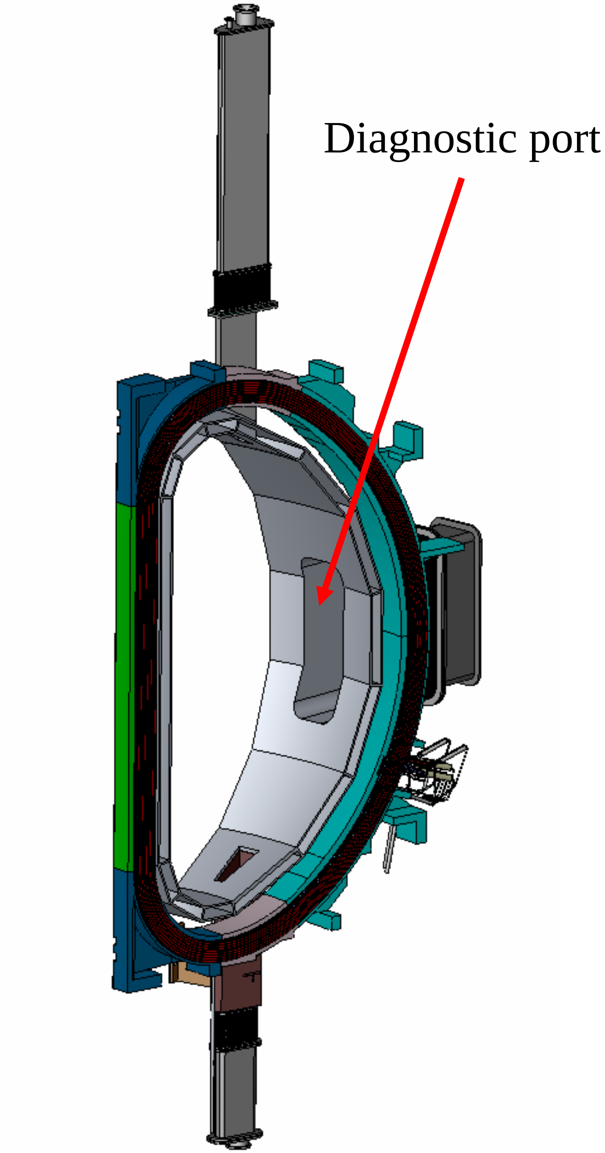




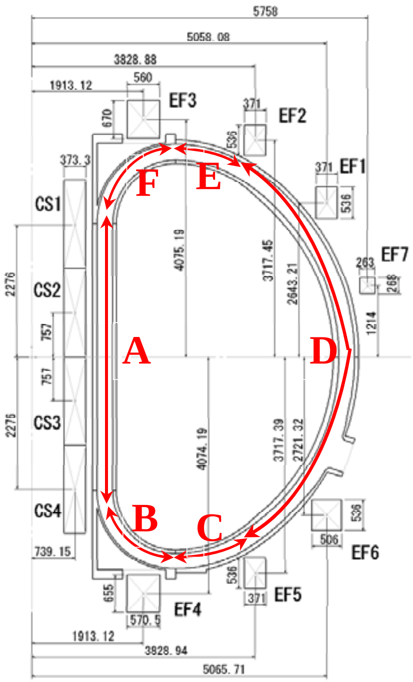
- First wall, divertor modules will be feasible for the maintenance by remote handling system.
- Mono-block target (15MW/m^2) will be adopted after the relliability is established bysignficant R&D.
- Exchange with full metal plasma facing components will be decided after experimental and computational analyses.

Fig.8. A design of divertor cassette, first wall and baffle plats.

Nuclear heating of TF coil by 3D calculation



3D model used in nuclear heating at superconducting coil



Estimated points

Cal. Condition

- **Sn=4x10^{17} (n/sec)**
- **Borated water (40℃)**
- **Rib (20%)**

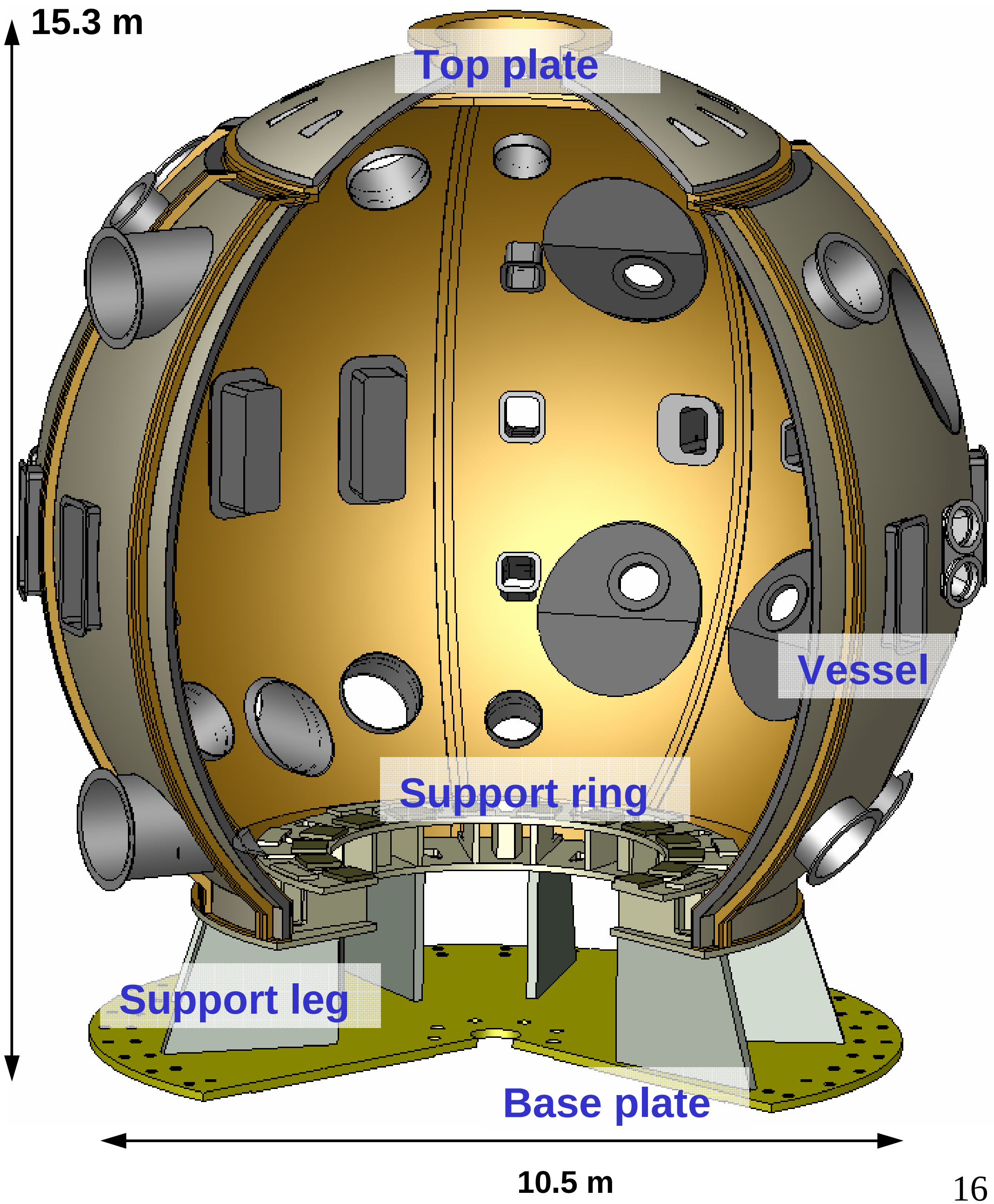
Estimation points are six sections (A~F).

- **Maximum nuclear heating at superconductor layer**

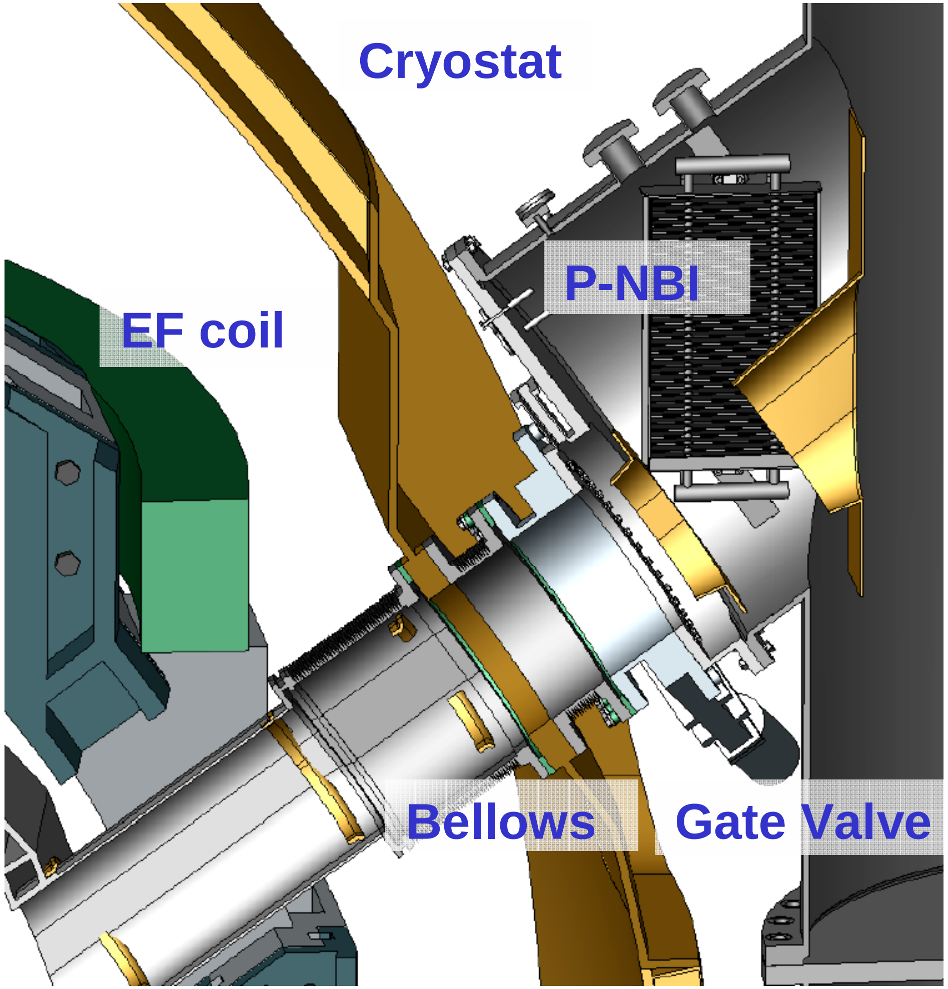
	(watt/cc)	error (%)
A	1.33E-04	3.85%
B	9.65E-05	6.06%
C	1.27E-04	5.21%
D	2.44E-04	2.12%
E	1.11E-04	6.89%
F	8.06E-05	6.58%

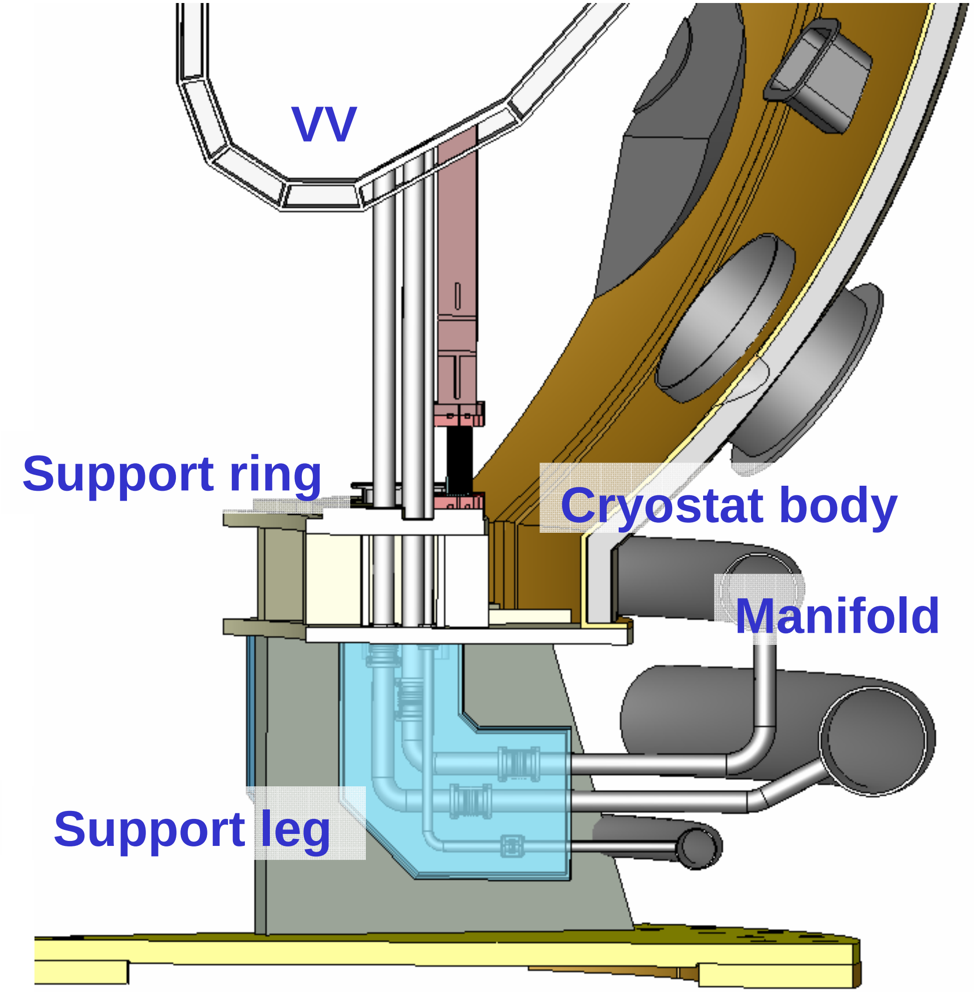
Overall structure of JT-60SA cryostat

- Spherical shape and 18 sections
- Double wall structure of type 304 stainless steel (Co < 0.05 wt%)
  (Inner 34 mm, Outer 6 mm)
- Boron doped concrete between inner and outer wall
- Bolts and lip seals at flanges
- Super-conducting coil & VV fixed on support ring
- 9 legs of gravity support
- Base plates fixed onto the existing building
- 70 ton of cryostat total weight



Detailed integration concept





· Outside gate valves design

→ Maintenance of the gate valves without disassembling

· Outside manifolds design

→ Water supply for Shielding of VV

→ Coolant for divertor and first wall

Upgrade of NBI for JT-60SA

JT-60U (~15MW x 30 s)

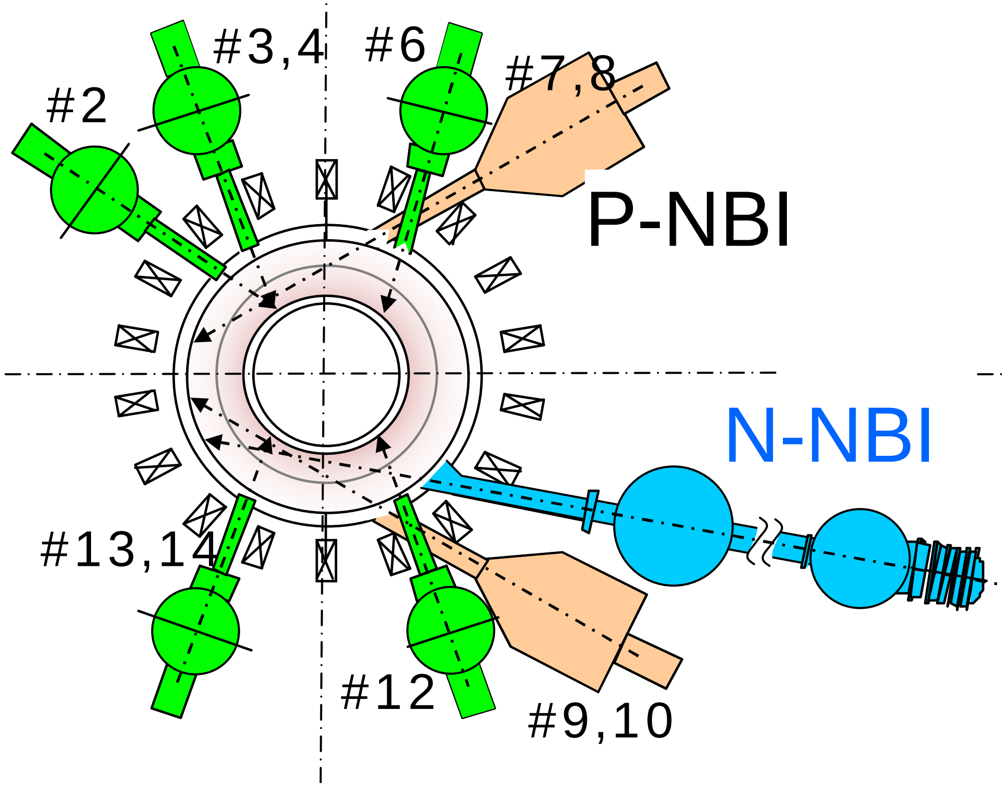
P-NBI (12-14 MW at 85 keV)
- 4 tanj.(co+ctr) units: 30s
- 7 perp. units: 10 s x 3

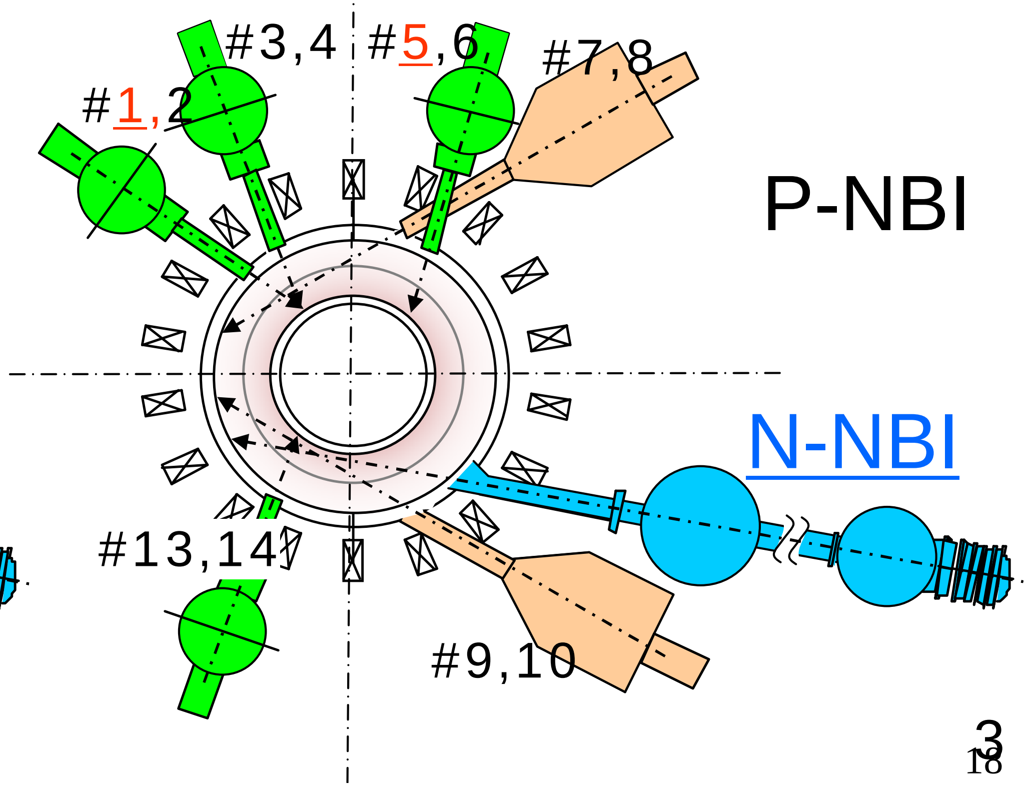
N-NBI
- 3.2 MW x 20 s at 320keV
- 3.6 MW x 18 s at 340keV

JT-60SA (44 MW x100s)

P-NBI (24 MW at 85 keV)
- 4 tanj.(co) units
- 8 perp. units: 100 s

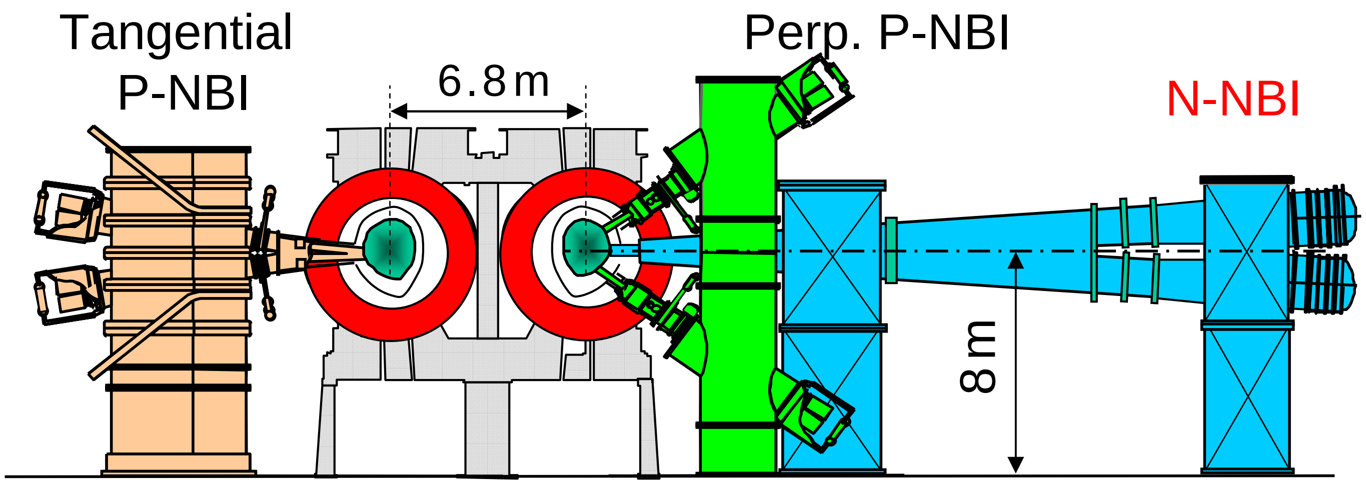
N-NBI (10 MW at 500 keV)

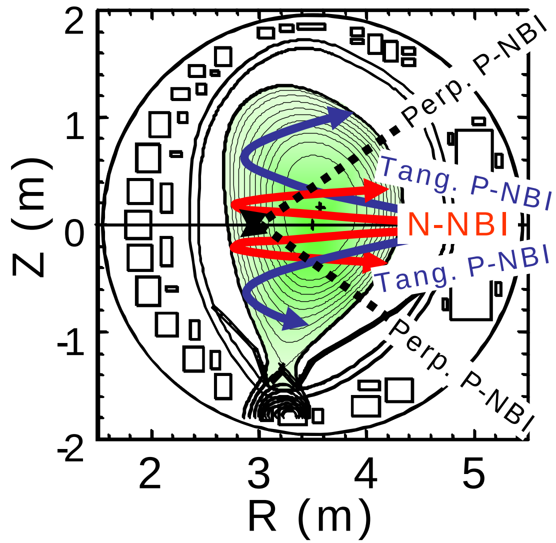




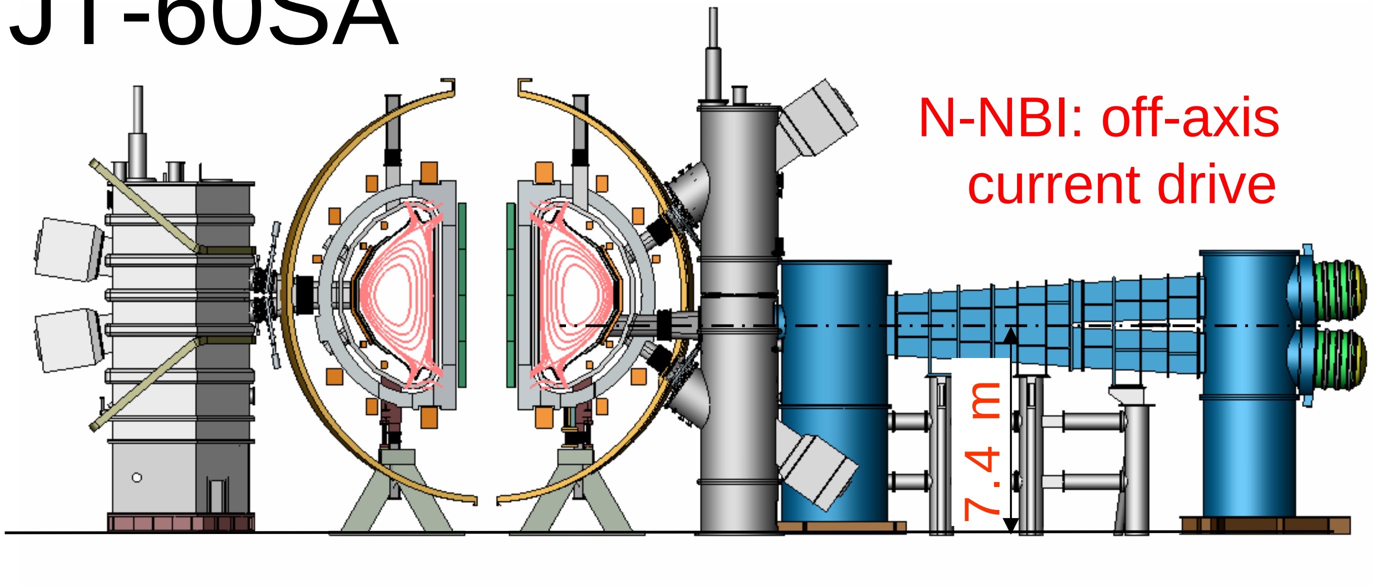
Deposition profile

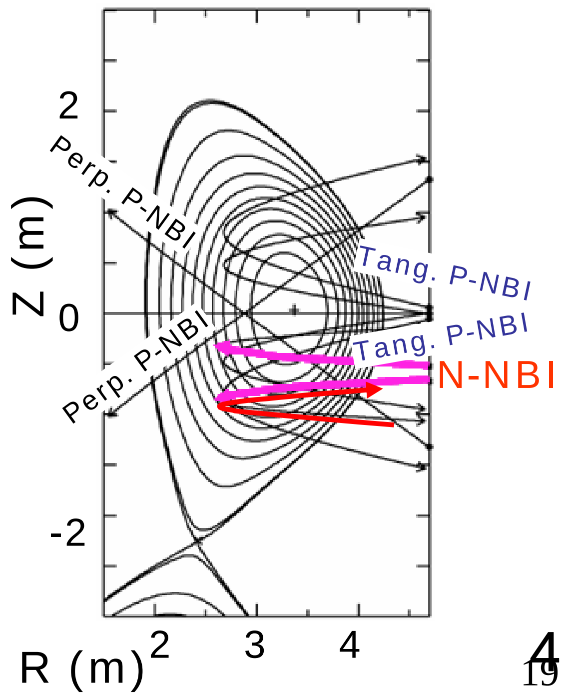
JT-60U





JT-60SA

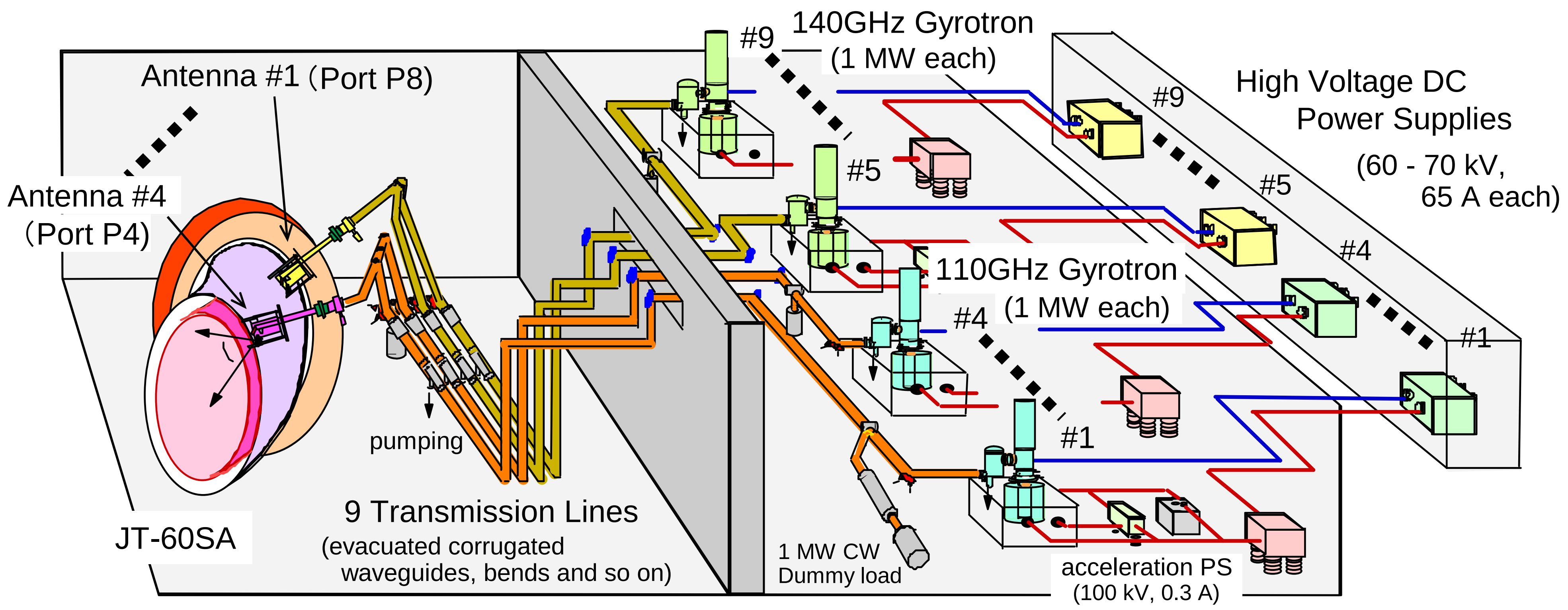




Outline of the 7 MW ECRF System in JT-60SA

- A 140 GHz system will be constructed newly, 3 gyrotron sets and DC power supplies by EU and the others by Japan
- As a 110 GHz system, the present system will be upgraded with new gyrotrons, DC power Supplies and antennas by Japan

	Injection Power	Pulse Duration	Number of Units	Number of Antennas	Power at Gyrotron	Transmission Efficiency	Diameter of Waveguides
140 GHz System	4 MW	100 s	5 units	2 units	1 MW	80 %	63.5 mm
110 GHz System	3 MW	100 s	4 units	2 units	1 MW	75 %	31.75 mm



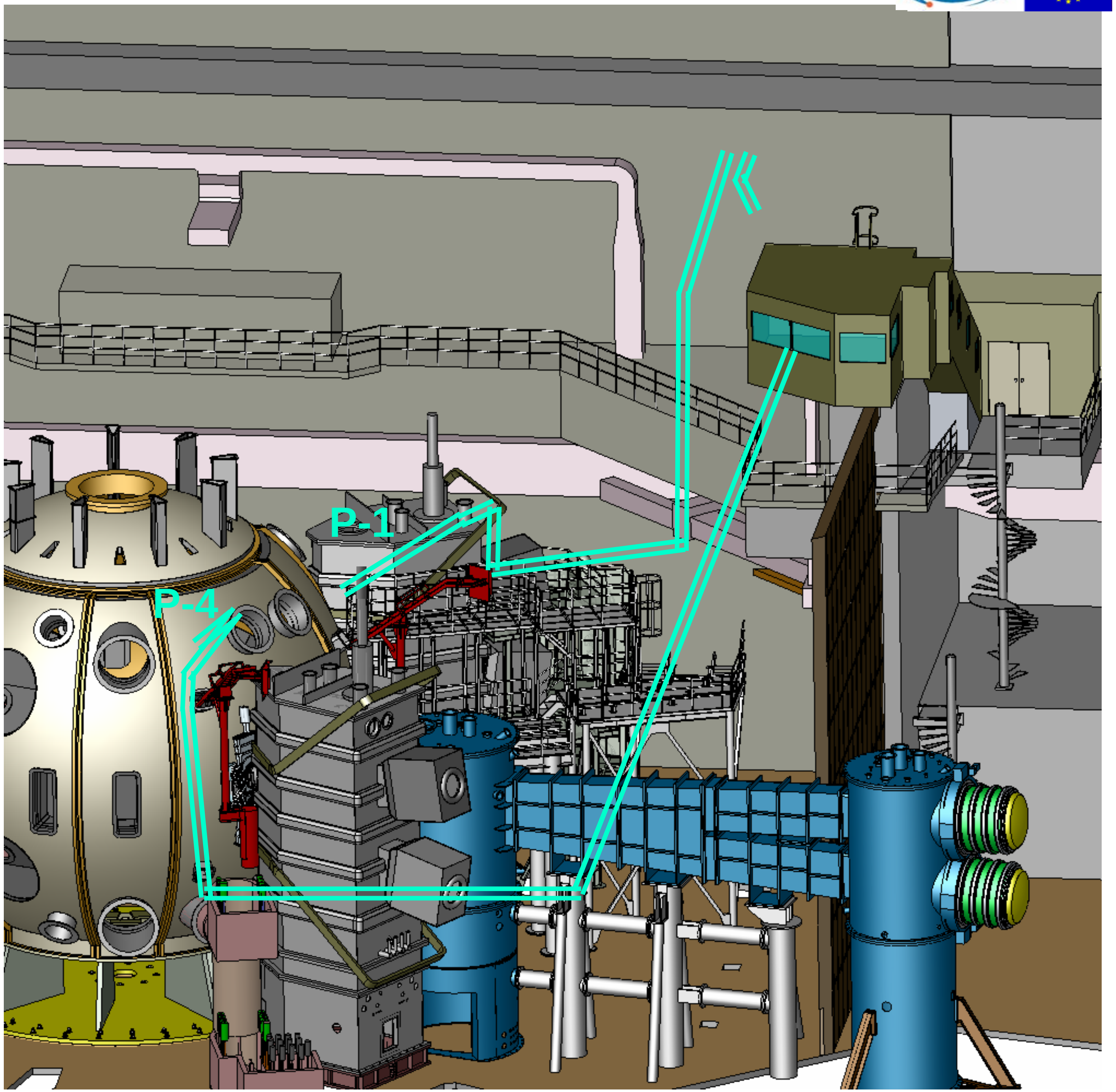
Plan of Waveguides Layout

Basic plan:

- •Port-1, 4 will be used for 110 GHz antennas.
- •WG diameter : 31.75mm

+ Port-1 is close to the present JT-60 antenna location, most of waveguides and their support/maintenunce stages can be therefore reusable.

- Relatively long waveguides and new support stages will be needed for Port-4.



AC Power System

TABLE III: SUMMARY OF REQUIRED AC POWER.

	Heating Power (MW)	Efficiency	Power factor	Active Power (MW)	Reactive Power (MVAR)	Energy (GJ)	Comment
P-NBI	24.0	0.40	0.60	60.3	80.1	6.0	2MW-12unit-100s
N-NBI	10.0	0.25	0.60	40.5	54.0	2.0	5MW-2unit-100s
ECH	7.0	0.25	0.80	28.0	21.0	2.8	7 MW
total	41.0	0.32	0.64	128.8	155.1	12.9	41MW-100s

Comparison of MG and Power Grid

Priority of Power Source	Merit	demerit
Motor-Generator	**Small SVC, Filter, dummy load**	Poor energy conversion coefficient
Power Grid	High energy conversion coefficient	**Large SVC, Filter, dummy load**

We preceded a Motor-Generator to suppress the initial investment.

AC Power System(2)

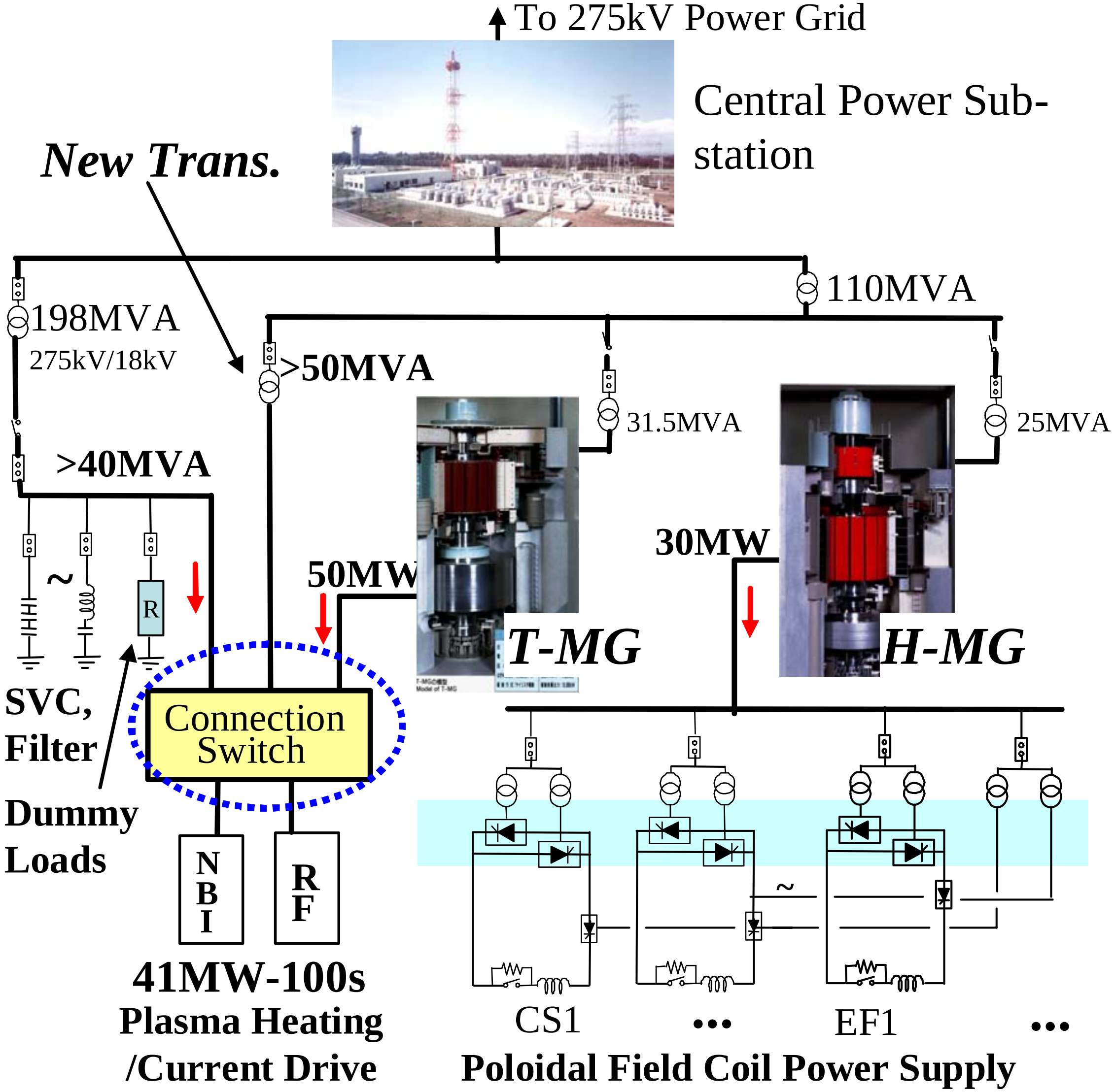
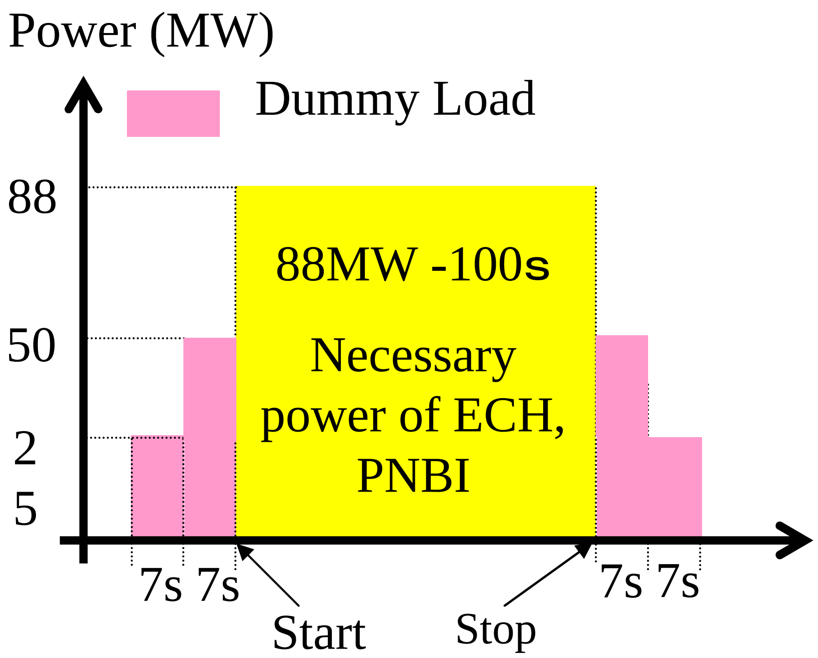


Fig. 9. Outline of AC power sources of JT-60SA.



Smoothing a large Power Step

Outline of Divertor Cooling System

Basic specification

Flow rate for the divertor cooling: 4800m^3/h

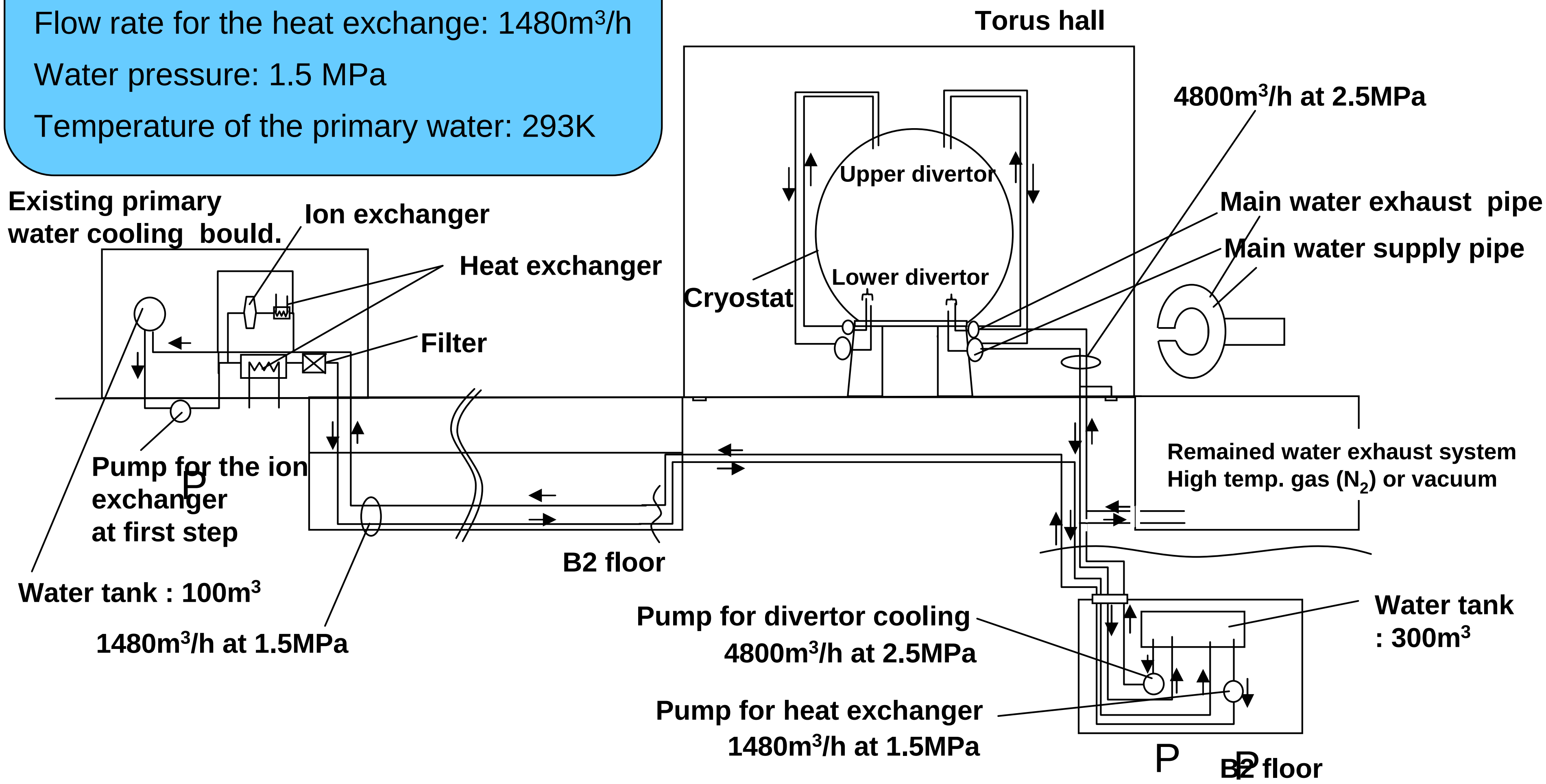
Water pressure: 2.5 MPa

Flow rate for the heat exchange: 1480m^3/h

Water pressure: 1.5 MPa

Temperature of the primary water: 293K

Divertor heat load: <50MW x 100sec
30 min. interval



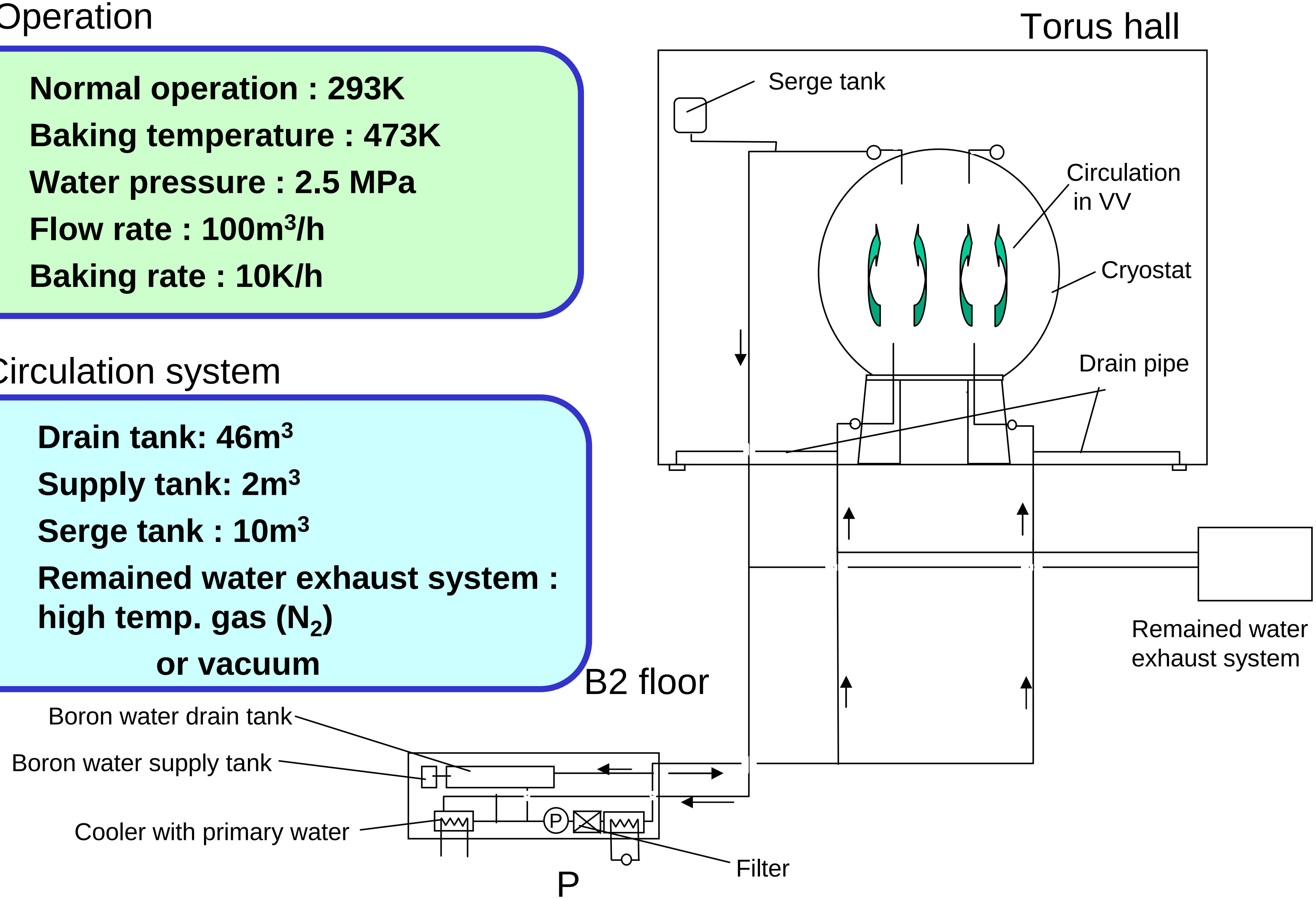
Outline of Boronic acid water circulation system

Operation

- Normal operation : 293K
- Baking temperature : 473K
- Water pressure : 2.5 MPa
- Flow rate : 100m^3/h
- Baking rate : 10K/h

Circulation system

- Drain tank: 46m^3
- Supply tank: 2m^3
- Serge tank : 10m^3
- Remained water exhaust system : high temp. gas (N_2) or vacuum



Conclusion

The JT-60SA design has much progressed and its feasibility has been increased remarkably with help of EU colleagues as a part of ITER Broader Approach. It is definitely possible to start this project immediately after the ratification expected at middle of 2007. The period of manufacturing, construction, assembling and test is expected to 7 years.

Time Schedule

Schedule of construction and operation agreed in JA-EU WG:
Construction: 7 years + exploitation: 3 years