Wed-Mo-Po3.03-01

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

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

QST

Design of JT-60SA cryodistribution components

Kyohei NATSUME, Kazuma FUKUI, Haruyuki MURAKAMI, Kaname KIZU, Takaaki ISONO, Kazuya HAMADA

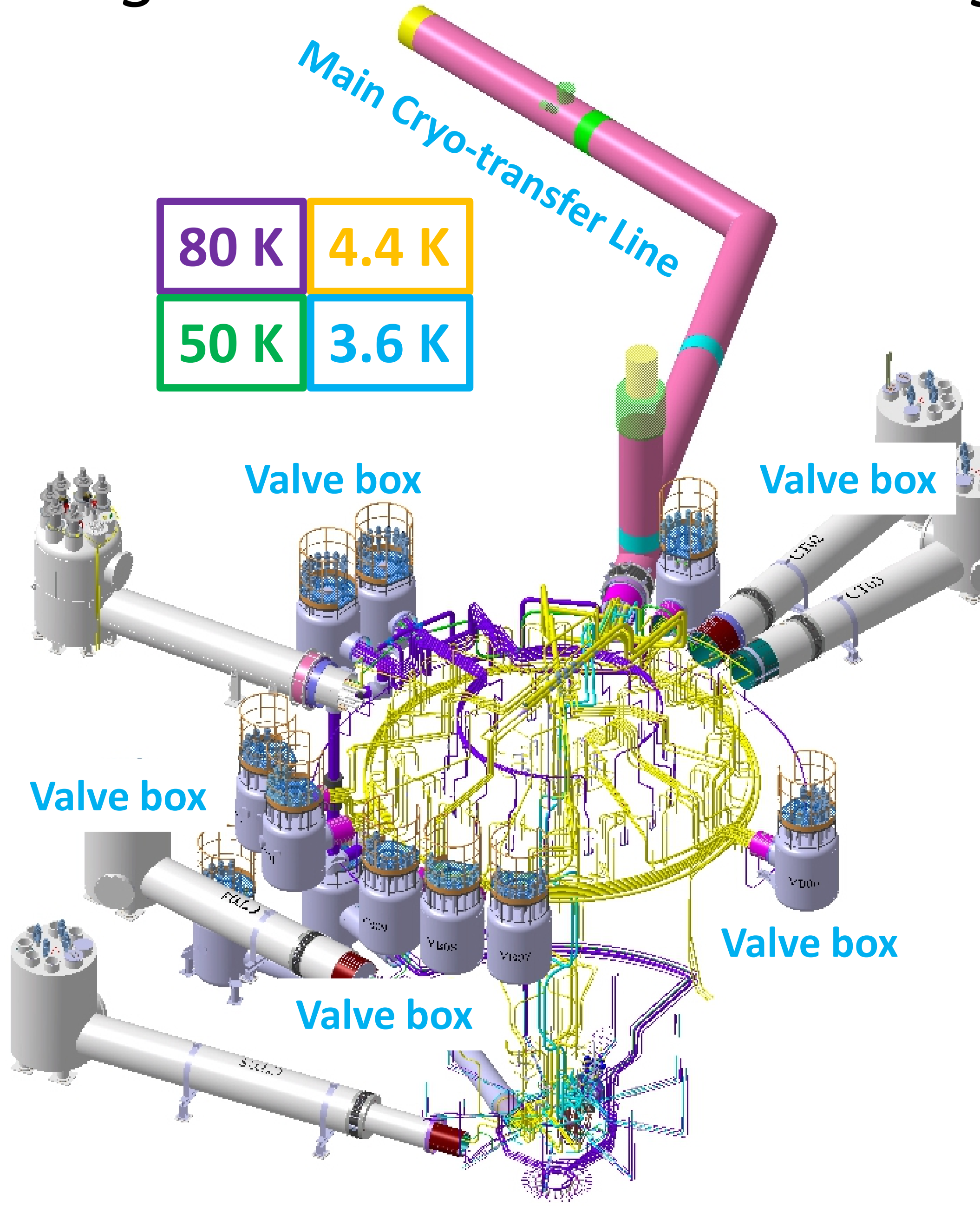
National Institutes for Quantum and Radiological Science and Technology

= ABSTRACT =

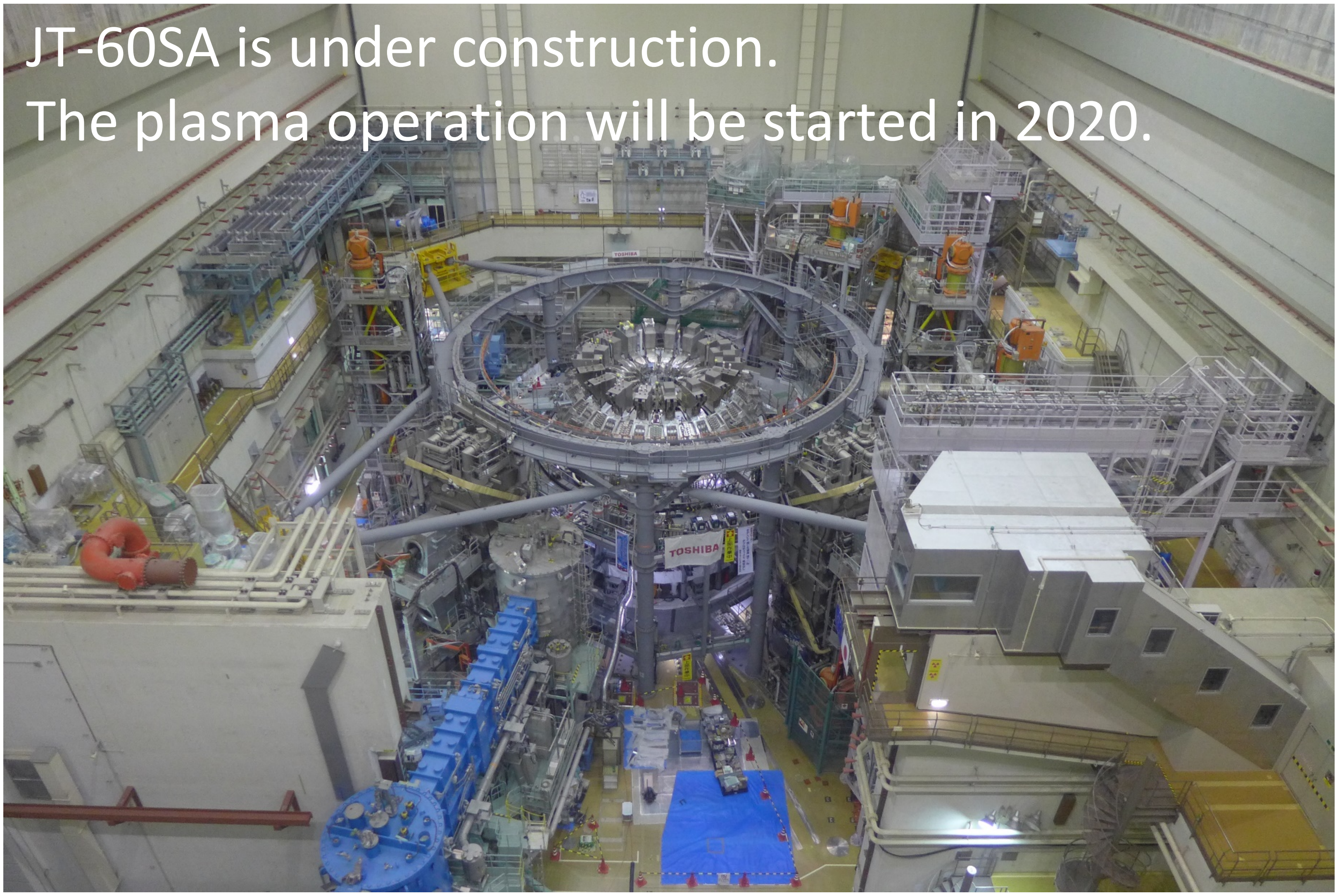
JT-60SA is a fusion experiment tokamak device using superconducting magnets to be built in Japan. This joint international project involves Japan and Europe. In this work, we presents the design of cryodistribution components which are named **main cryo-transfer line (CryoL)** and **valve boxes (VB)**.

CyoL is a vacuum heat-insulation multiple piping of which the outer diameter is 965.5 mm. It connects between the helium refrigerator system and the tokamak cryostat. All 5 supply lines and 4 return lines are installed in CryoL.

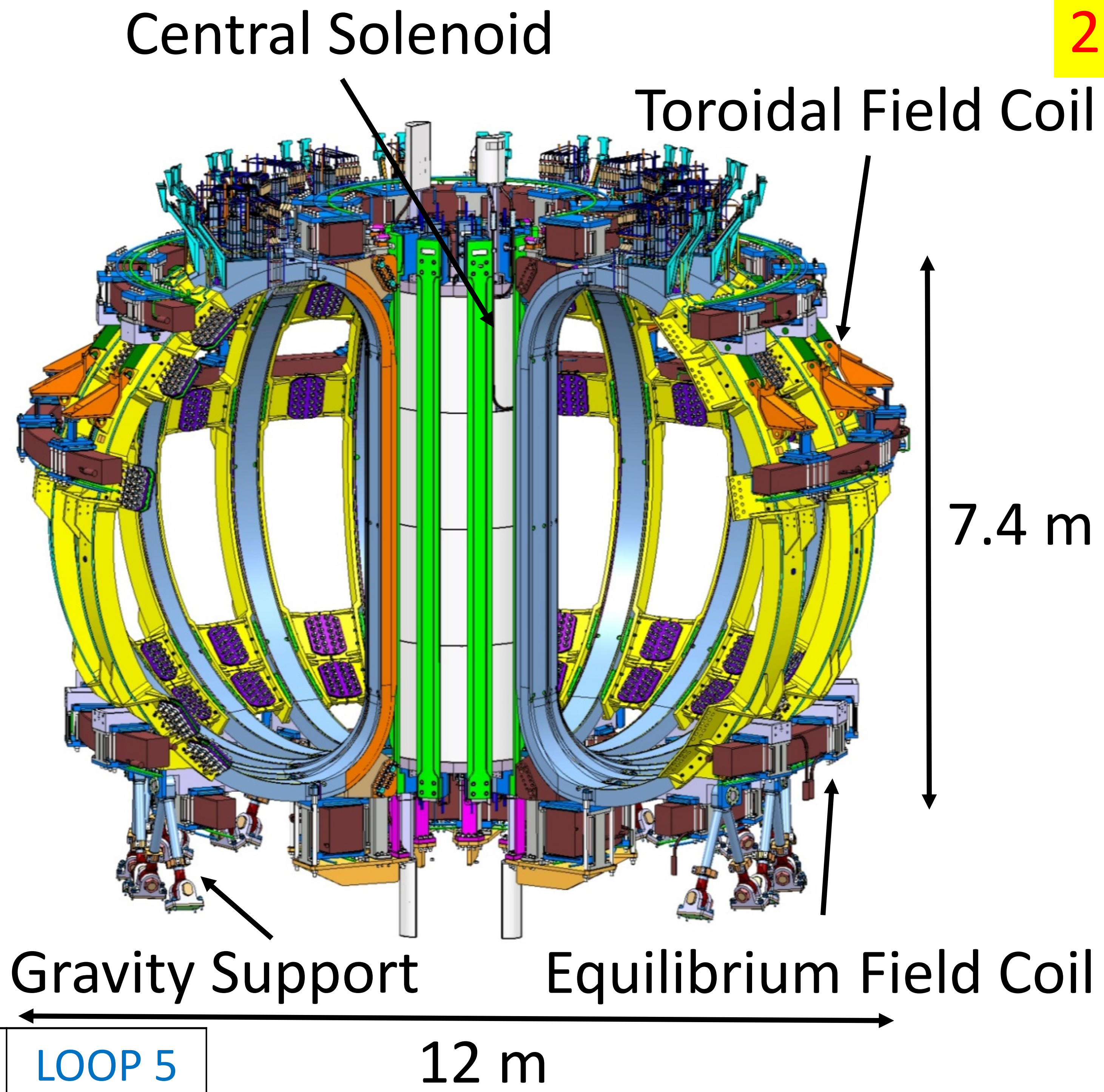
VB contains cryogenic valves and measurement devices to control the cold helium flow. Eleven VBs are installed around the tokamak cryostat asymmetrically.



= Introduction of JT-60SA =

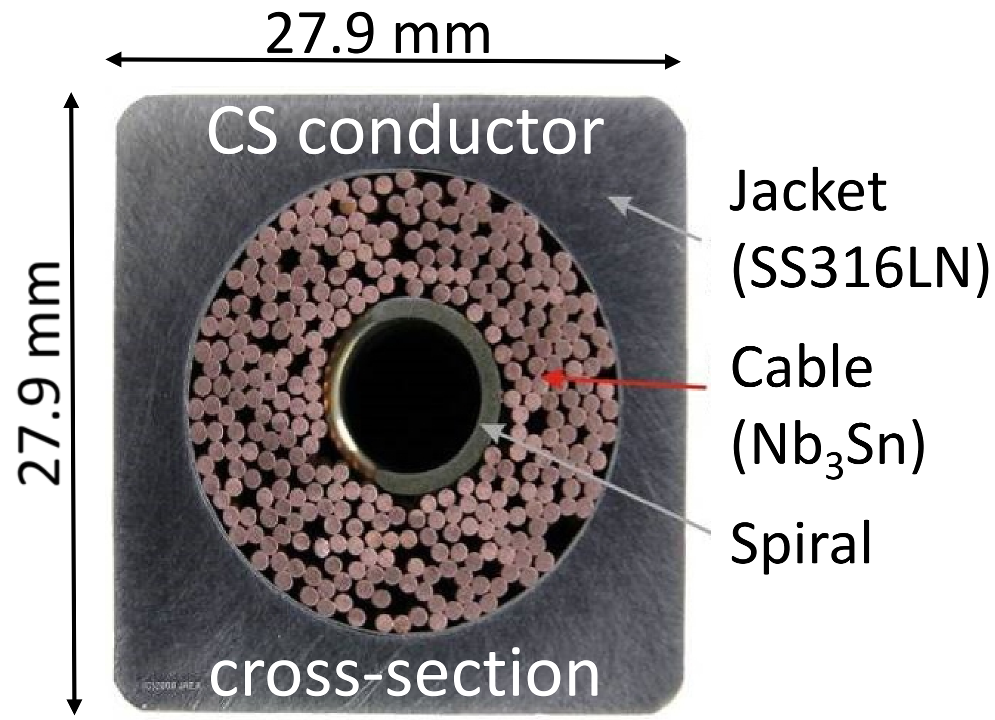


Tokamak Hall Overview



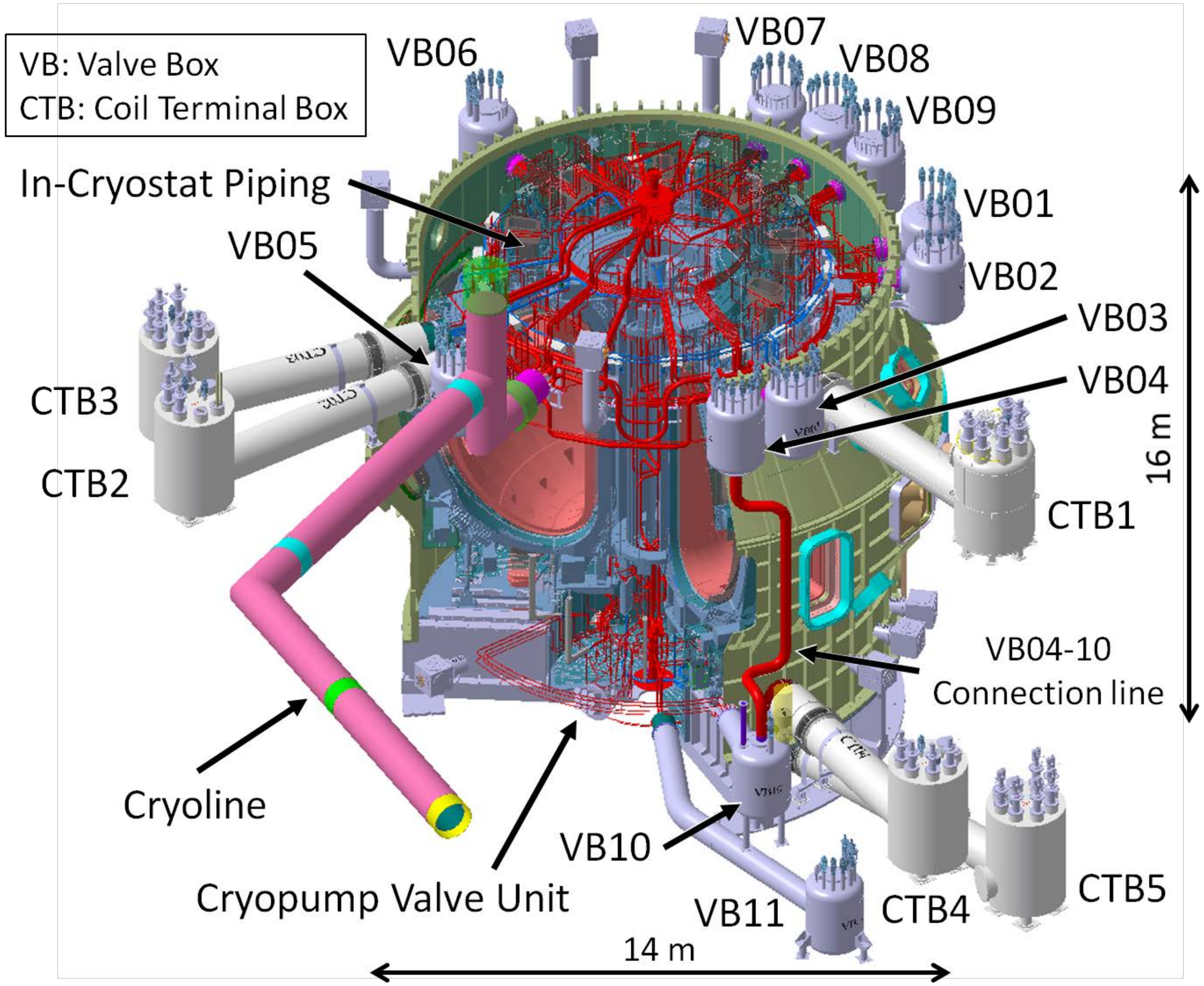
Cryodistribution specification

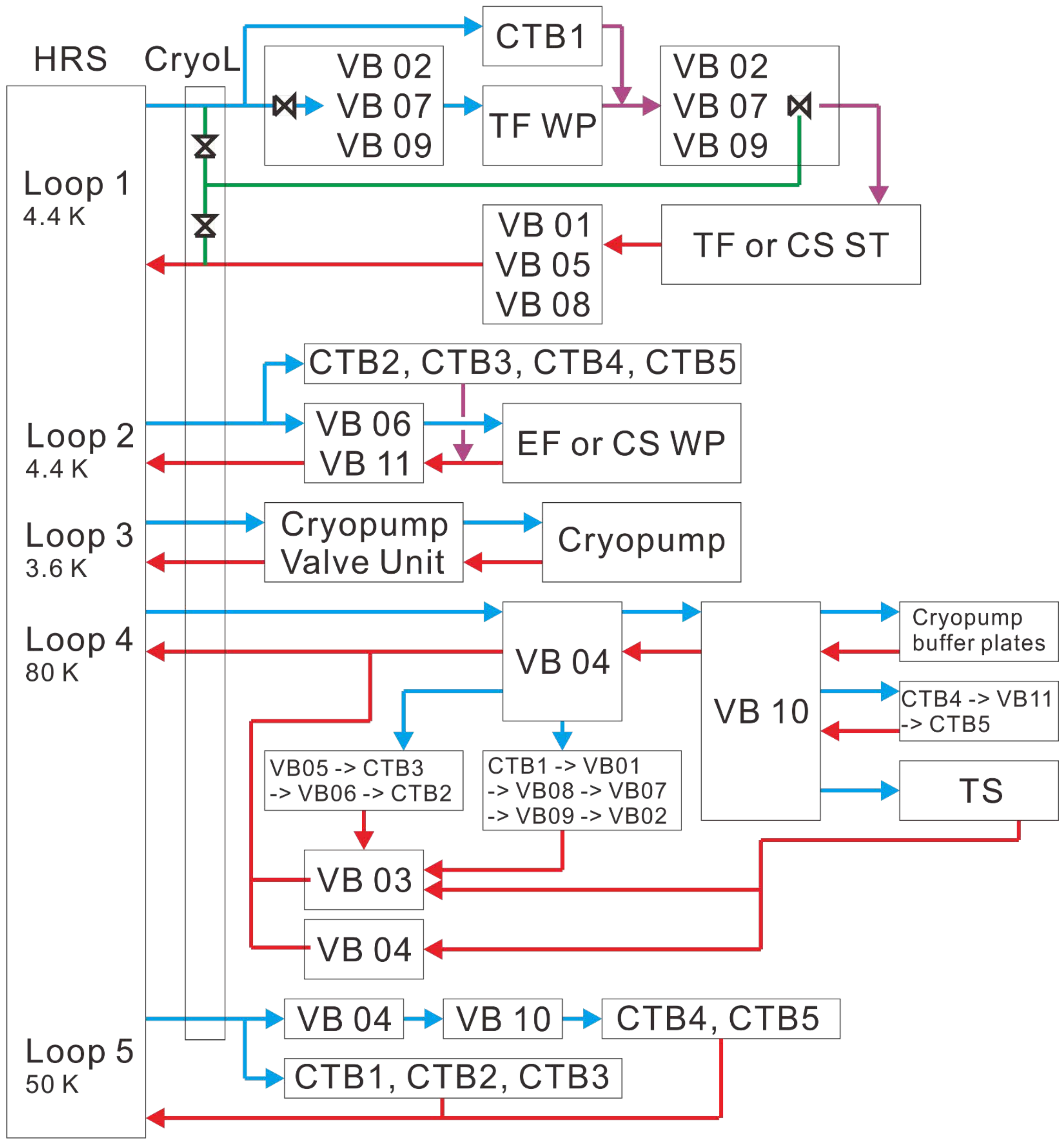
Loop No. (Component)	LOOP 1 (TFC)	LOOP 2 (PFC)	LOOP 3 (CP)	LOOP 4 (TS)	LOOP 5 (HTSCL)
Temperature (K)	4.5	4.5	3.7	80	50
Pressure (MPa)	0.53	0.48	0.48	1.35	0.40
Flow rate (g/s)	876	960	270	404	30
Pressure loss (MPa)	0.13	0.08	0.05	0.15	0.29
Average heat load (W)	1794	1850	84	42,000	-
Branch Number	32	10	9	30	26
Cold weight (Ton)	434	257	-	96	-



= Functions of Cryodistribution =

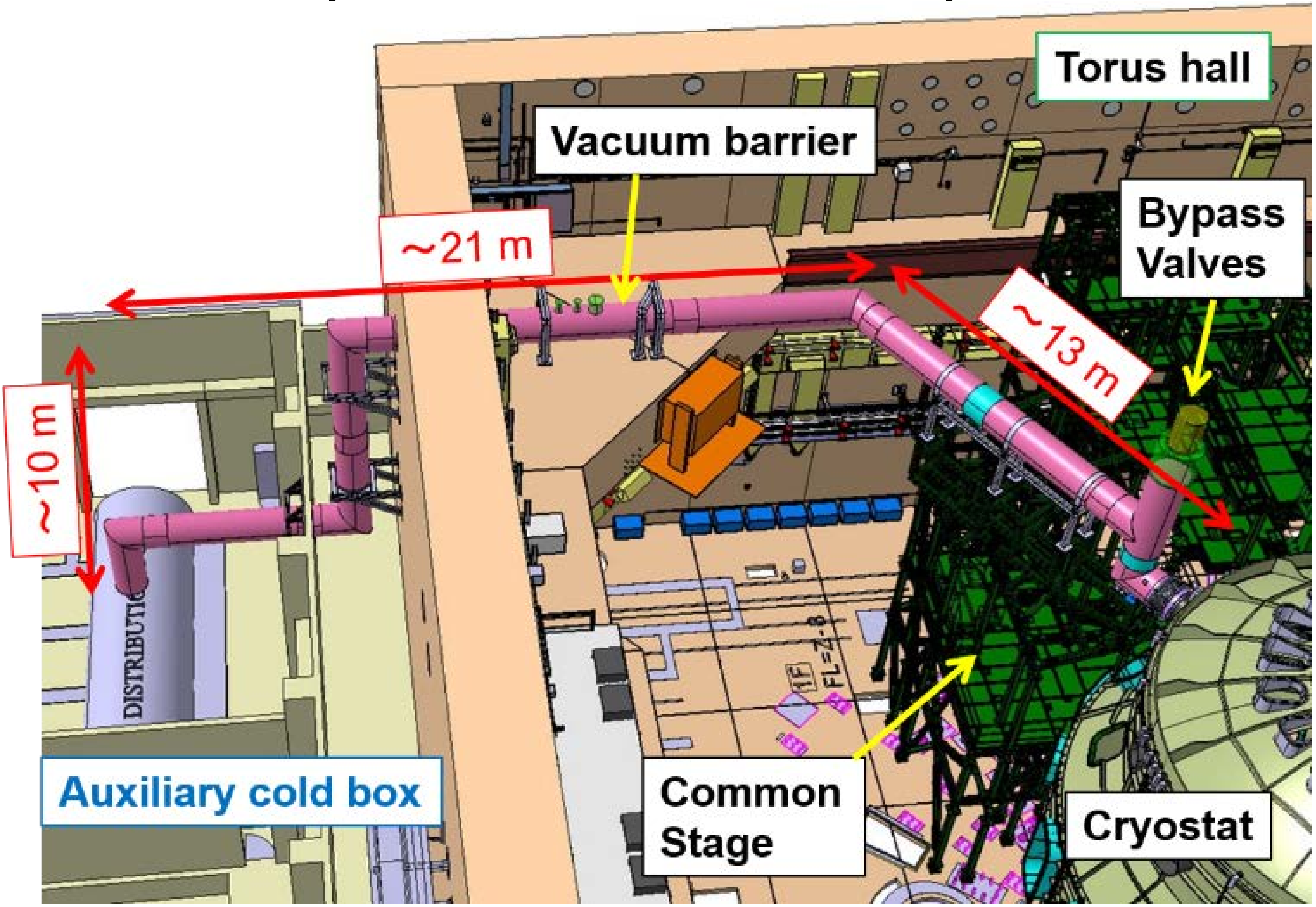
1. Connection between the helium refrigerator and cooled components by pipes
2. Measurement of coolant status: temperature, pressure, and flow rate.
3. Adjustment the flow rate by valves

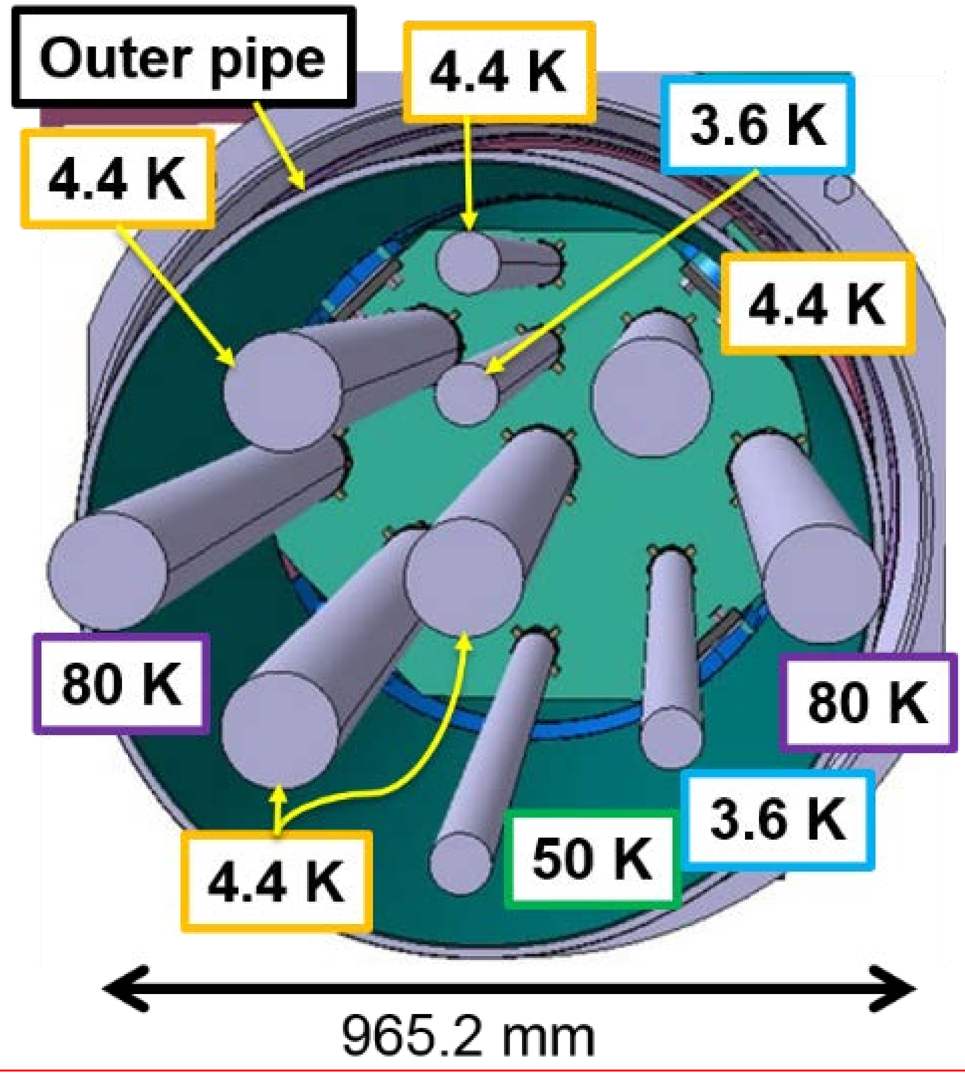




HRS: He Refrigerator System	TF: Toroidal Field Coil	CS: Central Solenoid	EF: Equilibrium Field Coil
CryoL: Main Cryo-transfer Line	VB: Valve Box	CTB: Coil Terminal BOX	TS: Thermal Shield
CP: Divertor Cryopump	WP: Coil Winding Pack	ST: Coil Support Structure	HTSCL: HTS Current Lead

= Main Cryo-transfer line (CryoL) =





Design Requirement: main factors

- Pressure loss derived from HRS specification
- Mechanical soundness toward seismic event and thermal contraction
- Heat load: conduction and radiation

- Pressure Loss -

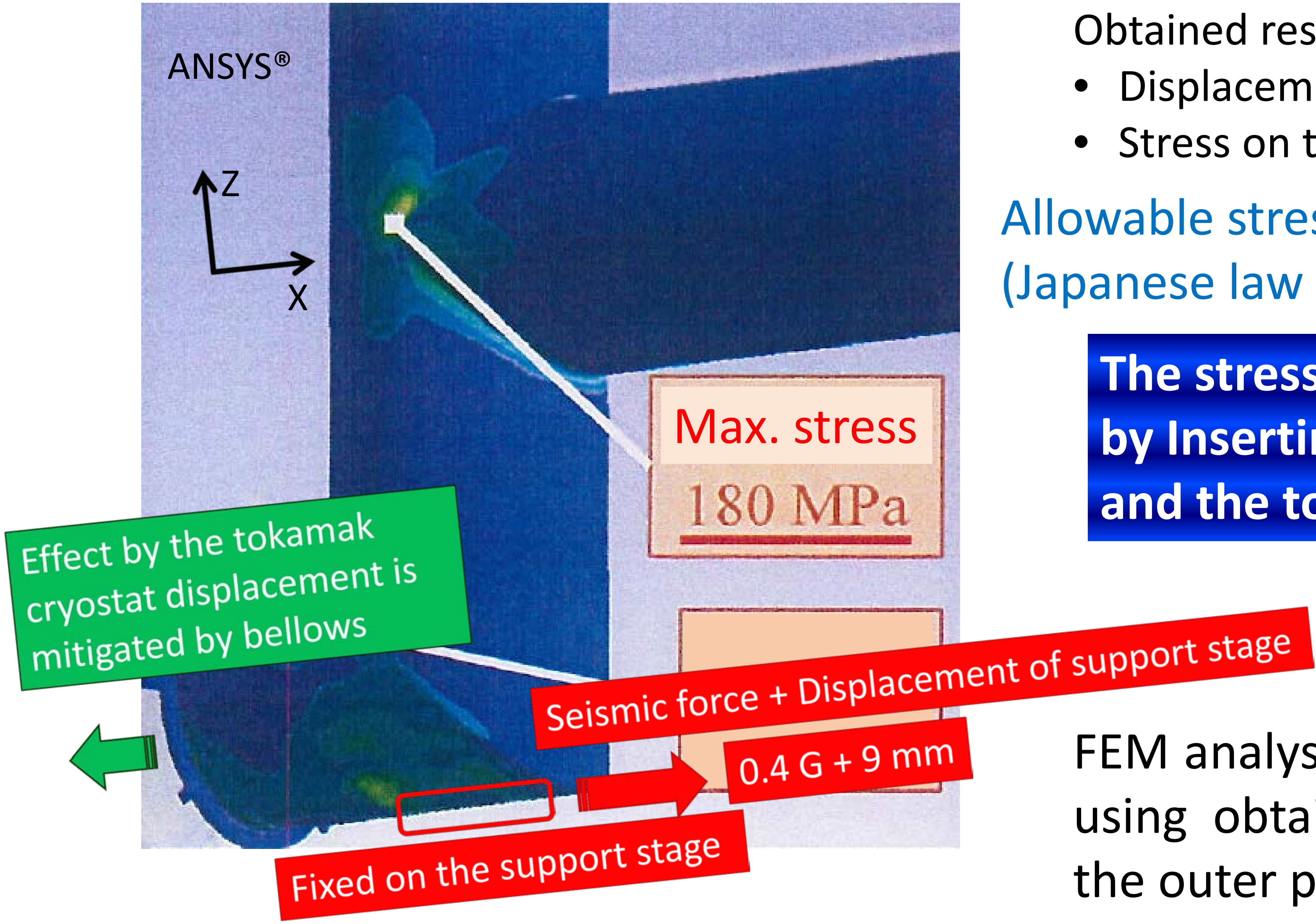
	Ourter diameter (mm)	Flow rate (g/s)	A: △P in CryoL (kPa)	B: △P in the cryodistribution (kPa)	C: △P in component (kPa)	Total △P A+B+C (kPa)	Requirement (kPa)
Loop1	114.3	876	0.9	7.4	118	126	≤ 130
Loop2	114.3	960	3.1	12.5	59.5	75	≤ 80
Loop3	60.5	270	2.2	3.3	37.5	43	≤ 50
Loop4	114.3	404	3.2	100	26.8	130	≤ 150
Loop5	60.5	21.8	0.3	18.8	90	109	≤ 110

- Mechanical strength of outer pipe for seismic event -

Condition of FEM analysis for the outer pipe

- Dead weight: total ~17 ton
- Outer pressure: 0.1 MPa
- Contraction of bellows due to vacuum
- Enforced displacement of interface
- Seismic force

Enforced displacement	**horizontal**	**vertical**
Interface of support stage	9 mm	-
Interface of tokamak cryostat	5 mm	− 5 mm
Seismic force	**horizontal**	**vertical**
Static load	0.4 G	-



Obtained results by FEM analysis

- Displacement of the outer pipe
- Stress on the outer pipe

Allowable stress of SS304 : 205 MPa
(Japanese law about high pressure gas safety

The stress on outer pipe is reduced by Inserting bellows between CyoL and the tokamak cryostat.

Next step

FEM analysis of Inner pipes is conducted using obtained displacement results of the outer pipe as boundary conditions.

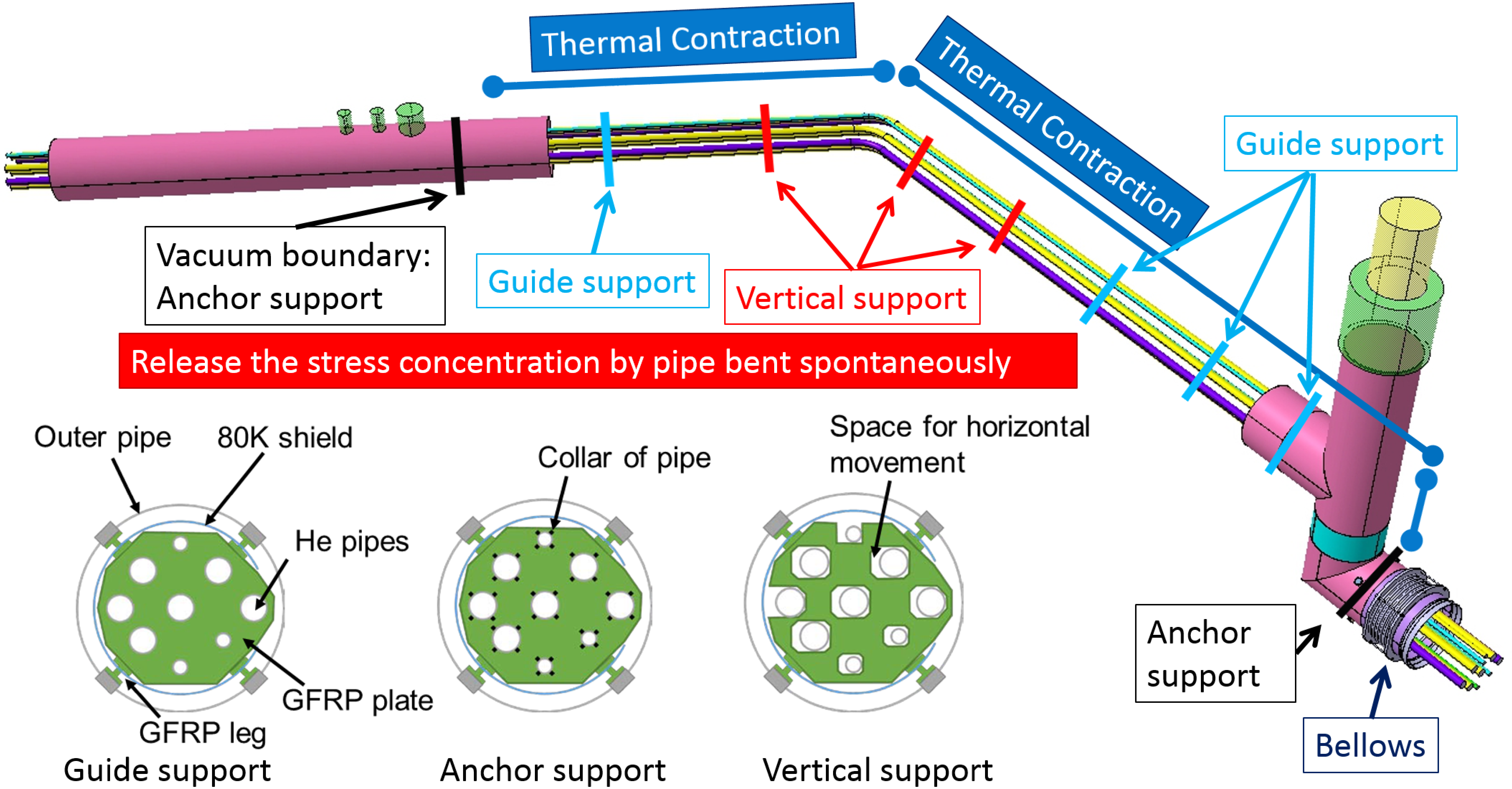
- Mechanical strength of inner pipes for thermal contraction -

The support structure or pipe might be broken, if the excess stress is induced by thermal contraction.

[Ordinary solution]
- Inserting flexible tube
- Inserting crank pipe

[JT-60SA solution]
- Using 3 support types properly

(We named them guide, anchor, and vertical support.)

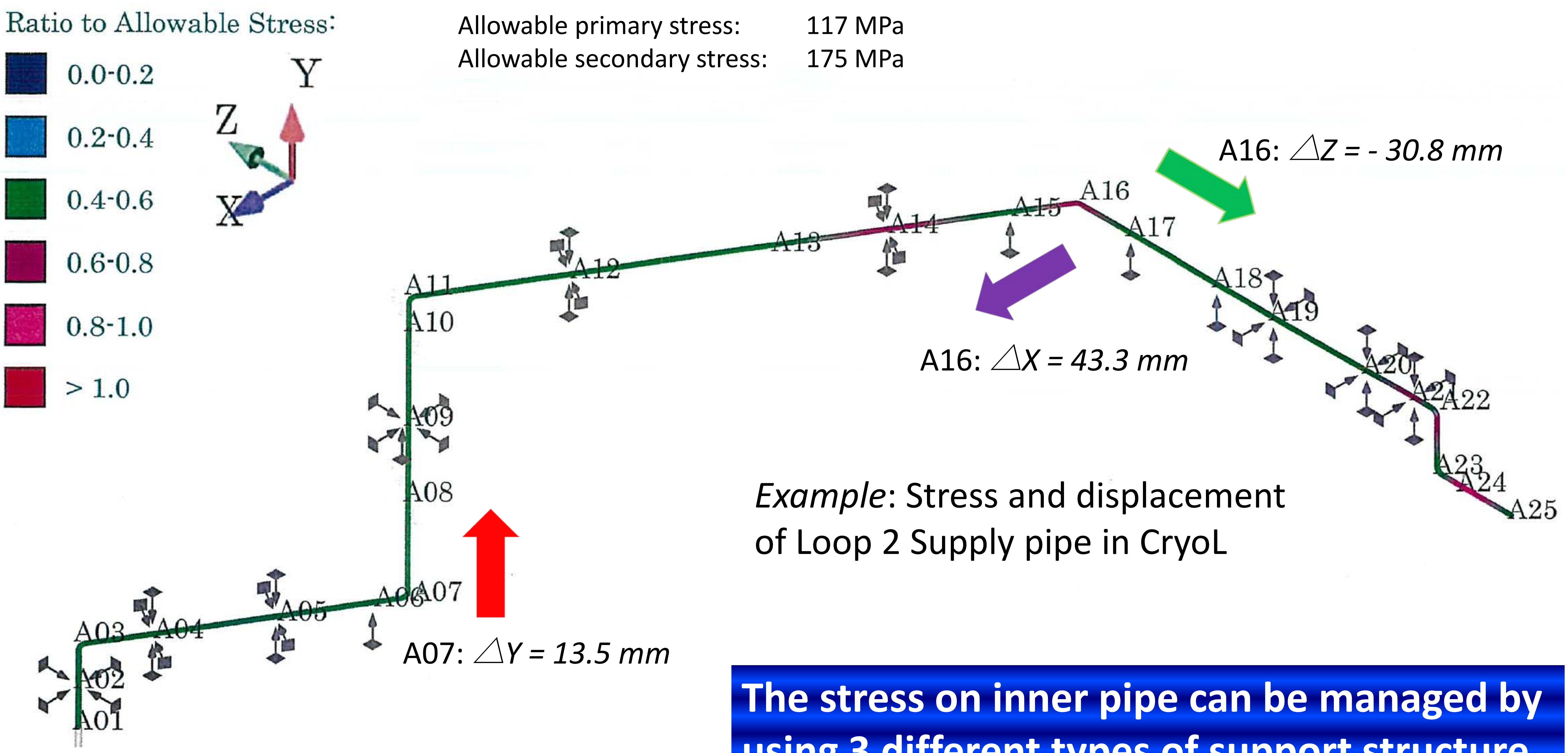


[*Analysis result of FEM for inner pipes*]

Condition of FEM analysis for inner pipes
- Dead weight: ~400 kg
- Inner pressure: 2.0 MPa (Safety valve open threshold)
- Displacements of the outer pipe
- Seismic force

Obtained results by FEM analysis
- Displacement of inner pipes
- Stress on inner pipes

Allowable primary stress: 117 MPa
Allowable secondary stress: 175 MPa



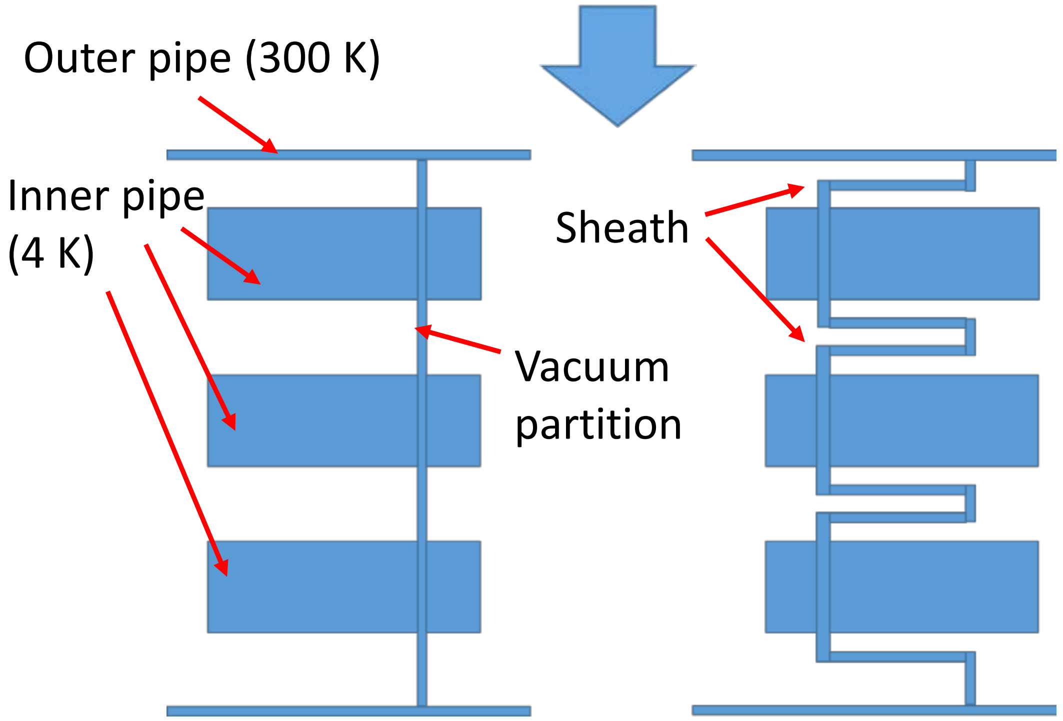
Example: Stress and displacement of Loop 2 Supply pipe in CryoL

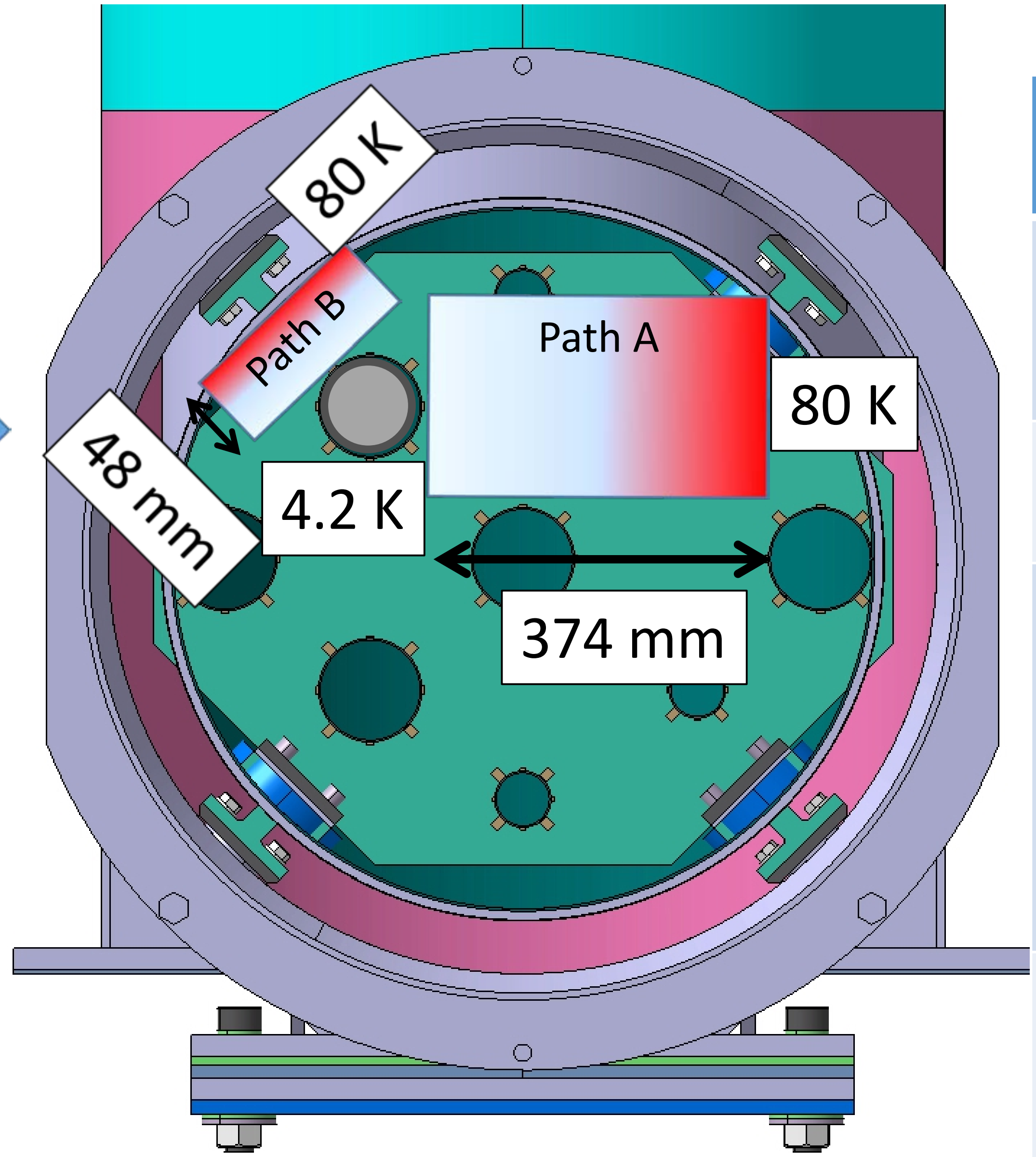
The stress on inner pipe can be managed by using 3 different types of support structure.

- Heat load -

Heat load sources

- Conduction
  - ✓ Pipe support
    - ➢ Adopted thin epoxy legs and plates
  - ✓ Vacuum Partition
    - ➢ Extended conduction path by sheaths





3D model for pipe support

Conduction path	Path A	Path B	. . .
Cross section: S (mm^2)	745	745	. . .
Length: L (mm)	374	48	. . .
Thermal conductivity Integral 80K→ 4.2K : λ (W/m)	19.6	19.6	. . .
Heat input (W) $Q = \lambda S/L$ $\times 10^{-3}$	0.039	0.304	. . .

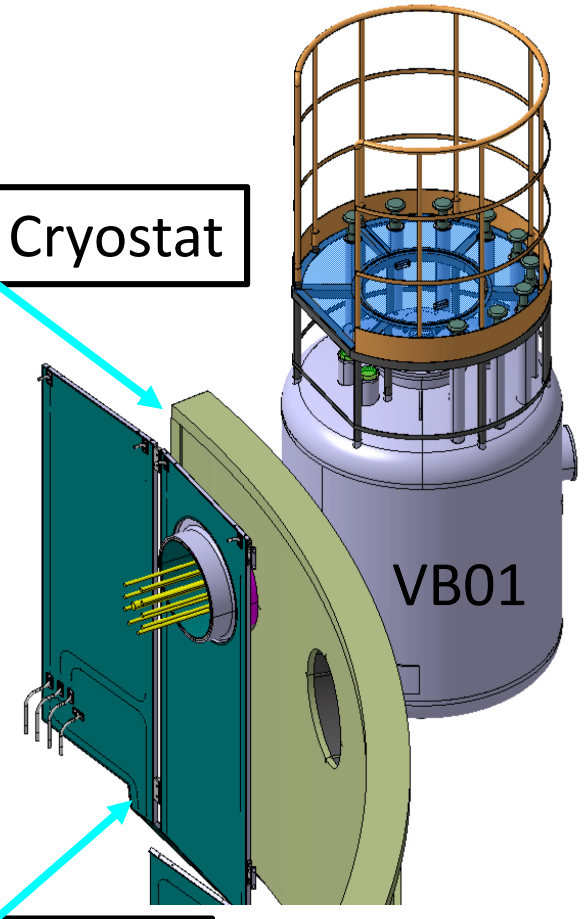
- Radiation
  - ➢ Covered pipes and the thermal shield by multi-layer insulator (MLI)

The heat load to thermal shield from outer pipe through MLI (40 layers) is estimated of 0.41 W/m^2 in our case.

The total heat load to 4 K, 50 K, and 80 K are estimated by summing calculation results of all conduction paths and the radiation using the Stefan–Boltzmann formula of two concentric cylinders.

	4 K	50 K	80 K
Estimation	91.6 W	5.5 W	393 W
Requirement	97 W	9 W	434 W

= *Valve box* (VB) - Measurement and adjustment coolant flow - =



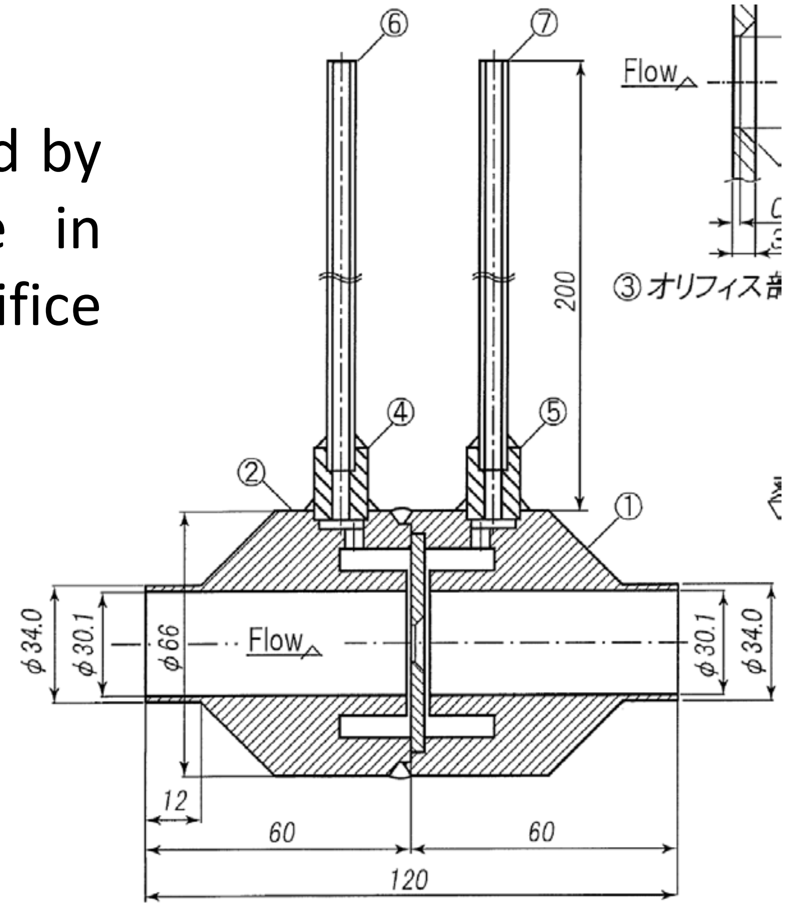
VB vessel
1.4 m diameter
2.0 m height
1.2 ton weight

Satisfaction of requirement in the pressure loss, heat load, and mechanical strength are also confirmed by similar methods to CryoL.

Orifice plate

The flow rate is obtained by measuring the pressure in front of and behind an orifice plate.

Lead pipes for the pressure measurement are connected to vacuum feedthroughs on the tokamak cryostat.



Cryogenic valve

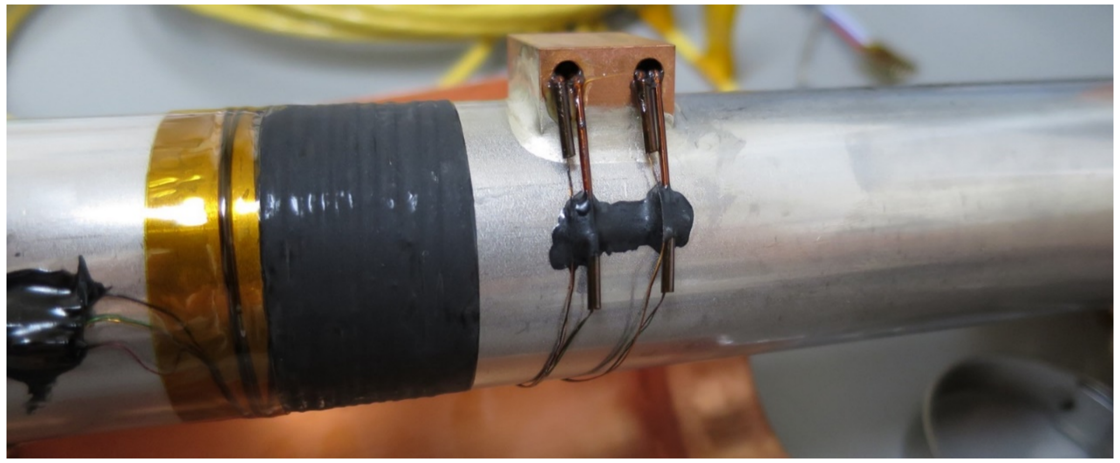
Remote control valves are operated pneumatically. These valves are installed in VBs and controls coolant helium flow.

Safety valves are connected inlet and outlet side of each coolant loop for cooled components [2].

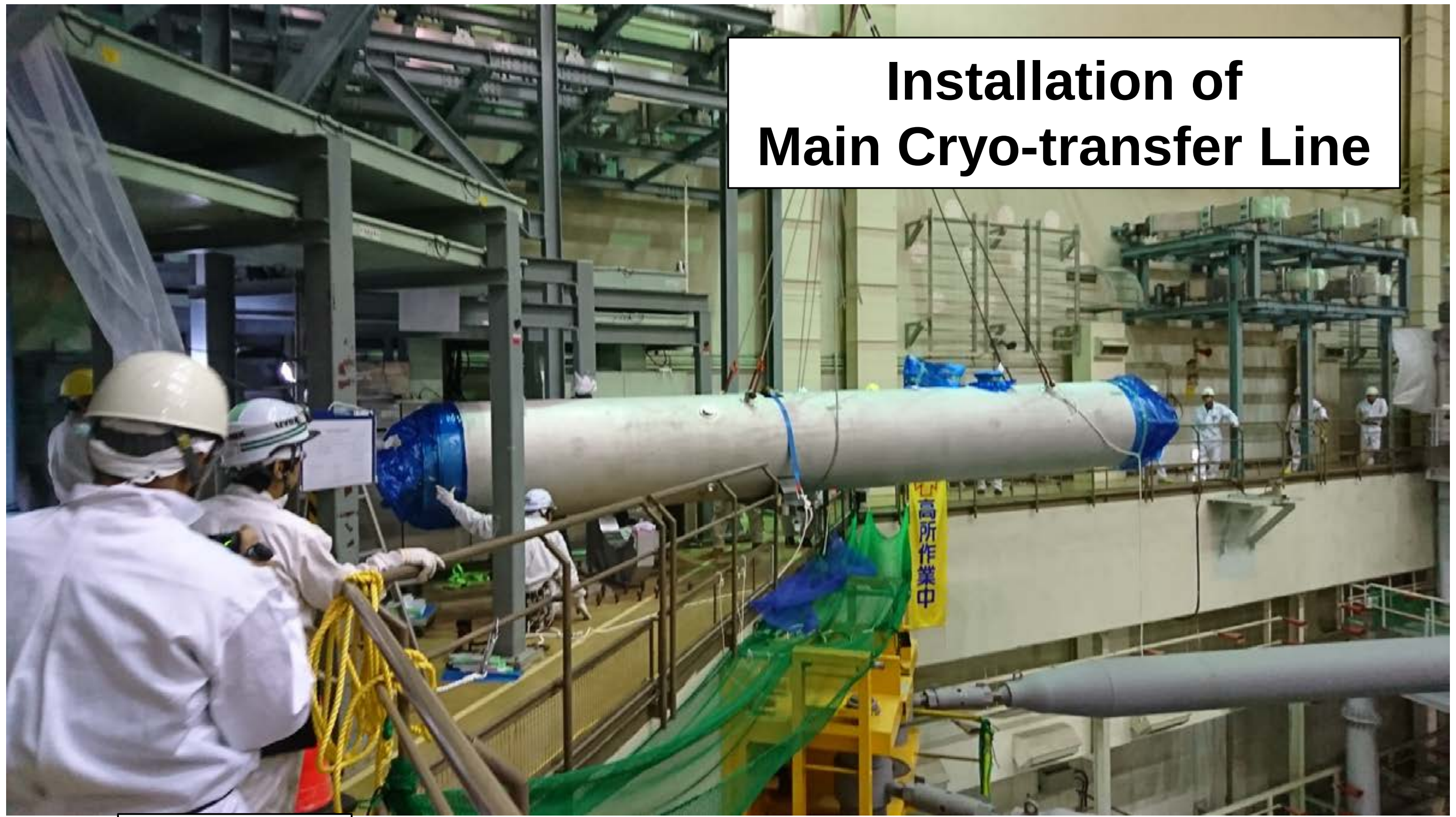
Thermometer

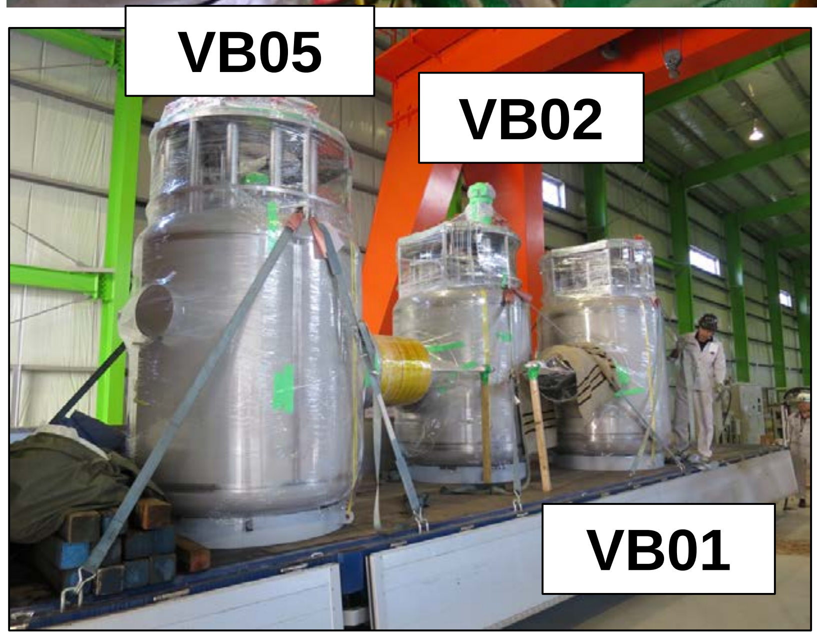
Two resistive thermometer devices which are made of carbon ceramics (TVO) are installed on each lines in VBs.

They are inserted with Apiezon N grease in holes of a copper block which is attached on the pipe surface by brazing [1].



= Manufacture =





= Conclusion =

Design of all cryodistribution components of JT-60SA has been completed. Calculated pressure loss, heat load, and mechanical strength are satisfied requirements.

- Inner pipes of main cryo-transfer line are able to withstand toward the force due to the thermal contraction and the seismic event by managing support positions and shapes.
- TVO sensors and orifice plates are installed in valve boxes to measure the temperature and the flow rate of coolant in pipes.

Reference:
[1] K. Natsume, et al. *IOP Conf. Series: Materials Science and Engineering* 101 (2015) 012114.
[2] K. Natsume, et al. *IEEE Trans. Appl. Supercond.*, VOL. 28, NO. 4, (2018) 3800504.