Design of Solid Breeder Test Blanket Modules in JAERI

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Contents

Blanket Development in Japan

Blanket Development for ITER and DEMO

- Universities and NIFS are developing advanced blanket concepts: Helium-cooled, Li/V, molten salt, and LiPb will be attempted for the module testing in ITER and DEMO.
- JAERI pursues solid breeder blanket concepts: Water-cooled, Helium-cooled

TBM testing in ITER is the most important milestone for the development DEMO blanket system.

Solid Breeder Test Blanket Module (JAERI)

1. JAERI is now pursuing two types of Solid Breeder TBMs;
   - Water-cooled TBM (Solid Breeder Pebble Bed and RAFS)
   - Helium-cooled TBM (Solid Breeder Pebble Bed and RAFS)

2. Basic option of coolant condition is pressurized water(@15 MPa).

3. Supercritical pressure water cooling (@25 MPa) is also taken into account as an advanced option of solid breeder blanket.

4. Helium-cooled TBM has similar structure with the water-cooled TBM design.
   - Provide data for a backup option of DEMO blanket system.
   - Preliminary test for high temperature SiC-He cooled blanket.
   - Provide the simulated data of SCW TBM with high coolant temperature.

Major design parameters of solid breeder TBMs

Items	Unit	Water Cooled	He Cooled
Structural Material		F82H	F82H
Coolant		Water	He gas
Multiplier		Be, or $Be_{12}Ti$	Be, or $Be_{12}Ti$
Breeder		Li_2TiO_3, or other Li ceramics	Li_2TiO_3, or other Li ceramics
Surface Heat Flux	MW/m^2	0.5	0.5
Neutron Wall Load	MW/m^2	0.78	0.78
Area of First Wall	m^2	0.53 x 1.74	1.29 x 0.76
Coolant Pressure	MPa	15(25)	8.5
Coolant Inlet/Outlet Temp.	^oC	280 /323 (360/380*)	300/432
Total Heat Deposit in TBM	MW	1.27	1.36
Total Tritium Production	g/FPD	0.156	0.180
Coolant Flow Rate	kg/s	5.3	2.0

Outlines of Solid Breeder TBM designed by JAERI

(1) TBMs with slit structure are adopted to withstand electro-magnetic force in VDE and internal over-pressure in case of fracture of cooling tube.

(2) Thermo-mechanical analyses of FW and tritium release performance have been performed to show the feasibility of the TBM design.

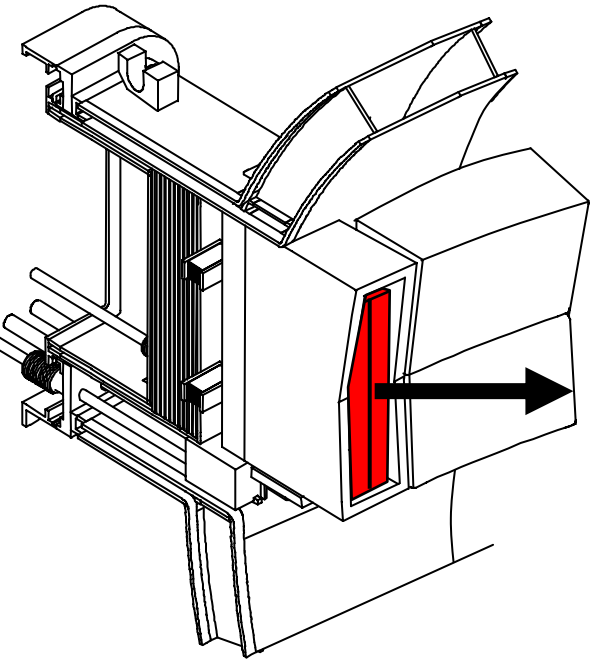
(3) Detailed structures are developed with consideration of fabrication procedure and welding lines. Coolant flow route is considered from the view points of hydraulics and heat transfer.

(4) Pressure relief route is planned at the top and bottom of the module in case of internal over-pressure.

(5) In the TBM cooling system, circulation pump is doubled to avoid loss of coolant.

(6) Rear wall interface configuration is developed based on the structure design of TBM. Dimensions and structures of interfaces are clarified.

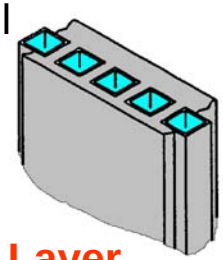
Configuration of Water-Cooled Solid Breeder TBM

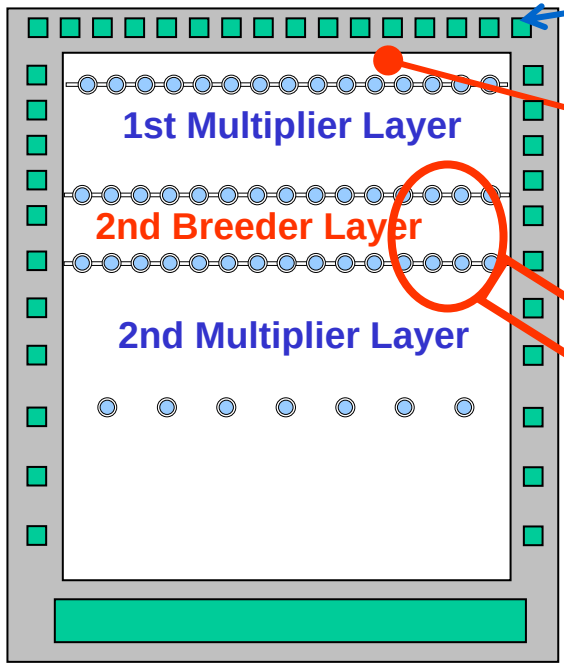


ITER-TBM test port

Plasma side

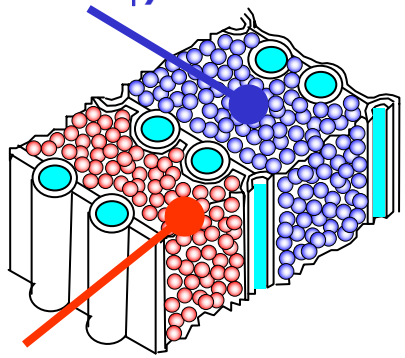
First Wall
(F82H)





1st Breeding Layer

Neutron Multiplier
(Be, 0.2 - 2mmϕ)



Tritium Breeder
(Li_2TiO_3, 0.2 - 2mmϕ)

Horizontal Cross Sectional View

Ceramic breeder(Li_2TiO_3) and Be neutron multiplier are packed in a form of small pebble bed in layered structure separated by cooling tube with wall.

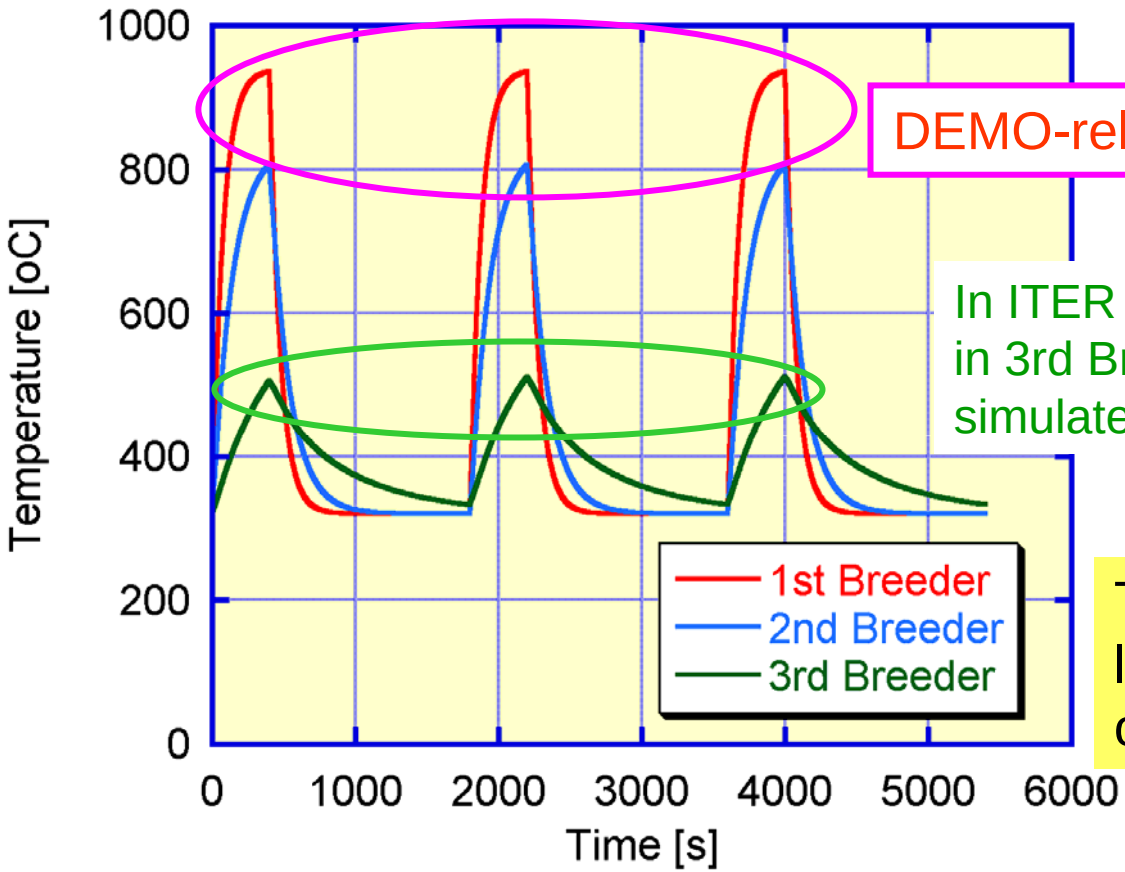
Design support analyses

- Temperature response of breeder layer
  - To evaluate whether our TBM configuration can simulate temperature range in a DEMO breeder layer or not.
  - 1D thermal analyses based on nuclear heating rate by ANIHEAT

- T-release response in breeder layer
  - To obtain basic data on T production for ITER TBM testing and T-recovery system
  - T-release model developed by Kyushu Univ. (Prof. Nishikawa, et al.)

- Thermo-mechanical behavior of FW
  - To confirm the maximum temperature of FW made of F82H within the allowable limit (=550^{o}C).
  - To confirm an excess of stress and strain does not occur.

Transient temperature response of breeder layer



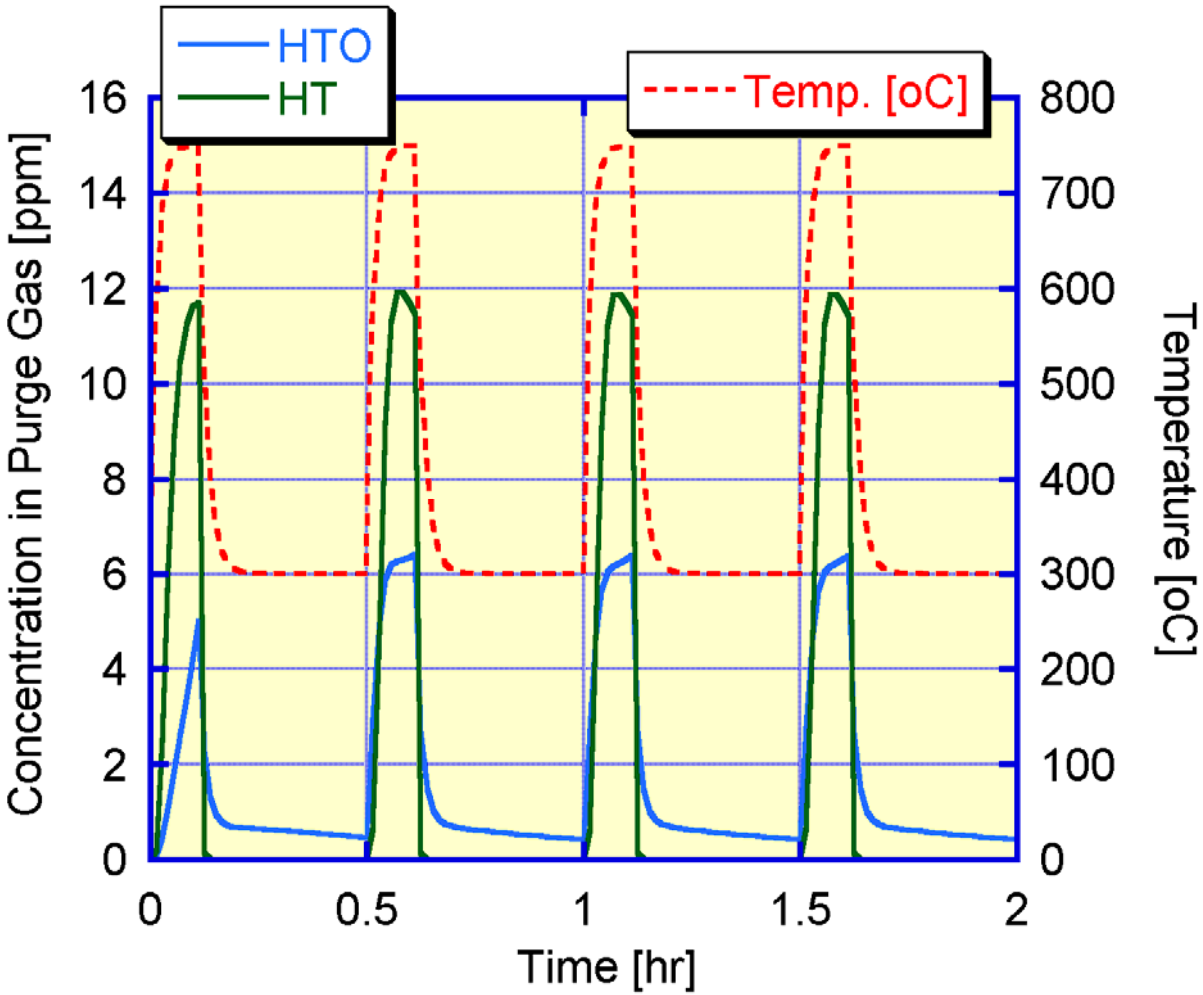
DEMO-relevant temperature range

In ITER NWL, temperature response in 3rd Breeder layer is not sufficient to simulate DEMO breeder condition

The number of breeder layer in WC-TBM is <u>two</u> in our design.

Time evolution of peak temperature of three breeder layers of water-cooled TBM with 400 sec burn/ 1400sec dwell cooled by 15MPa, 320^{o}C water.

Transient tritium release behavior of 1st breeder layer



Purge gas condition:
He(0.1MPa) with H_2(100Pa)

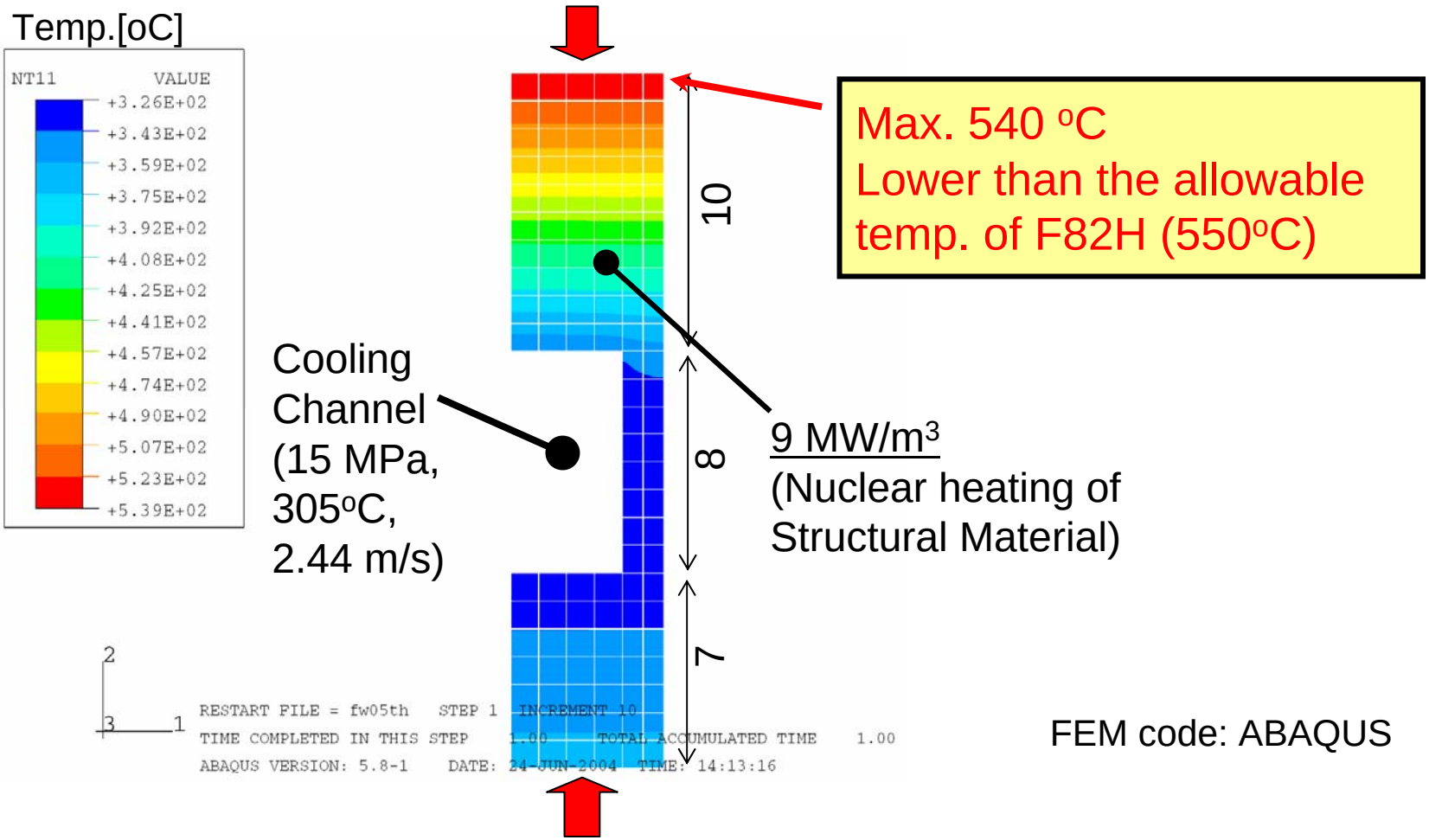
T-concent. at outlet: 1Pa

T-release model developed by Prof. Nishikawa, Kyushu Univ.

Tritium release from 1st breeder layer shows quick response due to high tritium generation rate and quick response of temperature transient (due to high nuclear heating rate). Performance of 2nd layer is also similar.

Thermo-mechanical analysis of FW of Water-Cooled TBM

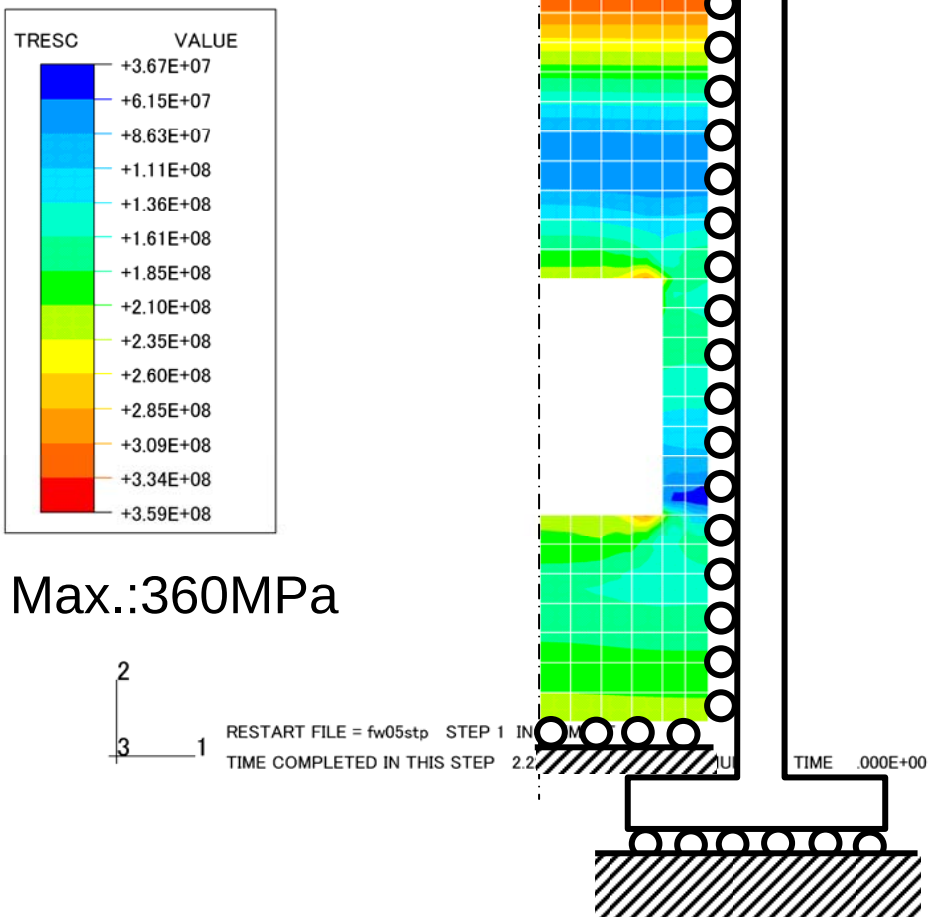
SHF:0.5 MW/m^2 + 0.1 MW/m^2
(Nuclear heating of Be armor)



FEM code: ABAQUS

Stress Analysis of water-cooled FW

Equiv. Stress (Tresca) distribution

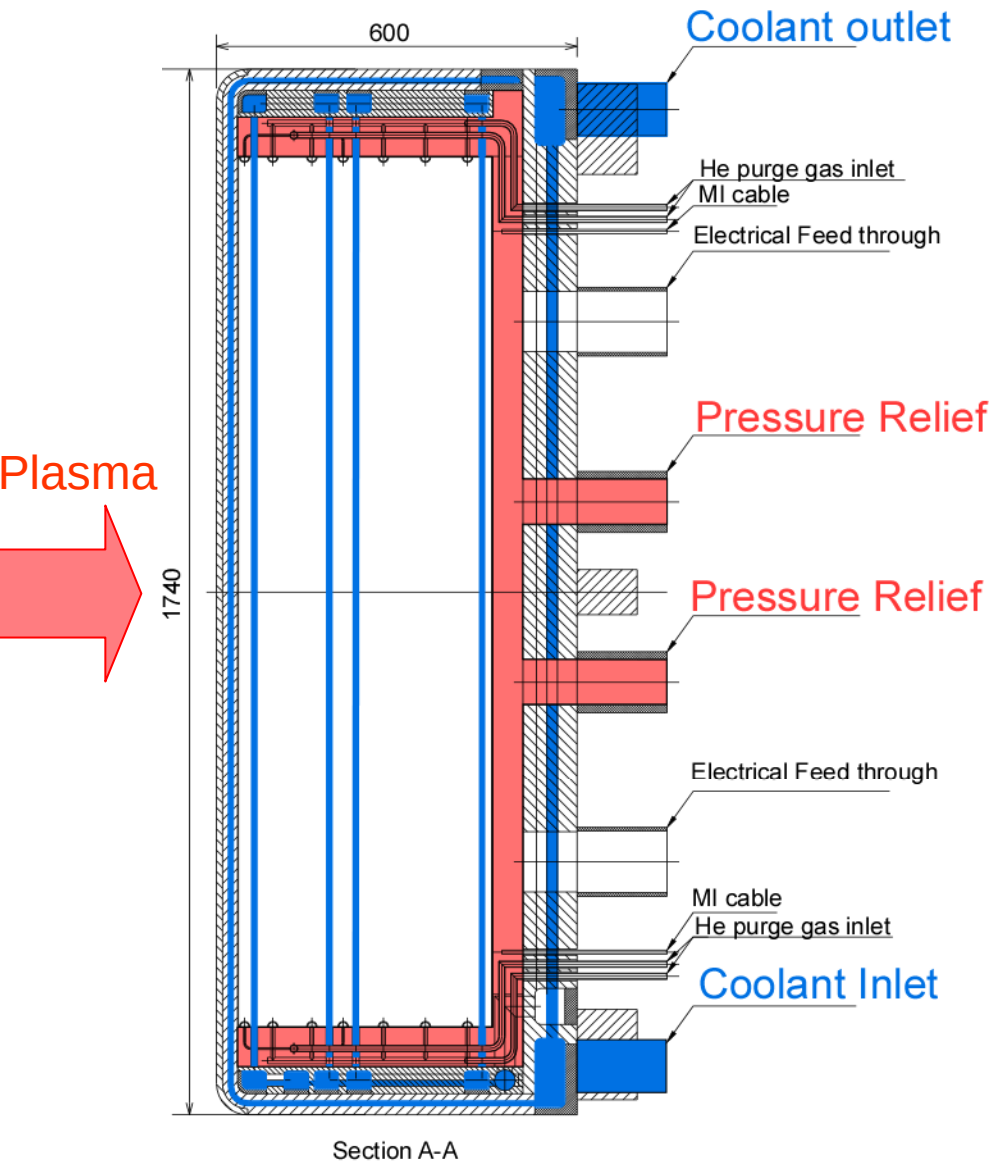


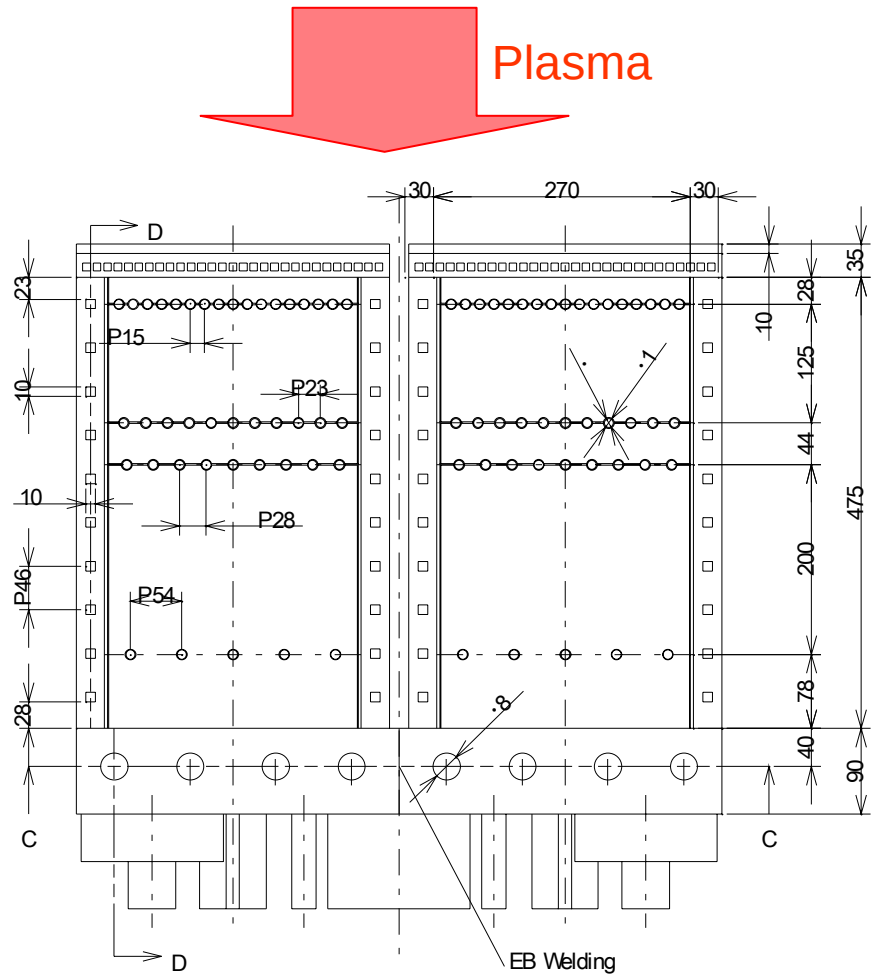
Max.:360MPa

- 10-nodes generalized plane strain elements
(Out-of-plane bending was constrained.)

Stress field of the FW is within elastic range. No plastic (permanent) deformation is expected.

Detail structure of water-cooled TBM



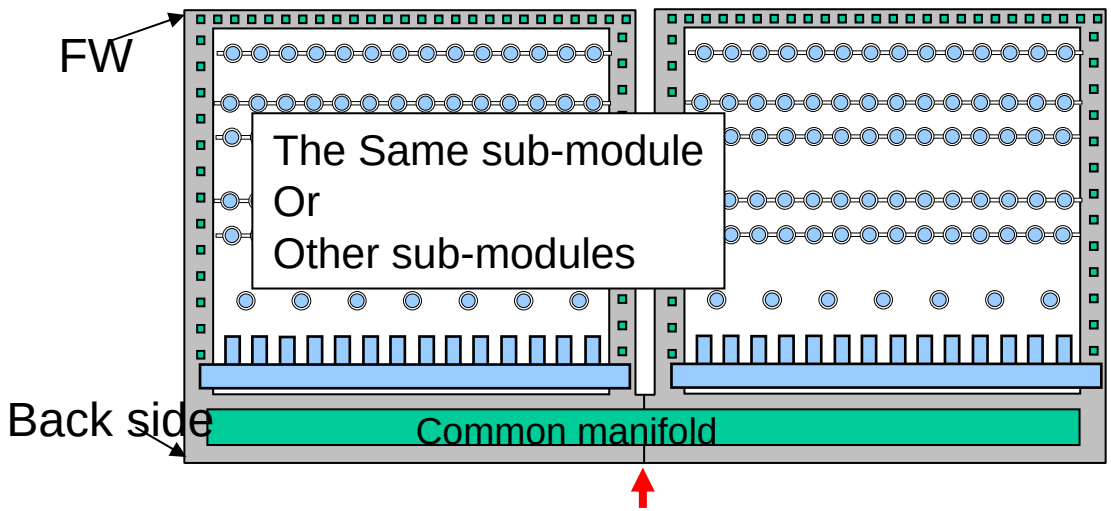


Helium-cooled TBM design

- From the viewpoint of EMF in DEMO blanket, slit structure is adopted. For this reason, sub-modules concept is the updated He-cooled TBM concept.

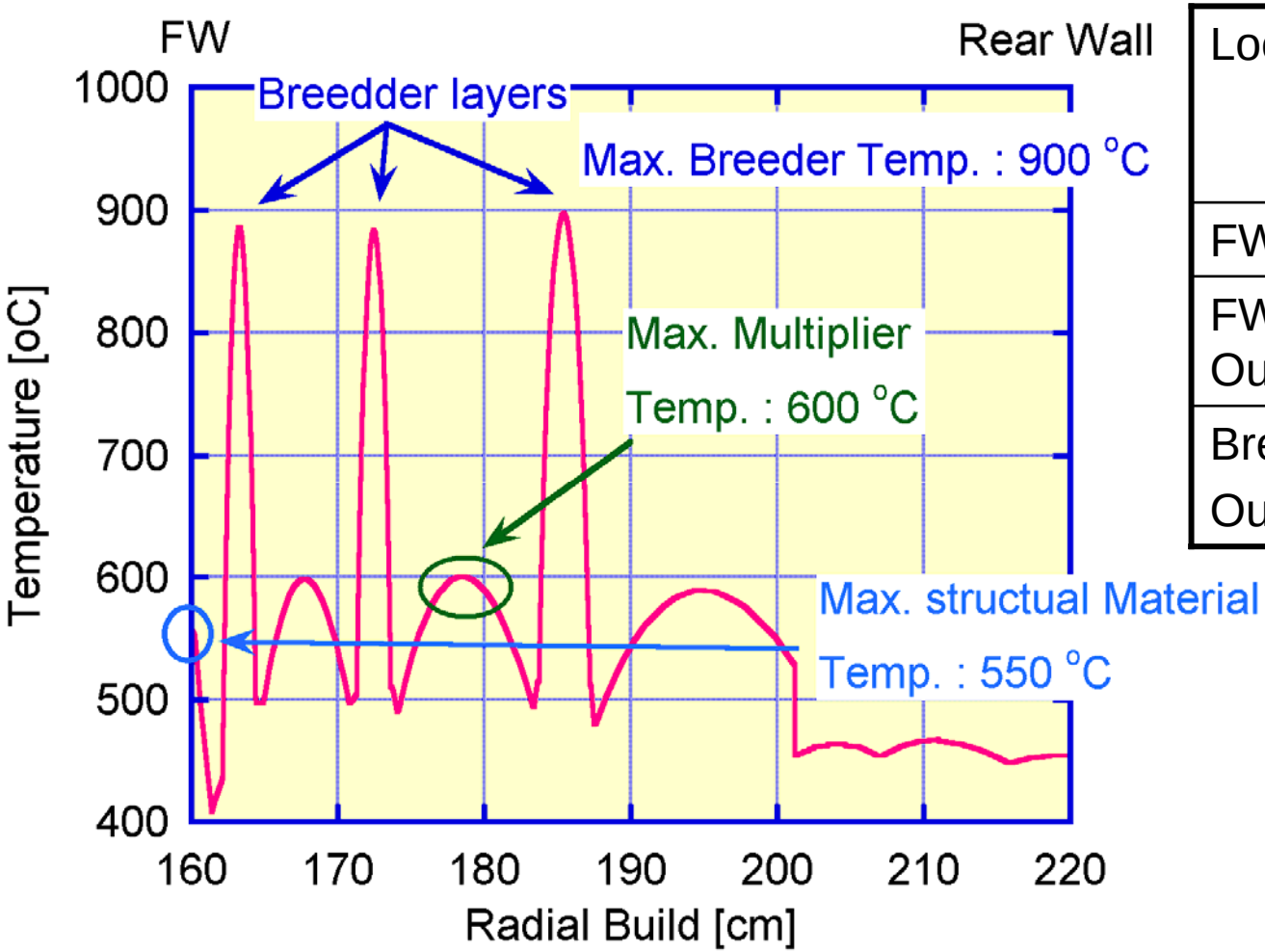
- From the results of temperature and tritium release transient analyses, the number of breeder layer is three.

- From the viewpoint of FW cooling for SHF of 0.5 MW/m^2, coolant temperature is 300 ^{o}C. Total flow rate of helium of 1.99 kg/s is divided into two after TBM manifold. Coolant He condition for one sub-module is 8.5MPa, Inlet:300^{o}C, Outlet 432^{o}C, 0.99 kg/s.



Electron beam welding of two sub-modules. Then, common manifolds and rear wall equipments such as keys and flexible supports will be fabricated.

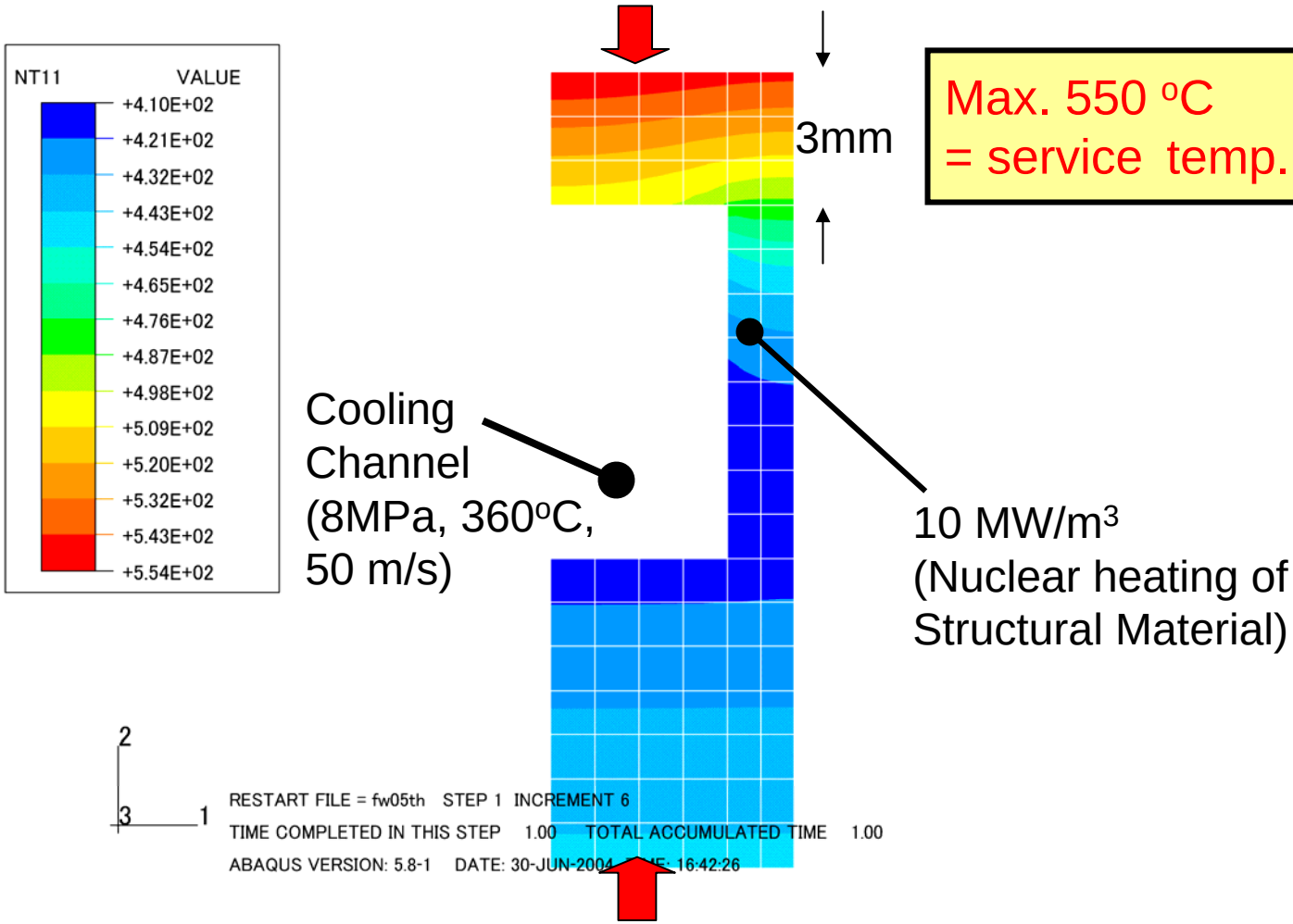
Temperature distribution of FW and PB at 0.5 MW/m^2



Location	He Temp. [°C]	Struct. Temp. [°C]
FW Inlet	300	-
FW Outlet	370	548
Breeder Outlet	432	550

Thermal Analysis of He-cooled FW

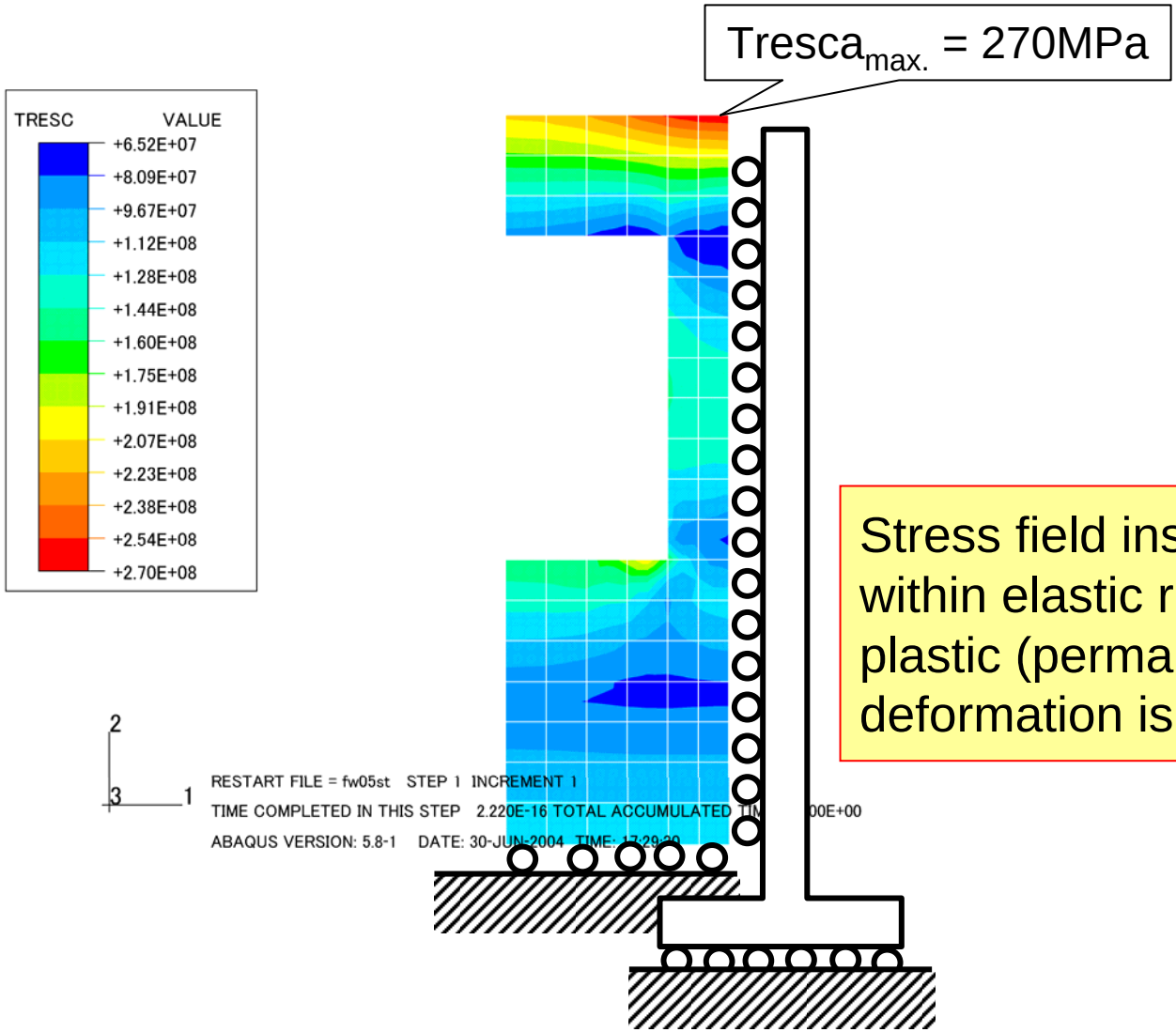
SHF: 0.5 MW/m^2 + 0.1 MW/m^2
(Nuclear heating of armor)



Max. 550 °C
= service temp. of F82H

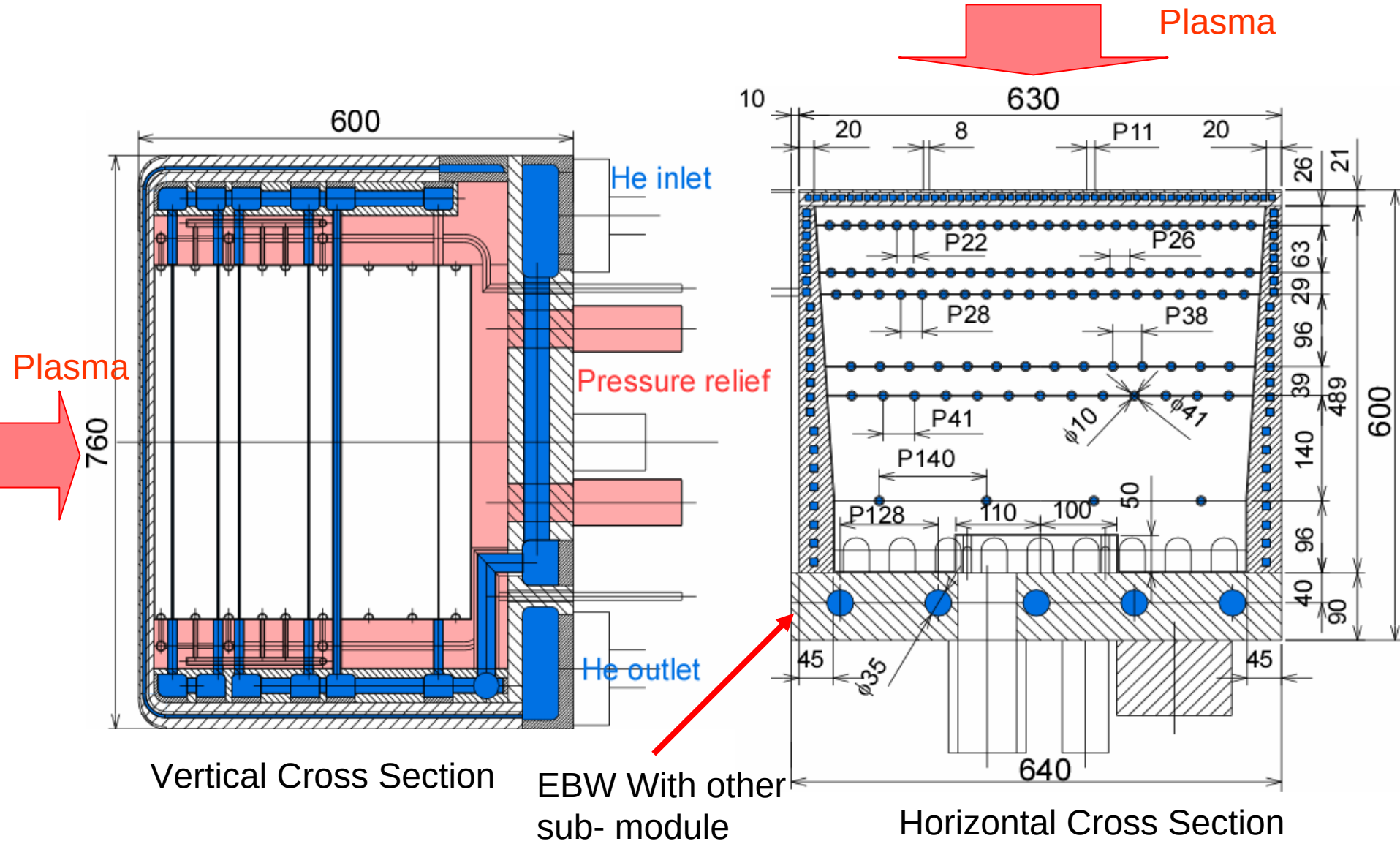
0.110 MW/m^2(Nuclear heating of Breeder)

Stress Analysis of FW



Stress field inside FW is within elastic range. No plastic (permanent) deformation is expected.

Detailed Structure of Japanese He Cooled Sub-module



Summary

- JAERI is now developing two concepts of solid breeder TBM; Water-cooled and He-cooled TBMs.
  - In both concepts, ceramic breeder (Li_2TiO_3) and Be neutron multiplier are packed in a form of small pebble bed in layered structure separated by cooling tube with wall.
  - Configurations of TBMs are simplified based on performance analyses of temperature response of breeder and T-release. Based on the analyses, the number of breeder layer is reduced to 2 in the water-cooled TBM design.

- The elemental technology phase has been almost completed. JAERI is taking further steps to engineering test phase including fabrication of scalable mock-ups of TBM to demonstrate its structural integrity.

Modification of HHF test facility (PBEF)

High pressure cooling system
- Max.Pressure = 25 MPa
- Temperature = ~ 100°C → 400°C
- Flow Rate = approx. 100 L/min

(Super critical water is available from FY2005.)

Major Specifications
Max. Accl. Voltage : 50kV
Max. Beam Current : 30A
Pulse duration : up to 1,000s