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Progress in design and engineering issues on JA DEMO

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INTRODUCTION

The paper presents solutions for critical problems in Japan's DEMO (JA DEMO), which include common DEMO design issues beyond ITER-relevant technologies.

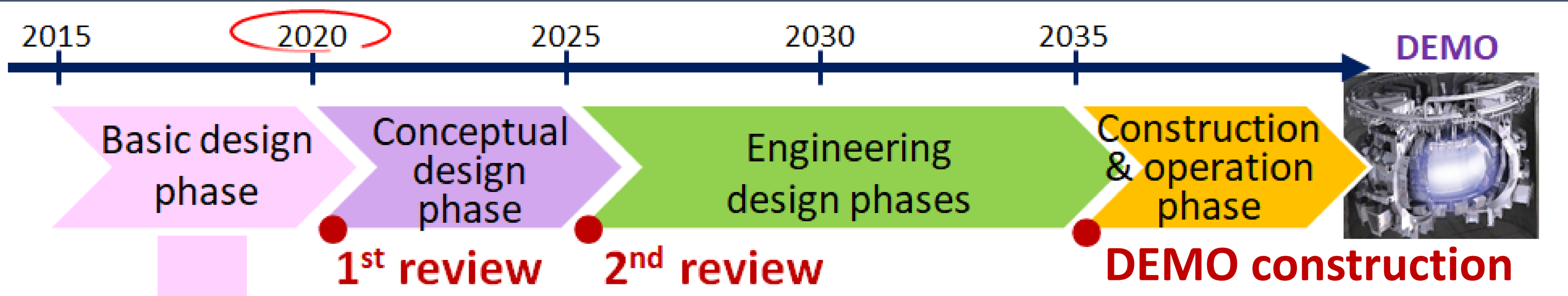
- ✓ The highlights of this design study are (1) Novel concept for water-cooled pebble bed blanket and tritium recovery, (2) System design for electric power generation with a management of the T concentration in the primary cooling system, (3) Identification of the classification for the rad-waste of JA DEMO, and (4) Identification of an accident sequences for safety guideline.
- ✓ **The proposed concept as JA DEMO will be the foundation for Japan's DEMO that can be envisioned in the next stage of ITER.**

CONCLUSION

➢ **In order to increase the feasibility of JA DEMO concept, studies on the following engineering issues were performed.**

1. **Countermeasure against a loss of coolant accident inside blanket (in-box LOCA)**
   - ✓ In the "honeycomb-shape", little retention of tritium was found by flow analysis of purge gas.
   - ✓ Simple concept of cylindrical structure are designed to meet the target TBR in the condition of the pressure tightness.
2. **An outlook of the steady and stable power generation beyond several 100 MW**
   - ✓ The total power consumption was found to be 386 MW, and the electric output was evaluated to be 254 MWe
   - ✓ Consistency between cooling system and T concentration control was confirmed for safety management.
3. **Rad-waste management**
   - ✓ Even if uranium impurity in the beryllium as neutron multiplier was considered, all radwaste is classified as LLW and qualified for a shallow land burial.
4. **Safety**
   - ✓ An accident sequences and mitigation systems are being sorted out.
   - ✓ A mitigation systems of the countermeasures were confirmed on the safety analysis

DEVELOPMENT OF DEMO DESIGN ACTIVITY IN JAPAN



Objective of DEMO

- ✓ Steady and stable power generation beyond several 100 MW
- ✓ Reasonable availability leading to commercialization
- ✓ Overall tritium breeding to fulfil self-sufficiency of fuels

Design principle in the basic design phase

- ✓ Application of as reliable technology as possible

Table DEMO Parameter [Ref.1]

	Steady state	2hrs pulse
R_p (m) / a_p (m)	8.5 / 2.4	
A	3.5	
κ_{95}	1.65	
q_{95}	4.1	
I_p (MA)	12.3	
B_T (T)	5.94	
P_{fus}	～1.5	～1.0
Ave. NWL(MW/m²)	1.0	0.7
Coolant water	290-325℃,15.5MPa	
Q	17.5	13
P_{ADD} (MW)	～83.7	
n_e (10^{19} m³)	6.6	
HH $_{98y2}$	1.31	1.13
β_N	3.4	2.6
f_{BS}	0.61	0.46
n_e/n_{GW}	1.2	

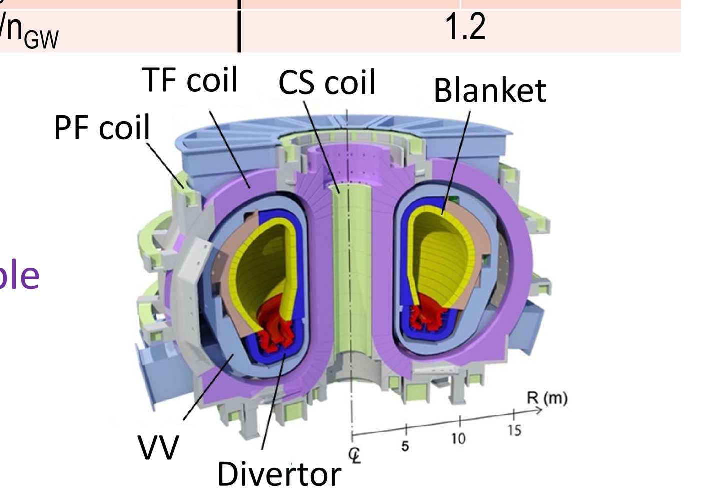
Pre-conceptual design of JA DEMO

Plasma operation

- Major radius, R_p = ～ 8.5 m
  Arrangement of large CS coil for a few hour pulse operation in the commissioning phase
- Plasma perform., β_N=3.4, HH=1.3
  Study-state operation
- Fusion power P_{fus} = 1.5
  Allowable divertor heat load
  (Div. des. based on ITER technol.)

Engineering technology ➔ ITER technol. as much as possible

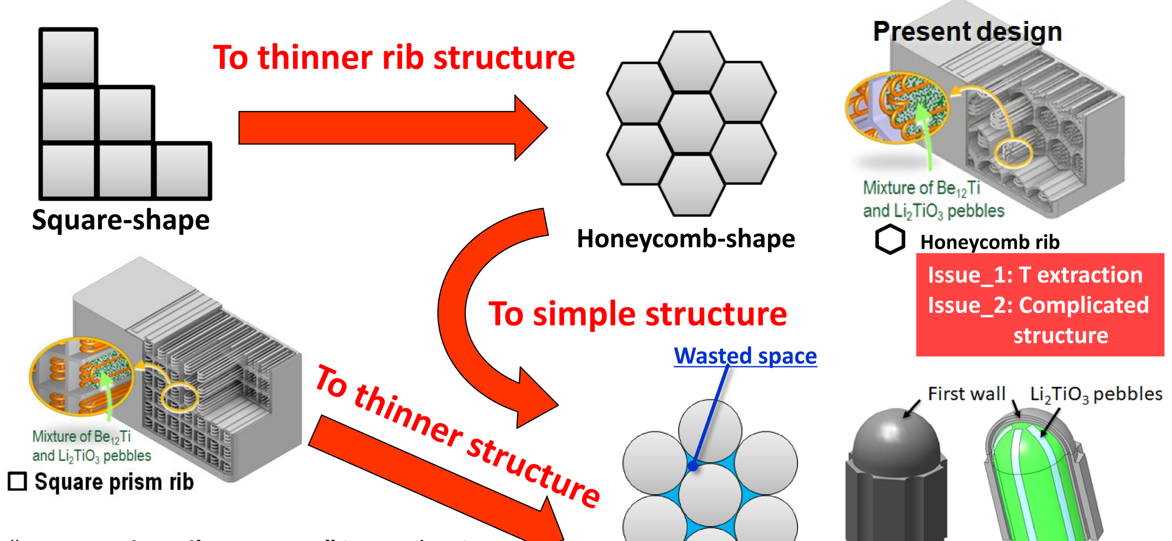
- T breeding blanket: JA TBM strategy
- Divertor: Water cooling, W mono block
- Magnet: Radial Plate struc. CIC conductor (Nb_3Sn)



RECENT PROGRESS ON DESIGN ISSUES FOR JA DEMO

1. Countermeasure against a loss of coolant accident inside blanket (in-box LOCA)

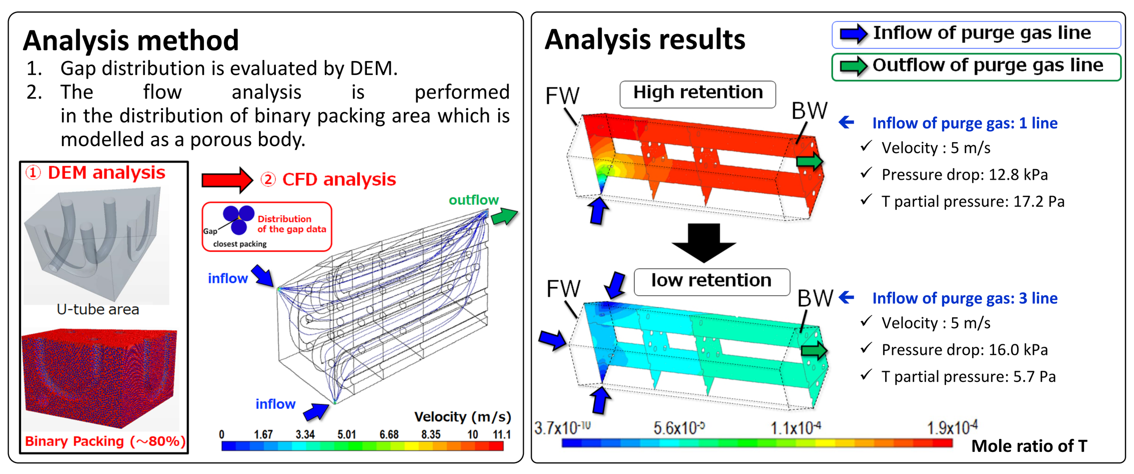
A conceptual design of blanket with pressure tightness against in-box LOCA has been carried out for safety of the JA DEMO.



"square prism rib structure" is a reduction in the volume fraction of T breeder. [Ref.2]
➔ Overall TBR ≈ 1.0 (Target value≧1.05)

Issue_1: T extraction is confirmed by CFD analysis with "honeycomb-shape"

- Target of TBR (≧ 1.05) was achievable with a honeycomb-rib
- For the achievement of TBR target, P.F. to 80% with B.P. is necessary.
- Issue: Amount of tritium retained in the breeding area may increase, due to the increase in pressure drop as a result of high packing.
  ➢ The flow of He-purge gas was analyzed to confirm tritium retention



3 inflow points of He-purge gas are arranged near the FW
➔ Little retention of tritium in the area was found.

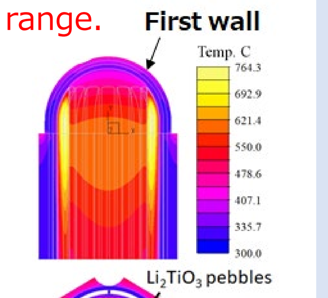
Issue_2: Simple concept of "cylindrical structure" is designed to meet the target TBR in the condition of the pressure tightness.

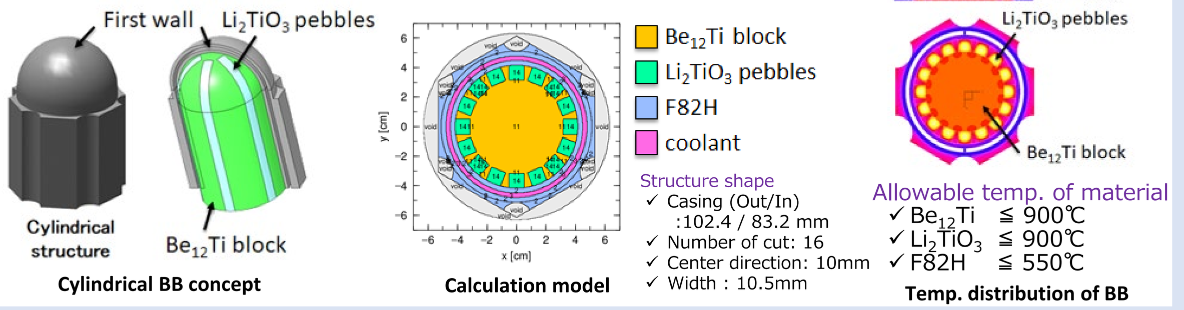
A simplified BB structure was proposed with a cylindrical structure .
➔ Characteristics of cylindrical concepts with Beryllide($Be_{12}Ti$) block.

- ✓$Be_{12}Ti$ has little swelling compared to Be.➔$Be_{12}Ti$ can be used as blocks.

Using blocks with a higher thermal conductivity than pebbles eliminates cooling piping inside the module.

- ✓ Allowable temp. of the materials is confirmed on the temp. distribution.
- ✓ All materials were within the allowable temperature range.
- ✓ The design is embodied with keeping the highest percentage of TBR values (Li_2TiO_3 pebbles =25%).
  Dents around the $Be_{12}Ti$ block are designed to have the Li_2TiO_3 ratio of 25%
- ✓ Target of overall TBR (>1.05) is achievable.





2. Outlook of the steady and stable power generation beyond several 100 MW

Power generation systems is developed without inter. HEX.

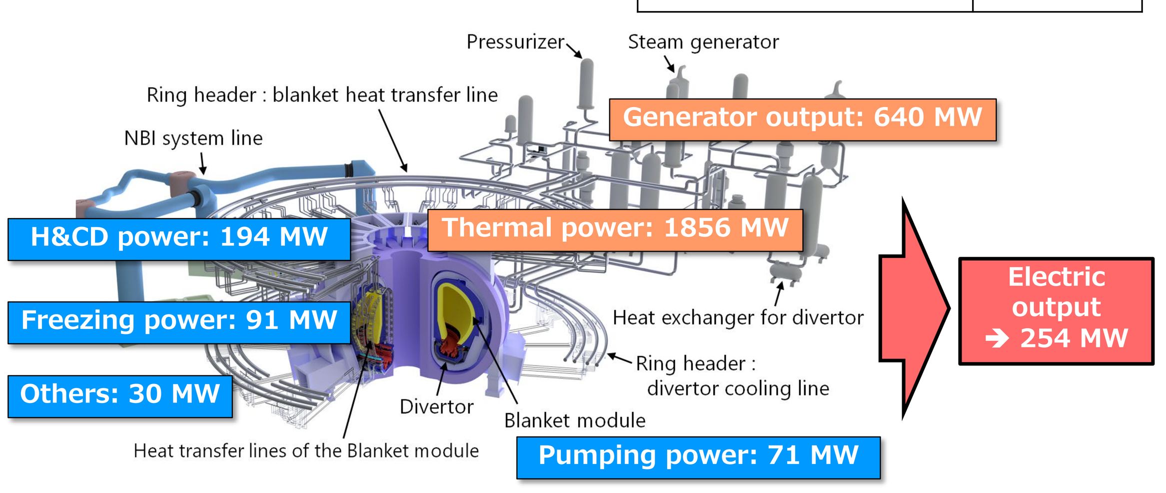
➢ T permeation through the SG to the secondary cooling system in the PHTS is found to be less than the restricted amount of T disposal for PWR in Japan [Ref.3].

Issue_1: Evaluation of the power for DEMO plant consumption

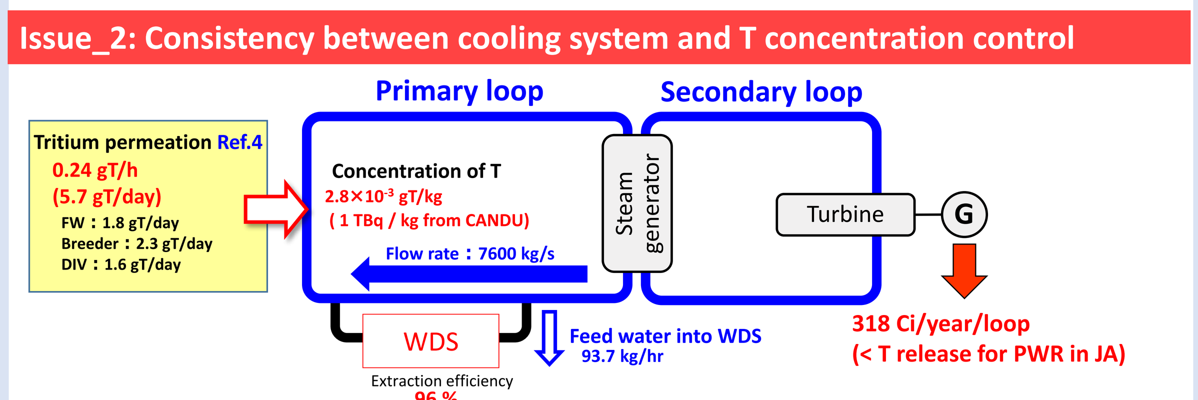
- **Cooling system**
  - ✓ PWR coolant water condition ➔ 15.5MPa, 290～325℃
  - ✓ Thermal efficiency : 34.4%

Breakdown of power balance

Fusion power	1500 MW
Thermal power	1865 MW
Generator output	640 MW
Power consumption	**386 MW**
Electric output	**254 MW**



Issue_2: Consistency between cooling system and T concentration control



Tritium impact in the primary coolant line

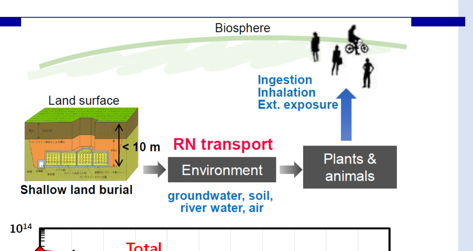
- ✓ T concentration at 1TBq/l was managed to apply the existing WDS for CANDU
- ✓ T permeation reduction factor is estimated to be 2077 from CANDU [Ref. 5]
- ✓ T permeation through a SG to the turbine system evaluated at 318 Ci/y/loop

➔This value is less than restricted amount of T release for a PWR in JA [Ref.3]

3. Rad-waste management for JA DEMO

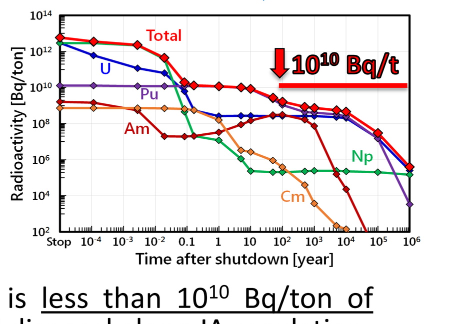
Disposal scenario

- ✓ Radioactive nuclide (RN) transport via likely pathways assessed based on JA regulation.
- ✓ All radwaste is classified as LLW and qualified for a shallow land burial.



Issue: U impurities in Be as N multiplier

- ✓ Using neutron multiplier is essential to ensure sufficient TBR.
- ✓ Amount of beryllide ($Be_{12}Ti$) in DEMO is 500 t, which contain 6.8 kg of U. (※U in Be:20 wppm)



Calculation results

Np, U, Pu, Am and Cm produced from uranium is less than 10^{10} Bq/ton of the total radioactive concentration for shallow land disposal along JA regulation.

➔ The U content in Be needs to be less than approximately 0.85 wppm in order that the total radioactive concentration of α nuclides

New purification process of QST has the ability to easily and safely remove U contained in Be until its content drops below allowable concentration (< 0.85 wppm) for shallow land disposal. ➔ The concentration of U is removed to less than 0.1 ppm [Ref.6].

4. Safety

Previous safety study focus on the "bounding sequences"

➔ **Lessons learned from "bounding sequences"**

- Even for extremely hypothetical accidents, environmental release of tritium will be within a dose for evacuation-free. [Ref.7]
- However, in-vessel LOCA due to a large scale break of cooling pipe could result in a failure of VV (primary confinement boundary).

Identification of an accident sequences and mitigation systems

➔ **Mechanisms and countermeasures against threats are sorted out.**

Threats Loss of soundness of VV

Mechanisms

- Overpressure in VV by coolant
  ➔ In-VV LOCA
- Overpressure in VV due to decay heat
  ➔ After the in/ex-VV LOCA, LOOP...
- Overpressure in VV due to H explosion
  ➔ Air intrusion after In-VV LOCA
- External pressure load on VV
  ➔ LOCA in Cryostat
  ➔ Short-circuit in TF coils, etc.
- Damage to VV due to flying objects, falling objects, etc.
  ➔ Pipe whipping and jet during cooling pipe breaking
  ➔ Blanket module fall

Countermeasures

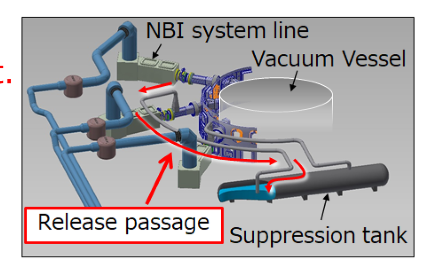
➔ Confirmed by the analysis.

- Installation of Suppression tank
- Installation of safety limiter
- Installation of decay heat removal system
- Installation of isolation valve, etc.
- Adoption of N multiplier of low H production reaction rate
- Installation of guard pipes
- Gap management between VV and TF coil
- Double walling of vacuum vessels and arrangement of fine reinforced ribs

Confirmation of countermeasures by analysis

✓ **Installation of suppression tank on the VV**

- ➢ Suppression tank is connected via the NBI port.
- ➢ Max. pressure at VV could be reduced to 15%.
  - ✓*Tank of volume (water): 5,600 m³ (2,800 m³)*
  - ✓*Rupture disk: 0.2 MPa (Differential pressure)*
  - ✓*Cross section of the NB port: 4.2 m²*



✓ **A check valves are arranged to suppress**

- ➢ Maximum pressure of VV is smaller than design pressure when the check valve arranges in the cooling system of the divertor baffle.
  - ✓*Break area of the div. baffle is assumed to the all of the cooling pipe.*
- ➢ Since the blanket has more amount of the water coolant than other IVCs, It can hardly contribute to suppress the max. pressure by check valve.

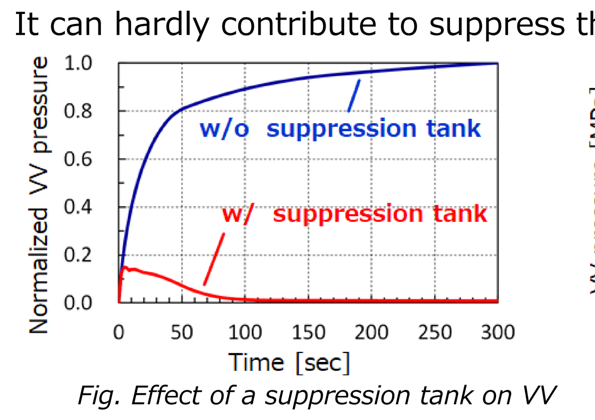


Fig. Effect of a suppression tank on VV

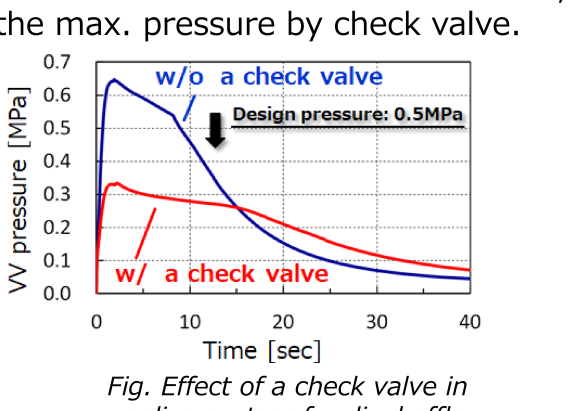


Fig. Effect of a check valve in cooling system for div. baffle

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