TECH/2 DEMO & Advance Technology

# TECH/2-1 : Progress in design and engineering issues on JA DEMO

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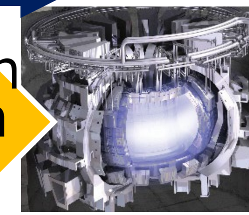
# Development of DEMO design activity in JA



2015 2020 2025 2030 2035 DEMO



Basic design phase | Conceptual design phase | Engineering design phases | Construction & operation phase

1st review

2nd review

Decision point for DEMO construction

## 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

**Pre-conceptual design of JA DEMO**

# Pre-conceptual design of JA DEMO

Parameter [Y. Sakamoto, IAEA, FEC 2018]

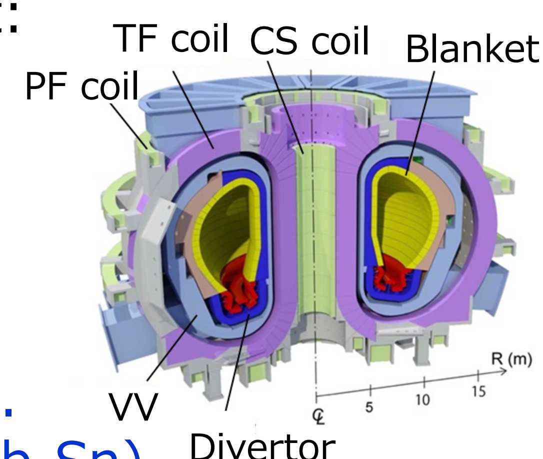
## Plasma operation

- Major radius, $R_P$ = ～ 8.5 m
  Arrangement of large CS coil for a few hour pulse operation in the commissioning phase
- Plasma perform., $\beta_N$=3.4, HH=1.3
  Study-state operation
- Fusion power $P_{fus}$ = 1.5 GW
  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 ($Nb_3Sn$)




| | Steady state | 2hrs pulse |
|---|---|---|
| $R_p$ (m) / $a_p$ (m) | 8.5 / 2.4 | |
| A | 3.5 | |
| $\kappa_{95}$ | 1.65 | |
| $q_{95}$ | 4.1 | |
| $I_P$ (MA) | 12.3 | |
| $B_T$ (T) | 5.94 | |
| $P_{fus}$ | ～1.5 | ～ 1.0 |
| Ave. NWL ($MW/m^2$) | 1.0 | 0.7 |
| Coolant water | 290-325℃,15.5MPa | |
| Q | 17.5 | 13 |
| $P_{ADD}$ (MW) | ～83.7 | |
| $n_e$ ($10^{19}$ $m^3$) | 6.6 | |
| HH $_{98y2}$ | 1.31 | 1.13 |
| $\beta_N$ | 3.4 | 2.6 |
| $f_{BS}$ | 0.61 | 0.46 |
| $n_e/n_{GW}$ | 1.2 | |

# Basic design for JA DEMO

Parameter [Y. Sakamoto, IAEA, FEC 2018]

## Plasma operation

- Major radius, $R_p$ = ~ 8.5 m
  Arrangement of large CS coil for
  a few hour pulse operation in the

13 May 2021, 17:00 (Oral)

ID:TECH/3-2Rb, N. Asakura, et. al.,

Plasma Exhaust and Divertor Designs in Japan and Europe Broader Approach, DEMO Design Activity

## Engineering

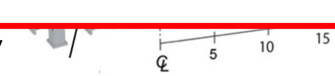
➔ ITER t... much as possible

- T bre... blanket
  - JA TBM strategy
- Divertor:
  - Water cooling
  - W mono blo...
- Magnet:
  - Radial Plate struc.
  - CIC conductor ($Nb_3Sn$)

13 May 2021, 08:30 (Poster)

ID: TECH/P5-1, H. Utoh et. al.,

Design study of large superconducting coil system for JA DEMO




| | Steady state | 2hrs pulse |
|---|---|---|
| $R_p$ (m) / $a_p$ (m) | 8.5 / 2.4 | |
| A | 3.5 | |
| Ave. NWL ($MW/m^2$) | 1.0 | 0. 7 |
| Coolant ... | 290-325°C 15.5MPa | |
| $f_{BS}$ | 0.61 | 0. 46 |
| $n_e/n_{GW}$ | 1.2 | |

# Recent progress on design issues for JA DEMO



**In order to increase the feasibility of JA DEMO concept, studies on the following engineering issues have been progressed.**

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

➔ Blanket concept of a honeycomb shape was proposed with pressure tightness.

- ✓ **Issue_1: Increase in tritium retention due to stagnation of purge gas flow**
- ✓ **Issue_2: Complicated structure of the support rib arrangement**

**2. An outlook of the steady and stable power generation beyond several 100 MW**

➔ The power generation system followed the PWR with close cooling conditions.

- ✓ **Issue_1: Evaluation of the power for DEMO plant consumption**
- ✓ **Issue_2: Consistency between cooling system and T concentration control**

**3. Safety**

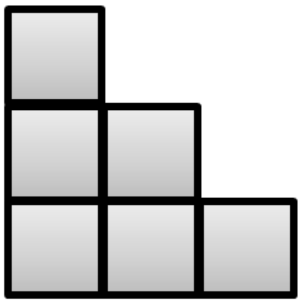
➔ An accident sequences and mitigation systems are being sorted out.

- ✓ **Issue_1: Identification of an accident sequences**

# Design structure of the pressure tightness against in-box LOCA

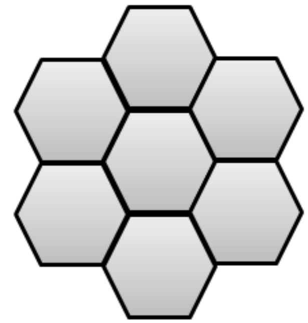


A conceptual design of breeding blanket with pressure tightness against in-box LOCA has been carried out for safety of the JA DEMO.



Square-shape

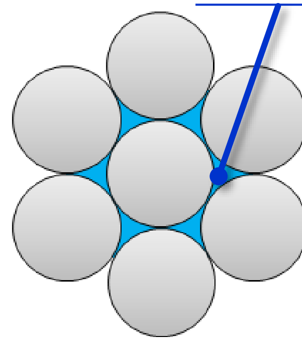
To thinner rib structure



Honeycomb-shape

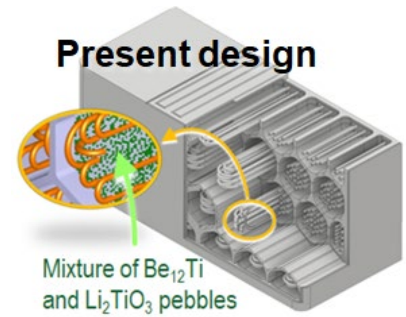
To simple structure

To thinner structure




Circle-shape

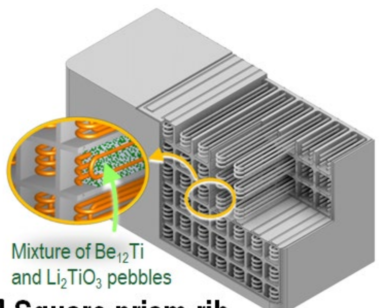
Present design




⬡ Honeycomb rib

Issue_1: T extraction

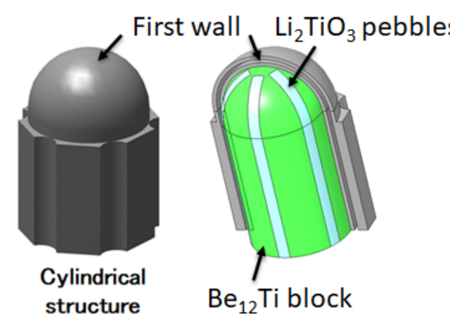
Issue_2: Complicated structure




☐ Square prism rib

"**square prism rib structure**" is a reduction in the volume fraction of T breeder.

➔ Overall TBR ≈ 1.0 (Target value≧1.05)




○ Cylindrical structure

① T extraction is confirmed by CFD analysis with "**honeycomb-shape**"

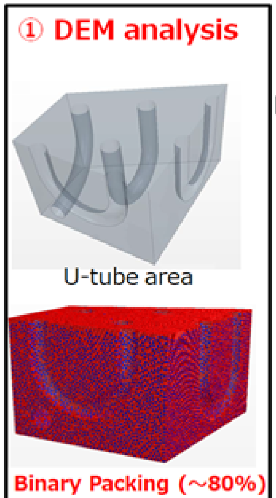
② Simple concept of "**cylindrical structure**" is designed to meet the target TBR in the condition of the pressure tightness.

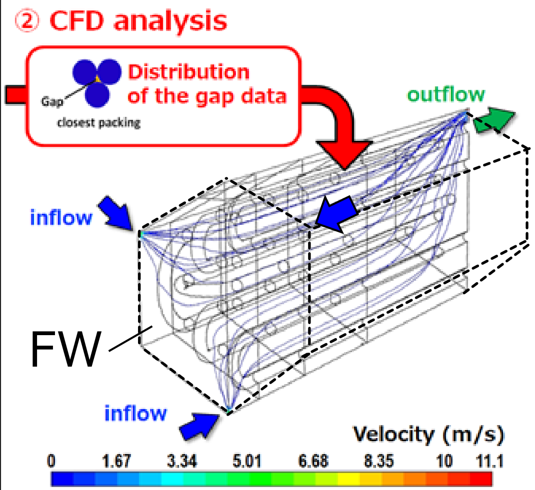
# Tritium extraction with honeycomb-shape

- **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 binary packing.
  - ➢ The flow of He-purge gas was analyzed to confirm tritium retention

## Analysis method

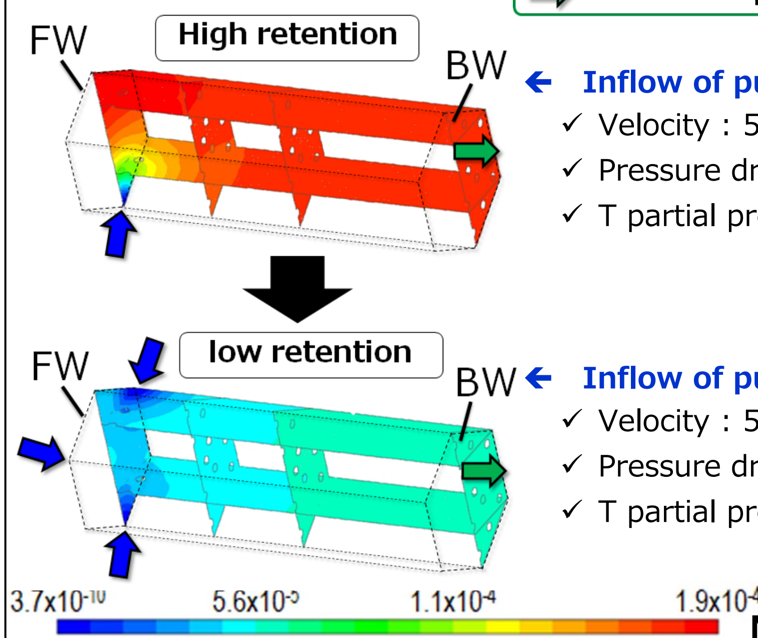
1. Gap distribution is evaluated by DEM.
2. The flow analysis is performed in the distribution of binary packing area which is modelled as a porous body.




## Analysis results

- Inflow of purge gas line
- Outflow of purge gas line




**Inflow of purge gas: 1 line**
- ✓ Velocity : 5 m/s
- ✓ Pressure drop: 12.8 kPa
- ✓ T partial pressure: 17.2 Pa

**Inflow of purge gas: 3 line**
- ✓ Velocity : 5 m/s
- ✓ Pressure drop: 16.0 kPa
- ✓ T partial pressure: 5.7 Pa

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

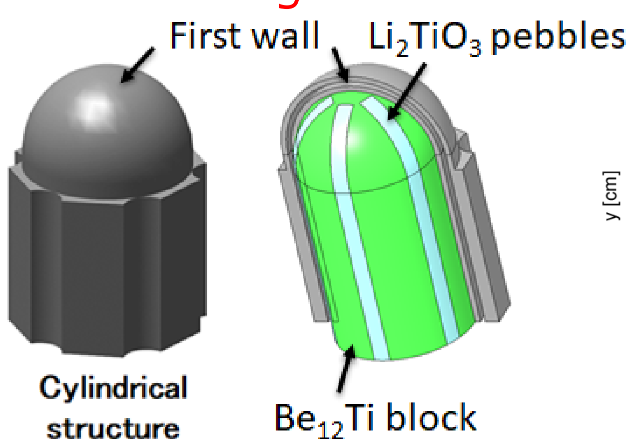
# Countermeasure against structural complexity of BB



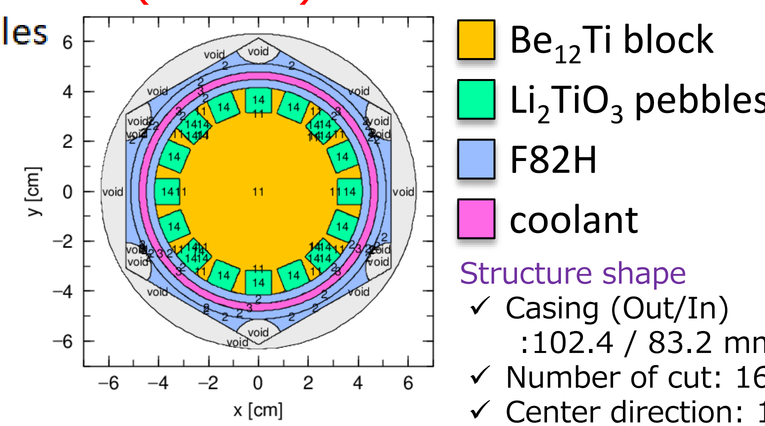
## A simplified BB structure was proposed with a cylindrical structure .

## ➔ 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. (2 to 45 W/m•K)
  - ✓ 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.

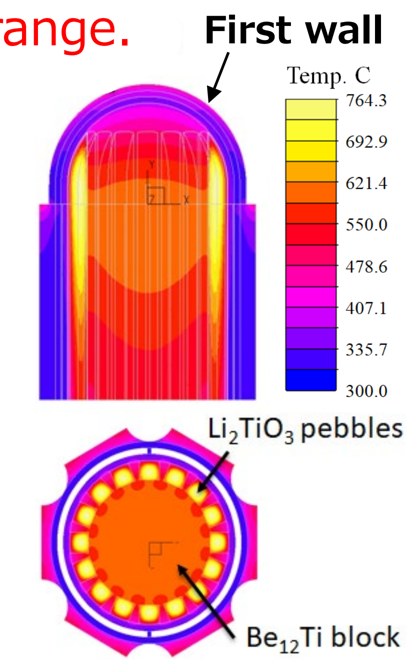



Cylindrical BB concept




Calculation model

Structure shape
- ✓ Casing (Out/In) :102.4 / 83.2 mm
- ✓ Number of cut: 16
- ✓ Center direction: 10mm
- ✓ Width : 10.5mm




Allowable temp. of material
- ✓ $Be_{12}Ti$ ≦ 900℃
- ✓ $Li_2TiO_3$ ≦ 900℃
- ✓ F82H ≦ 550℃

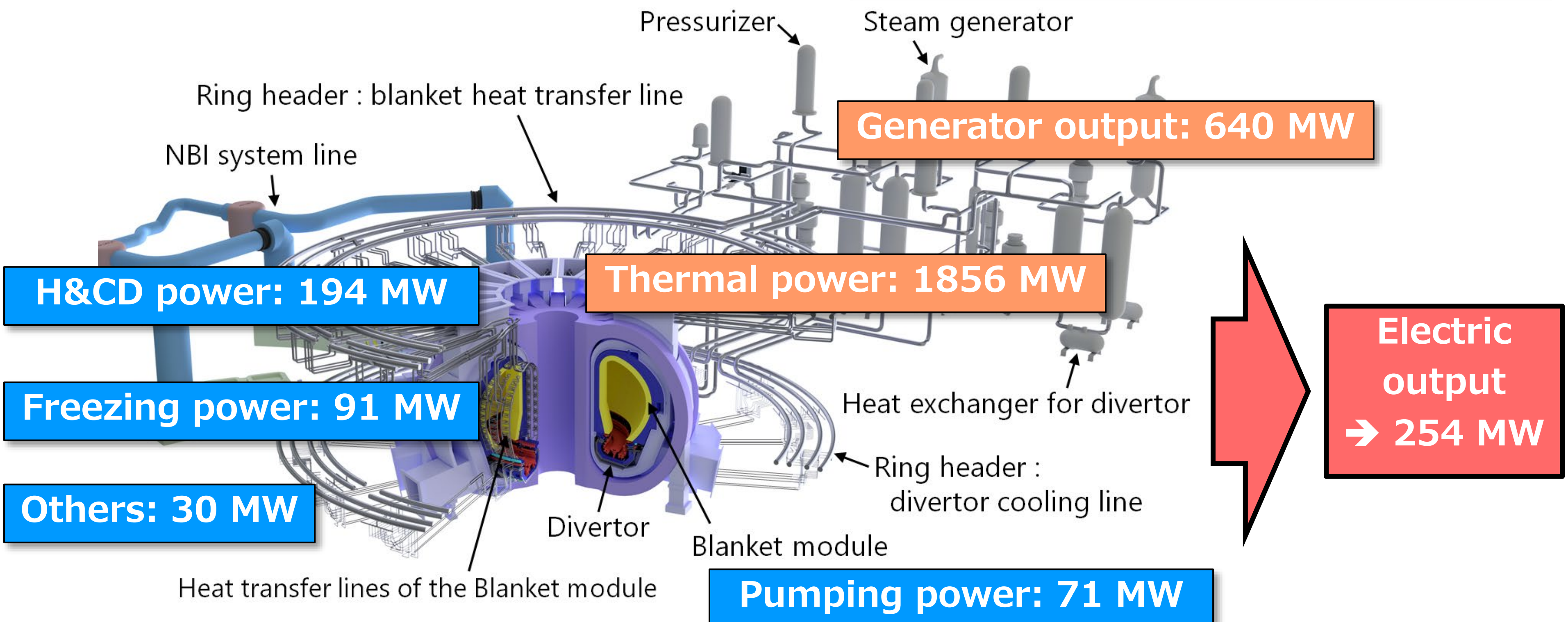
Temp. distribution of BB

# Evaluation of the electric output for JA DEMO

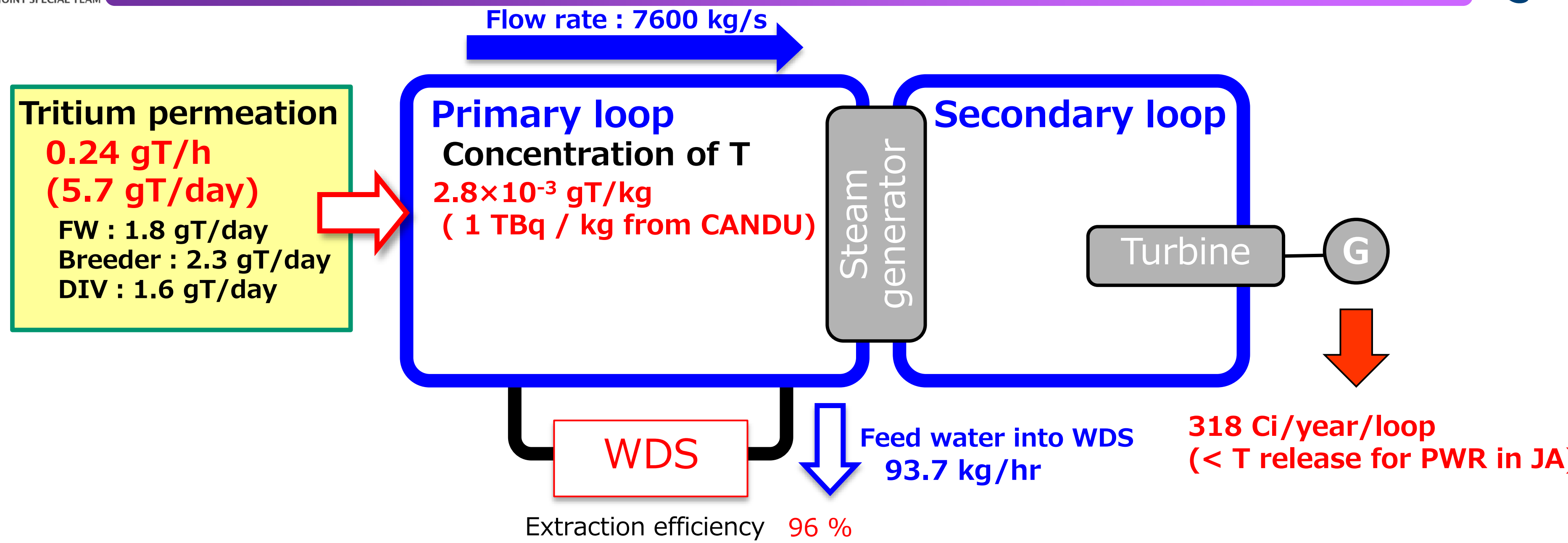
- **Primary heat transfer system**
  - ✓ PWR coolant water condition
    - ➔ 15.5MPa, 290～325℃
- **Turbine system**
  - ✓ Thermal efficiency : 34.4%
  - ✓ Gross power generation : 640MW

**Breakdown of power balance**

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



# 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 was estimated to be as low as 5.7 gT/day at most. **[Ref. 1]**
- T permeation reduction factor was estimated to be 2077 from CANDU**[Ref. 2]**
- 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]**


[Ref1] K.Katayama et al., Fusion science tech.71(2017)261

[Ref2] S. Tosti et al., Fusion Engin. Des. 43 (1998) 29–35

[Ref3] R. Hiwatari et al., Fusion Eng. Des. 143 (2019) 259-266

# Safety for JA DEMO

## 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.]**

  [Ref.] Nakamura, et al., IEEE Trans. Plasma Sci. 44, 1689 (2016)

- 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

**Countermeasures**

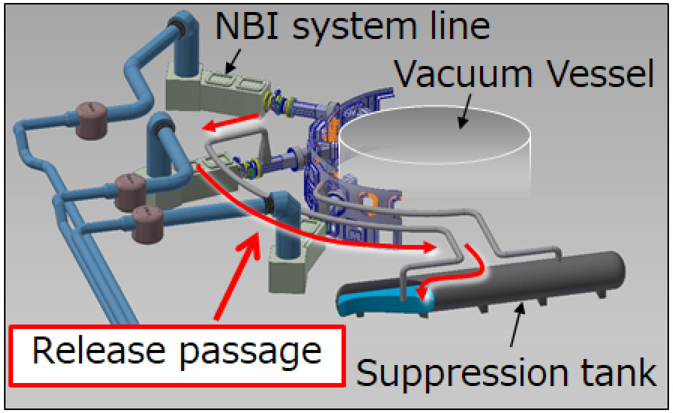
➔ Confirmed by the analysis.

- Installation of Suppression tank
- Installation of safety limiter
- Installation of decay heat removal system
- Adoption of N multiplier of low H production reaction rate

# 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 $m^3$ (2,800 $m^3$)*
  - ✓ *Rupture disk: 0.2 MPa (Differential pressure)*
  - ✓ *Cross section of the NB port: 4.2 $m^2$*




✓ **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.
  - ✓ *Soundness of BB first wall is protected 🡐 the safety limiter is sacrificed.*

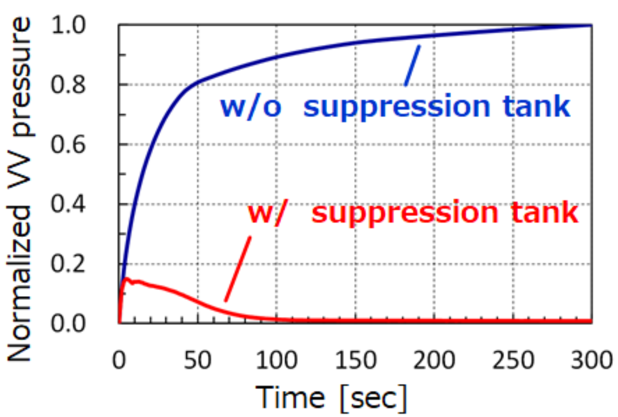



*Fig. Effect of a suppression tank on VV*

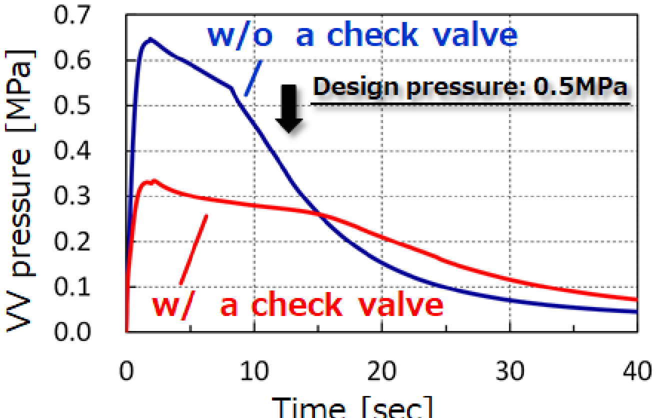



*Fig. Effect of a check valve in cooling system for div. baffle*

# Conclusions





- **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 the flow analysis of the 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. Safety**

➔ An accident sequences and mitigation systems are being sorted out.

➔ A mitigation systems of the countermeasures were confirmed on the safety analysis

➢ **The proposed concept as JA DEMO is the foundation for Japan's DEMO that can be envisioned in the next stage of ITER.**