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

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

Plasma operation
- Major radius, $R_p = \sim 8.5 \text{ m}$
- Arrangement of large CS coil for a few hour pulse operation in the commissioning phase
- Plasma perform., $\beta_N = 3.4$, $\text{HH} = 1.3$
- Study-state operation
- Fusion power $P_{\text{fus}} = 1.5 \text{ GW}$
- 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 ($\text{Nb}_3\text{Sn}$)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Steady state</th>
<th>2hrs pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_p (m) / a_p (m)$</td>
<td>8.5 / 2.4</td>
<td></td>
</tr>
<tr>
<td>$A$</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>$K_{95}$</td>
<td>1.65</td>
<td></td>
</tr>
<tr>
<td>$q_{95}$</td>
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<td></td>
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<tr>
<td>$I_p (\text{MA})$</td>
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<td></td>
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<tr>
<td>$B_T (T)$</td>
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<tr>
<td>$P_{\text{fus}}$</td>
<td>$\sim 1.5$</td>
<td>$\sim 1.0$</td>
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<tr>
<td>Ave. NWL (MW/m²)</td>
<td>1.0</td>
<td>0.7</td>
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<tr>
<td>Coolant water</td>
<td>290-325°C, 15.5MPa</td>
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<tr>
<td>$Q$</td>
<td>17.5</td>
<td>13</td>
</tr>
<tr>
<td>$P_{\text{ADD}} (\text{MW})$</td>
<td>$\sim 83.7$</td>
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<tr>
<td>$n_e \left(10^{19} \text{ m}^3\right)$</td>
<td>6.6</td>
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<tr>
<td>$\text{HH}_{98y2}$</td>
<td>1.31</td>
<td>1.13</td>
</tr>
<tr>
<td>$\beta_N$</td>
<td>3.4</td>
<td>2.6</td>
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<tr>
<td>$f_{BS}$</td>
<td>0.61</td>
<td>0.46</td>
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<tr>
<td>$n_e/n_{\text{GW}}$</td>
<td>1.2</td>
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Basic design for JA DEMO

**Plasma operation**
- Major radius, $R_p \approx 8.5 \text{ m}$
- Arrangement of large CS coil for a few hour pulse operation in the commissioning phase
- Plasma performance, $\beta_N = 3.4$, $HH = 1.3$

**Engineering**
- ITER technology as much as possible
  - T breeding blanket:
    - JA TBM strategy
  - Divertor:
    - Water cooling
    - W mono block
  - Magnet:
    - Radial Plate structure
    - CIC conductor (Nb$_3$Sn)

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<td>2.6</td>
</tr>
<tr>
<td>$HH$</td>
<td>1.3</td>
<td>1.13</td>
</tr>
<tr>
<td>$T_{BS}$</td>
<td>0.61</td>
<td>0.46</td>
</tr>
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<td>$n_e/n_{GW}$</td>
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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

13 May 2021, 08:30 (Poster)
**ID:** TECH/P5-1, H. Utoh et. al.,
Design study of large superconducting coil system for JA DEMO
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 is a reduction in the volume fraction of T breeder.

Overall TBR $\approx 1.0$ (Target value $\geq 1.05$)

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

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.

Issue_1: T extraction
Issue_2: Complicated structure

“square prism rib structure” is a reduction in the volume fraction of T breeder.

Overall TBR $\approx 1.0$ (Target value $\geq 1.05$)
Tritium extraction with honeycomb-shape

- Target of TBR ($\geq 1.05$) 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

3 inflow points of He-purge gas are arranged near the FW
  - Little retention of tritium in the area was found.
A simplified BB structure was proposed with a cylindrical structure.

- Characteristics of cylindrical concepts with Beryllide (Be\textsubscript{12}Ti) block.
  - Be\textsubscript{12}Ti has little swelling compared to Be. ➔ Be\textsubscript{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\textsubscript{2}TiO\textsubscript{3} pebbles = 25%). Dents around the Be\textsubscript{12}Ti block are designed to have the Li\textsubscript{2}TiO\textsubscript{3} ratio of 25%
  - Target of overall TBR (>1.05) is achievable.

First wall

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\textsubscript{12}Ti ≤ 900°C
- Li\textsubscript{2}TiO\textsubscript{3} ≤ 900°C
- F82H ≤ 550°C

Temp. distribution of BB

First wall
Evaluation of the electric output for JA DEMO

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

Breakdown of power balance

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Fusion power</td>
<td>1500 MW</td>
</tr>
<tr>
<td>Thermal power</td>
<td>1865 MW</td>
</tr>
<tr>
<td>Generator output</td>
<td>640 MW</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td><strong>386 MW</strong></td>
</tr>
<tr>
<td><strong>Electric output</strong></td>
<td><strong>254 MW</strong></td>
</tr>
</tbody>
</table>

- Freezing power: 91 MW
- Others: 30 MW
- H&CD power: 194 MW
- Pumping power: 71 MW

Generator output: 640 MW

Heat exchanger for divertor
Ring header: divertor cooling line
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/year/loop (< T release for PWR in JA) [Ref. 3]

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

- 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.

**Countermeasures**

- Confirmed by the analysis.

**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

- 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 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.
  - Soundness of BB first wall is protected \( \leftarrow \) 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.