Application of Li$_2$TiO$_3$ and Be$_{12}$Ti in Supercritical water cooled solid blanket for DEMO

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Objective and Background

Objective
To clarify the DEMO blanket design which
- can be achieved as soon as possible
- have possibility of economical improvement
, based on the reactor condition similar to SSTR.

Background
A conceptual design of the solid blanket cooled by supercritical water was introduced in the last workshop. The design showed possibility of the blanket concept with reduced activation ferritic steel as the structural material and Li$_2$O and Be as the breeder and multiplier.

This work
The possibility of the application of Li$_2$TiO$_3$, and Be$_{12}$Ti was shown from the viewpoint of TBR and temperature design.
Blanket Concepts in JAPAN

Background
(1) Solid blankets are regarded as one of candidate designs for near term target of the blanket in DEMO reactor such as SSTR. Because it has potential
- to be achieved as soon as possible
- to have possibility of economical improvement
(2) Liquid blankets have merit of
- better cooling of first wall and divertor
- no radiation damage to breeder.
Thus, it is suitable to higher output density. It is regarded as advanced options.

Concepts
Solid Breeder Blanket (Key organization: JAERI)
- Reference Water cooled blanket with RAFS = near term target
- Advance He gas cooling system with SiC/SiC

Liquid Breeder Blanket (Key organization: NIFS and Universities)
- Research on several advanced concepts are on going in parallel; FLiBe, Li, LiPb,
### Basic Parameters of Supercritical Water Cooled Solid Blanket

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma major, minor radius</td>
<td>5.8 m, 1.45m</td>
</tr>
<tr>
<td>Plasma current</td>
<td>12 MA</td>
</tr>
<tr>
<td>Fusion power</td>
<td>2300 MW</td>
</tr>
<tr>
<td>Neutron wall load</td>
<td>average 3.5, peak 5 MW/m²</td>
</tr>
<tr>
<td>FW surface heat flux</td>
<td>average 0.5, peak 1 MW/m²</td>
</tr>
<tr>
<td>Neutron fluence</td>
<td>7.5 Mwa/m² in 2 y</td>
</tr>
<tr>
<td>Tritium breeder</td>
<td>Li₂O or Li₂TiO₃</td>
</tr>
<tr>
<td>Neutron multiplier</td>
<td>Be or Be₁₂Ti</td>
</tr>
<tr>
<td>6-Li enrichment</td>
<td>Natural to 90 %</td>
</tr>
<tr>
<td>Structural material</td>
<td>Reduced activation ferritic steel</td>
</tr>
<tr>
<td>Coolant</td>
<td>Supercritical water (25 MPa, 280 – 510 °C)</td>
</tr>
<tr>
<td>Blanket structure</td>
<td>Modular structure, front access by remote handling</td>
</tr>
<tr>
<td>Dimension</td>
<td>1 m x 2m, &lt; 4 ton</td>
</tr>
</tbody>
</table>
Comparison of the Dimension of Reactors

JT-60U
R = 3.4 m
I_p = 6 MA
V_p = 100 m³

ITER-FEAT (2001)
R = 6.2 m
I_p = 15 MA
V_p = 837 m³

SSTR (1990)
R = 7.0 m
I_p = 12 MA
V_p = 760 m³

DEMO (2000)
for this study
R = 5.8 m
I_p = 12 MA
V_p = 386 m³

5 m
- Modular structure ; remote handling replacement

- Built-in cooling channels FW ; heat removal

- Pebble bed type of breeder and multiplier ; Avoid change of thermal performance due to cracking

- Series flow path starting from FW to breeder zone ; low coolant temperature to relax the load to the FW
Procedure of TBR Estimation

The blanket structure was modeled by 1D layered configuration of cooling layer (F82H/H2O/F82H), breeder layer (Li2TiO3), and multiplier layer (Be or Be12Ti), contained in the FW and rear wall. Cooling temperature were given at cooling layer and temperature limits were set to breeder and multiplier. Thickness of the layer was adjusted to obtain higher TBR.

Calculation methods

(1) Neutron and gamma transport
   Calculation code :ANISN
      (1D S_N calculation code )
   Cross section :FUSION-40
      (JENDL3.2)
   Neutron 42 groups,
   Gamma 21 groups
   Calculation parameter :P5-S8

(2) Temperature calculation
   :1D heat conduction
Coverage of Plasma Facing Component

<table>
<thead>
<tr>
<th>Components</th>
<th>Surface area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blanket</td>
<td>420</td>
</tr>
<tr>
<td>Blanket (port)</td>
<td>65</td>
</tr>
<tr>
<td>NBI port</td>
<td>6</td>
</tr>
<tr>
<td>ECH port</td>
<td>1</td>
</tr>
<tr>
<td>Divertor</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>522</strong></td>
</tr>
</tbody>
</table>
Coverage in a Module

Breeder area
Non-breeder area (purge gas header)
Box, Gap

Cross section of a blanket module

Breeder area
- Height of module: 2 m
- Rib interval: 0.5 m

Non-breeder area
- Gap between modules: 10 mm
- Side wall thickness: 30 mm
- Front access holes: 60 mm dia. x 6
- Headers: <50 mm
- Thickness of ribs: 20 mm
<table>
<thead>
<tr>
<th>Location</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap between modules</td>
<td>1%</td>
</tr>
<tr>
<td>Side wall</td>
<td>8%</td>
</tr>
<tr>
<td>Header</td>
<td>2 - 9%</td>
</tr>
<tr>
<td>Strengthening ribs</td>
<td>3%</td>
</tr>
<tr>
<td>Front access holes</td>
<td>1%</td>
</tr>
<tr>
<td>Breeder zone</td>
<td>71 - 78%</td>
</tr>
<tr>
<td>Blanket total</td>
<td>93%</td>
</tr>
<tr>
<td>Divertors and ports</td>
<td>7%</td>
</tr>
</tbody>
</table>

**Net TBR**

<table>
<thead>
<tr>
<th>Net TBR</th>
<th>Local TBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>1.28 - 1.41</td>
</tr>
<tr>
<td>1.05</td>
<td>1.35 - 1.48</td>
</tr>
<tr>
<td>1.10</td>
<td>1.41 - 1.55</td>
</tr>
</tbody>
</table>

**Requirement**

- **Gap between modules**: 1%
- **Side wall**: 8%
- **Header**: 2 - 9%
- **Strengthening ribs**: 3%
- **Front access holes**: 1%
- **Breeder zone**: 71 - 78%
- **Blanket total**: 93%
- **Divertors and ports**: 7%
Volume Ratio of Multiplier to Breeder

Rough survey by homogenized model of
- cooling layer (F82H + H₂O) + breeder (Li₂TiO₃) + multiplier (Be or Be₁₂Ti)

Multiplier/Breeder ratio [-]

TBR [-]

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2

Multiplier/Breeder ratio [-]

Be / Li₂TiO₃

Be₁₂Ti / Li₂TiO₃

Nat. Li
30%6Li
90%6Li

TBR leveled off in multiplier/breeder ratio of more than 3 to 4.
Example of TBR and Temperature Calculation

Point of interest
- Applicability of Li$_2$TiO$_3$
- Applicability of Be$_{12}$Ti
- Applicability of Mixed packing of Li$_2$TiO$_3$ and Be$_{12}$Ti

Li$_2$TiO$_3$ / Be separated packing, 6Li enrichment 30%
- TBR is 4 – 5 % higher in mixed packing than separate packing
- Mix packing of Li$_2$TiO$_3$ and Be$_{12}$Ti < Separate packing of Li$_2$TiO$_3$ and Be
Summary and Evaluation of TBR Calculation Results

<table>
<thead>
<tr>
<th>Breeder/Multiplier</th>
<th>Li$_2$TiO$_3$/Be</th>
<th>Li$_2$TiO$<em>3$/Be$</em>{12}$Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>6Li enrichment</td>
<td>90%</td>
<td>30% 30% 90%</td>
</tr>
<tr>
<td>Mix or separate</td>
<td>separate</td>
<td>sep. mix</td>
</tr>
<tr>
<td>Temp. limit</td>
<td>900°C breeder</td>
<td>900°C 600°C multiplier</td>
</tr>
<tr>
<td></td>
<td>900°C</td>
<td>600°C 900°C</td>
</tr>
<tr>
<td>TBR</td>
<td>1.41 1.52</td>
<td>1.37 1.24 1.35 1.35 1.43</td>
</tr>
<tr>
<td>Li$_2$O/Be case</td>
<td>1.53 1.56</td>
<td></td>
</tr>
<tr>
<td>Judge from TBR</td>
<td>good good</td>
<td>fare poor fare fare good</td>
</tr>
</tbody>
</table>

For mix packing, material compatibility is required.
Conclusions

1. Separated packing $\text{Li}_2\text{TiO}_3$ and Be was applicable.

2. Mix packing of $\text{Li}_2\text{TiO}_3$ and $\text{Be}_{12}\text{Ti}$ is possible. Further detailed analysis is needed.

3. Separate packing of $\text{Li}_2\text{TiO}_3$ and $\text{Be}_{12}\text{Ti}$ is possible. Further detailed analysis is needed.

4. Detailed structure modeling and analysis by MCNP will be performed. Neutronics experiments are being performed based on this design.