Preliminary Safety Analysis of CH HCSB TBM

Presented by: Chen Zhi

SWIP ITER TBM Workshop, China

Vienna, Austria, IAEA, July 10-14, 2006
Outline

- Introduction
- Calculation model
- Review of CH HCSB TBM preliminary safety analysis
- Summary
Introduction

- Safety has been a part of fusion design and operations since the inception of fusion research.
- Safety considerations are a part of the design process to ensure that the test blanket modules (TBM) do not adversely affect the safety of ITER operation.
- Safety analyses for Chinese ITER TBM design with helium-cooled solid breeder (HCSB) concept for testing in ITER device have been performed and submitted it to international test blanket work group (TBWG).
- Further safety analyses on CH HCSB TBM design are ongoing.
Structure View of Chinese ITER Test Blanket Module Design

For 1/4 ITER Port

For 1/2 ITER Port
Calculation Model

Plasma

First wall

Cooling pipe

neutron multiplier

breeder material

He

Shield

He
Input Conditions for Safety Analysis

- **Dimension:** 664mm × 890mm × 670mm (1/4 C port)
- **Codes:** BISON3.0/FDKR
- **Operation power:** 500MW
- **Operation factor:** 22%
- **Operation time:** 0.53y
- **Neutron wall load:** 0.78MW/m²
- **Material selection:**
  - **Structure material:** EUROFER
  - **Neutron multiplier:** Be
  - **Tritium breeder material:** Li₄SiO₄
  - **Coolant and purge gas:** He
Review of CH HCSB TBM Preliminary Safety Analysis
**Direction:**

The relevant safety analysis has to be consistent with the system safety analysis as presented in GSSR and French Nuclear Safety Authority (NSA) requests.

**Comments:**

- Some results of safety analyses are reported in the CH TBM DDD.
- The related safety analysis of EM-TBM are ongoing, some results have been got.
- Safety working groups have been built in China for licensing, QA and safety report of CH HCSB TBM, which consists of China nuclear safety office, China environment protection office, nuclear design institute, and so on.
- A systematic approach (such as FMEA or similar approach) will be built immediately.
Some Analyses Done

**NT-TBM design:**
- Decay heat and activation;
- BHP analysis;
- Waste estimation;
- Preliminary LOCA analysis;
- Electromagnetic analysis;
- Tritium penetration analysis;

**EM-TBM design:**
- Preliminary LOCA&LOFA analysis and electromagnetic analysis;
- Modeling, debugging and Preliminary application by RELAP5/MOD3.2;
Activity and Decay Heat Analysis

At shutdown, the total decay heat is $\sim 8.77 \times 10^{-3}$ MW with a contribution of $8.71 \times 10^{-3}$ MW and $6.36 \times 10^{-5}$ MW from structure material and Li$_4$SiO$_4$, respectively.

A total activity of $5.43 \times 10^5$ Ci is attained at shutdown with a contribution of $5.39 \times 10^5$ Ci from the structure, $3.7 \times 10^3$ Ci from the Li$_4$SiO$_4$. 

Total activity generated and contribution from each material

Total afterheat generated from each material
### Main Nuclides for Contribution to Activity

<table>
<thead>
<tr>
<th>Nuclides</th>
<th>Half life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe 55</td>
<td>2.7 yr</td>
</tr>
<tr>
<td>Cr 51</td>
<td>27.7d</td>
</tr>
<tr>
<td>Mn 54</td>
<td>312 d</td>
</tr>
<tr>
<td>Mn 56</td>
<td>2.56 h</td>
</tr>
<tr>
<td>W 187</td>
<td>23.9 h</td>
</tr>
</tbody>
</table>

Activity, afterheat and BHP all have nearly relation with activation products. The afterheat is primarily due to the decay heat of activated elements, specially Mn56, because decay energy of Mn56 per decay is 2.53MeV. Decay heat of Mn56 is 86.2% of all decay heat.
According to the US 10CFR61 regulation, if the waste contains a mixture of nuclides, then the waste disposal must meet the requirement of WDR<1. According to Class C limits of it, structure material is qualified for shallow land burial.

The waste disposal rating (WDR)

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>$^{59}$Ni</th>
<th>$^{93}$Zr</th>
<th>$^{94}$Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half life</td>
<td>75ky</td>
<td>1.5My</td>
<td>20ky</td>
</tr>
<tr>
<td>WDR</td>
<td>$1.48 \times 10^{-2}$</td>
<td>$4.72 \times 10^{-9}$</td>
<td>$1.03 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

From a fraction of an hour up to 1,000 years after shutdown, the total BHP is attributed to the contribution from the structure. The BHP levels after 1 hour, 1 day, 1 year, 10 years, and 100 years are 68.99 km$^3$/kW, 41.70 km$^3$/kW, 9.61 km$^3$/kW, 0.57 km$^3$/kW, and $1.35 \times 10^{-3}$ km$^3$/kW, respectively.
Tritium Permeation Control *

- Tritium production rate: \(2.23 \times 10^{-2}\) g/day
- Tritium extraction: He-H\(_2\) (0.1% vol. H\(_2\))
- Permeation barriers: \(\text{Al}_2\text{O}_3\)
- Tritium permeation release to the environment: less than 50\(\mu\)g/FPD

Note: This part is completed by China Academic of Engineering Physics, China
Reference Accidents Analysis

- In-vessel TBM coolant leak analysis to demonstrate:
  - A small pressurization of first confinement barrier (i.e., ITER VV)
  - Passive removal of TBM decay heat
  - Limited chemical reactions and hydrogen formation

- Coolant leak into TBM breeder or multiplier zone analysis to assess:
  - Module and tritium purge gas system pressurization
  - Chemical reactions and hydrogen formation
  - Subsequent in-vessel leakage

- Ex-vessel LOCA analysis to determine:
  - Pressurization of TBM vault
  - Behavior of TBM without active plasma shutdown

- Complete loss of TBM active cooling
Preliminary LOCA Analysis*

LOCA analysis shows depressurization of the TBM helium coolant occurs within 10 to 15s. Contribution to the pressure build-up in the VV is small (17.8 kPa). Tritium and activation products released from the TBM into the VV are insignificant compared to the total amount mobilized from non-TBM components. The TBM FW temperature can be kept, after the disruption burst has decayed variant to the reference case, with postulated unlimited steam access to the pebble beds, the estimated hydrogen production is the order of g only and the chemical heat is negligible.

* Note: This part is completed by Tsinghua university.
Preliminary NT-TBM Electromagnetic Analysis*

The simplified 3D model

The maximum induced eddy currents under CDII

The maximum stresses components of model B

The maximum stresses of model A

The EM torques of model A and model B

The EM torques of the nine sub-modules

* Note: this part is completed by university of electronic and technology of China
Preliminary NT-TBM Electromagnetic Analysis (cont.)

E-M stress distribution of different directions for model B

E-M stress distribution of different components for model B
Summary

◆ The radiological inventories of CH HCSB TBM, tritium inventories, decay heat, and waste disposal rating were investigated for the TBM concept. The radioactivity isotopes Fe-55, Mn-56, Cr-51 and W-185 dominate the radioactivity levels of TBM design.

◆ The waste disposal rating (WDR) depends on the level of the long-term activation. The results show that the WDR values are very low (<<1), according to Class C limits, these materials are qualified for shallow land burial.

◆ LOCA analysis shows that the effects is not serious under in-vessel loss of coolant. Electromagnetic safety analysis show that the structure design of HCSB TBM is reasonable based on EM safety analysis for the centered disruption.

◆ Further research for CH HCSB TBM are ongoing.
Welcome to Comment!