Tritium Safety
of Russian Test Blanket Module

V.K. Kapyshev, V.G. Kovalenko, Y.S. Strebkov

N.A. Dollezhal Research and Development Institute of Power Engineering,
PO Box 788, Moscow 101000, Russia

*Presented by V.K. Kapyshev*

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Objectives

1. Experimental Test Breeding Module (TBM) for RF DEMO fusion reactor and test of it in International Thermonuclear Experimental Reactor (ITER).

2. The Tritium Cycle System (TCS) of the Module for tritium extracting, processing of gaseous mixtures containing tritium and ensuring tritium radiation safety.

3. The classification of the TCS modes of operation, adopted at the present stage of the module development. The main initial events that may result in accidents.

4. The flow sheet of technological operations at the maintenance and repair works and ensuring their safety by the System of Radiological Safety. Tritium waste management.

5. The maximum design accident and its consequences
RF TBM program

The main objective of the International Experimental Thermonuclear Reactor (ITER) to confirm the technical feasibility of an installation with the plasma parameters which provide the fusion reaction over a long period of time. ITER, when in operation, would demonstrate the possibilities to ignite and to confine for long time the large-in-volume plasma.

At the same time, ITER will serve as a unique experimental basis for multifunctional tests of promising structural materials and approval of technical solutions for Demonstration Thermonuclear Reactor (DEMO) design.

The RF Team has designed the helium-cooled TBM with a ceramic breeder and lithium cooled TBM. For this purpose, some special places were selected for testing of TBM of the DEMO reactor.
Principal tasks of TBM tests in ITER

- test of TBM’s parts and auxiliary systems;
- attainment necessary coolant temperature;
- demonstration of tritium breeding in the breeding zone while providing tritium extraction, monitoring of its composition, transport and recovery.

These tasks are the main activities to be undertaken under the TBM Test Program in ITER.

The RF proposals for TBM and auxiliary systems are based on the DEMO reactor concept developed in 1997-2002.

The design developed provides for adaptation of the TBM components to one of the ITER vacuum vessel ports and interfaces between the TBM system equipment and ITER installations and reactor buildings.
Ceramic Helium Cooled Test Breeder Module

Special horizontal ports are envisaged to test DEMO experimental breeder blanket modules in ITER. TBM are installed in the horizontal port and attached to the support frame connected with the shielding plug (fig. 1). The frame sizes determine the overall sizes of TBM, which, with consideration for 20 mm gaps, are 840 mm in height and 514 mm in width. This frame serves for fastening of the experimental modules. Tightening of the ITER vacuum vessel is provided by welding between the shielding plug and vacuum vessel. The flexible supports (fig. 2) are used to fasten TBM to the support frame and the shear keys to take rotational moments.

The auxiliary systems comprise a helium cooling system, tritium cycle system, control system and monitoring system. The horizontal port space behind the shielding plug and rooms in the ITER reactor building are provided for the equipment of these systems.
Fig. 1.
TBM layout in the support frame

Fig. 2.
Isometric view of the RF TBM in the support frame
**Table 1. Main parameters of RF TBM**

<table>
<thead>
<tr>
<th>Coolant</th>
<th>Helium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breeder</td>
<td>Li$_4$SiO$_4$</td>
</tr>
<tr>
<td>Coolant temperature, °C:</td>
<td></td>
</tr>
<tr>
<td>- inlet</td>
<td>300</td>
</tr>
<tr>
<td>- outlet</td>
<td>500</td>
</tr>
<tr>
<td>Coolant temperature rise, °C</td>
<td>200</td>
</tr>
<tr>
<td>Coolant pressure, MPa</td>
<td>10</td>
</tr>
<tr>
<td>Coolant velocity (maximum), m/sec</td>
<td>13.6</td>
</tr>
<tr>
<td>Structural material</td>
<td>Ferritic steel: Cr (8-10%), Mo (0,5-0,7%), V (0,2-0,35%)</td>
</tr>
<tr>
<td>Maximum temperature of structural materials, °C</td>
<td>600</td>
</tr>
<tr>
<td>Neutron multiplier</td>
<td>Be</td>
</tr>
<tr>
<td>Maximum temperature of neutron multiplier, °C</td>
<td>650</td>
</tr>
<tr>
<td>Maximum temperature of breeder, °C</td>
<td>1000</td>
</tr>
</tbody>
</table>
TBM Tritium Systems

Conception of Tritium Cycle System (TCS) (fig. 3) is included:
1. Tritium extraction system;
2. Monitoring system of TBSM;
3. Coolant purification system.
The Tritium Extraction System (TES) provides the purge-gas circulation through the TBZ, extraction of bred tritium, tritium processing in order to remove from the TBM systems, tritium transportation from the reactor and analytical monitoring on purge-gas chemical composition.

Fig. 3. Conceptual diagram of the TCS

1-tritium breeding zone (TBZ); 2-test blanket sub-module; 3-tritium extraction system; 4-purge-gas circuit; 5-monitoring system of tritium breeding in TBZ; 6-coolant purification system; 7-helium coolant circuit.
Modes of T-cycle operations

normal operations and abnormal situation

1. Normal modes are:

1.1 Operations of tritium cycle systems under plasma pulses

1.2 Ancillary operations

1.2.1 Maintenance

1.2.2 Module replacements

1.2.3 Completion of Module Program

2. Abnormal situations:

2.1 Incidents

2.1.1 Stoppage of analysis system activity

2.1.2 Break a modes of operations of chemical purification absorbers

2.1.3 Break of SAT system

2.2 Accidents

2.2.1 Failure of vacuum pipe on TES

2.2.2 Accidents of technology systems

2.3 Maximum design accident

2.4 Hypothetical accident – break of all barriers
Conceptual diagram of reactor/installation tritium systems

There are three interconnected parts: reactor tritium complex, tritium process system and radiation safely system (Fig. 4). Sources of tritiated waste may be described and discussed using a scheme of a reactor tritium cycle to be proposed for DEMO [3]. The scheme may be applied for every controlled fusion facility or reactor. Each part delivers some LRW, SRW and GRW under reactor operation.

Fig. 4. Tritium cycle of controlled fusion reactor/installation
Flow sheet of TBM Tritium Cycle System

The flow sheet of the Tritium Cycle System is presented in fig. 5. It is intended for tritium extraction from impurities and its utilization, coolant purification, tritium monitoring in TBZ. The System includes:

- tritium breeding zone (TBZ) – Item No. 1,
- tritium gas system (TGS) – Item No 3,
- monitoring of tritium breeder in TBZ (MTBS)– Item No 5,
- coolant purification system – Item No 6.
- tritium safety system – Item No 7.

Fig. 5. Flow sheet of TBM Tritium Cycle System

1-tritium breeding zone (TBZ); 2-test blanket sub-module; 3- lithium ceramic zone; 4- beryllium zone; 5-purge-gas circuit; 6-monitoring system of tritium breeding in TBZ; 7- tritium extraction system; 8- beryllium purge-gas circuit ; 9-helium coolant circuit; 10-coolant purification system; 11-RSS; 12- safety devices; 13- ASS; 14- reactor zone; 15- ventilation system; 16- transport of radioactivity
Tritium monitoring

ASS provides monitoring of the tritium concentration in purge-gas and the relation between tritium gaseous and oxide forms. Tritium concentration and relation between tritium forms are measured by two radiometric ionization chambers (RIC). The adsorption apparatus adsorbs HTO and T$_2$O and the second RIC measures HT and T$_2$.

The monitoring of hydrogen and impurity content is carried out by sampling.

Measurement of tritium breeding ratio (TBR) in TBZ will be provided for MTBS. The tritium balance operations and estimation of TBR can be carried out using ASS and MTBS. MTBS is a reactor assembly for TBM, which contains ampoules with lithium-6, lithium-7 isotopes and neutron detectors. The ampoules with lithium isotopes will be removed and replaced after a pulse during a plasma pause.
**Tritium purification**

The Tritium Gas System (TGS) provides the purge-gas circulation through TBZ, extraction of bred tritium, tritium processing to remove it from the TBM systems, tritium transportation from the reactor and analytical monitoring of purge-gas chemical composition. TGS includes an analytical sub-system (ASS) and a technological sub-system (TES).

Processing of tritium-containing gaseous mixtures from the breeding zone and the ASS is provided for TES system based on using Zr-based hydride-generating intermetallic compounds. It is assumed to use two parallel technological chains (absorbers connected in series to absorb chemical impurities). One chain is intended for absorption and the other for segregation.

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**Fig. 6. Tritium Extraction System for purge-gas**

1-6 - absorbers (t=700°C); 7 – filter; 8 - flow meter; 9-11 - vacuum pump; 12 – receiver; 13 – sampling; 14 - pressure monitoring; 15 - purge-gas circuit; 16 – RSS; 17 - purge-gas; 18 – air; 19 - sampling
1-tritium breeding zone (TBZ); 1-test blanket sub-module; 2-transporter; 3- T-plant; 4- T-laboratory; 5- tritium purification of purge-gas; 6 - tritium purification device in helium coolant circuit; 7- purge-gas circuit; 8- helium coolant circuit; 9- gas waste from purge-gas circuit; 10- gas waste from helium coolant circuit; 11- tritiated waste

Fig. 7. Conception diagram of TCS location
Tritium waste management


Initial proposals of a waste flowsheet treatment for the DEMO are shown in Fig. 8.

The process contains two main parts: block-1, block-2, and block-3 are placed at a reactor site, a block-4 and a block-5 means some operations with radioactive waste on outside.

The block-1 embraces all three parts of a tritium cycle (Fig. 4) and comprises all units and devices of the main and auxiliary systems of a reactor/facility contained with tritium.

The block-2 and the block-3 are parts of the RSS. Systems of the block-2 containes a Hot Cell and some facilities to provide tritiated LLW of SRW and prepare of the waste from the block-3 for next storage and disposal.

The RF classification for the solid β-radioactive waste is shown in Table 2.

Table 2. Classification of solid and liquid β-radioactive waste

<table>
<thead>
<tr>
<th>Activity level</th>
<th>Specific β-activity of waste, kBq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt;10³</td>
</tr>
<tr>
<td>Intermediate</td>
<td>10³-10⁷</td>
</tr>
<tr>
<td>High</td>
<td>&gt;10⁷</td>
</tr>
</tbody>
</table>
Fig. 8. Block-diagram of Radioactive waste Management for DEMO

1 - 2 - Transport of Waste from Block-1 to Block-2,

\( n - m \) - Transport of Solid Waste from Block-\( n \) to Block-\( m \)
2. Amount of tritiated waste under maintenance mode of reactor operation

Amount of the GRW from TCS depends very strongly on the modes of the reaction operations. A main part of the waste is a result of maintenance and decommissioning and some replacements of Plasma Facing Components (PFC) are the most part for a maintenance mode of the operation.

However use emphasize that the sources of tritium SRW produce some secondary solid, liquid and gaseous tritium waste as result of the operations, decontamination processes and waste treatment.

Some details of a maintenance technology have to be discussed in order to evaluate the amount of the waste arisen as a result of the operations with the reactor devices. A scheme of PFC removal from a vacuum vessel is shown in Fig. 9.

There are four main stages of the operation and an each stage supplies cross contamination waste. Some essential points of the technology and amounts of the waste are in Table 3. The modes of the operations are associated with surface decontamination.

Dimensions of a technology zone (pos. 5, Fig. 3) have to comply with maximum sizes of a PFC. In the case this is TBM (~3.6 m long, ~2 m high, ~1.5 m wide).
Fig. 9. System of PFC/Module Transportation from Vacuum Vessel to Transport Cask

1 – Vacuum Vessel (VV), 2 – PFC/Module, 3 – Vacuum Port of VV, 4 – Technological Space (TS), 5 – Technological Zone for Decontamination Device, 6 – Transport Cask (TC), 7 and 8 – Doors, 9 – Exit Parts of Port and Cask, 10 – Separable Protective Covers, L<sub>in</sub> and G<sub>in</sub> – Inlet of Decontamination Liquid and Gas in TC, L<sub>out</sub> and G<sub>out</sub> – Outlet of Liquid and Gas after Decontamination, (a)-(b) – Transfer Way of PFC
<table>
<thead>
<tr>
<th>Operations</th>
<th>Interim tritiated waste</th>
<th>Gas (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hooking up Transport Cask to Vacuum Port of the Vacuum Vessel, evacuation of Technological Zone, evacuation of Transport Cask, detritiation of PFC, opening of Vacuum Seals of VV and TC</td>
<td></td>
<td>11.5</td>
</tr>
<tr>
<td>2. Disassemble and replacement of PFC, transportation of Auxiliary Devices to Blanket, dewatering from Cooling System, decontamination of Inner Surface of Cooling System, cutting Pipelines, sealing of the Pipelines, transportation of the PFC from VV to TC</td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>3. Transportation of new PFC in VV and assembly, transportation of PFC from TC to VV, hooking up PFC to Reactor System, preparation of PFC for operation, sealing of VV and TC</td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>3. Decontamination and transportation of PFC to RSS</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>14.0</td>
</tr>
</tbody>
</table>
**Tritium leakage in accidents**

Conservative estimations for maximum and hypothetical accidents are based on experimental data provided as results of researches with nuclear reactor models.

Tritium inventory for TBZ and TGS under normal reactor operation is in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Tritium inventory for TBM</th>
<th>Table 4.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Inventory TBZ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 TBZ (ceramic)</td>
<td>500-1000 Ci</td>
<td></td>
</tr>
<tr>
<td>1.2 Purge-gas circuit</td>
<td>50 Ci</td>
<td></td>
</tr>
<tr>
<td>2. Tritium breeding and inventory in TGS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tritium breeding in TBZ</td>
<td>20 g/y</td>
<td></td>
</tr>
<tr>
<td>Ratio HT/HTO</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2.1 Tritium in analytical sub-system</td>
<td>$2 \times 10^3$ Ci/weak</td>
<td></td>
</tr>
<tr>
<td>2.2 Tritium in extraction system</td>
<td>$2 \times 10^3$ Ci/weak</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$5 \times 10^3$ Ci/weak</td>
<td></td>
</tr>
</tbody>
</table>

Total leakage can be decreased up to 1000 Ci if tritium extraction period will be reduced to 1 day and tritium inventory TBZ 400 Ci using results of in-pile experiments.
Conclusion

1. Flow sheet of Tritium Cycle System demonstrates that the research programs under ITER operations can be carried out.

2. An international interface between TBM’s systems and T-plant is necessary under all modes of TBM operations.

3. Developed block-diagram of tritiated gas waste treatment may be a base for providing of radioactive waste in a DEMO to tritium LLW.

4. Tritium release for accidents can be decreased using new methods of tritium extraction from ceramic