# Development of HCCP TBM Shield Manufacturing Procedures and HCCP TBM-set Assembly Procedures

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## 1. Introduction

One of the primary objectives of the ITER Test Blanket Module (TBM) program is to demonstrate tritium breeding capability and heat extraction performance under fusion-relevant operating conditions [1–8]. Various TBM concepts have been independently developed by ITER member parties, including the Helium Cooled Ceramic Reflector (HCCR), the Helium Cooled Pebble Bed (HCPB), and the Water-Cooled Lithium Lead (WCLL) concepts. Recently, Korea and the European Union agreed to collaborate on the development of a new TBM concept, the Helium Cooled Ceramic Pebble (HCCP) TBM, which integrates the major design features of the HCCR and HCPB concepts [9].

The HCCP TBM consists of two principal components, namely the TBM box and the TBM shield, as shown in Fig. 1. The TBM box includes the First Wall, Side Cover, Stiff Grid, Breeder Units, and Back Plates. Within the current collaboration framework, the European Union is responsible for the TBM box except for the breeder units, whereas Korea is responsible for the design and fabrication of the TBM shield and Breeder Units.

The HCCP TBM shield adopts a five-block configuration and incorporates multiple penetrations connected to the TBM manifold. These penetrations accommodate cooling water inlet and outlet pipes, helium inlet and outlet lines, purge gas lines, and NAS instrumentation and control piping. Owing to this multi-penetration configuration and the severe thermo-mechanical loading conditions expected during ITER operation, the shield must simultaneously ensure structural integrity, fabrication feasibility, and reliable weld quality.

In the conventional HCPB TBM shield design, the internal structure consists of three blocks, thirty-two internal stiffening plates, and four transverse stiffeners. Although this configuration provides sufficient structural robustness, it results in a highly complex internal geometry that requires numerous precision welds. The narrow spacing between internal plates significantly restricts welding accessibility and limits the application of non-destructive testing (NDT), thereby increasing fabrication time and the potential risk of welding defects. To overcome these limitations, the present study proposes a revised fabrication concept for the HCCP TBM shield that simplifies the internal structure while maintaining structural performance. In addition, a preliminary assembly procedure for integrating the TBM shield and TBM box into the HCCP TBM-set has been developed.

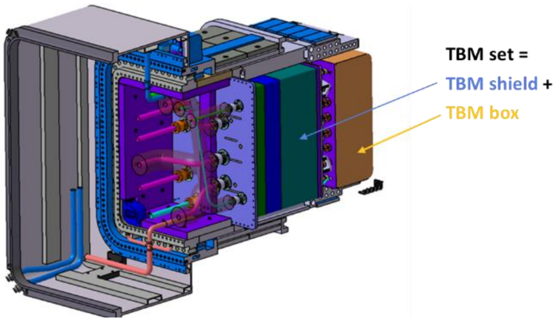

Fig. 1. HCCP TBM geometry diagram

## 2. Development of Manufacturing Procedure for the HCCP TBM Shield

The optimization of the HCCP TBM shield fabrication process was initiated through a detailed assessment of operational loading conditions, including thermal stresses and mechanical loads anticipated during ITER operation. Thermo-mechanical structural analyses were conducted to evaluate the structural behavior of the shield under combined loading conditions.

Based on these analyses, the internal structural configuration was modified to enhance manufacturability. The number of internal stiffening plates was reduced in order to simplify the internal geometry and decrease the total number of weld joints. By reducing the number of stiffeners, the overall welding volume and the number of critical weld seams were significantly lowered. Furthermore, the spacing between internal plates was increased, which improved accessibility for welding torches and inspection equipment. This modification directly addressed previous limitations associated with welding operations and NDT implementation.

To compensate for the potential reduction in structural stiffness caused by the removal of stiffeners, the thicknesses of both the internal plates and the outer walls were increased. The thermo-mechanical analysis results demonstrated that the increased plate thickness effectively restored the structural stiffness and maintained acceptable stress levels under representative ITER loading conditions. Consequently, the proposed design achieves improved manufacturability and inspectability without compromising structural integrity.

## 3. Development of the HCCP TBM-set Assembly Procedure

In addition to fabrication optimization, a preliminary assembly procedure for the HCCP TBM-set was established. The TBM-set is formed by integrating the TBM shield, manufactured in Korea, with the TBM box, manufactured in Europe. The assembled configuration of the TBM box and TBM shield using attachment structures is shown in Fig. 2.

The HCCP TBM-set assembly process begins with sub-assembly of TBM box components (including the First Wall, Side Covers, Stiff Grid, Breeder Units assembly, and Back Plates). Subsequently, the TBM shield structure, composed of five blocks including He pipes, He purge gas pipes, NAS pipe, and Feedthrough pipes for sensors, is assembled. The TBM shield and TBM box are then mechanically joined using dedicated attachment structures designed to provide structural stability during operation.

Following mechanical integration, the cooling water lines, helium inlet and outlet lines, purge gas lines, and NAS piping interfaces are connected. Particular attention is given to alignment tolerances and welding quality at the interface between the shield and the box. Since multiple coolant and instrumentation lines pass through the shield, precise geometric alignment and reliable sealing are essential to ensure safe and stable operation under ITER conditions. The proposed assembly sequence establishes a systematic integration framework, which will be further validated and refined through future fabrication trials and mock-up testing.

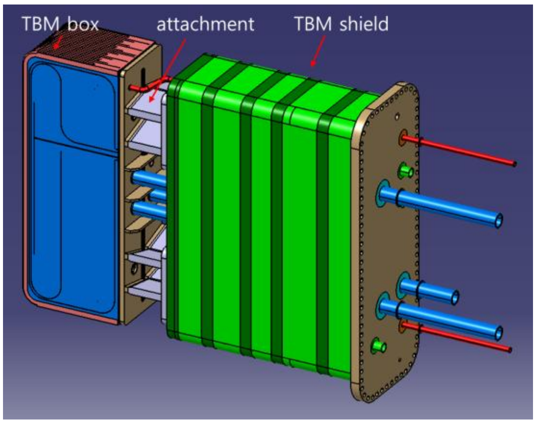

Fig. 2. Assembled HCCP TBM box and TBM shield

## 4. Conclusions

This study presented an optimized manufacturing procedure for the HCCP TBM shield and a preliminary assembly procedure for the HCCP TBM-set within the framework of the Korea–EU collaboration for the ITER TBM program. The conventional HCPB-based shield design posed significant manufacturing challenges due to its numerous internal stiffeners and complex welding requirements. To address these issues, the internal structure of the HCCP TBM shield was simplified by reducing the number of stiffeners and increasing the spacing between internal plates, thereby enhancing welding accessibility and NDT feasibility. The increase in plate thickness compensated for the reduction in stiffening elements, and thermo-mechanical analyses confirmed that structural integrity is maintained under representative ITER loading conditions. Furthermore, the establishment of a preliminary assembly procedure for integrating the TBM shield and TBM box provides a practical basis for detailed assembly planning, qualification testing, and future ITER implementation.

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