Status of the Design Tool Development for ITER TBM and Fusion Reactor System in Korea

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1. Introduction

Korea has developed a Helium Cooled Molten Lithium (HCML) Test Blanket Module (TBM) and Helium Cooled Ceramic Reflector (HCCR) TBM to be tested in the ITER [1-4]. The main purpose for developing the TBM is to develop the design technology for the DEMO and fusion reactor, and it should be proved experimentally in the ITER. Therefore, we have developed the design scheme and codes including the safety analysis capability for obtaining the license for testing in the ITER. In this study, the current status of the design tool development is summarized.

2. Design and system codes development scheme

For the design of the TBM, several commercial or common codes were used, such as a 3D CAD, neutronics codes, and thermal-hydraulic/mechanical CFD/FEM codes including Electro-Magnetic (EM) analysis tools. For a safety analysis, the GAMMA+ (GAs Multi-component Mixture Analysis) code has been used, which was developed in Gen. IV reactor development projects as the system analysis codes. For the liquid metal breeders, MARS-FR and GAMMA-FR have been developed based on MARS and GAMMA+. Table I shows the final goals and current status of the system code development and validation for each area.

2.1 System code development for He coolant

A performance analysis for the thermal-hydraulics and a safety analysis for an accident caused by a loss of coolant for the KO TBM have been carried out using a commercial CFD code, ANSYS-CFX [5], MARS, and GAMMA. To verify the codes, a preliminary study was performed by Lee [6] and Yum [7,8] using a single TBM First Wall (FW) mock-up made from the same material as the KO TBM, i.e., Ferritic Martensitic (FM) steel. From a comparison of the experimental data with the ANSYS-CFX, MARS, and GAMMA codes, the 3-dimensional (3D) analysis shows a much better estimation of the heat transfer compared to the existing 1-dimensional (1D) analysis with systems codes considering the unique feature that there is a one-side heat source from the plasma side in a fusion environment. Actually, the GAMMA code adopts a well-known heat transfer correlation, a Dittus-Boelter correlation, which is developed under the condition where the temperature difference between the surface and fluid is less than 10 ^oC. Moreover, GAMMA has been adapted to use the film temperature for calculating the Reynolds number. Actually, however, because the viscosity is a function of bulk temperature, using film temperature makes the viscosity higher than its real value. In addition, this also makes the Reynolds number from GAMMA be smaller. Because GAMMA underestimates the Reynolds number, the heat transfer coefficient from this code is hard to trust. In 1965, McEligot et al. developed a heat transfer correlation known to be valid for the following three conditions: using helium coolant, $1 < (Ts/T) < 2.5$ and $15000 < Re < 600000$. The present experiment covers these conditions, and the correlation can be adopted.

2.2 Tritium permeation model implementation

The TBEC (Tritium Behavior Evaluation Code) is a computer code developed for the purpose of analyzing tritium permeation and distribution in HTGR systems (Yook, 2009) [9].

Table I Status and plan of the code development.

Fields	Final goals	Current status
Neutronics	- CAD conversion tools development - Fusion library development (Int. collaboration) - Neutronic analysis scheme development with existing codes (MCNP/MCCARD)	- Using Free CAD and developing CAD conversion tools - Participating FENDL-3.0 libraries (IAEA collaboration) - For HCCR TBM, MCNP was applied
Gas Coolant	- Verifying the commercial (ANSYS-CFX) and developed system codes (MARS-GCR, GAMMA)	- 2010; N_2 gas, 6 MPa, 0.3 kg/sec, ~0.1 MW/m^2 heat flux - 2011: He gas, 9 MPa, 0.5 kg/sec, ~0.5MW/m^2 heat flux - 2012: He gas, 9 MPa, 0.5 kg/sec, 5 MW/m^2 heat flux
Liquid metal breeder	- Developing and verifying MARS-FR & GAMMA-FR - MHD model implementation and verification	- 2010: material properties (PbLi, Li) implementation - 2011: basic heat transfer correlation implementation - 2012: MHD model implementation and verification
Tritium	- Developing and verifying GAMMA-T	- 2010: evaluation of the existing codes such as TRITGO etc. - 2011/2012 T permeation model implementation
Other commercial codes	- Verifying MHD with commercial CFX EM-module	- 2009-2011 Verification of CFX EM-module with the previous experimental data

Integration	- Base structure development for integration of MARS-FR & GAMMA-FR	- Base structure development considering the integration
Fusion System Design code	- Developing a design code for system parameters	-2013: Coupling system design code (SUPERCODE) with the GAMMA-FR

The TBEC+GAMMA code was developed and tested with an NHDD (Nuclear Hydrogen Development & Demonstration) hydrogen production system. The PRF (Permeation Reduction Factor) is about 10–1000 in the case of Incoloy 800 owing to the formation of the oxide layer. In this study, the permeation model including the Deal-Grove model for oxide layer formation was suggested and validated against the experimental data. The transfer rate of tritium decreases over time, showing a big difference from that of constant PRF. This is very optimistic in terms of safety.

2.3 MHD model implementation in system codes

In a momentum field equation, an MHD driven pressure drop was applied using Miyazaki's correlation (1989) [10]. Several previous MHD experiments were simulated, and they show a good agreement with the experimental values. Actually, there are no experimental data with a higher range of magenetic field above 5 T. More verification work is required for this range.

2.4 SUPERCODE coupling

The SUPERCODE is a well-known system design code for a fusion reactor, which has been developed to fill the gap between zero dimensional system codes and multi-dimensional plasma performance codes [11]. We decided that the Korean fusion code should adopt the SUPERCODE code's design capability, and it was successfully implemented in GAMMA-FR GUI environments.

2.5 MCNP CAD conversion Tool coupling

MCNP is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, and is one of the most representative neutronics codes used in this field.

To improve the user interface, 3-dimensional CAD data need to convert the MCNP text input automatically. This workbench style of code coupling is underway this year.

3. Conclusion

For developing the design scheme and system codes of the ITER TBM program in Korea, the developed system codes such as MARS and GAMMA+ from Gen. IV projects were modified and verified considering the fusion application. (1) For He coolant, 3D analysis and a McEligot correlation as the heat transfer model were proposed and validated considering the high heat from the plasma side and extreme temperature difference between the wall and fluid. (2) For tritium behavior in the He coolant, the TBEC+GAMMA code was developed, and the oxidation layer growth and its permeation rate change were considered in this development. (3) For a liquid metal breeder such as PbLi and Li, GAMMA-FR was developed including physical properties of the generation model and basic heat transfer model in them. (4) For MHD simulation, the Miyazaki model was implemented in GAMMA, and it was validated successfully with the experimental data. (5) Extending the capability of GAMMA-FR, a fusion system design code (SUPERCODE) is going to be coupled with a 3D neutronics code (MCNP).

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