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Design tools and scheme for ITER TBM and Fusion Reactor 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 by experiment in the ITER. Therefore, we have developed the design scheme and related codes including the safety analysis for obtaining the license for testing in the ITER. Using the prepared facilities and related experiments, developed codes were validated.

In the present study, the overall design and system codes development scheme, and some development results are introduced.

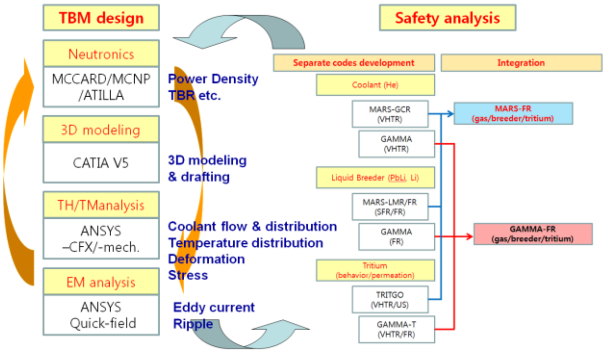

Fig. 1 Design and system analysis codes development scheme.

2. Design and system codes development scheme

For the design of the TBM itself, several commercial and common codes were used for a 3D CAD, neutronics codes and thermal-hydraulic/mechanical CFD/FEM codes including Electro-Magnetic (EM) analysis tools. For safety analysis, system codes such as a MARS-GCR (Multi-dimensional Analysis of Reactor Safety for Gas Cooled Reactor) and a GAMMA (GAs Multi-component Mixture Analysis) codes have been used, which were developed in Gen. IV reactors development projects as the system codes for system analysis. For the liquid metal breeders, the MARS-FR and GAMMA-FR have been developed based on the MARS and GAMMA from GEN.IV reactor codes in Korea. Figure 1 shows the overall codes scheme used in the TBM design and safety analysis. Table I shows the final goals and current status of the system codes 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], Yum [7,8], etc. using a single TBM First Wall (FW) mock-up made from the same material as the KO TBM, Ferritic Martensitic (FM) steel. From the comparison of the experimental data with the ANSYS-CFX, MARS and GAMMA codes, the 3-dimensional (3D) analysis shows much better estimation of the heat transfer compared to the existing 1-dimensional (1D) one with systems codes considering the unique feature that there is one-side heat source from plasma side in fusion environment. Actually GAMMA code adopts the well-known heat transfer correlation, Dittus-Boelter correlation which is developed in the condition where temperature difference between surface and fluid is less than 10 ^{o}C. Moreover, the GAMMA has adapted is to use the film temperature for calculating Reynolds number. But actually, because viscosity is the function of bulk temperature, using film temperature makes the viscosity be higher than its real value. And this also makes the Reynolds number from GAMMA be smaller. Because GAMMA underestimates the Reynolds number, heat transfer coefficient from this code is hard to trust. In 1965, McEligot et al. developed heat transfer correlation and it is known to be valid for the following three conditions; using helium coolant, $1 < (Ts/T) < 2.5$ and $15000 < Re < 600000$. Present experiment covers these conditions, 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 the HTGR systems (Yook, 2009) [9].

Table I Status and plan of the codes 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 ATILLA 3D 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	- 2010; N_2 gas, 6 MPa, 0.3 kg/sec, ~0.1 MW/m^2 heat flux

	developed system codes (MARS-GCR, GAMMA)	- 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

The TBEC+GAMMA code was developed and tested with NHDD (Nuclear Hydrogen Development & Demonstration) hydrogen production system. PRF (Permeation Reduction Factor) is about 10~1000 in case of Incoloy 800 due 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. It is a very optimistic aspect in terms of safety.

2.3 System codes development for liquid breeders

MARS code has been developed and used as a fluid system analysis code for the water cooling reactor. The present paper describes theories and models for introducing the properties of Lithium and Lead Lithium, which were induced the following application ranges; 500 ~ 3000 K of temperature and 1.0 Pa ~ 9.0 MPa pressure for Lithium; 400 ~ 3000 K of temperature and 1.0 Pa ~ 1.0 MPa pressure for Lead-Lithium. In the MARS source program, the following subroutines in the directory of "Envrl" were modified or developed; eclock.f90, edate.f90, stgli.f90, stglipb.f90. The induced properties were compared with the previous experimental results in the ranges and the raw values were attached in the appendix. The developed properties will be used in the MARS-FR.

2.4 MHD model implementation in system codes

In a momentum field equation, MHD driven pressure drop was applied by using the Miyazaki's correlation (1989) [10]. With developed code in section III.C, several previous MHD experiments were simulated and they show a good agreement with the experimental ones. Actually, there is no experimental data with the higher range of magenetic field above 5 T. More verification is required with this range.

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 in Gen. IV projects were modified and verified considering the fusion application; (1) For He coolant, 3D analysis and McEligot correlation as the heat transfer model was proposed and validated considering the high heat from plasma side and extreme temperature difference between wall and fluid. (2) For tritium behavior in He coolant, TBEC+GAMMA code was developed and oxidation layer growth and its permeation rate change were considered in this development. (3) For liquid metal breeder such as PbLi and Li, MARS-FR and GAMMA-FR were developed including physical properties generation model and basic heat transfer model in them. (4) For MHD simulation, Miyazaki model was implemented in GAMMA and it was validated successfully with the experimental data. These separate codes will be modified more considering the unique fusion conditions and they will be integrated.

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