Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Status and Strategy of the GAMMA-FR code Validation 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, which should be proved experimentally in the ITER. Therefore, we developed a design scheme and codes including the safety analysis capability for obtaining the license for testing in the ITER. The GAMMA-FR code is a domestic system analysis code to predict the thermal hydraulic and chemical reaction phenomena expected to occur during the thermo-fluid transients in a nuclear fusion system. A safety analysis of the Korea TBS (Test Blanket System) is underway using this code, and not MELCOR, which is a representative code for ITER. Therefore, validation of GAMMA-FR is one of the most primary interests, and validation using MELCOR V&V list has top priority.

2. The GAMMA-FR code

For developing the design scheme and system codes of the ITER TBM program in Korea, the developed system codes (the GAMMA+ code) were modified to consider the fusion application. (1) For He coolant, a 3D analysis and McEligot correlation as a 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 He coolant, the TBEC+GAMMA code was developed, and 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 the physical properties of the generation model and the basic heat transfer model in them. (4) For MHD simulation, the Miyazaki model was implemented in GAMMA-FR, and was validated successfully using the experimental data.

2. Status of the GAMMA-FR code Validation

GAMMA-FR is a sub-breach of the GAMMA+ code, and therefore the general thermal hydraulic validation of the mother code is directly inherited to GAMMA-FR. Under a subcontract with General Atomics [5], KAERI has carried out transient analyses for the conceptual design of the NGNP plant. The GAMMA+ code with a version of Rev00-Mod11, which is the base code of the GAMMA-FR code, was used for the analyses. The SVVR (Software Verification and Validation Report: SVVR-NHDD-CD-10-01) was written to support the GAMMA+ code to enhance the reliability of the numerical results for the NGNP project. Table 1 shows the list of selected cases for verification and validation.

Table 1. Selected Cases for Verification & Validation of GAMMA+

Problem	Reference
Fundamental Problems	
- Laminar duct flow (analytic)	Burmeister, 1993
- Backward facing step experiment	Armaly, 1983
- Thermal heat conduction (analytic)	SWLee, 2008a
- Radiation heat transfer (analytic)	SWLee, 2008b
Pebble Bed	
- SANA-1 test facility	IAEA, 2000
Reactor Cavity Cooling System	
- Square cavity natural convection	Davis, 1983
HTTR	
- HTTR simulator for DCC	Kunitomi, 1989
HTR-10	
- HTR-10 steady state	Dong, 2003
- HTR-10 LOFC ATWS	INET, 2006

3. Strategies of the GAMMA-FR code

In the early days of the ITER program (prior to 1995), the MELCOR 1.8.2 code was chosen as one of several codes to be used to perform ITER safety analyses. Korea fusion reactor system code development is underway to achieve a reliable safety analysis code, replacing MELCOR for the HCCR TBM analysis.

GAMMA-FR validation has two methods, i.e., fusion system related experimental validation and code to code validation using MELCOR. A validation document list is given in table 2 and was used for MELCOR validation. As a code to code validation, the reference accident scenarios (Tale 3) that will be used, and the MELCOR results, will be compared with those of the GAMMA-FR code.

This work is part of UCLA-NFRI collaboration on R&D. The collaboration will utilize U.S. modelling and analysis capabilities and U.S. laboratory facilities. NFRI will utilize the results of this R&D work to support the Korean ITER TBS program effort as well as other longer range research activities.

Table 2. Documents List for the Validation

#	Document title	Date of issue
1	ITER/US/95/TE/SA-23 : MELCOR Reference Problem Calculations for JCT Benchmarking Exercise	Sep. 1995
2	ITER/US/96/TE/SA-22 : MELCOR Pretest Predictions of ICE Experiments	Nov. 1996
3	ITER/US/97/TE/SA-9: Preliminary Post-test Analysis of ICE Experiments Using MELCOR	Mar. 1997
4	ITER/US/97/TE/SA-10: Pretest predictions of ICE and LOVA Experiments Using MELCOR	Mar. 1997
5	ITER/US/98/TE/SA-6: MELCOR analysis of ICE Experiments for February 1998 ICE/LOVA Meeting	Mar. 1998
6	ITER/US/98/TE/SA-7: MELCOR analysis of LOVA Experiments for February 1998 ICE/LOVA Meeting	Mar. 1998
7	L. Topilski, MELCOR model for ICE experiment: ICE post-test calculations, IEA Meeting, ITER report G 84 IP 3 00-10-16 F 1	June 2000
8	P. Sardain, Modelling of two-phase flow under accidental conditions fusion codes benchmark, Fusion Engineering and Design 54 (2001) 555–561	Apr. 2001
9	L. Topilski, Validation and Benchmarking in support of ITER-FEAT safety analysis," Fusion Engineering and Design 54 (2001) 627–633	Apr. 2001
10	L.N.Topilski, MELCOR model for ICE experiment: basic parameters, results of ICE post-test calculations, G 84 IP 8 01-12-11 F 1	Oct. 2001
11	L.N.Topilski, Comparison of the results of the ICE post-test calculations for cases P1-P8, G 84 RI 20 03-05-16 R 0.1	May 2003
12	MELCOR Gap Analysis, DOE-EH-4.2.1.3-Interim-MELCOR, U.S. Department of Energy Office of Environment, Safety and Health	Jan. 2004
13	P. Sardain, Validation of Thermalhydraulic Codes for Fusion Reactors Safety, 24th Symposium on Fusion Technology, 11-15 September 2006, Varsaw – Poland	Sep. 2006
14	ITER_D_26LDP4, MELCOR 1.8.2 Fusion Installation Guide	May 2007
15	INL/EXT-07-12856, Pedigree Analysis of the MELCOR 1.8.2 Code to be Used for ITER's Report Preliminary on Safety	June 2007

Table 3. Accident Scenario List for the Validation

Reference Accident	Description
In-vessel LOCA	In-vessel Loss Of Coolant Accident (LOCA) is initiated by a multiple rupture of TBM FW cooling channels, causing a plasma disruption and pressurization of VV.
In-box LOCA	This accident starts with rupture of cooling plates in the Breeding Zone (BZ) pressurizing the BZ box structure, thus subsequent pressurization of the TES..
Ev-vessel LOCA in Port Interspace or Port Cell	This accident is initiated by rupture of TBM coolant pipe in Port Interpsace or Port Cell, causing radioactive release and pressurization in Port Interspace and Port Cell.
Ex-vessel LOCA in TCWS VA	This accident is initiated by rupture of TBM coolant pipe in TCWS VA where major components of the HCS are located, causing radioactive release and pressurization in TCWS VA.
LOFA	Loss Of Flow Accident (LOFA) is caused by failure of cooling circulator, leading to a temperature excursion of the TBM FW and pressurization of the coolant in the TBM FW.
LOHSA	Loss Of Heat Sink Accident (LOHSA) is caused by housing rupture of cooling circuit heat exchanger, leading to a temperature excursion of the TBM FW due to heat sink loss and pressurization of the coolant in the TBM FW
TES pipe rupture in Port Cell	This accident is initiated by purge pipe rupture at upstream position of the TES circulator inside Port Cell. Due to suction pressure, air ingress with moisture discharges to TBM BZ followed by reaction with beryllium and graphite pebbles.

4. Conclusion

The GAMMA-FR code was scheduled for validation during the next three years under UCLA-NFRI collaboration. Through this research, GAMMA-FR will be validated with representative fusion experiments and reference accident cases.

4. Acknowledgement

This work was supported by the R&D Program through the National Fusion Research Institute (NFRI) funded by the Ministry of Science, ICT and Future Planning of the Republic of Korea (NFRI-IN1303).

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