Fusion Engineering and Design 87 (2012) 706–711

Contents lists available at SciVerse ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

R&D activities of the liquid breeder blanket in Korea

Dong Won Lee[a,*], Eo Hwak Lee[a], Suk Kwon Kim[a], Jae Sung Yoon[a], Seungyon Cho[b]

[a] Korea Atomic Energy Research Institute, Daejeon, Republic of Korea
[b] National Fusion Research Institute, Daejeon, Republic of Korea

ARTICLE INFO

Article history:
Available online 26 February 2012

Keywords:
ITER
TBM
Liquid breeder
Breeding blanket

ABSTRACT

A liquid breeder blanket has been developed in parallel with the International Thermonuclear Experimental Reactor (ITER) Test Blanket Module (TBM) program in Korea. The Korea Atomic Energy Research Institute (KAERI) has developed the common fields of a solid TBM such as design tools, structural material, fabrication methods, and He cooling technology to support this concept for the ITER. Also, other fields such as a liquid breeder technology and tritium extraction have been developed from the designed liquid TBM. For design tools, system codes for safety analysis such as Multi-dimensional Analysis of Reactor Safety (MARS) and GAs Multi-component Mixture Analysis (GAMMA) were developed for He coolant and liquid breeder. For the fabrication methods, Ferritic Martensitic Steel (FMS) to FMS and Be to FMS joinings with a Hot Isostatic Pressing (HIP) were developed and verified with a high heat flux test of up to 0.5–1.0 MW/m^2. Moreover, three mockups were successfully fabricated and a 10-channel prototype is being fabricated to make a rectangular channel FW. For the integrity of the joining, two high heat flux test facilities were constructed, and one using an electron beam has been constructed. With the 6 MPa nitrogen loop, a basic heat transfer experiment for code validation was performed. From the verification of the components such as preheater and circulator, a 9 MPa He loop was constructed, and it supplies high temperature (500 °C) and pressure (8 MPa) He to the high heat flux test facility. For an electromagnetic (EM) pump development for circulating the liquid breeder, magneto-hydrodynamic (MHD) experiment, and flow corrosion test, a PbLi breeder loop was constructed. From the performance test, the EM pump and magnet show their capability, and flow and static corrosion tests including oxide coating for corrosion protection were performed. For tritium extraction from the liquid breeder, a gas–liquid contact method was adopted and a tritium extraction chamber was constructed. For measurement of the tritium amount in the liquid breeder, permeation sensors have been developed.

1. Introduction

Korea has proposed and designed two types of Test Blanket Module (TBM): He Cooled Solid Breeder (HCSB) and Helium Cooled Molten Lithium (HCML) TBMs, which are to be tested in the International Thermonuclear Experimental Reactor (ITER). The main purpose for developing a TBM is to develop the design technology for the DEMO and fusion reactor, and it should be proven 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. Several technologies to be installed at the ITER have been developed simultaneously.

According to the domestic plan, a solid-type HCSB TBM was adopted as the leading concept for testing in the ITER, and the other has been developed as a general liquid breeder concept. In order to install and test the TBM, there are several major fields to be developed: design, performance analysis, and development of the design tools, structural material, fabrication methods, cooling technology, blanket tritium technology, and so on. Among them, the Korea Atomic Energy Research Institute (KAERI) has developed the common fields of a solid TBM such as the design tools, structural material, and He cooling technologies for supporting the National Fusion Research Institute (NFRI) to be able to lead the solid TBM concept, and other fields for the liquid breeder blankets such as the liquid metal breeder technology and tritium extraction methods. The domestic R&D arrangements are summarized as shown in Fig. 1.

In the present paper, the R&D for a liquid breeder blanket from KAERI is introduced. This research has been performed based on the designed HCML TBM concept, in which Ferrite Martensitic steel (FMS) is used as the structural material and helium (He) is used as a coolant to cool the first wall (FW) and breeding zone. Liquid lithium (Li) is circulated for tritium breeding [1–4].

* Corresponding author. Tel.: +82 42 868 4659.
E-mail address: dwlee@kaeri.re.kr (D.W. Lee).

0920-3796/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.fusengdes.2012.02.004

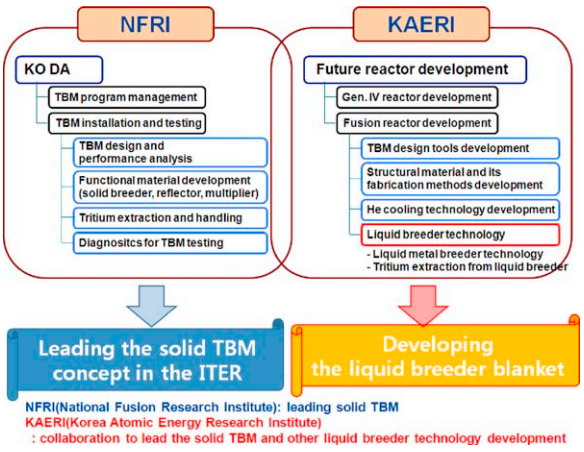

Fig. 1. Breeding blanket development program in Korea.

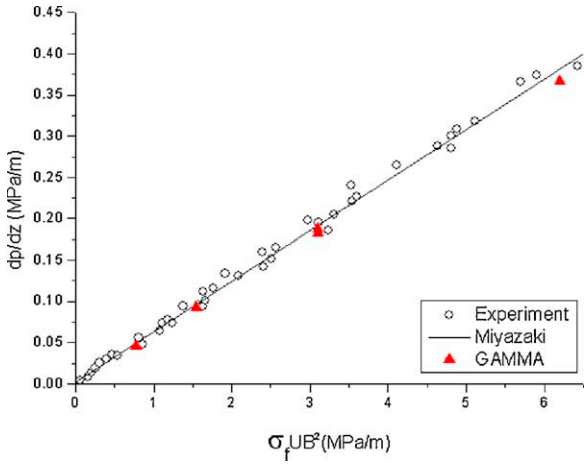

Fig. 3. The developed GAMMA code validation with the previous experimental data.

2. Development of the design scheme and related codes

The overall schematic of the design and system codes is shown in Fig. 2. For the design of the TBM itself, a 3D CAD was used with CATIA V5 and the thermal–hydraulic/mechanical performance was evaluated using ANSYS codes: -CFX [5] and -mechanical classic version. In the neutronic analysis, MCCARD and MCNP were used, and the ATILLA code was prepared for a 3D analysis. For the accident analysis, the decay heat and activation materials were obtained through MCCARD and MCNP codes.

The transient performance after an accident was evaluated using ANSYS, Multi-dimensional Analysis of Reactor Safety for Gas Cooled Reactor (MARS-GCR), and GAs Multi-component Mixture Analysis (GAMMA) codes for the TBM temperature evaluation and coolant behavior. MARS and GAMMA codes were developed in KAERI for a commercial pressurized water reactor and gas cooled reactor. The developed codes were validated with the heat transfer experiments using the constructed high temperature gas loops: one is a 6 MPa nitrogen loop and the other is a 9 MPa He loop. In both loops, a TBM first wall (FW) mockup, which was made from the same material as the designed TBM, FM steel, and high-heat flux (HHF) test facility, in which the heat flux was about 0.5 MW/m^2 were used. Currently, tritium permeation and behavior models have been applied in these codes.

For a performance analysis of the liquid metal breeder in a high magnetic field, a newly developed commercial code, ANSYS-CFX, with electro-magnetic (EM) module, was used and validated with the previous experimental data. For the liquid breeder analysis, MARS-FR (Fusion Reactor) and GAMMA-FR have been developed. The based codes were the above system codes, and the physical properties such as PbLi and Li were encoded. Basic heat transfer and magneto-hydrodynamic (MHD) equations were included. Like ANSYS code validation, the GAMMA code with MHD model was validated with the previous experimental data, as shown in Fig. 3.

Fig. 4. Fabrication technology development: FMS/FMS and Be/FMS joining.

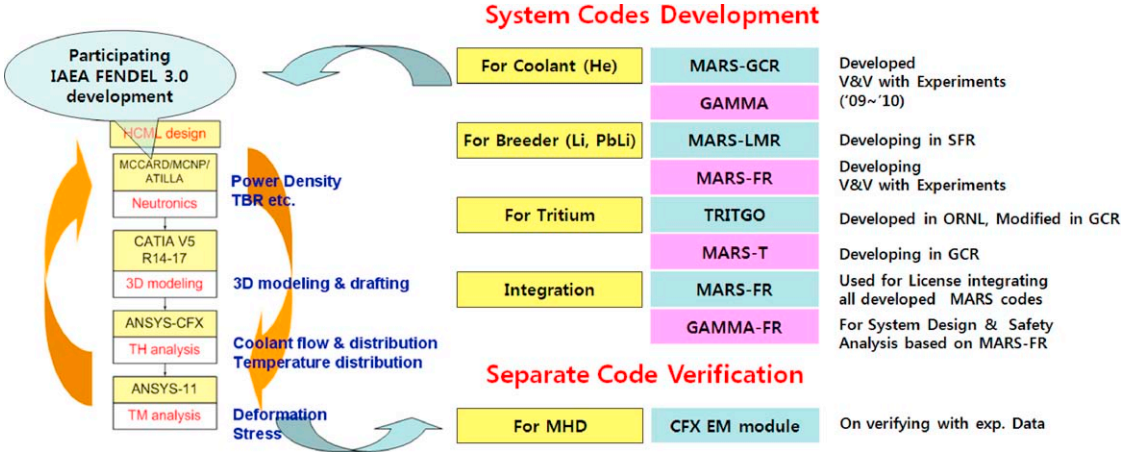

Fig. 2. The overall schematic of the design and system codes for breeding blanket.