Irradiation Test Plan for Alloy 690 Steam Generator Tube Material of the SMART in HANARO

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1. Introduction

Owing to its native characteristics, the application area of the Small and Medium sized Reactors (SMR) can be easily expanded to a non-electricity field such as a sea water desalination and a district heating. SMRs have the beneficial advantages of being safe and economical due to the easy implementation of advanced design concepts and technology. The System-integrated Modular Advanced ReacTor (SMART) is one of the advanced SMRs [1].

In order to fundamentally eliminate the possibility of a large break loss of coolant accidents, to improve the natural circulation capability, and to better accommodate and thus enhance a resistance to a wide range of transients and accidents, major components of the reactor coolant system such as the pressurizer, the reactor coolant pump, and steam generators are located inside the reactor vessel in the SMART system [2], as shown in Figure 1.

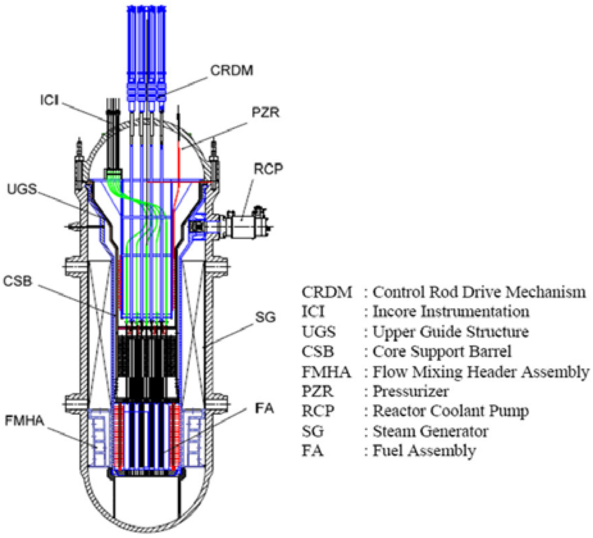

Figure 1. SMART Reactor Assembly

Alloy 690 was selected as the candidate material for the heat exchanger tube of the steam generator of SMART [2]. The SMART R&D is now facing the stage of so-called 'engineering verification and approval of standard design' toward application to DEMO reactors. Therefore, the material performance under the relevant environment is required to be evaluated. One of the important materials performance issues is fracture toughness for which the engineering database is necessary to design a steam generator. However, the neutron irradiation characteristics of the alloy are barely known.

Therefore, an irradiation test plan of the Alloy 690 materials to obtain the neutron irradiation characteristics of the alloy using HANARO irradiation capsules is discussed in this study.

2. Material and Specimens

Because the SMART steam generators are located inside the reactor vessel, the degradation of the fracture toughness of the Alloy 690 heat exchanger tube should be clearly determined for a design lifetime neutron fluence.

Due to the thickness limitation of the ASTM standard for a measure of fracture toughness, Alloy 690 rods having a diameter of about 180mm were used in this work. Because the neutron embrittlement of a material is known to be related to the interaction between neutron and alloying elements, general neutron embrittlement models are mainly explained by chemical composition and neutron fluence. Therefore, rod-type materials can be used for the measurement of neutron characteristics of the SMART steam generator tube [3].

Standard-size tensile and 1/2-T compact tension specimens of different 3 heat Alloy 690 were prepared and tested at room temperature according to the ASTM test standards [4,5].

3. Irradiation Test Plan in HANARO

The fast neutron fluence of the specimens was required to be $1x10^{19}$ n/cm^2, $1x10^{20}$ n/cm^2, and $1x10^{21}$ n/cm^2 (E>1.0 MeV), considering the lifetime neutron fluence of the SMART steam generator. To obtain these neutron fluences, 3 different irradiation capsules [6] will be irradiated in the OR5 and CT test holes of HANARO, as shown in Figures 2 and 3. Irradiation tests will be performed according to the SMART R&D schedule which was decided by the Korean government to be developed by 2011.

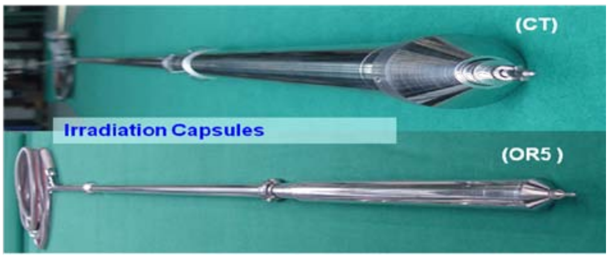

Figure 2. Irradiation capsules of CT and OR5 test holes

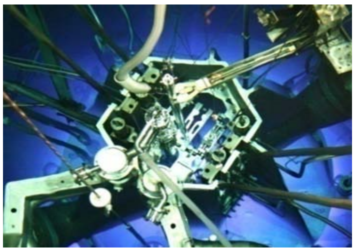

Figure 3. HANARO core region

For an irradiation test in the reactor, the in-reactor safety of a capsule should be examined thoroughly before an irradiation test. Thus, nuclear characteristics and the irradiation temperature of the capsule parts are basically necessary for the safety analysis of the capsule.

Based on a specimen's configuration and the basic design of a capsule, the reactivity effect, neutron flux/fluence, and gamma heating of specimens are calculated by the MCNP code. The irradiation of Alloy 690 will be carried out for the first time in HANARO. Therefore, the irradiation of the Alloy 690 specimens in the capsules has to be examined to attain an admission of the 'Reactor Safety Review Committee of HANARO', based on the capsule design and safety analysis. Considering that Ni has about 2 times higher absorption cross-section of thermal neutron than Fe, the nuclear characteristics of the specimens in HANARO, including neutron reactivity, gamma heating rate, and neutron flux, were preliminary analyzed [7].

The amount of neutron fluence of the specimens was calculated by the MCNP code [8], as shown in Figure 4. Fast neutron fluence of the specimens which were irradiated in the OR5 and CT test holes for 1 cycle (24 days) were obtained in the range of 1.20~3.46×10^{19} and 1.29~2.98×10^{20} (n/cm2) (E>0.1 MeV), respectively.

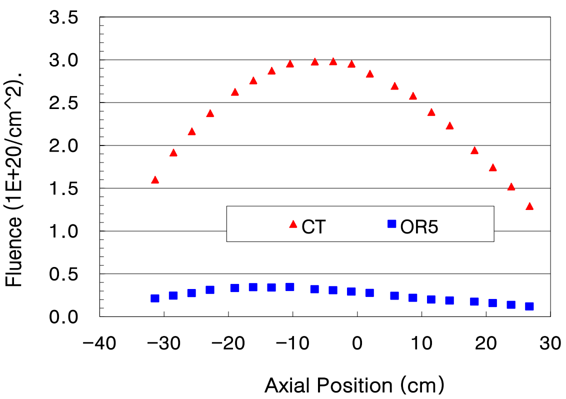

Figure 4. Fast neutron fluence of the specimens (E>1MeV) irradiated in CT and OR5 holes for 24 days

Although the design operating temperature of the heat exchanger tube of the SMART steam generator is 296~323℃ [1], the irradiation temperature of the specimens was decided to be 300℃ in a conservative point of view. Generally, the neutron irradiation degradation effect appears more clearly in a lower temperature.

The irradiation temperature of the specimens was preliminarily analyzed by using the GENGTC and ANSYS codes. The irradiation temperature of the specimens is determined by the gamma heating, the He gas pressure, and widths of gaps between the capsule parts. The structural safety of the capsule parts is also examined by using the ANSYS code. The temperature of the specimens during an irradiation was initially increased by the gamma heating and then roughly adjusted to an optimum condition by a gas control system. It was then finally adjusted to a desired value by micro-electric heaters. During an irradiation test, the temperatures of the specimens were measured and monitored with thermocouples installed in the capsule.

Based on the above nuclear and thermal analysis, the irradiation tests of Alloy 690 can be safely performed in HANARO.

3. Conclusion

To obtain the neutron irradiation characteristics of the heat exchanger tube of the SMART steam generator, an irradiation test plan of the Alloy 690 materials using irradiation capsules was provided in HANARO. The design parameters of the irradiation capsules, including nuclear and thermal properties, were discussed and it was proven to be safe for the irradiation tests of Alloy 690 in the CT and OR5 test holes of HANARO. 3 irradiation capsules are scheduled to be irradiated in HANARO next year.

ACKNOWLEDGEMENTS

This work was supported by the Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).

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