Alternative Irradiation Methods during HANARO Safety Reinforcement Project

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1. Introduction

The High Flux Advanced Neutron Application Reactor (HANARO) has been operating as a platform for basic nuclear research in Korea, and the functions of its systems have been improved continuously since its first criticality in February 1995 [1]. Various neutron irradiation facilities such as rabbit irradiation facilities, loop facilities, and capsule irradiation facilities for irradiation tests of nuclear materials and fuels have been developed at HANARO [2-4].

After the Fukushima nuclear accident in Japan, Special Safety Inspections by the Nuclear Safety and Security Commission (NSSC) on HANARO were conducted. A part of the reactor building did not meet the seismic performance assessment standard of a magnitude 6.5 on the Richter scale (ground acceleration of 0.2 g). HANARO has been temporarily shut down since July, 2014 for a safety reinforcement construction and was completed in April, 2017. Although approval for restarting HANARO was granted in November, 2017 by NSSC, the reactor will go through a series of tests, and it will take a number of days until it is operating stably at full power. The unusually long start-up is to guarantee that every system is working safely.

During the reactor stoppage, a number of user requests for neutron irradiation testing have been accumulated, and a schedule for the material testing after the reoperation of the reactor was determined at HANARO. During that time, a foreign reactor (UCI reactor in USA) has been utilized and several alternative irradiation methods have been introduced to minimize the effect of the HANARO shut down.

In this paper, the status of material irradiation testing requested by users and the irradiation testing schedule determined after reoperation of the reactor, irradiation using a foreign reactor, and alternative irradiation methods are described.

2. Status of HANARO Irradiation Testing

Because the reactor has not been in operation for more than three years, a number of irradiation testing requests from various users have been accumulated. Table I shows a list of material irradiation tests requested from HANARO users up to March of this year. Owing to the limited test holes in the core of HANARO (CT, IR, OR, IP), there are currently two or three users waiting for neutron irradiation testing per test hole. Based on the importance and urgency of the user irradiation testing, an irradiation testing schedule at HANARO was determined, as shown in Fig. 2. Although the IP test holes (having a low neutron flux and temperature limit) are available for irradiation after reactor reoperation, the CT/OR test holes in the reactor core were already scheduled for more than three years after reactor reoperation.

Fig. 1. HANARO after seismic reinforcement

Table I: Neutron irradiation tests requested by users at HANARO (Mar. 2018)

Materials	Irradiation Temp.(℃)	Rx. Cycle (dpa)	User
Fusion ARAA	300~350	>8 (>3)	KAERI
ARAA Welds	320	8~15 (3-5)	KAERI
AR Cladding	300	4~6	KAERI
PWR Cladding	350~400	2~4	University
VHTR Core	300~1000	8~24 (3~10)	KAERI
Long Life SPND	300	8~24	KHNP
U-Mo Fuel		8	KAERI
SiC Epoxy	~200	8	KAERI
Fission Mo		1	KAERI
Th-based Fuel		8~24	KAERI
SiC Composite	900~1600	8	KAERI
SFR ODS steel	300～500	>8 (>3 dpa)	KAERI
Low Alloy RPV	300	2	KAERI
Fuel Cladding	RT	33 (13 dpa)	KAERI
U-Mo Fuel		>16	KAERI-ANL
VHTR Fuel	800~1300	~40 (15 dpa)	KAERI-JAEA
Fuel Assembly	300	8	KNF, KAERI

(3D Printing)			
Power Rx. P-C	300	~25	KAERI
Research Rx. (Be coating)	RT	4, 8	KAERI
Mortar, ENFMS, Advanced Mat.s	RT	<1	Univ., KAERI, Industries

ARAA: Advanced Reduced Activation Alloy, AR: Accident-Resistant, SPND: Self-Powered Neutron Detector, ODS: Oxide Dispersion Strengthened, dpa: displacement per atom

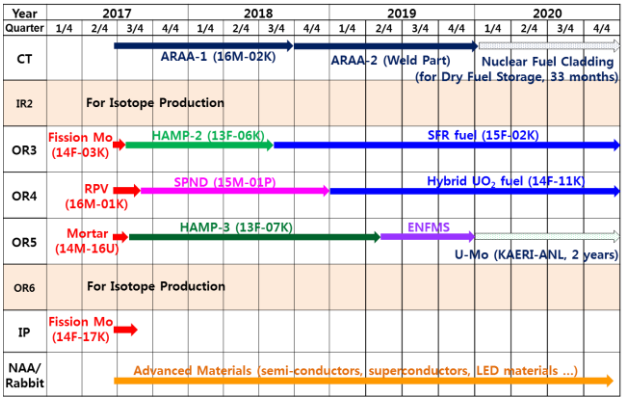

Fig. 2. Irradiation testing schedule after reoperation of HANARO

According to the irradiation testing schedule, several irradiation capsules were already designed, fabricated (as shown in Fig. 3), and safety-analyzed. They will be installed and irradiated at each dedicated test hole after the reoperation of HANARO.

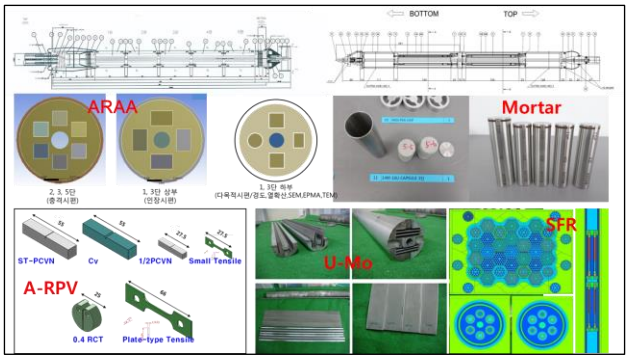

Fig. 3. Various irradiation capsules and specimens that will be irradiated at HANARO

3. Alternative Irradiation Testing

During the HANARO shut down, irradiation testing using foreign research reactors was attempted. The Long Life SPND testing and ENFMS (Ex-core Neutron Flux Monitoring System) testing, which require a relatively low fluence level, were conducted at the UCI (Univ. of California, Irvine) research reactor in the USA, as shown in Fig. 4 [5, 6].

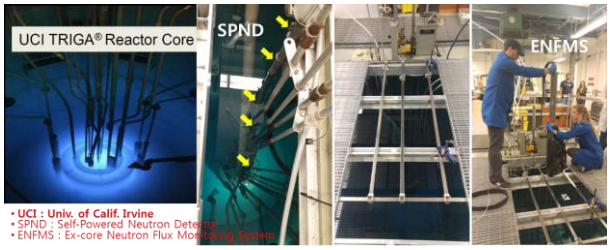

Fig. 4. Irradiation testing at the UCI research reactor (USA)

In addition, several alternative irradiation testing methods, such as electron beam irradiation, neutron and gamma ray irradiation using radioisotopes, and neutron irradiation using a cyclotron, were conducted. Figure 5 shows the alternative irradiation testing facilities used during HANARO shut down. Am-241 and Cf-252 radioisotopes were used as the irradiation source for irradiation testing. They provided fast neutron flux levels of 6.9×10^4 and 2.0×10^5 n/cm^2.s, respectively. The cyclotron provided a neutron flux level of ~1.0×10^8 n/cm^2.s. Those alternative methods can be utilized effectively considering the fast neutron flux level of HANARO of 1.45×10^9 ~ 1.5×10^{14} n/cm^2.s.

Fig. 5. Alternative irradiation testing facilities used during HANARO shut down

Nuclear instruments such as diamond detectors, and advanced materials such as superconductors (YBCO and MgB_2) and semiconductors (Oxide and Si), were irradiated with these alternative methods during HANARO shut down. Figure 6 shows the variation of reaction output of a Gd-doped diamond neutron detector under various irradiation conditions using a cyclotron at KAERI.

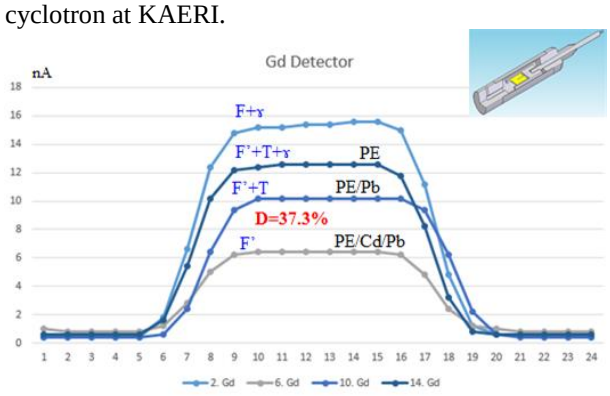

Fig. 6. The reaction output of Gd-doped diamond neutron detector under various irradiation conditions

(F, γ, T mean fast neutron, gamma, thermal neutron irradiation and PE, Pb, Cd mean HDPE, Pb, and Cd screens were used)

To scope out the increasing user necessity for neutron irradiation testing at HANARO, two possibilities have been considered at HANARO as a long-term schedule. The first is the removal of the FTL system, which is currently not working. A related working schedule is being planned to remove the FTL system. Therefore, the IR1 test hole of the reactor might be available for material irradiation testing. Another possibility is the construction of the Ki-Jang Research Reactor (KJTR). After the start-up of the new reactor, HANARO will specialize more on the irradiation research of nuclear materials. However, the construction schedule of KJRR, which was planned to start up in 2019, seems to be delayed.

4. Summary

HANARO has been temporarily shut down for a safety reinforcement, which was completed by April 2017. The reactor will go through a series of tests, and it will take a number of days until it is operating stably at full power. During the reactor stop, a number of user requests for neutron irradiation testing have been accumulated at HANARO. During this period, a foreign reactor was utilized and several alternative irradiation methods such as electron beam irradiation, neutron and gamma ray irradiation using radioisotopes, and neutron irradiation using a cyclotron were conducted to minimize the effect of the HANARO shut down. To scope out the increasing user necessity for neutron irradiation testing at HANARO, several possible methods have been considered at HANARO as a long-term schedule.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2013M2A8A1035822)

REFERENCES

[1] K.N. Choo, M.S. Cho, B.G. Kim, Y.H. Kang, and Y.K. Kim, “Material Irradiation at HANARO, Korea,” Research Reactor Application for Materials under High Neutron Fluence, IAEA-TECDOC-1659, 2011, IAEA.
[2] K.N. Choo, M.S. Cho, S.W. Yang, and S.J. Park, “Contribution of HANARO Irradiation Technologies to National Nuclear R&D”, *Nuclear Engineering and Technology*, **46**, 4, 501 (2014).
[3] M.S. Cho, et al., “Material Irradiation by Capsules at HANARO,” *Nucl. Technol.*, **193**, 330 (2016).
[4] K.N. Choo, B.G. Kim, M.S. Cho, Y.K. Kim, and J.J. Ha, “Development of a Low-Temperature Irradiation Capsule for Research Reactor Materials at HANARO,” *Nucl. Technol.*, **195**, 213 (2016).
[5] S.W. Yang et al., In-pile test of self-powered neutron detector (SPND) at HANARO, KAERI/CR-608/2015.
[6] S.W. Yang et al., Integration test for ex-core neutron flux monitoring system of pressurized water reactor using research reactor, KAERI/CR-632/2016.