Preliminary Evaluation on the Possibility of Neutron Irradiation Testing Requested by Foreign Users at HANARO

Kee-Nam Choo [a*], Sung-Woo Yang [a], Man-Soon Cho [a], Seng-Jae Park [a], Yoon-Taek Shin [a]
[a] *Korea Atomic Energy Research Institute 111 Daedeok-daero, 989beon-gil, Yuseong-gu, Daejeon 34057, Korea*
[*] *Corresponding author: knchoo@kaeri.re.kr*

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. 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. Irradiation facilities have been actively utilized for the irradiation tests requested by numerous users to support the national research and development programs on nuclear reactors and nuclear fuel cycle technology in Korea [1,2].

However, the large majority of foreign Material Testing Reactors (MTRs) will be more than 50 years old this decade, leading to the increasing probability of some shutdowns for various reasons (life-limiting factors, heavy maintenance constraints, possible new regulatory requirements, experimental facility obsolescence…). Shutdown of old material testing reactors including the OSIRIS (France, 2015), JMTR (Japan, 2016), NRU (Canada, 2018) and HWBR (Norway, 2018) have already been announced. Therefore, foreign request on the HANARO utilization for material irradiation testing is increasing these days owing to the shutdown of old material testing reactors.

In this paper, the irradiation request from foreign users is summarized and a possibility of irradiation testing at HANARO is preliminary evaluated.

2. Irradiation Testing at HANARO

Among the irradiation facilities, the rabbit is very useful for numerous irradiation tests of small specimens at a low temperature (below 200 ℃) and neutron flux conditions. The capsule is the most useful device for coping with the various test requirements at HANARO. Therefore, it has played an important role in the integrity evaluation of reactor core materials and the development of new materials through precise irradiation tests of specimens. As the irradiation technology at HANARO was basically developed for irradiation testing under a commercial reactor operation environment, there are limitations on the irradiation condition. Table 1 summarizes the current status of irradiation technology at HANARO compared with the advanced foreign technology.

Table I: Status of irradiation technology of HANARO

Irradiation	KAERI	Worldwide	Under Development
Temp. (℃)	30～700	30～1000	30～1000
Cycle (days) Fluence (n/cm^2 (dpa))	8 (～200) $1.9x10^{21}$ (3.0)	No limit	15 (～375) $4.0x10^{21}$ (5.0)

3. Requests from Foreign Users and Preliminary Evaluation of Testing Possibility

There is an increasing necessity and more sophisticated requirements of users from foreign countries for neutron irradiation testing at HANARO due to the recent decision to shut down of foreign research reactors. Figure 1 shows the foreign users requesting irradiation testing cooperation at HANARO these days.

Fig. 1. HANARO foreign users requesting irradiation testing

Table II shows the requested neutron irradiation testing by foreign users these days. Most of them are related to a development and qualification of materials and fuels to support future reactors design. Although most foreign users require long cycle reactor operation and high dpa irradiation, HANARO irradiation capsule had been limited to an irradiation of 1.5 dpa due to vibration-induced fatigue cracking in a very high speed of coolant flow in the reactor [3]. Recently, the development process of long-term irradiation testing technology has been performed in three steps (3, 5, 10 dpa) at HANARO. A new capsule was developed for 3 dpa irradiation testing, and was successfully applied for irradiation testing of research reactor materials for up to eight reactor operation cycles (equivalent to 3 dpa) at HANARO [4]. The irradiation capsule technology for 5 and 10 dpa irradiation testing are under development at HANARO.

Table II: Neutron irradiation tests requested by users at HANARO (Feb. 2017)

Materials	Irradiation Temp.(℃)	Rx. Cycle (dpa)	User
ARAA and Welds	300~350	8~15 (3~5)	KAERI-ITER(EU)
VHTR Fuel & Material	300~1300	8~24 (3~12)	KAERI-JAEA(Japan)
CANDU Fuel/Material	~300	4~8	COG(Canada)
U-Mo Fuel	<100	>16 (5)	KAERI-ANL(USA)
Li Oxide, Be alloy	300~1000	<8 (3)	QST(Japan)
Pu/U Fuel in LiF/ThF/NaF	600~800	<8 (3)	SEABORG/ThorCon (Denmark/USA)
ATF UN	-	-	RITS (Sweden)
U_3Si_2 Plate Fuel	<100	<8 (3)	KAERI-ANSTO(Australia)

ARAA: Advanced Reduced-Activation Alloy, VHTR: Very-High-Temperature Reactor System, ATF: Accident Tolerant Fuels

The ARAA has been developed since 2011, as a structural material of fusion reactor [5]. A reduced activation ferritic-martensitic (RAFM) steel is being developed in many countries as a structural material for international thermonuclear experimental reactor (ITER). As the requested irradiation condition is within the HANARO capability of Table I, an irradiation capsule of the 16M-02K was already designed and is under irradiation testing at HANARO up to eight reactor operation cycles equivalent to 3 dpa. High dpa (up to 5 dpa) irradiation technology has been developed and will be applied at HANARO.

The irradiation test of the VHTR fuel was requested as a joint project between the KAERI (VHTR project) and the Japan Atomic Energy Agency (JAEA). It requires an irradiation testing of the TRISO (tristructural isotropic)-coated particle fuel element and graphite at up to 1,300℃ for 24 cycles. As the HANARO have an irradiation experience of TRISO fuel element and graphite (12F-01K capsule [6]) at up to 1,083℃ [7], the higher temperature of the specimen seems to be attainable within the HANARO capability. However, the longer irradiation testing of 24 cycles should be fully safety- approved prior to irradiation testing at HANARO. Especially, the burnup and composition of fuel materials such as TRISO and U-Mo fuel are changed as the reactor operation cycle passes during the long-term testing. Therefore, the effect on the core e.g. power distribution should be considered in the safety-approval step prior to irradiation.

In addition, the irradiation schedule must be properly adjusted between users. The irradiation test holes in the reactor were already scheduled for more than 3 years because the reactor has not been in operation for a long time these days due to several issues.

The irradiation test of CANDU nuclear fuels and core materials was requested by the COG (CANDU Owner Group). Because the CANDU reactor system is very similar to the PWR reactor system, there is no serious technical limits on the irradiation testing of the materials at HANARO.

As U-Mo has been frequently irradiated at HANARO for new research reactor programs, the RERTR program, and fission Mo project, there is no limit for the testing. 13F-06K and 13F-07K capsules were designed for an evaluation of the nuclear performance of an U-Mo fuel for a new research reactor. The 13F-06K capsule was designed for half-size U-Mo plate fuels and the 13F-07K was designed for full-sized U-Mo plate fuels to qualify the nuclear performance of the new fuel designed for the Gijang research reactor. 14F-03K and 14F-17K capsules were designed for the development of a fission Mo production technology in the Gijang research reactor. The 14F-03K capsule was designed for an evaluation of the reactor performance of a fission Mo target (U-Al_x plate) and the 14F-17K capsule was designed for a verification of the Mo-99 extraction process from an irradiated DU fission Mo target.

The irradiation test of Li Oxide and Be alloy was requested by the QST (National Institutes for Quantum and Radiological Science and Technology, Japan). The materials have been studied as candidate materials of blanket systems of fusion reactor. Although HANARO has an irradiation experience of Be at low temperature (below 100℃) [8], several technical issues including the required higher irradiation temperature and tritium (T) monitoring and treatment systems should be fully discussed before irradiation testing at HANARO.

There is several required irradiation testings related to the MSR (Molten Salt Reactor) by the SEABORG Technologies and the ThorCon. They are starting research companies of the MSR located in Denmark and the USA. Although HANARO has a little irradiation experience of sodium (Na) [9] and lead-bismuth eutectic alloy (LBE) [10], the feasibility of the irradiation testing in corrosive high-temperature salts should be fully checked for an irradiation testing. The irradiation testing in high-temperature salts environment seems to require lots of preliminary safety analysis and approval from the reactor safety committee of HANARO.

The use of Uranium nitride (UN) in fast reactors has been studied in Sweden and the Royal Institute of Technology in Stockholm (RITS) is developing accident tolerant fuels for water cooled reactors, in particular uranium nitride [11]. An irradiation campaign scheduled for the Halden reactor on Norway, which unfortunately has been closed, was discussed to host an irradiation of uranium nitride fuel in HANARO. Soluble properties of the UN in water should be checked for an irradiation at HANARO.

An irradiation testing of U_3Si_2 uranium silicide fuel of the OPAL reactor of ANSTO was discussed at HANARO. As HANARO has lots of experience of similar U_3Si uranium silicide fuel, the irradiation testing of the U_3Si_2 fuel can be performed at HANARO. However, there is a limitation of specimen size within the size of the test hole of the reactor.

4. Summary

There is an increasing necessity and more sophisticated requirements of users from foreign countries for neutron irradiation testing at HANARO due to recent decision to shut down of foreign research reactors. Based on the user requirements of the foreign users, a possibility of irradiation testing at HANARO is preliminary evaluated. Development of improved irradiation technology including higher neutron fluence and irradiation temperature will extend the present HANARO capability. In addition, several technical issues, such as 1) irradiation schedule adjustment between users, 2) tritium (T) monitoring and treatment systems, 3) corrosive environment of high-temperature salts, 4) soluble properties of the UN in water, should be strictly discussed before an irradiation testing at HANARO.

ACKNOWLEDGEMENTS

This work was supported by the Korea government (MSIT)

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] K.N. Choo, et. al., “Development of a low-temperature irradiation capsule for research reactor materials at HANARO,” *Nuclear Technology*, **195**, 213 (2016).

[4] K.N. Choo, et. al., “Design Optimization of HANARO Irradiation Capsule for Long-Term Irradiation Testing,” *Science and Technology of Nuclear Installations*, **2016**, Article ID 3908610 (2016).

[5] Y. B. Chun, S. H. Kang, D. W. Lee, S. Cho, Y. H. Jeong, A. Żywczak and C. K. Rhee, Development of Zr-containing advanced reduced-activation alloy (ARAA) as structural material for fusion reactor, Fusion Engineering and Design, Vol.109-111, Part.1, p. 629-633, 2016.

[6] B. G. Kim, et al., Design and Manufacturing Report on Irradiation Testing Device(12F-01K) of Coated Particle Fuel, KAERI Technical Report, KAERI/TR-4874/2013.

[7] B. G. Kim, S. Yeo, K.-C. Jeong, Y.-K. Kim, Y. W. Lee, and M. S. Cho, PIE Results of Irradiated TRISO-Coated Particle Fuel at HANARO, Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 27-28, 2016.

[8] B. G. Kim, et al., [6] B. G. Kim, et al., The Irradiation Test Report for Research Reactor Materials at HANARO, KAERI Technical Report, KAERI/TR-5494/2014.

[9] B. G. Kim, et al., B. G. Kim, et al., PIE(Non-destructive test) Report of Irradiated Metallic Fuel for SFR, KAERI technical report, KAERI/TP-4714/2012.

[10] Y. H. Kang, et al., Design improvements and thermal analysis of an irradiation capsule using an LBE, KAERI technical report, KAERI/TP-4147/2010.

[11] Kyle D. Johnson, et al., Spark plasma sintering and porosity studies of uranium nitride, *JNM*, **473,** 13 (2016).