In-reactor Testing using Capsules at HANARO: Current Status and Future Plan

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1. Introduction

HANARO has contributed to national nuclear research and development program by in-reactor testing[1]. In the 2000s, we concentrated the development and testing of materials for commercial power reactor. Since 2010, various licensing and technical issues associated newly developing nuclear system have been resolved. A representative example is the in-reactor testing of SMART steam generator tube material that is installed inside the reactor vessel under neutron irradiation environment. We verified its neutron-resistant performance using HANARO irradiation facility. Recently, we have conducted the tests for fuel[2], core materials[3] and Fission Moly targets[4,5] of research reactor. Therefore, the in-reactor testing technology is an important field for the national nuclear research and development.

In this paper, the current status, future plan and research and development in progress of in-reactor testing are shown. Although it has been difficult to conduct a number of tests for 5 years due to seismic reinforcement of reactor building and unexpected shutdown, it is possible to actively use the in-reactor testing according to the international environment and the increase of testing demands. In addition, it is expected that the small nuclear system will be actively developed according to the domestic and global research trends. Therefore, the stable support is necessary for the in-reactor testing at HANARO.

2. Irradiation testing in progress

Fig. 1 shows the current status and future plans of the in-reactor testing using capsules at HANARO. In recent 5 years, HANARO was operated only 2 cycles. We conducted the two tests for Fission Moly target at that time. Except for these tests, long-term duration is necessary for most of tests. We will continue these tests if HANARO is operated again.

2.1 ARAA

ARAA (Advanced Reduced Activation Alloy) is being developed as a material for fusion reactor by Korea Atomic Energy Research Institute. Its testing at HANARO was planned since 2014, but it is still in progress due to the long-term suspension of HANARO operation. A total of 166 test specimens for the observation of its neutron-resistant performance were installed in an instrumented capsule, 16M-02K. The important test requirements are the specimen temperature during the test of 300 ~ 340℃ and the neutron fluence of at most 3 dpa. Fig. 2 shows the result of measuring the temperatures with thermocouples mounted around representative specimens. We could observe that most of them meet the target temperatures. Until now, the maximum fluence of 0.776 dpa was irradiated during 40.414 EFPD. It is estimated that testing duration more than 120 EFPD is required to satisfy the neutron fluence requirement. As the result of this test, the maximum neutron fluence rate is about 52 EFPD/dpa. Therefore, if HANARO's stable operation is guaranteed, we can achieve relatively high neutron fluence test.

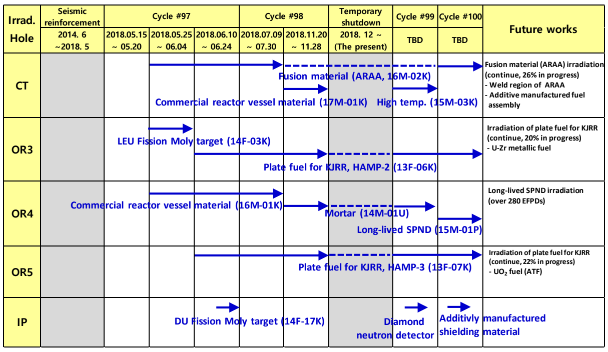

Fig. 1. Current status and future plan of in-reactor testing at HANARO irradiation holes

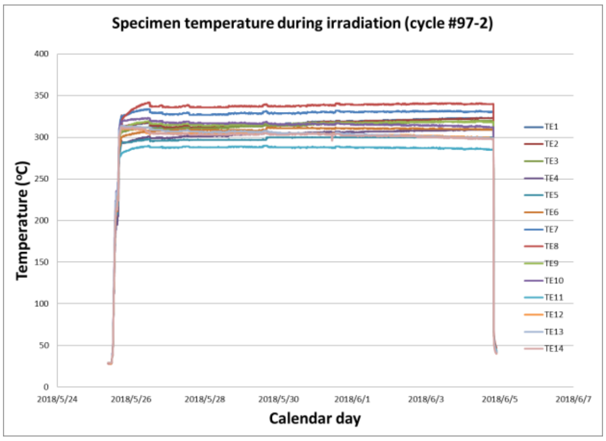

Fig. 2. Measured temperatures during the ARAA testing

2.2 Plate fuels for KJRR

High uranium density U-Mo fuel to be applied to KJRR is being developed for the first application in the world. In order to evaluate the in-core performance of

U-Mo fuel, the test (HAMP-1) of mini plate fuels were conducted in 2014[2], and the in-pile test of lead test assembly was successfully completed at Advanced Test Reactor of Idaho Nation Laboratory in U.S. Two additional tests (HAMP-2, 3) are being conducted in HANARO. The target requirements are an average U-235 depletion of 70% for HAMP-2 and a local maximum U-235 depletion of 93% for HAMP-3. The progresses are 20% for HAMP-2 and 22% for HAMP-3 up to now. In particular, the post irradiation examination result of HAMP-3 will be significantly used for licensing of KJRR operation.

2.3 High temperature (~1,000 ℃) testing

Until now, the in-reactor testing has been mainly performed at the specimen temperature of around 300℃, which is the operating condition of commercial reactor. However, the specimen temperature must be raised to 1,000℃ for the tests in an extreme environment or VHTR-related material. In order to increase the specimen temperature, a capsule for high temperature testing was designed and manufactured. The test will be conducted at the next operation cycle. If this test is successfully performed, the temperature range up to 1,000℃ of the specimen can be reached during the test, so it will be possible to accept high temperature test demands.

2.4 Mortar

Since a reactor vessel for commercial nuclear power plant is supported by concrete structure, it is necessary to check how leaking neutrons affect the performance of concrete. The in-reactor testing for mortar, a core material of concrete, was planned to observe the performance after the neutron irradiation. The test will be conducted for one cycle at OR4 irradiation hole. This is the first test for concrete structural material in Korea. It can contribute to safety evaluation of concrete support structure and development of new materials.

2.5 Long-lived SPND

Korea Hydro & Nuclear Power Co., Ltd. is developing a long-lived SPND that has several advantages such as reduced waste disposal and budget because it has a longer life span than currently used SPND. Its target life span is more than 10 years. Therefore, the SPND test was planned to measure the signal characteristics by emitter depletion. Since the thermal neutron flux of HANARO is about three times higher than that of commercial nuclear power plant, the test at HANARO is suitable to observe depletion characteristics of SPND. An instrumented capsule was designed and manufactured for the test of SPND. The test will be conducted during more than 280 EFPD.

2.6 Etc.

As shown in Fig. 1, conducting a new test at the most of the irradiation holes is difficult because long-term tests were scheduled. The tests using IP irradiation holes, which are alternative irradiation holes, are being promoted. Since the IP holes are located in the reflector tank outside the core, the fast neutron flux is low and the thermal neutron flux is relatively high. However, unlike the irradiation holes located in the core, the coolant is not forcibly circulated, so some tests are limited. When HANARO is operated, the tests for diamond neutron detector, which is a measuring instrument for length and pressure change, and shielding materials manufactured by additive process.

3. Candidate testing materials

When the current tests are completed, a follow-up tests will be conducted. In the CT hole, the tests for ARAA welded part and fuel assembly part manufactured by additive process are scheduled after the ARAA test. The test capsules for U-Zr metallic fuel and ATF will be inserted OR3 and OR5 holes after HAMP-2, 3 tests, respectively. Therefore, the in-reactor testing demands has already been filled over the next three years. Table 1 shows the inquiries for in-reactor testing at HANARO during HANARO's shutdown duration. Recently, the inquiries from foreign users are increased because the decommissioning of major material testing reactors in the world was determined. It is expected that the tests at HANARO can be actively conducted if the HANARO can be stably operated.

Table 1. Requested test specimens and requestors

Test specimen	Requestor
ATF fuel cladding	KAERI
Fuel cladding (Commercial reactor)	DGU, HYU
Fission Moly target (mini)	KAERI
U_3Si_2 plate fuel	KAERI
VHTR core material	KAERI
SFR structural material (ODS)	KAERI
Epoxy, SiC	KAERI
Th-based fuel	KAERI
SiC composite	KAERI
Ex-core Neutron Flux Monitoring System	USERS
Fuel cladding (Commercial reactor)	KAERI
Fuel and control rod	KAERI
Fusion material	KIMS
Research reactor core material (Be coating)	KAERI
VHTR fuel	KAERI-JAEA (Japan)
Fuel and material for MSR	Seaborg (Denmark)
Fusion material (Li ceramic, Be)	QST (Japan)
MSR material	Thorcon (U.S.)
Fuel and material for CANDU	COG (Canada)
Uranium Nitride	KTH (Sweden)
Lightbridge fuel	Lightbridge (U.S.)

4. R&D of irradiation technology

The development of in-reactor testing technology has been focused on advancement of existing technologies such as achieving higher specimen temperatures and developing more accurate evaluation techniques. However, since future tests are expected to require more extreme environments and dynamic tests, we are developing the in-reactor testing technology that can satisfy them. Due to the suspension of HANARO's operation, most of out-of-pile performance tests are currently being conducted, but if HANARO is operated, the in-core test may be performed.

4.1 Long-term irradiation

Until now, the most long-term test performed in HANARO was a test for research reactor core materials (Graphite, Beryllium and Zircaloy-4). It was conducted in the CT hole for 202.5 EFPD. However, it is predicted that neutron fluence more than 10 dpa will be required to conduct the tests for core materials of fusion reactor, commercial reactor, research reactor and Gen-IV reactors. Therefore, long-term testing should be necessary to reach higher neutron fluence. In order to verify the integrity of the capsule, the out-of-pile hydraulic test is currently conducting under conservative condition (flow rate of 110% than normal condition)[6]. It aims to maintain the integrity without damage for more than 30 months. If this long-term test technology is guaranteed, it is expected that HANARO can conduct the high neutron fluence tests more than 10 dpa.

4.2 RAMP for nuclear fuel testing

Most of fuel tests at HANARO were conducted under static environment. The test fuel rods were installed in a capsule, so the fission rate of fuel was dependently determined by the position of the fuel and HANARO's operation strategy. We are developing a technology that can control the fission rate by allowing the axial position of test fuel to be changed during the test[7]. This technique can be used to observe the behavior of fuel under abnormal condition. In addition, since a load-following operational capability of nuclear power plant will be required in the future, the study of fuel performance under changing environment of fission power will be necessary. The testing device was manufactured and the out-of-pile test will be conducted after hydraulic test of long-term irradiation.

4.3 Instrumentation

The measuring instrument is an important device because it acts like the human nervous system and accurately communicates the current situation to the observer. In particular, it is important to ensure safety because the in-reactor testing is conducted in the core. In addition, an appropriate instrument must be installed and monitored to improve the quality of the test. Recently, neutron detectors using CVD diamonds[8] and gamma bias detector are being developed. The developed technology can be also applied for dosimetry.

4.4 Boosting

Since the neutron flux of HANARO is almost unchanged due to its inherent characteristics, when a high neutron fluence is required, the test duration is dependently increased. For example, when a test of 10 dpa or more is required, the expected test duration is several years. In order to reduce the test duration, the boosting concept that booster fuels are located around the test specimen was proposed. If we use HANARO fuel rods as the booster fuel, it is evaluated that the neutron fluence rate increases over 30%[9]. Therefore, applying boosting technology can shorten the test duration of 3~4 years to 2~3 years for 10 dpa test, which is useful in solving the test demands.

5. Conclusions

We examined the current status and future plan of in-reactor testing at HANARO in this paper. Since the most of tests need long-term test duration, it is necessary to secure the additional irradiation hole if possible. In addition, it is important to use IP holes as an alternative method. We are developing in-reactor testing technology that enables dynamic testing and accurately performs higher neutron fluence in a short time. In order to ensure activities related to the in-reactor testing, stable operation of HANARO should be guaranteed in the future.

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