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# Low-Temperature and Long-Term Irradiation Testing of HANARO Instrumented Capsule

Kee Nam Choo[a]*, Man Soon Cho[a], Cheol Yong Lee[a], Sung Woo Yang[a], Yoon-Taek Shin[a], Seng-Jae Park[a], Young Hwan Kang[a] and Sang Jun Park[a]

[a]*Korea Atomic Energy Research Institute 150 Deokjin-dong, Yuseong-gu, Daejeon 305-353, Korea,*
[*]*Corresponding author: knchoo@kaeri.re.kr*

## 1. Introduction

HANARO instrumented irradiation capsules have been actively used for the irradiation of nuclear fuels and materials [1]. Capsule technology was basically developed for irradiation testing under a commercial reactor operation environment. Most irradiation testing using capsules has been performed at specimen temperatures of 250-500℃ within 4 reactor operation cycles (about 100 days) at HANARO.

Recently, as a part of the research reactor development's project, irradiation testing of materials used as reflector materials in a research reactor such as graphite, beryllium, and zircaloy-4 was required up to 8 reactor operation cycles at low temperature (<100℃) of specimens. Therefore, a new capsule was designed and prepared for irradiating the reflector materials of research reactors [2]. The safety of the new capsule should be fully checked before irradiation testing. Out-pile performance and endurance testing before HANARO irradiation testing was performed on an accelerate condition of a reactor. In addition, several parts of the capsule system including a junction box and guide tube were revised to improve the safety of long-term irradiation testing.

Based on the out-pile test results, two irradiation capsules were designed and successfully irradiated up to 8 reactor operation cycles at low temperature (<100℃) at HANARO. In this paper, the low-temperature and long-term irradiation capsule technology developed for the irradiation testing of research reactor materials at HANARO are described.

## 2. Verification of New Irradiation Capsule

As the specimens of the reactor materials was required to be irradiated at low temperature of less than 100℃, a new irradiation capsule was designed to be directly cooled by a reactor coolant of 30℃. The capsule was first designed at HANARO to have the coolant flow through the capsule to cool down the irradiation temperature of the specimens, as shown in Fig. 1 [2]. The capsule has the same outward shape of a typical capsule used for a closed He gas atmosphere. The specimens with different shapes are basically canned by a tube of 1 mm in thickness made of stainless steel. The surfaces of the canning tubes and the external tube come into contact with cooling water during the irradiation tests. Based on a preliminary geometrical shape of specimens with different shapes, as shown in Fig 1, neutron fluxes and heat generation rates of the capsule parts at 30MW thermal power of HANARO were evaluated using the MCNP5 code. The temperature of the specimens was evaluated using the ANSYS code, and the specimen size and allocation in the capsule were controlled to have a low temperature of less than 100℃ regardless of the shape of the specimen and the location in the axial direction of the reactor core.

The safety of a new designed capsule should be fully checked before irradiation testing in the reactor. Based on the basic design of the capsule, an out-pile test capsule was designed and fabricated. To evaluate the soundness of the new capsule design, the capsule was out-pile tested in the single channel out-pile test loop. The capsule was evaluated to satisfy several reactor requirements concerning the coolant flow and vibration properties. The vibration characteristics of the capsule were measured by a laser vibrometer (Polytec Model VD-09).

Owing to the internal flow of the coolant, the bottom part of the capsule was suspected to be susceptible to a vibration-induced fatigue failure. To strengthen the soundness of the bottom parts, the material of the rod tip was changed from stainless 304 to stainless 316L, and the welding method was also changed from TIG welding to an EB welding method. An out-pile endurance test was performed on a 110% accelerated condition of a reactor coolant flow amount in the single channel out-pile test loop.

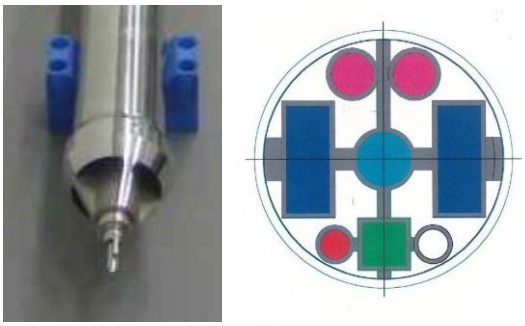

Fig. 1. Low-temperature irradiation capsule and design concept.

## 3. Capsule System for Long-Term Irradiation

For long-term irradiation testing at HANARO, the soundness of the capsule system was estimated. After every irradiation cycle, the capsule and capsule system have to be re-assembled for a reactor fuel maintenance work. The junction box was revised such that capsule

instruments including heaters and thermocouples can be safely connected and separated to/from the capsule controlling system before/after irradiation testing by changing the dimension and adopting quick clamps, as shown in Fig. 2. A guide tube was also replaced from a venerable PVC spring hose system to a stainless steel braid/bellows system for long-term irradiation.

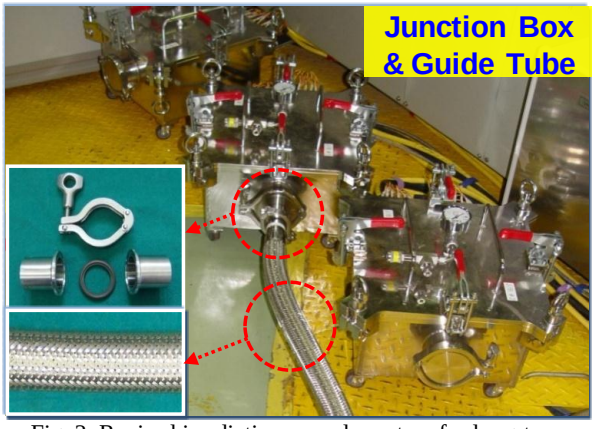


Fig. 2. Revised irradiation capsule system for long-term irradiation testing at HANARO.

## 4. Irradiation Testing at HANARO

Based on the out-pile test results, two irradiation capsules of 11M-20K and 11M-21K were designed and fabricated [2] for an evaluation of the neutron irradiation properties of core materials (Graphite, Be, Zircaloy-4) of a research reactor for the National Project of 'Research Reactor Development'. Irradiation testing of the capsules was undertaken under the condition of examination from the 'Reactor Safety Review Committee of HANARO'.


Fig. 3. Low-temperature and long-term irradiation capsules of research reactor materials.

The safety of the irradiation of the capsules was evaluated based on the accelerated out-pile endurance test results [3] and the irradiation of the capsules was allowed from the 'Reactor Safety Review Committee of HANARO'. The capsules (11M-20K and 11M-21K) were loaded and irradiated in the CT and IR2 test holes of HANARO, respectively. Figure 4 shows a variation of the temperatures of the specimens of the 11M-20K capsule irradiated in the CT Hole of HANARO. The 11M-20K capsule was successfully irradiated for 4 cycles and transferred to a hot cell of IMEF. The rod tip of the capsule was sectioned into two parts, and the internal area was examined with an optical microscope and SEM to see an occurrence of fatigue cracks. Cracks or defects were not found in the rod tip of the irradiated capsule. The 11M-21K capsule was irradiated for 4 cycles in the IR2 test hole and then transferred to the CT test hole and irradiated up to 8 cycles as required by the user.

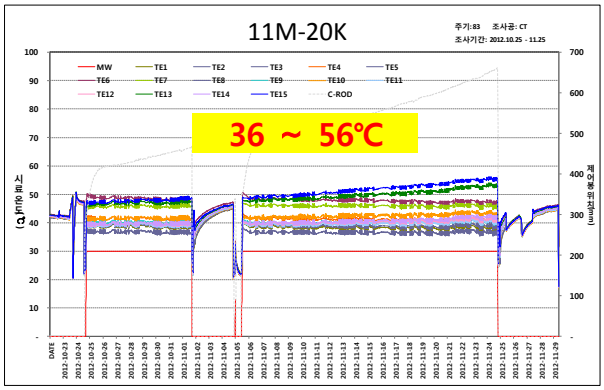


Fig. 4. Variation of the temperature of the 11M-20K capsule irradiated in the CT hole of HANARO (Cycle No. 83).

## 5. Conclusion

A new capsule and capsule system for long-term irradiation at low temperature was designed, fabricated, and irradiated for an evaluation of the neutron irradiation properties of the core materials (Graphite, Be, Zircaloy-4) of a research reactor for the National Project of 'Research Reactor Development'. Two capsules were first designed and fabricated to irradiate materials at low temperature (36-56℃) for a long cycle of 8 irradiation cycles at HANARO. The safety of the new irradiation capsule and capsule system was thoroughly evaluated through the out-pile and in-pile testing. The new capsule was successfully irradiated for up to 8 cycles at HANARO.

## ACKNOWLEDGEMENTS

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