# FLUENCE MONITOR (F/M) CONTAINER LOADED IN A CAPSULE FOR IRRADIATING MATERIALS BELOW 100℃ AT HANARO

BONG GOO KIM, SUNG JAE PARK, SEONG WOO YANG, and TAE KYU KIM
*Korea Atomic Energy Research Institute*
*Deadeok-daero 989-111, Yuseong-gu, Daejeon, 305-353 - Republic of Korea*

ABSTRACT

Irradiation testing is being carried out to evaluate the irradiation performance of various kinds of materials including nuclear fuels using capsules at HANARO. Most of the irradiation testing of nuclear materials has been performed under helium gas and at temperatures between 300-500℃. Recently, the irradiation testing of materials, such as graphite, beryllium, and zircaloy-4, using the reflector materials in a research reactor, was required at low temperature (< 100℃). A new type of capsule was designed and prepared for irradiating reflector materials of research reactors. In addition, a new fluence monitor (F/M) container, into which fluence wires can be easily assembled under a helium atmosphere was designed and prepared. These containers will be easily dismantled from the capsule, and fluence wires will be easily separated from the containers in a hot cell after irradiation testing. These containers, 20 sets, will be installed in a capsule, and the containers will be loaded with the specimens in the capsule. The capsule will be irradiated at one of the test holes from September 2012 at HANARO. In this paper, the detailed design of the F/M container, results of the out-of-pile test of the container, and our future plans are described.

## 1. Introduction

The High flux Advanced Neutron Application ReactOr (HANARO) is a multi-purpose research reactor of an open-tank-in-pool type with 30MW of thermal power. Its general design features are given in Table 1 [1]. Detailed information is available in the International Atomic Energy Agency (IAEA) Research Reactor Data Base (RRDB) or at the HANARO home page (http://hanaro.kaeri.re.kr).

The reactor is now being successfully utilized in such areas as neutron beam research, fuel and materials irradiation tests, radioisotopes production, neutron activation analysis, and neutron transmutation doping, etc. The arrangement of the vertical holes and the beam ports are shown in Fig. 1 [1]. Three flux traps in the core (CT; Central Flux Trap, IR1 and IR2; Irradiation Hole in the Inner Core), providing a high fast neutron flux, can be used for material and fuel irradiation tests. They are also suitable for the production of high specific activity radioisotopes (RI). Four vertical holes (OR) in the outer core region, abundant in epithermal neutrons, are used for the fuel or material irradiation tests and radioisotope production. Several isotope production (IP) holes of the 25 vertical holes which have high quality neutrons are also used to irradiate materials and nuclear fuels in the heavy water reflector region. Thermal and fast neutron fluxes of these test holes are listed in Table 2 [1]. At present, capsules have been developed and are being utilized for the irradiation tests of materials and nuclear fuels at HANARO [2–4].

## 2. Irradiation device for material irradiation testing at HANARO

There are three kinds of capsules used for material and nuclear fuel irradiation testing: a non-instrumented capsule, an instrumented capsule, and an advanced capsule to perform creep testing or fatigue testing, etc. At present, capsules have been developed and are being utilized for the irradiation tests of materials and nuclear fuels at HANARO, and have been developed to study the creep or fatigue behavior of materials.

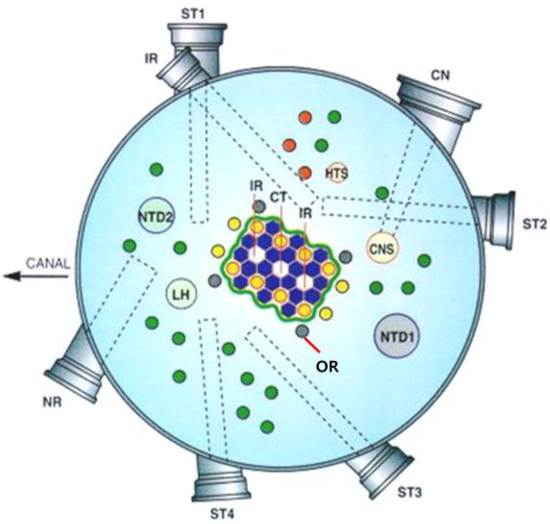
Table 1. General Design Features of HANARO

| | |
|---|---|
| Reactor Type | Open-Tank-In-Pool |
| Thermal Power | 30 MW |
| Thermal Neutron Flux (peak) | $5.4\times10^{14}$ n/cm$^2$-s (E<0.625 eV) |
| Fast Neutron Flux (peak) | $2.1\times10^{14}$ n/cm$^2$-s (E>1.0 MeV) |
| Fuel Element | 19.75% enrichment, $U_3Si$-Al Matrix, Al Clad |
| Coolant | $H_2O$ |
| Moderator | $H_2O/D_2O$ |
| Reflector | $D_2O$ |
| Core Cooling | Upward Forced Convection Flow |
| Absorber Material | Hafnium |

Table 2. Neutron Flux of Vertical Holes

| Location | Hole | | Inside Dia. (cm) | Neutron flux(n/cm$^2$•sec) | | Remarks |
|---|---|---|---|---|---|---|
| | Name | No. | | Fast (>0.82MeV) | Thermal (<0.625eV) | |
| Core | CT<br>IR<br>OR | 1<br>2<br>4 | 7.44<br>7.44<br>6.00 | $2.10\times10^{14}$<br>$1.95\times10^{14}$<br>$2.23\times10^{13}$ | $4.39\times10^{14}$<br>$3.93\times10^{14}$<br>$3.36\times10^{14}$ | Fuel/Mat. Irradiation and RI Production |
| Reflector | LH*<br>HTS*<br>IP | 1<br>1<br>17 | 15.0<br>10.0<br>6.0 | $6.62\times10^{11}$<br>$9.44\times10^{10}$<br>$1.45\times10^{9}$ ~$2.10\times10^{12}$ | $9.77\times10^{13}$<br>$4.79\times10^{13}$<br>$2.40\times10^{13}$ ~$1.95\times10^{14}$ | Fuel/Mat. Irradiation and RI Production |

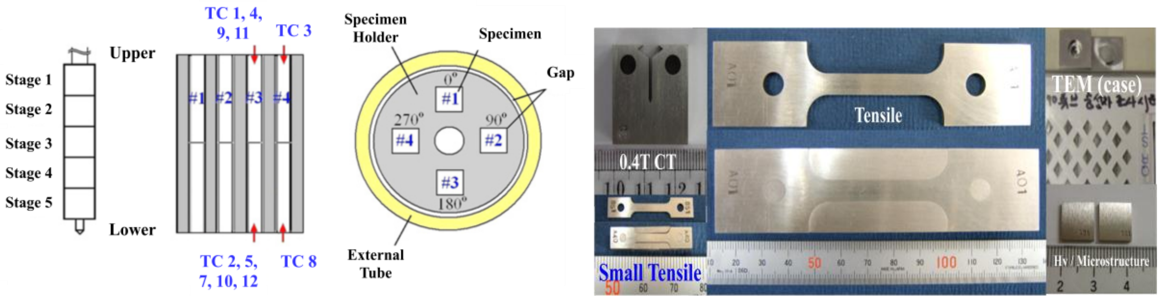
* LH; Large Hole in the Reflector, HTS; Hydraulic Transfer System




(LH; Large Hole, CNS; Cold Neutron Housing Hole, NTD; Neutron Transmutation Doping Hole)
Fig. 1. Core Arrangement of HANARO

The irradiation test has been conducted to evaluate the irradiation performance of many materials by a material capsule at HANARO. Since the fluence of a fast neutron above 1 MeV is important for the irradiation test of the material, it must be measured and evaluated exactly in the irradiation hole. Fig. 2 shows a geometrical shape of the instrumented capsules for the material irradiation tests, which consists of the bottom guide structure, the main body, the protection tube, and the guide tube etc. The rod tip of the bottom guide structure is assembled with a receptacle in the reactor core, and the protection and guide tubes play the role of a guide for various lines such as the thermocouples, micro-heaters, and helium supply tubes up to the control unit system on the outside of the reactor. The main body is a major part of the capsule in which specimens, measuring devices, and various components are installed, and it includes an external tube of a cylindrical shell with a 60 mm external diameter, 2.0 mm thickness, and 870 mm length. The five holders in the main body are arranged in the axial direction, and the insulators, made of alumina between the holders, are placed to prevent the heat from transferring between the stages and to control the temperature of each stage independently. Table 3 shows an example of the geometrical data of a cross section including the specimens. The specimen's dimensions for the rectangular shape are 10×10×114 mm, and the centers of the specimen holes are located at an equal distance, 15 mm from the center of the holder. The specimen holder is a cylinder with four rectangular specimen holes, one circular center hole 12 mm in diameter, with a length of 114 mm. Fig. 3 shows a typical schematic view of the holder and its section including the thermocouple positions, and several typical specimens for the irradiation testing. A total of 12 thermocouples are used (three for Stages 1 and 3, and two for Stages 2, 4 and 5), and they are installed on the top and bottom edges of the specimen inserted in hole #3 and/or #4.

Fig. 2. Instrumented capsule for the material irradiation testing.



(a) (b)

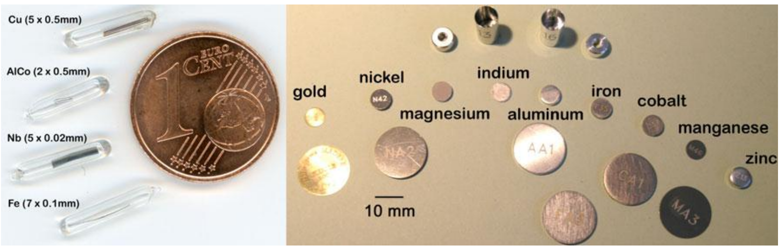
Fig. 3. (a) Typical schematic view of the specimen arrangement and thermocouple positions, and (b) Typical specimens for the irradiation testing.

Table 3.Geometrical data for the cross section of the capsule

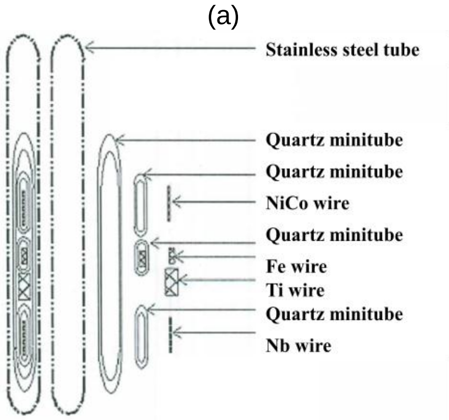
| Descriptions | Dimensions (mm) |
|---|---|
| Outer diameter of the external tube | 60 |
| Inner diameter of the external tube | 56 |
| Center hole diameter of the holder | 12 |
| Specimen size (width × height× length) | 10×10×114 |
| Distance between the center hole and the specimen hole | 15 |

## 3. Fluence Monitors

The accumulated neutron flux profile and/or fluence in irradiation devices can be evaluated from flux wires or foils placed near specimens in experimental devices. Elements placed in a neutron flux may activate and emit delayed gamma rays. When the material is removed from the reactor, its gamma emissions can be measured on a germanium detector, and the neutron flux profile within an experiment or fluence can be calculated using data from the germanium detector. Fluence monitors are usually made of alloys of materials such as Ag, Fe, Nb, Ni, Cu, or Co (see Fig. 4) [5, 6]. Flux wires are typically encased in a capsule made of vanadium [7] or quartz. To separate the fast versus thermal neutron flux, covers fabricated from materials with high thermal absorption cross sections such as cadmium or boron can be placed around these foils or wires. Typical precision estimates for these fluence monitors are estimated to range from 3% to 10%. Dimension limitations of container and temperature limitations depend on the available space in irradiation devices and the element selected respectively, and the materials in which the wires or foils are encased.



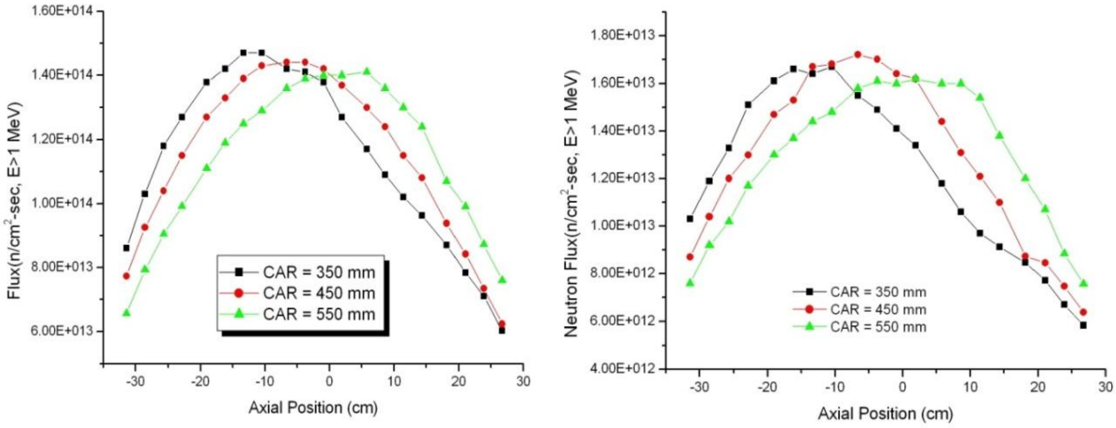

(a)




(b)

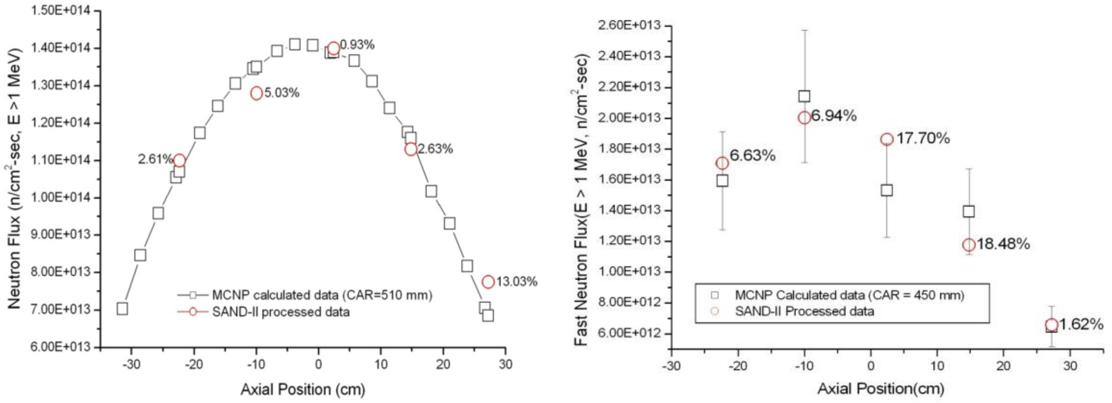
Fig. 4. (a) Fluence monitors usually manufactured and operated by CEA[5], and (b) An example of fluence monitor sets (ACORD type 1) by NRG[6].

As shown in Fig. 5, the neutron flux and spectrum was calculated for each irradiation hole using an MCNP code before the irradiation test at HANARO. After the irradiation test, the activity of the fluence monitor was measured by an HPGe detector and the reaction rate was calculated. Therefore, a fast neutron flux was measured and evaluated by a capsule irradiated in an OR irradiation hole and a capsule irradiated in a CT irradiation hole. For one of the OR irradiation holes, the radial difference of the fast neutron flux was observed from a calculated data due to the OR irradiation hole being located outside the core. Furthermore, a control absorber rod was withdrawn from the core as the increase of the irradiation time at the same irradiation cycle, so the distribution of neutron flux was changed from the beginning to the end of the cycle. These effects were considered to evaluate the fast neutron flux. Neutron spectrums of the CT and OR irradiation hole were adjusted by the measured data. The fluxes of a fast neutron above 1 MeV were compared with calculated and measured value. The evaluated axial fast neutron flux is shown in Fig. 6. As shown in this figure, most of the results showed good agreement although the maximum difference in the OR test hole was shown at 18.48%. It depends on irradiation position in the core of HANARO. Fig. 7 shows a typical flux wires (monitors) and fluence monitor (F/M) container (pure aluminum) used for irradiation tests of materials at HANARO. Five sets of F/M containers are positioned one per stage in the capsule. Iron, nickel, and titanium wires as the fluence monitor were used for the detection of fast neutron flux, as shown in this figure.




(a) (b)

Fig. 5. Calculated axial fast neutron flux by MCNP5; (a) CT test hole and (b) OR test hole.




(a) (b)

Fig. 6. Evaluated axial fast neutron flux; (a) CT test hole and (b) OR test hole.

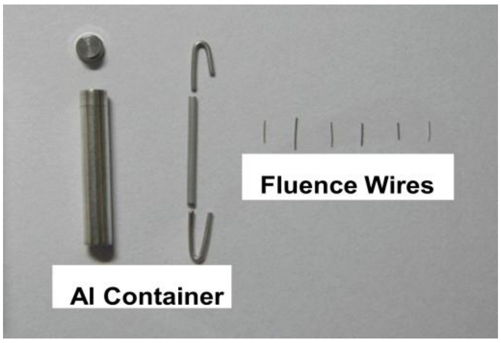



Fig. 7. Flux wires (monitors) and F/M container used for irradiation tests at HANARO

## 4. New Type of Fluence Monitor Container

A new type of fluence monitor (F/M) container (see Fig. 8) was designed and prepared for irradiating nuclear materials and reflector materials of research reactors. It has some difference as compared with that in Fig. 7. Each container will contain wires encapsulated in Al 6061 tube. The encapsulation will be about 18 mm long with an outer diameter of 6 mm, and will be engraved with a unique identification number. Wires will also be placed within holes drilled of each pure aluminum sample holder or within tube, which will be directly exposed to the coolant. So, the out-of-pile experiment under the similar condition of

HANARO was undertaken to confirm doing not let in water into an F/M container, which was exposed to coolant for about 22 days. As shown in Fig 9 using cobalt chloride paper, the F/M container was watertight after finishing this testing. In addition, a new type of F/M container, into which fluence wires such as Fe, Ni, Ti, and Nb can be easily assembled under a helium atmosphere using a special tool, as shown in Fig. 10. These containers will be easily dismantled from the capsule, and fluence wires will be easily separated from the containers using a special tool (see Fig. 11) in a hot cell after irradiation testing. These containers, 10 sets, as shown in Fig. 12, were installed in a capsule, and the containers will be loaded with the specimens in the capsule. These capsules will be irradiated at one of the test holes from September 2012 at HANARO.

Fig. 8. New type of F/M container.

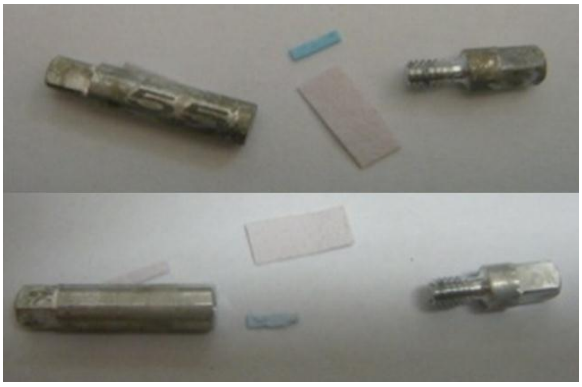


Fig. 9. F/M containers confirmed waterproof

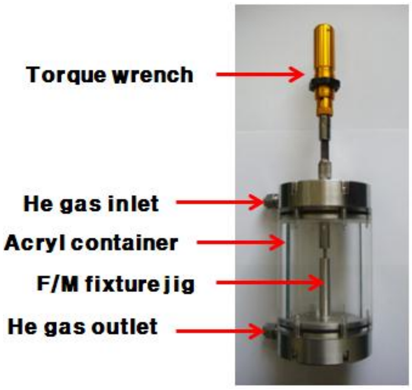


Fig. 10. Tool to assemble a new F/M.

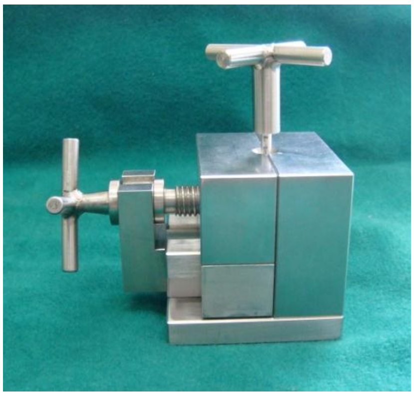


Fig. 11. Tool to dismantle a new F/M in hot cell.

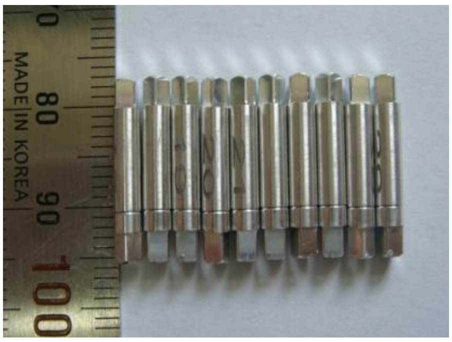


Fig. 12. New type of F/M containers with flux wires.

Also, the new type of F/M contained fluence wires will be also used in capsules to irradiate nuclear materials under helium gas and at temperatures between 300-500℃. As shown in

Fig. 13, a new type of F/Ms will be axially and radially located at each stage in the capsule. After irradiation testing of the capsule, the radial and axial fluence distribution will be estimated in the near future.

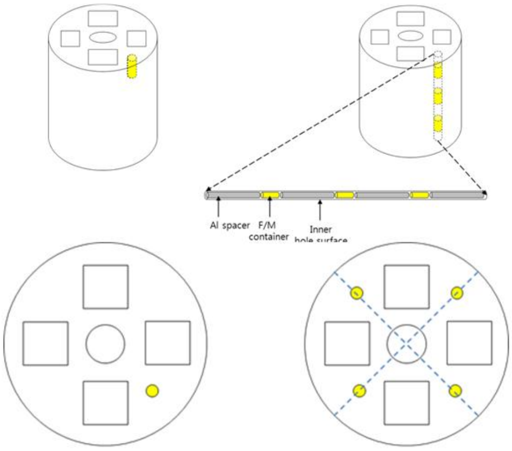



Fig. 13. Schematic diagram to locate new type of F/Ms in the capsule.

## 5. Summary

A new type of capsule was designed and prepared for irradiating reflector materials of research reactors at low temperature (< 100℃). In addition, a new fluence monitor (F/M) container, into which fluence wires can be easily assembled under a helium atmosphere was also designed and prepared. These containers will be easily dismantled from the capsule, and fluence wires will be easily separated from the containers in a hot cell after irradiation testing. These containers, 10 sets, will be installed in a capsule, and two capsules will be irradiated at one of the test holes from September 2012 at HANARO, and will be also used in capsules to irradiate nuclear materials under helium gas and at temperatures between 300-500℃. After finishing the irradiation testing of the capsules, radial and/or axial fluence distribution of test holes in HANARO will be estimated in the near future.

## Acknowledgement

This work was supported by the Korea Atomic Energy Research Institute (KAERI) for the award of a grant funded by the Ministry of Education, Science and Technology (MEST) of the Republic of Korea.

## References

[1] Bong Goo KIM, Jae Min Sohn and Kee-Nam CHOO, “Development Status of Irradiation Devices and Instrumentation for Material and Nuclear Fuel Irradiation Tests in HANARO,” Nuclear Engineering and Technology, Vol.42, No.2, APRIL 2010.

[2] J.M. Sohn, J.M. Oh, S.J. Park, Y.T. Shin, B.G. Kim, H.R. Kim, Y.J. Kim, in: Proceedings of 2005 JAEA-KAERI Joint Seminar on Advanced Irradiation and PIE Technologies, Oarai, 2005, p. 194.

[3] K.N. Choo, Y.H. Kang, T. Hoshiya, M. Niimi, T. Saito, J. Korean Nucl. Soc. 29 (1997) 148.

[4] K.N. Choo, Y.H. Kang, M.H. Choi, M.S. Cho, J.M. Sohn, Y.T. Shin, S.J. Park, B.G. Kim, in: International Symposium on Research Reactor and Neutron Science, Daejeon, 2005, p. 233.

[5] Bong Goo Kim, Joy L. Rempe, Jean-François Villard and Steinar Solstad, Review of Instrumentation for Irradiation Testing of Nuclear Fuels and Materials, Nucl. Tech., Vol. 176 , No. 2, Nov. 2011

[6] ftp://ftp.nrg.eu/pub/www/nrg/2004composite/NRG_Laan.pdf (current as of August 7, 2012), Jaap G. van der Laan, materials Irradiation testing.

[7] S. Blaine Grover, The Next Generation Nuclear Plant/Advanced Gas Reactor Fuel Irradiation Experiments in the Advanced Test Reactor, Proceedings of Global 2009, Paris, France, September 6-11, 2009, Paper 9319.