# Application of Multi-Hole Structures to the HANARO Irradiation Capsule

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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 [2,3]. Among the irradiation facilities, the capsule is the most useful device for coping with the various test requirements at HANARO. Irradiation capsules have been developed and 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 [1-3]. As a capsule design, 1-hole (centered) or 4-hole specimen allocation has been generally applied as standard structures of the irradiation capsule at HANARO.

Recently, HANARO was temporarily shut down for a long time for a safety reinforcement construction and due to several technical problems of the reactor. During the reactor stop, a number of user requests for neutron irradiation testing have accumulated at HANARO. Based on the accumulated user requests and an economic point of view of an expensive cost of the irradiation testing, a need for a multi-hole design of the capsule has been increased. 5 or 6-hole structured designs had been partially tried already in several capsules at HANARO. At present, a 6-hole structured capsule of the 16M-02K was designed and is under irradiation testing for an evaluation of the neutron irradiation properties of the Advanced Reduced Activation Alloy (ARRA) of a Fusion reactor.

In this paper, the progress and status of a development of a multi-hole irradiation capsule are described.

## 2. Design History of a Specimen Allocation in an Irradiation Capsule

A typical HANARO irradiation material capsule consists of three main parts: a protection tube (5 m), a guide tube (9.5 m), and the capsule's main body including specimens, as shown in Figure 1. The irradiation specimens are generally located in the center of the standard irradiation capsule. However, multi-hole designs of the specimens, as shown in Figure 2, have been frequently adopted in several capsules to increase an economic efficiency of the volume or to improve the uniformity of specimen temperature at HANARO. Although a lot of 4-hole structured capsules have been successfully irradiated at HANARO [4,5], 5-hole and 6-hole structured capsules were scarcely tested, as shown in Table 1. Therefore, the safety of those multi-hole capsules was not fully proved.

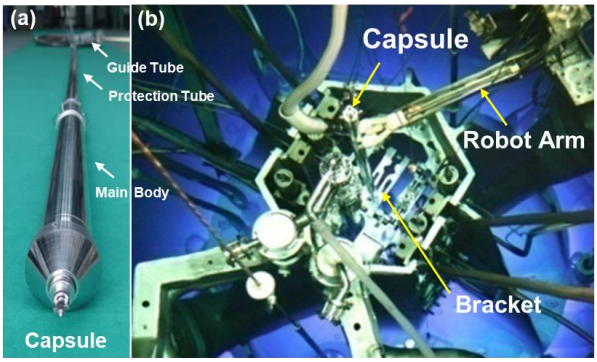


Fig. 1. HANARO irradiation capsule systems: (a) A standard irradiation capsule and (b) an irradiation capsule system installed in the reactor core.

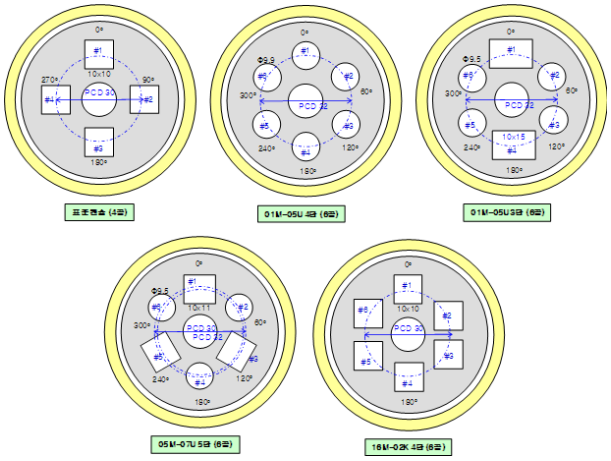

Fig. 2. Cross sections of the irradiation capsules having different specimen-hole designs irradiated in HANARO.

Table I: Neutron irradiation capsules having multi-hole structures irradiated at HANARO

| Capsule | Irradiation Condition | Specimen Design | Temp. Trend |
|---|---|---|---|
| 01M-05U | 24MW CT | Zr, Ti alloy 6 hole | 280~350℃ |
| 05M-07U | 30MW CT | Zr, Ti alloy 6 hole | 292~344 |
| 16M-02K | 30MW CT | ARAA (Fe) 6 hole | 300~329℃ |
| 04M-22K 05M-06K | Out-pile test | STS (Fe) 5 hole | - |

ARAA: Advanced Reduced Activation Alloy

## 3. Temperature Analysis of the 16M-02K Capsule having a 6-Hole Design

A new capsule (16M-02K) having a 6-hole specimen allocation was designed, fabricated, and irradiated for an evaluation of the neutron irradiation properties of the Advanced Reduced Activation Alloy (ARRA) of a Fusion reactor. The irradiation temperature of the specimens was preliminary analyzed by using the GENGTC and compared to the results by the ANSYS codes [6], as shown in Table 2.

Table 2: Temperatures of the 16M-02K capsule at 30 MW power

| Stage | TC | GENGTC | | ANSYS | | Measured* | |
|---|---|---|---|---|---|---|---|
| | | He 1atm | 0.4K He | He 1atm | 0.4K He | He 1atm | He 40torr |
| 1 | TC1 | 201 | 281 | 198 | <370 | 222 | 338 |
| | TC2 | 201 | 281 | 198 | <370 | 214 | 332 |
| | TC3 | 230 | 312 | 204 | <370 | 220 | 324 |
| | TC4 | 230 | 312 | 204 | <370 | 215 | 310 |
| 2 | TC5 | 226 | 296 | 206 | <441 | 218 | 312 |
| | TC6 | 243 | 305 | 220 | <441 | 224 | 313 |
| 3 | TC7 | 245 | 303 | 282 | 369 | 230 | 334 |
| | TC8 | 245 | 303 | 282 | 369 | 232 | 337 |
| | TC9 | 265 | 329 | 274 | 369 | 231 | 311 |
| | TC11 | 265 | 329 | 274 | 369 | 225 | 288 |
| 4 | TC10 | 251 | 311 | 235 | <369 | 242 | 315 |
| | TC13 | 241 | 303 | 217 | <370 | 239 | 299 |
| 5 | TC12 | 233 | 300 | 211 | <370 | 227 | 302 |
| | TC14 | 206 | 282 | 187 | <370 | 221 | 300 |
| * Heater power 0, control rod at 468mm | | | | | | | |

The temperature of the ARAA specimens was stably controlled in the range of 295-337℃ during a reactor operation cycle(100th cycle) at HANARO. Considering the stable behavior of the specimen temperatures and design experience of the capsule, the 6-hole design could be safely applicable for an irradiation testing of the most Fe and Zr-based nuclear materials at HANARO.

## 4. Summary

The progress and status of a development of a multi-hole irradiation capsule at HANARO to increase an economic efficiency of the volume or to improve the uniformity of specimen temperature were summarized. The 6-hole structured capsule of the 16M-02K was designed, fabricated, and successfully irradiated for an evaluation of the neutron irradiation properties of the Advanced Reduced Activation Alloy (ARRA) of a Fusion reactor. Considering the stable behavior of the specimen temperatures and design experience of the capsule, the 6-hole design could be safely applicable for an irradiation testing of the most Fe and Zr-based nuclear materials at HANARO.

## 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., “Development of a low-temperature irradiation capsule for research reactor materials at HANARO”, *Nucl. Technol.*, **193**, 330 (2016).
[4] K.N. Choo, et al., “Design, fabrication and irradiation test report on HANARO instrumented capsule (04M-17U) for the researches of universities in 2004”, KAERI Technical Report, KAERI/TR-3178/2006, 2005.
[5] K.N. Choo, et al., “Design, fabrication and test report on HANARO instrumented capsule (08M-09K) for irradiation test of high temperature materials for Gen IV program”, KAERI Technical Report, KAERI/TR-3782/2009, 2009.
[6] S.R. Kim, “Thermal design for an irradiation testing of the ARAA alloys”, HANARO internal report, HAN-IC-CR-14-11, 2014. 8. 4.