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In-Reactor Testing of Target for Fission ^{99}Mo Production at HANARO Irradiation Facility

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) is developing the target for ^{99}Mo production from the fission of ^{235}U manufactured by atomization technology [1,2]. It will be applied in KiJang Research Reactor (KJRR), so the performance during the irradiation and separation process of fission ^{99}Mo shall be verified for its purpose. Since HANARO is a unique research reactor in Korea that has a post irradiation examination (PIE) facility, it is good for the verification test for the target. Therefore, the tests of target at HANARO have been planned, which is expected to contribute to the production of licensing database and export.

This paper presents the in-reactor testing of target for the performance verification. The tests are classified into two, the verification of in-core performance of target during the irradiation and the process for fission ^{99}Mo separation. The target material and irradiation hole in HANARO were selected and the devices for the irradiation were designed and fabricated considering the purpose of tests. Since the target contains fissile material, the performance and safety during the test were analyzed. The decay heat for the target after the irradiation was also calculated for the transportation from the HANARO to PIE facility.

2. In-Reactor Testing Design at HANARO

Fig. 1 schematically shows the flow chart of application from the fabrication to disposal of target for KJRR application. The meat of target is U-Al/Al and its U loading density is 2.6 g/cc. It contains a relatively small amount of uranium than candidate fuel material of KJRR that the meat is U-Mo/Al-Si and its U loading density is 8 g/cc. However, the thickness of target meat is thicker. In KJRR, eight targets are composed of an assembly that is irradiated in the core during a week. The expected burnup is U-235 depletion ratio of 5%. After the irradiation, the assembly is transferred to hotcell for the separation of ^{99}Mo. Therefore, the performance of target and fission ^{99}Mo separation must be verified through in-reactor testing at HANARO before the application in KJRR.

2.1 In-core performance test of target

Since the irradiation test for the target that will be applied in KJRR is not conducted until now, we have planned the test at HANARO irradiation facility. The target contains low enriched uranium (LEU), so the irradiation should be selected where forced convection is applied to cool the target. In 2014, the in-core test was conducted for the candidate fuel of KJRR at HANARO OR3 irradiation hole [3]. Since both irradiated materials are similar, OR3 irradiation hole was selected for the in-core performance test of target. In the case of the test for candidate fuel of KJRR, the reduced fuels were irradiated due to the limitation of accommodation size. The actual size of target is acceptable in OR3 irradiation hole. However, since the target size is relatively larger than the reduced fuel, the design of irradiation device was slightly different as shown in fig. 2. The irradiation device can accommodate six targets in upper and lower housing blocks.

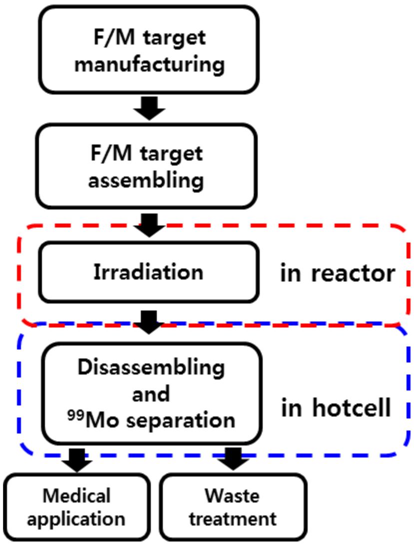


Fig. 1. The schematic flow chart of target application in KJRR

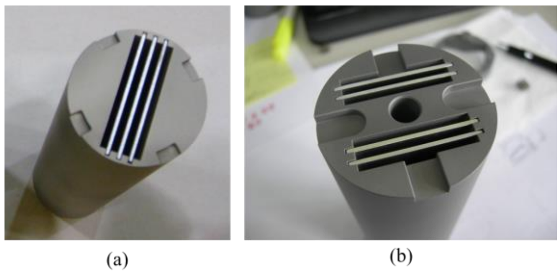


Fig. 2. The housing block of irradiation device for (a) target and (b) reduced fuel

2.2 ^{99}Mo separation process

The test for fission ^{99}Mo separation in hotcell of PIE facility was planned by the application of in-reactor testing for the target. However, the application of LEU target for ^{99}Mo separation has some problems such as the handling of irradiated target, management and disposal of waste and the control of the amount of fission ^{99}Mo. Therefore, the target manufactured by depleted uranium (DU) and the separation of fission ^{99}Mo of 1 Ci was proposed in this test. The application DU target has an advantage that the irradiation hole where natural convection is applied can be used. Fig. 3 shows an assembly for the irradiation of DU target in IP5 irradiation hole. The coolant channel is maximized considering the natural convection. The device was designed to be easily handled in the reactor pool and PIE facility. Two DU targets can be irradiated at the same time.

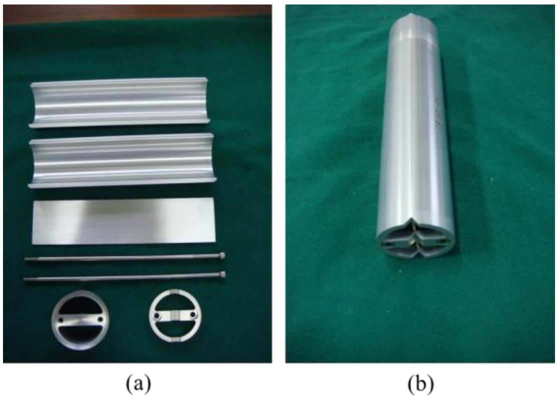


Fig. 3. The irradiation device for DU target in IP5 : (a) Disassembled parts and (b) assembled device

3. Performance and Safety analysis

3.1 LEU target irradiation in OR3

The LEU target was expected to be irradiated at HANARO OR3 irradiation hole under conservative condition than KJRR irradiation. As a result of the comparison of neutronic analysis, the average power of target is about 73 W/cm^2 in KJRR [4], while it is about 137 W/cm^2 in HANARO. The discharge burnup of target is about 5% U-235 depletion by a week irradiation in KJRR, while it is about 10% U-235 depletion by 10 days irradiation in HANARO. Therefore, if the performance was verified under severe environment HANARO, the LEU target will be normally applied in KJRR.

Although the irradiation environment in HANARO is more severe than KJRR, the LEU target will be able to maintain its integrity. The reduced fuel for KJRR was irradiated under the average fuel power of about 200 W/cm^2 during 111.4 effective full power days (EFPD) in 2014 [3]. The amount of loaded uranium in LEU target is sufficiently smaller than reduced fuel. Moreover, the irradiation duration of 10 EFPD is very short. U-Al is also known to have more inherent safety than U-Mo. The thermal hydraulic test and analysis based on the ex-core experiment showed sufficient margin.

3.2 DU target in IP5

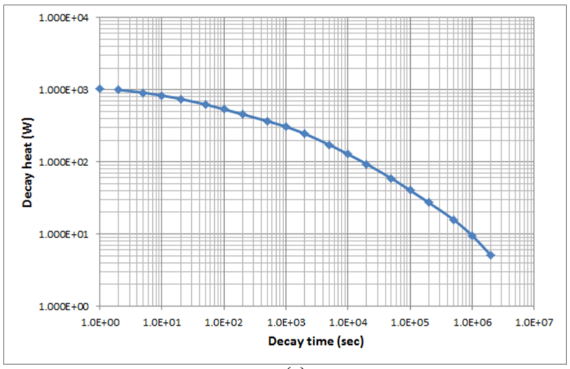
Since the irradiation test will be use DU target in IP5 that is farther than OR3, the average power is much lower about 0.96 W/cm^2. Therefore, the thermal hydraulic analysis showed that it will be sufficiently cooled by natural convection. The purpose of this test is the separation of fission ^{99}Mo of 1 Ci, so that the schedule of the irradiation, transportation, handling and separation test must be accurately planned since the half-life of ^{99}Mo is as short as 2.747 days. For this test, it was conservatively assumed that the time duration from the end of irradiation to the separation test is a week. Therefore, at the end of the irradiation, fission ^{99}Mo of more than 10 Ci is necessary. The need of irradiation duration more than a week was calculated from two DU targets by the depletion calculation using MCNP [5] and ORIGEN 2.2 [6].

4. Decay heat calculation

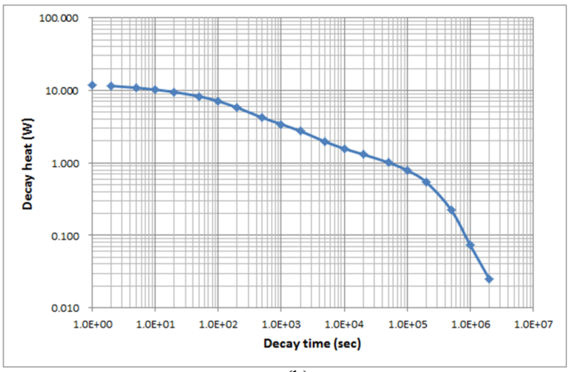
In the case of target tests, because they are much delayed due to the reinforcement construction of HANARO reactor building, it is necessary to minimize the cooling time of irradiated target. In particular, irradiated DU target must be transported quickly for the fission ^{99}Mo separation. The irradiated material at HANARO is transferred to PIE facility by HANARO fuel cask, which has sufficient shielding performance for the target transfer because it was designed considering the transportation of a single HANARO fuel assembly with 36 rods. However, if the target is damaged by decay heat during the transportation, the test result may be distorted. Therefore, the decay heat of irradiated target must be evaluated accurately.

ORIGEN 2.2 was used for the decay heat calculation. Since ORIGEN 2.2 does not have the library data for the HANARO irradiation test, it was produced by the application of MCNP calculation that nuclear cross section data of ENDF/B-VII.1 [7] was utilized and one group neutron flux and reaction rate of 384 nuclides was calculated. Although MCNP can calculate the depletion of uranium, calculating the decay heat using it was not appropriate because it was very low than the reference [4]. It might be caused that MCNP depletion module concentrates the neutronic calculation than the evaluation of nuclide inventories.

Fig. 4 shows the decay heat calculation result for irradiated LEU and DU target. LEU target in HANARO OR3 irradiation hole will be irradiated under 1.6 times higher power than KJRR. As a result of comparison, the ratio between target power during the irradiation and decay heat according to the cooling time was similar or slightly higher in HANARO irradiation. In the case of KJRR, the cooling time of a day is only considered to prevent the melting. However, in the case of LEU target test in HANARO, a longer cooling time is required to meet the purpose of test. The cooling time for irradiated DU target can be short because the decay heat of DU is very low and it may be possible to allow minor damage to the target. This analysis can be used for safety analysis for the transportation to PIE facility.



(a)



(b)

Fig. 4. The decay heat calculation result :
(a) LEU target, (b) DU target

5. Conclusions

The tests were planned and prepared at HANARO irradiation facility for the need of verification of applied target for fission ^{99}Mo production to be applied in KJRR. We will conduct the in-reactor testing at OR3 irradiation hole for the verification of irradiation performance using LEU target, while we will also do at IP5 using DU target for the separation of ^{99}Mo in PIE facility. The results obtained from these tests can verify the superior performance of KAERI-made target, which can contribute to the production of licensing database and export. The tests will be carried out immediately when HANARO is operated in the future.

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