Safety Assessment for (n,γ)^{98}Mo Form Irradiation Test in HANARO

Gee-Yang Han*, Jun-Sig Lee, Guk-Hoon Ahn, Hoan-Sung Jung
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong, Daejeon, 305-353, Korea
**Corresponding author: gyhan@kaeri.re.kr*

1. Introduction

HANARO, a 30MWth, open-pool type multipurpose research reactor has been used for various purposes including irradiation tests for isotope production. An accurate prediction of the temperature distribution in the target capsule is a very important safety factor for an irradiation test in HANARO irradiation holes. The objective of this study is primarily to predict the temperature behavior through a certain heat flow in the target capsule heated from a nuclear heat generation, and to provide safety limits for the irradiation tests. This paper describes the safety assessment for the enriched $^{98}MoO_3$ powder target irradiated to produce ^{99}Mo radioisotopes in the OR3 and IP15 irradiation holes.

2. Calculation Method and Procedure

In this section, the calculation method and procedure used to model the target capsule for the irradiation test are described.

2.1 Mathematical Modeling

A half of the rig assembly was modeled with a 1-D axisymmetric cylindrical geometry. The target capsule is divided into connecting regions, and in each, there is a single material region containing the target material and aluminum. The calculation model includes the nuclear heating and conduction heat transfer with an aluminum capsule with an inside radius of 1.9 cm and forced and natural convection heat transfer within the coolant flow field with an outside radius of 1.9 cm, which is a boundary of the water flow region. The aluminum rig of the external target capsule is loaded in the OR3 and IP15 holes, and is 6 cm in diameter with a cylindrical geometry. The side view of the calculation model of the target capsule is shown in Figure 1.

2.2 Nuclear Heat Generation Rate

Nuclear heating values for the enriched ^{98}Mo of 60g were calculated using the MCNP code in the OR3 and IP15 holes [1]. The calculation of the nuclear heat generation rate was performed for the center position of the irradiation hole at 60 cm, which is the maximum neutron flux. Nearly all the energy absorbed in a material placed in the radiation field of a research reactor appears in the form of heat. As a nuclear heating research reactor arises from the interactions with fast and thermal neutrons, gamma-ray energy deposition in the aluminum capsules and target material. Nuclear heating values within a capsule were distributed as a function of the distance from the center of the capsule. The nuclear heating rate of the capsule is summarized in Table 1.

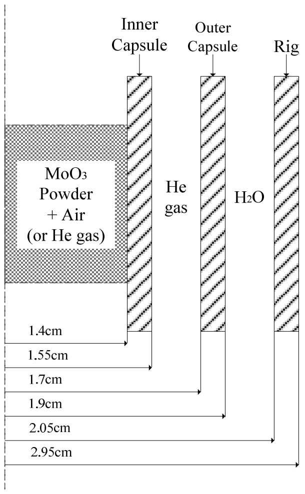

Fig. 1. Calculation model for $^{98}MoO_3$ powder irradiation test

Table 1. Heat generation rate of the enriched $^{98}MoO_3$ powder target in the OR3 and IP15 holes

	Heat generation rate (W/g)	
	OR3 hole	IP15 hole
Enriched $^{98}MoO_3$ powder (0.0~1.4 cm)	1.98	0.85
Inner target capsule (Al) (1.4~1.55 cm)	1.47	0.78
Outer target capsule (Al) (1.7~1.9 cm)	1.51	0.63

2.3 Thermo-Physical Properties

The use of thermo-physical material properties to calculate the heat source term is necessary. A summary of the thermo-physical properties for both the target material and aluminum used in these calculations are provided in Table 2. The target material of the metallic oxide generates the heat storage due to a bad heat transfer rate, and thus it predicts that the temperature in the target increases rapidly. Therefore, a plan in which the MoO_3 target is filled with He gas, which has better thermal conductivity than air in accordance with the temperature changes, should be drawn up. Thermal conductivity was used for the conduction heat transfer developed by the Ofuchi-Kunii relation [2, 3].

Table 2. Thermo-physical properties for $^{98}MoO_3$ powder

Density (g/cm^3)	1.35
Thermal conductivity (W/cm-℃)	
- Air	$1.84x10^{-3} – 8.0x10^{-9}T^2 + 9.0x10^{-12}T^3$
- He gas	$7.04x10^{-3} – 2.0x10^{-8}T^2 + 4.0x10^{-11}T^3$
Melting point (℃)	800

2.4 Heat Transfer Coefficients

The vertical irradiation holes in the core (OR holes) where the forced circulation of the core flow exists, and in the reflector tank (IP holes) where the natural convection of the pool water is available, are mostly used for irradiation purposes. Two vertical irradiation holes have a different operating temperature of 40℃ and 35℃, respectively.

The heat transfer coefficient for the forced circulation in smooth tubes was evaluated using the Dittus-Boelter relation [4]. Otherwise, the heat transfer coefficient for the natural convection from the vertical cylinder was calculated using the Churchill-Chu relation [5].

2.5 Results and Discussion

A numerical analysis was performed to determine the temperature distribution over the entire inner surface of the target capsule, whose target and capsule are heated differently, under a steady-state operating condition. It should be confirmed for any irradiation test to safely remove the heat induced by fission events or gamma heating during irradiation tests. The MoO_3 target should be evaluated for the irradiation tests in HANARO irradiation holes to determine whether the target is melting or not, according to the melting point of the target material.

The temperature distribution was calculated using the GENGTC code [6]. The maximum heat generation rate in each material composed of the target capsule was used for a conservative calculation of the temperature distribution along the radial direction. The safety assessment for the target capsule was considered for two cases: i) an enriched MoO_3 target capsule filled with air, ii) and an enriched MoO_3 target capsule filled with He gas.

The inner temperature of the MoO_3 target capsule filled with air in the OR3 hole was predicted up to about 1080℃, but the melting point of the target is within the limits of only 800℃. Therefore, it is necessary to reduce the amount of the target. The inner temperature of the MoO_3 target capsule filled with the He gas in the OR3 hole was predicted to be about 424℃. It was confirmed that the target capsule filled with the He gas was safe for the irradiation tests. The predicted inner temperatures of the target capsule filled with both air and He gas in the IP15 hole were considered such that there were no special problems for the irradiation tests, as given in Table 3.

Table 3. Results of temperature distribution in each region

	OR3 (Air/He)	IP15 (Air/He)
Heat transfer coeff. (W/cm^2-℃)	7.955	0.0716
Surface temp. outer capsule (℃)	40.6/40.3	50.8/50.7
Surface temp. inner capsule(℃)	218/217	134/134
Enriched MoO_3 target (℃)	1080/424	578/218

It was proved that the thermal safety for the target filled with He gas in the irradiation holes can be improved much more than any other materials.

3. Conclusions

The results showed that the performance of the irradiation tests in HANARO is very promising. The ^{99}Mo production capacity at HANARO was also evaluated. The safety limits and requirements provide the optimum irradiation conditions for $(n,\gamma)^{98}Mo$ reaction to produce ^{99m}Tc radioisotope by ^{99}Mo neutron activation at HANARO. It will provide better irradiation service through an appropriate safety assessment.

Additionally, high temperature generation and the safety problem when producing the specific activity of ^{99}Mo in the irradiation holes should be solved.

REFERENCES

[1] B. C. Lee, Calculation of Nuclear Heating for the Enriched MoO_3 Powder Target in the OR3 Hole, Speedy Memo, 2009.
[2] J. S. Lee, Estimation of Effective Thermal Conduction of MoO_3 Packed Bed, Private Communications, 2010.
[3] K. Ofuchi and D. Kunii, Heat Transfer Characteristics of Packed Beds with Stagnant Fluids, Int. Heat and Mass Transfer, Vol. 8, pp. 749-757, 1965.
[4] J. P. Holman, Heat Transfer, 7th Ed. McGraw-Hill, 1992.
[5] F. P. Incropera and D. P. DeWitt, Fundamentals of Heat and Mass Transfer, 3rd Edition, Wiley, 1990.
[6] GENGTC user's Manual.