Heat Transfer Analysis in Isotope Production Irradiation Hole of HANARO using COMSOL Multiphysics

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1. Introduction

The High-flux Advanced Neutron Application Reactor (HANARO) facilitates the production of radioisotopes (RIs) through neutron irradiation experiments [1, 2]. To ensure the thermal-hydraulic safety of HANARO, it is necessary to evaluate the nuclear heating induced in the RI production target material due to radiation emanating from HANARO. The optimal method for accurate determination of nuclear heating is through direct experimental measurement. Nonetheless, its implementation in HANARO presents inherent challenges. In such scenarios, the use of Monte Carlo simulation codes such as MCNP or finite element simulation software such as COMSOL Multiphysics emerges as an alternative strategy for nuclear heating calculations [3, 4].

In this study, we aimed to improve the accuracy of our previous study using MCNP6 and COMSOL Multiphysics, which confirmed the feasibility of producing ^{177}Lu using the isotope production (IP) hole of HANARO. Our previous study used a 2D model for heat transfer analysis in COMSOL Multiphysics, neglecting the effect of convective heat transfer by fluid. Hence, to enhance the precision of heat transfer analysis employing COMSOL Multiphysics, this study adopted a 3D model for the precise modeling of the IP irradiation hole, while accounting for the effects of convective heat transfer.

2. Materials and Methods

2.1 Monte Carlo simulation

The calculation of nuclear heating rates for the RI production target and the RI capsule in the IP irradiation hole of HANARO was performed using MCNP6 (version 6.2.0). For the production of ^{177}Lu, Dy_2O_3 was used as the RI production target. Nuclear heating rates used values obtained in our previous study and the detailed information of the MCNP simulation was described in our previous study [4].

2.1 COMSOL Multiphysics

Heat transfer analysis of the IP irradiation hole was performed using the heat transfer in the solids and fluids module and the laminar flow module of COMSOL Multiphysics (version 6.1). The IP irradiation hole, which was originally modeled using MCNP6, was modeled using the 3D model in COMSOL Multiphysics (see Fig. 1). The temperature distribution in the IP irradiation hole was calculated for a neutron irradiation time of 12 h. An initial temperature of 40°C for heavy water and 20°C for the remaining regions were assumed.

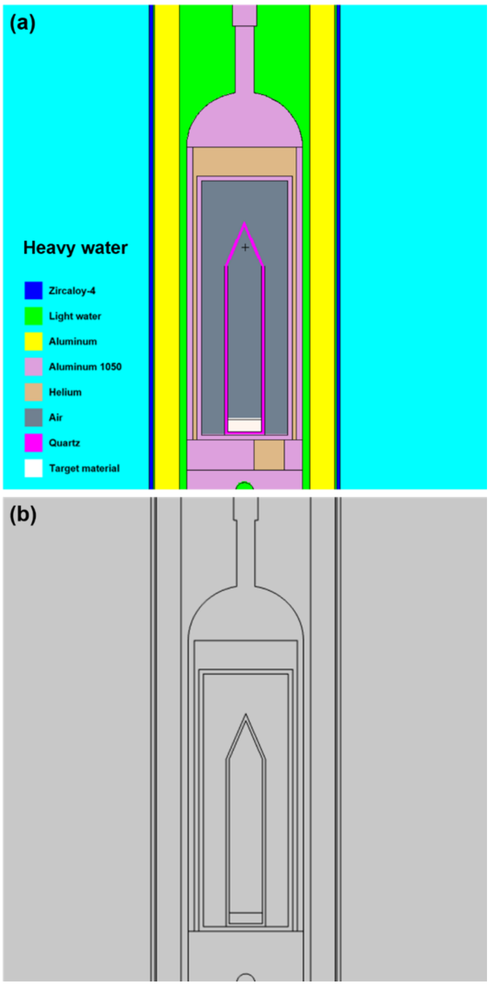

Fig. 1. Vertical cross-section of the RI capsule loaded in the IP irradiation hole modeled using (a) MCNP6 and (b) COMSOL Multiphysics.

3. Results and Discussion

3.1 Heat transfer analysis of IP irradiation hole

Fig. 2 shows the temperature distribution of the IP irradiation hole after 12 h of neutron irradiation. The Dy_2O_3 in the IP irradiation hole reached a maximum temperature of 55°C. Consistent with our previous results, the specified conditions of this study for producing ^{177}Lu suggested the absence of thermal implications on the safety of the RI capsule. In particular, the maximum temperature was lower compared to our previous study which used a 2D model is noteworthy. This outcome can be attributed to the implementation of the 3D model, which incorporates additional convective heat transfer in fluid regions and enhanced cooling due to the presence of air above the Dy_2O_3 sample.

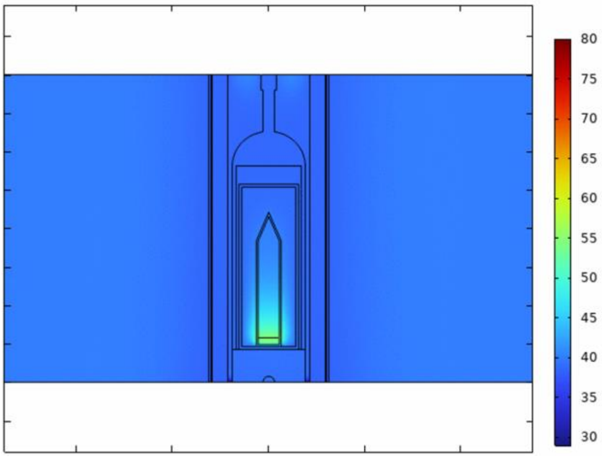

Fig. 2. Temperature distribution after 12 h of neutron irradiation of the IP irradiation hole.

4. Conclusions

For the calculation of temperature distribution during the production of ^{177}Lu through the IP irradiation hole of HANARO, we used COMSOL Multiphysics to evaluate the temperature distribution in the RI production target and RI capsule. A more accurate temperature distribution was obtained through heat transfer analysis using a 3D model. Nevertheless, for more realistic heat transfer analysis results, it is imperative to include not only the nuclear heating of the RI production target but also that of the RI capsule. We plan to undertake further research while considering this aspect in the future.

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