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Feasibility study of Lu-177 production in CANDU reactor based on MCNP simulation

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1. Introduction

Recently, β-emitters are getting attention in targeted radionuclide therapy (TRT). Its effectiveness can be explained by their decay properties. Beta's pathlength is quite short in viscera to destroy cancer cells while leaving normal cells undamaged. Among β-emitters, Lutetium-177 (Lu-177) has been shown in clinical trials to remove only cancer cells once it attaches to diseased area accurately by some ligands [1]. However, its supply is not sufficient to apply all patients and even cover clinical trials.

Many researchers have been developing effective ways to produce valuable Lu-177 [2-3]. In 2022, Korea Atomic Energy Research Institute (KAERI) produced 920 mCi of Lu-177 by irradiating a 70 mg Lu target in HANARO for the first time. However, the yield cannot resolve Lu-177 shortage and a large-scale production system or facility should be needed.

Nowadays, Korea Hydro & Nuclear Power Co., Ltd. (KHNP) is trying to find out the solution to produce mass Lu-177 with CANDU reactors. Its feasibility is evaluated based on computational analysis. Monte Carlo N-Particle transport (MCNP) version 6.2 and ORIGEN-ARP codes are used to calculate neutron flux and transmutation rate respectively.

2. Methods and Results

There are two major ways to produce Lu-177 based on neutron-induced reactions. First, Lu-177 is directly produced from $^{176}Lu(n,\gamma)^{177}Lu$ in Lu target where only Lu isotopes exist. However, the impurity Lu-176 makes its specific activity low. Second, Lu-177 is indirectly produced from $^{176}Yb(n,\gamma)^{177}Yb$ and sequential β-decay makes daughter Lu-177 in Yb target. With an affordable chemical partitioning, Lu-177 can be extracted with a high purity. In this work, the indirect way is adopted to get a qualitative Lu-177.

2.1 Candidate of Yb target

In general, an enriched Yb target is used in indirect way to enhance isotopic yield and Lu-177 purity. Table 1 describes isotopic composition of two Yb targets in previous works [4-5].

Table I: Isotopic abundance (%) of Yb target

Yb isotope	Natural	Case #1	Case #2
Yb-168	0.126	0.00043	< 0.01
Yb-170	3.02	0.02447	0.01
Yb-171	14.2	0.14769	0.02
Yb-172	21.8	0.28299	0.04
Yb-173	16.1	0.29354	0.05
Yb-174	31.9	2.24414	0.29
Yb-176	12.9	97.00675	99.59

2.2 Irradiation position in CANDU

To evaluate the feasibility of a large-scale production of Lu-177 in CANDU reactor, we calculate the isotopic yield of Lu-177 over irradiation and sequential cooling process for a single Yb target. We determined to insert the Yb target at empty tubes in vertical flux detector assembly (VFDA) where flux detectors are far from the target not to interfere with a detector's signal. Figure 1 describes 26 VFDA locations in CANDU reactor [6]. In this work, the Yb target is loaded at the nearest position from the core's center.

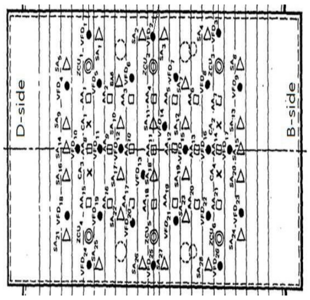

Fig. 1. Top-view to describe VFDA locations (black symbol) in CANDU reactor.

2.3 Isotopic yield and purity of Lu-177

When the target is irradiated for 40 days, the amount of Yb-176 and its daughter Lu-177 is a gradually increasing at first and begin to level off after 20 days as described in Fig. 2. The trend helps to determine the optimum irradiation time as 20 days. In this study, we assume that 24-hour is needed for target's extraction and chemical separation.

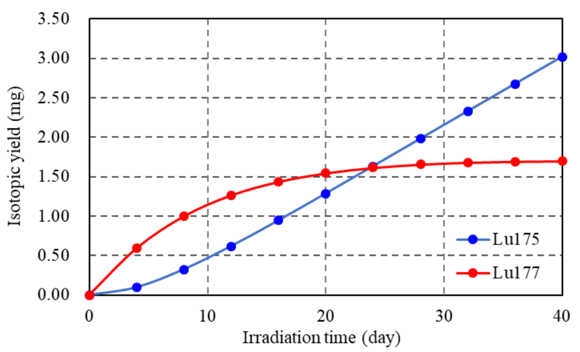

Fig. 2. Isotopic yield of Lu isotopes over irradiation time in case #1.

Table 2 compares the isotopic yield and purity of Lu-177 after chemical treatments (two cases in Table 1). Considering the maximum specific activity of Lu-177 (110 Ci/mg), both cases seem to give a noticeable yield for medical application. The purity in case #2 is higher than that in case #1 due to smaller Lu-174 yield during irradiation. Consequently, it is noteworthy that the enrichment process should be directed to reduce Yb-174 abundance.

Table II: Isotopic yield of Lu-177 and its purity

Case	Lu-177 yield (mg)	Lu-177 purity (%)	Specific activity of Lu-177 (Ci/mg)
#1	1.51	32.5	36.4
#2	1.55	79.3	88.2

3. Conclusions

This work is conducted to evaluate the feasibility of Lu-177 production in CANDU reactor. We calculate the isotopic yield and purity of Lu-177 for two cases. There is optimum irradiation period that the Lu-177 yield is levelled off. Its purity is mainly influenced by Yb-174 content. Therefore, special enrichment process should be preceded to get a qualitative Lu-177 before loading the target in CANDU reactor.

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