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The Optimizing Production Route for Tc-94m and Br-76 Medical Radioisotopes

J. H. Kim, S. K. Kim, S. J. Han, H. Park, J. S. Lee, K. S. Chun
Radiopharmaceuticals Laboratory, Korea Institute of Radiological and Medical Sciences (KIRAMS),
215-4 Gongreung-Dong, Nowon-Gu, Seoul, Korea, 139-706
jhkim68@kcch.re.kr

1. Introduction

The decay characteristics of medical radioisotopes of ^{76}Br ($T_{1/2}$ = 16.2 hr, $I_{\beta+}$ = 54 %, $E_{\beta+}$ = 3.94 MeV) and ^{94m}Tc ($T_{1/2}$ = 52.5 min, $I_{\beta+}$ = 72 %, $E_{\beta+}$ = 2.47 MeV) radionuclides produced by cyclotron have been considered useful agents as positron emitters for PET diagnostic imaging [1,2]. Increasing the availability of these radionuclides, the investigation for the high capacity target design and simple procedures yielding high activities is being carried at KIRAMS. Also, the quality and yield of products are evaluated theoretically from the excitation functions with respect to proton energies and target thickness. In this work, we will present the optimization of production route for medical ^{94m}Tc and ^{76}Br radioisotopes using (p,n) nuclear reaction data and proton stopping ranges.

2. Methods and Results

2.1. Method

Using a 4π solid target as shown in Figure 1, positron emitters such as ^{94m}Tc and ^{76}Br radionuclides will be produced by utilizing MC50 cyclotron. To maximize the yield of desired products and minimize the level of radionuclidic impurities, incident energy of proton beam should be optimized in the high cross-section ranges for (p,n) nuclear reaction.

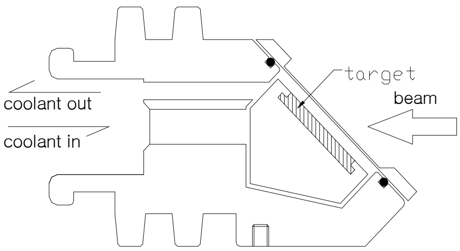

Figure 1. Schematic diagram of a 4π target (not scaled). The target inclined 45 degree with respect to the direction of the incident beam. Cooling water flows both front and back faces of the target.

In addition, to take a full benefit of the (p,n) reaction excitation curve, the physical thickness of the target layer (hence the cost price per target electroplated with expensive enriched material) inclined 45 degree with respect to the beam direction should be optimized within the desired energy ranges of beams passing through the layer. The energy loss of the beam in the layer can be calculated by well-known proton stopping range program [3]. The production routes for determining incident beam energy and target thickness will be discussed in detail at the following sections and a detail description for chemical processing method will be given elsewhere.

2.2. ^{76}Br Production Route

The excitation function for the ^{76}Se(p,n)^{76}Br reaction is shown in Figure 2, where the optimum energy range (E_p = 18 → 6 MeV) for the production is marked. The stopping ranges for the corresponding energies of proton are plotted in Figure 3. Due to the degradation of the projectile energy in the target material, the incident energy of 18 MeV proton losses its kinetic energy and reaches to 6 MeV at the depth of 500 um as traveling through the layer. However, the layer is inclined 45 degree so that the beam travels a longer path then the actual thickness by the factor of 1.414. Therefore, the optimized layer thickness of Cu_2Se layer to have full benefit of the reaction is to be about 350 um.

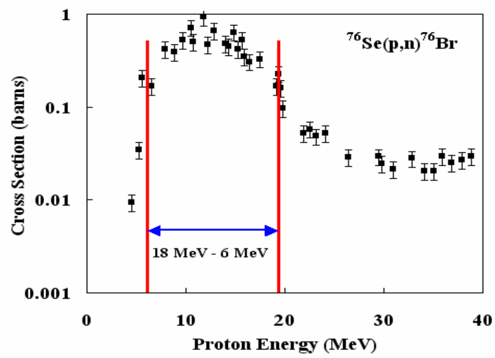

Figure 2. Excitation function of ^{76}Se(p,n)^{76}Br reaction (taken from ref.[4])

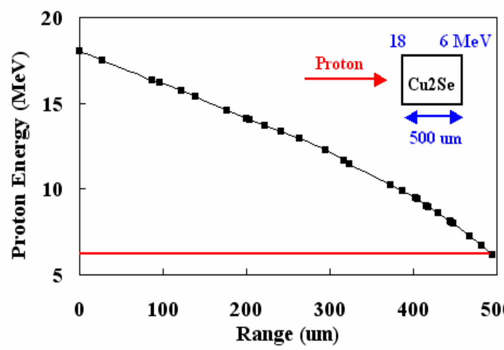

Figure 3. Energy degradation of proton passing through the Cu_2Se target layer.

2.3. ^{94m}Tc Production

The excitation function for the ^{94}Mo(p,n)^{94m}Tc reaction is plotted as a function of proton beam energy as shown in Figure 4 where the optimum energy ranges of E_p = 13 → 8 MeV for the production is marked. Figure 5 represents that the incident energy of 13 MeV proton losses its kinetic energy as traveling through the Mo layer and reached to 8 MeV at the range of 160 um. Due to 45-degree target-beam geometry, the optimized layer thickness to have high yield of the reaction is to be about 110 um.

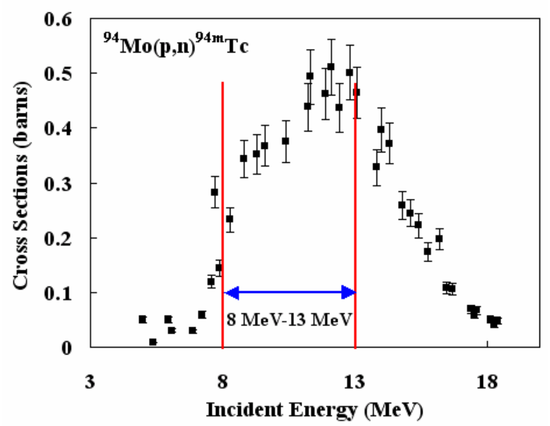

Figure 4. Excitation function of ^{94}Mo(p,n)^{94m}Tc reaction (taken from ref.[5])

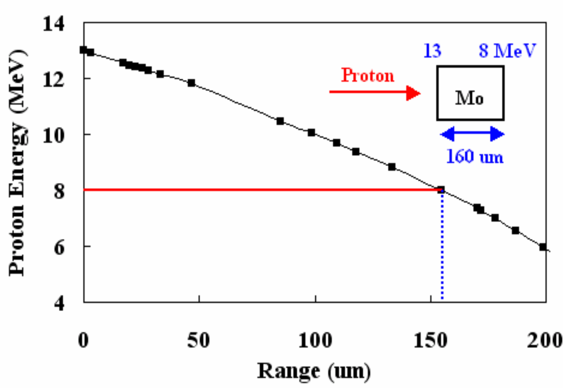

Figure 5. Energy degradation of proton beam traveling in the Mo layer.

2.3. Calculation of Expecting Yields

From a given excitation function, the expected yield of a product for a certain energy range (or target thickness) can be calculated using the equation (1):

$$Y = \frac{N_L \cdot H}{M} I(1 - e^{-\lambda t}) \int_{E1}^{E2} \left(\frac{dE}{d(\rho x)} \right)^{-1} \sigma(E) dE \quad (1)$$

where N_L is the Avogadro number, H the enrichment (or isotope abundance) of the target nuclide, M the mass number of the target element, I projectile current (uA), $(dE/d(\rho x))$ the stopping power, $\sigma(E)$ the cross section at energy E, λ the decay constant of the product and t the time of irradiation. The calculated yield value represents the maximum yield which can be expected from a given nuclear process, the production yields of Br-76 and Tc-94m radionuclides are calculated 2.4 mCi/uAh and 54 mCi/uAh, respectively. The results are comparable with measured yields reported in Refs [1,2].

3. Conclusion

Nuclear data is useful to medical application of a radioisotope, such as diagnostic applications. Due to the capability of low-energy nuclear reactions utilizing highly enriched target isotopes, the development of radioisotopes takes place actively. In addition, an understanding of the underlying reaction mechanisms is required as well as theoretical models with a good prediction. The quality and yield of products can be evaluated theoretically from the excitation functions with respect to proton energies and target thickness. In this work, we present the optimization of production route for medical ^{94m}Tc and ^{76}Br radioisotopes using (p,n) nuclear reaction data and proton stopping ranges.

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