Consideration of the production method for Auger electron emitter ^{77}Br using the CCONE-based calculation system

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Nuclear medicine therapy using nuclides emitting α rays and Auger electrons has recently attracted attention.[1] The SEKIGUCHI Three-Nucleon Force Project[2] aims to realise nuclear medicine therapy using the Auger electron emitter ^{77}Br, which has a half-life of 2.38 days[3] and is readily available for medical use. In addition, ^{77}Br is a Group 17 (halogen) element, such as ^{211}At, which is in rapidly increasing demand as an α ray emitter for nuclear medicine therapy. Further, its similar chemical properties are useful in understanding differences in biological effects between α rays and Auger electrons. However, reactions and pathways for producing ^{77}Br are diverse and the optimal production method is yet to be established. Therefore, we considered the optimal production method for ^{77}Br using the CCONE-based calculation system.[4]

The reactions that maximize the ^{77}Br production cross-section and ^{77}Br thick target yield[5] (TTY, yield for a target of infinite thickness) were confirmed under the following conditions.

- Projectile: n, p, d, α, and γ
- Kinetic energy of projectile (E_{proj}): 1–50 MeV
- Target: enriched target

TTY is obtained using

$$\mathrm{TTY} = \int_0^{E_{\mathrm{proj}}} \frac{\sigma(E)}{S(E)} dE, \qquad (1)$$

where $\sigma(E)$ and $S(E)$ represent the nuclide production cross section and stopping power, respectively. The stopping power is calculated using stopping and range of ions in matter (SRIM).[6] The TTY is calculated only when the projectile is p, d, or α. Consequently, the reaction that maximizes the ^{77}Br production cross-section is $\alpha + {}^{75}$As ($E_{\mathrm{proj}} \sim 25$ MeV). Although the reaction maximizing ^{77}Br TTY is found to be $p + {}^{78}$Se ($E_{\mathrm{proj}} \gtrsim 22$ MeV), the focus will be on $p + {}^{78}$Se.

All residual nuclei other than ^{77}Br that can be produced by $p + {}^{78}$Se are confirmed under the following conditions.

- The maximum nuclide production cross-section exceeds 1 Mb in the CCONE calculation.
- EXFOR[7] contains experimental values of the nuclide production cross-section.

Consequently, we found that ^{69,70}Ga, $^{72–74}$Ge, $^{72–77}$As, $^{74–77}$Se, and ^{75,76,78,79}Br can be produced besides ^{77}Br. Assuming that ^{69,70}Ga, $^{72–74}$Ge, $^{72–77}$As, and $^{74–78}$Se with an atomic number different from ^{77}Br can be chemically separated, and the production yields of ^{75,76,78,79}Br can become an issue. However, when E_{proj} is 23 MeV, only the production yields of ^{78,79}Br become an issue because the threshold energies of ^{75}Br and ^{76}Br are 33.34 and 23.97 MeV, respectively.[8]

The time variation of the nuclide production yield $N(t)$[5] was confirmed to estimate the number of ^{78,79}Br produced. $N(t)$ is defined as

$$N(t) = \frac{I_0 y T_{\mathrm{h}}}{\ln 2}\left\{1 - \exp\left(-\frac{\ln 2}{T_{\mathrm{h}}}t\right)\right\}, \qquad (2)$$

where I_0, y, T_{h}, and t represent the beam intensity [1/h] (this time we set $I_0 = 1$), TTY at a given E_{proj}, half-life [h], and beam irradiation time [h], respectively. For stable nuclei, $N(t) = I_0 y t$. Table 1 indicates that the $^{77–79}$Br TTYs by $p + {}^{78}$Se ($E_{\mathrm{proj}} = 23$ MeV), half-life of $^{77–79}$Br,[3] and $^{77–79}$Br production yields just after 24 hours of irradiation. Table 1 shows that the ^{78,79}Br production yields are less than 1% of the ^{77}Br production yield. In conclusion, $p + {}^{78}$Se ($E_{\mathrm{proj}} \sim 23$ MeV) seems to be optimal.

Table 1. $^{77–79}$Br TTYs by $p + {}^{78}$Se ($E_{\mathrm{proj}} = 23$ MeV) (y), half-life of $^{77–79}$Br[3] (T_{h}), and $^{77–79}$Br production yields just after 24 hours of irradiation (N ($t = 24$ h)).

Nuclide	y	T_{h}	N ($t = 24$ h)
^{77}Br	3.401×10^{-3}	2.38 d	7.081×10^{-2}
^{78}Br	2.609×10^{-3}	6.45 min	4.046×10^{-4}
^{79}Br	1.176×10^{-5}	-	2.880×10^{-4}

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