Examination of medical radionuclides production using an electron linear accelerator (3) Perspectives on ^{100}Mo enrichment in photonuclear production of ^{99}Mo

*Jaewoong Jang[1], Katsuyoshi Tatenuma[2], and Mitsuru Uesaka[1]
[1]Univ. of Tokyo, [2]Kaken Inc.

Abstract

Although the need of ^{100}Mo enrichment in realizing photonuclear production of ^{99}Mo has been widely recognized, its rationales other than the sheer increase in the abundance of ^{100}Mo have not been explored in depth. Here we examine the scientific implications of ^{100}Mo enrichment from physical and chemical perspectives.

Keywords: ^{99}Mo/^{99m}Tc, ^{100}Mo, isotopic enrichment, nuclear medicine, electron linear accelerator

1. Introduction

Oftentimes, the use of a Mo target enriched to >90% in ^{100}Mo is considered as a precondition for realizing mass production of ^{99}Mo via the photonuclear reaction ^{100}Mo(γ,n)^{99}Mo. Such enriched Mo, however, is as costly as USD 700–1,000 per gram, and therefore evaluating its necessity is crucial. This research is an attempt to justify the use of a ^{100}Mo-enriched Mo target through understanding its scientific implications.

2. Perspectives on ^{100}Mo enrichment

2.1. Physical aspect: ^{99}Mo yield

Writing the macroscopic cross section for ^{100}Mo(γ,n)^{99}Mo in terms of its component terms, we express the activity or yield of photonuclear-produced ^{99}Mo as a function of both the irradiation time t_{irr} and the mass fraction of ^{100}Mo, ω_{100} [1]:

$$A_p(t_{\mathrm{irr}}, \omega_{100}) = [1 - \exp(-\lambda_p t_{\mathrm{irr}})]\, \mathcal{V}_{\mathrm{tar}} I_b \left(\frac{\omega_{100}\rho_{\mathrm{tar}}}{M_{100}} N_A \right) \int_{E_{\gamma,\mathrm{min}}}^{E_{\gamma,\mathrm{max}}} \Phi_{\mathrm{MC}}(E_\gamma)\sigma_{100}(E_\gamma)\, dE_\gamma, \tag{1}$$

where λ_p is the decay constant of ^{99}Mo, $\mathcal{V}_{\mathrm{tar}}$ is the volume of a Mo target, I_b is the electron beam current, ρ_{tar} is the mass density of the Mo target, M_{100} is the molar mass of ^{100}Mo, N_A is the Avogadro constant, E_γ is the energy of incident bremsstrahlung, $\Phi_{\mathrm{MC}}(E_\gamma)$ is the bremsstrahlung fluence obtained from a Monte Carlo simulation platform, and $\sigma_{100}(E_\gamma)$ is the microscopic cross section.

Table 1 shows the ^{99}Mo yield obtained from Eq. (1) with the following conditions: (1) 35-MeV electron beams shone onto a 1-mm thick tungsten converter for $t_{\mathrm{irr}} = 72\,\mathrm{h}$, (2) $\mathcal{V}_{\mathrm{tar}} = 0.495\,\mathrm{cm}^3$, (3) $I_b = 260\,\mu\mathrm{A}$, (4) $\omega_{100} = 0.097$ to $\omega_{100} = 0.950$, (5) $\Phi_{\mathrm{MC}}(E_\gamma)$ obtained from PHITS, and (6) $\sigma_{100}(E_\gamma)$ contained in TENDL-2009. Also shown in the table is the number of electron linear accelerators (linacs) required to meet one million ^{99m}Tc-based medical procedures per year, the highest demand for ^{99m}Tc in Japan in this century, suggesting that ^{100}Mo enrichment to a certain degree may be unavoidable.

Table 1. ^{99}Mo yields and the numbers of electron (e^-) linacs to supply one million ^{99m}Tc annual procedures.

ω_{100}	A_p (GBq)	Number of e^- linacs
0.097	50.41	112
0.200	103.5	55
0.400	206.9	28
0.600	310.4	19
0.800	413.9	14
0.950	491.5	12

2.2. Chemical aspect: ^{99}Mo specific activity

Compared with fission-produced ^{99}Mo, photonuclear-produced ^{99}Mo inevitably exhibits low specific activity (LSA), discouraging the use of alumina for extracting [^{99m}Tc]TcO_4^- from [^{99}Mo]MoO_4^{2-}. This LSA further decreases with lower ω_{100}, in which case some ^{99m}Tc generators proposed as an alternative to the alumina generator may not function effectively.

One solution is to use a ^{99m}Tc-selective adsorbent: activated carbon, for example, selectively retains [^{99m}Tc]TcO_4^- when given [^{99}Mo]MoO_4^{2-} and [^{99m}Tc]TcO_4^- solutions [2], and therefore allows [^{99m}Tc]TcO_4^- to be concentrated to a sufficiently large extent even when the specific activity of given ^{99}Mo is extremely low.

3. Conclusion

Considering the low yield of ^{99}Mo at low ω_{100}, using ^{100}Mo-enriched Mo targets is deemed to be necessary. The specific activity of ^{99}Mo, on the other hand, will no longer be a factor that encourages ^{100}Mo enrichment, if ^{99m}Tc-selective ^{99m}Tc generators become widely available. The necessity of ^{100}Mo enrichment will then be judged based solely on the yield of ^{99}Mo, not on its specific activity, in which case the roles of t_{irr} and I_b will become ever more important.

References

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