Examination of medical radionuclides production using an electron linear accelerator

(3) Perspectives on $^{100}$Mo enrichment in photonuclear production of $^{99}$Mo

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**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$(\gamma,\nu)^{99m}$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$(\gamma,\nu)^{99m}$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, $\omega_{irr}$ [1]:

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

where $\lambda_p$ is the decay constant of $^{99}$Mo, $V_{tar}$ is the volume of a Mo target, $I_b$ is the electron beam current, $\rho_{tar}$ is the mass density of the Mo target, $M_{100}$ is the molar mass of $^{100}$Mo, $N_A$ is the Avogadro constant, $E_{\gamma}$ is the energy of incident bremsstrahlung, $\Phi_{MC}(E_{\gamma})$ is the bremsstrahlung fluence obtained from a Monte Carlo simulation platform, and $\sigma_{irr}(E_{\gamma})$ 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 $t_{irr} = 72$ h, (2) $V_{tar} = 0.495$ cm$^3$, (3) $I_b = 260$ mA, (4) $\omega_{irr} = 0.097$ to $0.950$, (5) $\Phi_{MC}(E_{\gamma})$ obtained from PHTS, and (6) $\sigma_{irr}(E_{\gamma})$ contained in TENDL-2009. Also shown in the table is the number of electron ($e^{-}$) linacs to supply one million $^{99m}$Tc annual procedures.

<table>
<thead>
<tr>
<th>$\omega_{irr}$</th>
<th>$A_p$ (GBq)</th>
<th>Number of $e^{-}$ linacs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.097</td>
<td>50.41</td>
<td>112</td>
</tr>
<tr>
<td>0.200</td>
<td>103.5</td>
<td>55</td>
</tr>
<tr>
<td>0.400</td>
<td>206.9</td>
<td>28</td>
</tr>
<tr>
<td>0.600</td>
<td>310.4</td>
<td>19</td>
</tr>
<tr>
<td>0.800</td>
<td>413.9</td>
<td>14</td>
</tr>
<tr>
<td>0.950</td>
<td>491.5</td>
<td>12</td>
</tr>
</tbody>
</table>

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 $[^{99m}\text{Tc}]\text{TcO}_4^-$ from $[^{99}\text{Mo}]\text{MoO}_2^{+}$. This LSA further decreases with lower $\omega_{irr}$, 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 $[^{99m}\text{Tc}]\text{TcO}_4^-$ when given $[^{99}\text{Mo}]\text{MoO}_2^{+}$ and $[^{99m}\text{Tc}]\text{TcO}_4^-$ solutions [2], and therefore allows $[^{99m}\text{Tc}]\text{TcO}_4^-$ 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 $\omega_{irr}$, 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 $^{99}$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**
