MONITORING OF HIGH-ENERGY PHOTON FLUENCE IN CLINAC USING Zn AND Cr PHOTOACTIVATION

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Monitoring of high-energy photon dose in radiation therapy is crucial for radiation protection, as well as to estimate the radiation effects in the operating microelectronic devices. The aim of this work was to investigate the possibility of using the photoactivation technique to monitor the high-energy photon fluence in the Varian 21EX 23MV CLINAC. The $^{52}$Cr($\gamma$,n)$^{51}$Cr and $^{66}$Zn($\gamma$,n)$^{65}$Zn reactions were used. It was found that $^{51}$Cr and $^{65}$Zn can be used successfully to monitor the fluence for short term (80 days) and long term (110 days), respectively.

INTRODUCTION

Monitoring of high-energy photon dose (dose) or fluence ($\Phi$) in CLINACs is crucial for radiation protection, induced radioactivity estimation as well as to estimate the radiation effects in the operating microelectronic devices. It is necessary to monitor $\Phi$ in the positions along the beam and its surrounding. These measurements are needed to control the irradiation quality and to validate dose calculations. $\Phi$ can be monitored using different techniques. It was monitored by thermoluminescence dosimeter.$^{(1)}$ However, this technique requires lengthy procedures. Photoactivation technique was used to measure gamma radiation dose in $^{60}$Co irradiation facilities using the nuclear interaction ($\gamma$,n)$^{2}$.$^{(2)}$ Application of this technique requires the photon energy to exceed a specific threshold, which is the main restriction.$^{(3)}$

A Varian 21EX 23MV CLINAC is operated in Al Bairouni hospital in Damascus, Syria. The operator determines the therapeutic dose on the control board as required. This work aims to monitor $\Phi$ in the treatment room of the CLINAC by photoactivation of stainless steel and zinc foils. The photoactivation reactions are $^{52}$Cr($\gamma$,n)$^{51}$Cr, $^{66}$Zn($\gamma$,n)$^{65}$Zn.

THEORY

Zinc and chromium nuclei are activated by high-energy photon provided the photon energy exceeds the threshold energy ($E_{th}$) of photoactivation reaction. The $E_{th}$ values are ~18 MeV, 16 MeV for $^{52}$Cr ($\gamma$,n)$^{51}$Cr and $^{66}$Zn($\gamma$,n)$^{65}$Zn reactions respectively. Table 1 lists the characteristics of $^{66}$Zn and $^{52}$Cr photoactivation used in this work.$^{(4)}$ $^{51}$Cr and $^{65}$Zn are formed through ($\gamma$,n) reaction. Therefore, the radioactivity of each of them can be used to monitor $\Phi$.

$\Phi$ is calculated using the measured $^{51}$Cr (or $^{65}$Zn) radioactivity for short irradiation periods (<0.4 half-life) by the following equation$^{(2)}$:

$$\Phi = A/(N\sigma) \tag{1}$$

Where, $A$ is the radioactivity; $N$ is the number of activable isotope in the foil; $\sigma$ is the photoactivation cross section; and $\lambda$ is the decay constant.

This equation was used to calculate $\Phi$ from the measured $^{51}$Cr and $^{65}$Zn radioactivities of stainless steel and zinc irradiated foils.

EXPERIMENTAL

Eleven stainless steel and five zinc foils were used to monitor $\Phi$ in CLINAC. The foils were prepared from the commercially available stainless steel and zinc foils. The Cr and Zn content in these foils were determined by XRF technique. It shows that Cr and Zn contents are 16.1 and 74%, respectively. The activated isotopes in the stainless steel, zinc foils are $^{52}$Cr and $^{66}$Zn, respectively. Accordingly, the foils will be hereafter denoted simply as Cr and Zn foils. Tables 2 and 3 show mass, thickness and diameter of these foils.

The Cr and Zn foils were placed on two positions in the CLINAC hall. The first one is on the ground in the isocenter (c). The second one is on the wall ($w$) ~3 m from the isocenter as shown in Figure 1.

The foils were left in their positions during patients’ treatment for different periods to monitor dose. Let us assign the index ($i$) for each foil, so the $i$-th foil located in the isocenter position monitors the treatment doses sum in the isocentre of the CLINAC ($D_{ois}$) during the monitoring period ($T_i$). Therefore, $D_{ois}$ is calculated by the following equation:

$$D_{ois} = \frac{A_i}{N_i\sigma_i} \tag{2}$$

Where, $A_i$ is the radioactivity of the $i$-th foil in the isocentre; $N_i$ is the number of activable isotope in the $i$-th foil; $\sigma_i$ is the photoactivation cross section of the $i$-th activable isotope.

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\[
\sum_i (\text{Dose}_i) = (\text{Dose}_2)_{ij}
\]

Where, Dose \(j\) is the treatment dose of \(j\)-th patient performed during \(T_i\). Therefore, each foil is exposed to a dose proportional to Dose\(i\) during \(T_i\) (Tables 2 and 3). Thus, a calibration \([\text{high-energy photon fluence} - \text{Dose}_i]\) can be obtained for the isocenter and wall positions.

The \(^{65}\text{Zn}\) and \(^{51}\text{Cr}\) activities of the irradiated foils were measured using HPGe coaxial gamma spectrometer. The peak area uncertainty forms the main component of the total measurement uncertainty. The maximum uncertainty in the measurement was estimated to be 20%.

**RESULTS AND DISCUSSION**

\(\Phi\) values were determined using equation 1. The obtained \(\Phi\) values were plotted versus the corresponding doses for each irradiation position (Figures 2-4). Analyzing Figures 2-4 shows the following:

- All \([\Phi = f(\text{Dose})]\) curves accept linear fitting (with \(R^2\) value better than 0.96) of the following form:

\[
\Phi = \text{const} \times \text{Dose}
\]

- This result shows that, the high-energy photon fluence (\(\Phi\)) in CLINAC has been successfully monitored using Zn and Cr photoactivation.
- Therefore, Zn and Cr photoactivated foils can be used as record for the accumulated dose and operation in CLINAC.

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**Table 1. Characteristics of \(^{65}\text{Zn}\) and \(^{51}\text{Cr}\) photoactivation.**

<table>
<thead>
<tr>
<th>Interacting isotope abundance %</th>
<th>Interaction</th>
<th>Activation product</th>
</tr>
</thead>
<tbody>
<tr>
<td>(83.70)</td>
<td>(^{52}\text{Cr}(\gamma, n))</td>
<td>(^{51}\text{Cr})</td>
</tr>
<tr>
<td>(27.92)</td>
<td>(^{65}\text{Zn}(\gamma, n))</td>
<td>(^{60}\text{Zn})</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(E_{\text{th}}) (MeV)</th>
<th>(\sigma) (mb)</th>
<th>Nuclide</th>
<th>(T_{1/2}) (d)</th>
<th>(E) (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>735</td>
<td>(^{51}\text{Cr})</td>
<td>27.7</td>
<td>320.1</td>
</tr>
<tr>
<td>16</td>
<td>573</td>
<td>(^{60}\text{Zn})</td>
<td>244</td>
<td>1115.5</td>
</tr>
</tbody>
</table>

**Table 2. The masses and monitoring period of stainless steel (Cr) foils.**

<table>
<thead>
<tr>
<th>(T_i) (d)</th>
<th>8</th>
<th>57</th>
<th>64</th>
<th>71</th>
<th>85</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Foil Thickness</th>
<th>1 mm</th>
<th>Diameter</th>
<th>2.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m_i) (g)</td>
<td></td>
<td>Isocenter</td>
<td>2.79 3.11 3.05 2.87 2.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wall</td>
<td>2.69 2.86 2.74 2.74 2.69</td>
</tr>
</tbody>
</table>

**Table 3. The masses and monitoring period of zinc foils.**

<table>
<thead>
<tr>
<th>(T_i) (d)</th>
<th>70</th>
<th>84</th>
<th>90</th>
<th>153</th>
<th>181</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Foil Thickness</th>
<th>1 mm</th>
<th>Diameter</th>
<th>3 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m_i) (g)</td>
<td></td>
<td>Isocenter</td>
<td>6.76 7.05 6.74 6.74 7.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wall</td>
<td>6.74 6.74 6.74 7.00</td>
</tr>
</tbody>
</table>

**Figure 1. Locations of the foils in experimental arrangement in and around the isocenter.**

**Figure 2. \(\Phi\) (Calculated from \(^{51}\text{Cr}\) radioactivity) variation versus dose on the ground of isocenter.**

\[
y = 0.0013x \\
R^2 = 0.98
\]
The value in the facility can be mapped using Zn and Cr photoactivation. Values on the isocenter are about three to four times more than the corresponding values on wall. This result can be interpreted as follows. On isocenter the high-energy photon beam is direct, whereas the wall gets only the scattered high-energy photon. $	ext{^{52}Cr(γ,n)^{51}Cr}$ reaction can be used to monitor $Φ$ for a period of ~1 month. $	ext{^{66}Zn(γ,n)^{65}Zn}$ reaction can be used to monitor $Φ$ for a period of ~4 months.

CONCLUSIONS

The photoactivation technique was applied successfully in this work to monitor the high-energy photon fluence in the Varian 21EX 23MV CLINAC. The $\text{^{52}Cr(γ,n)^{51}Cr}$ and $\text{^{66}Zn(γ,n)^{65}Zn}$ reactions were used. $\text{^{51}Cr}$ and $\text{^{65}Zn}$ activities were measured using HPGe gamma spectrometer. chromium (stainless steel) and zinc foils were used. It was found that $\text{^{51}Cr}$, $\text{^{65}Zn}$ can monitor the fluence for short term (30 days) and long term (110 days), respectively. These results offer accurate and easy technique for the dose monitoring, which is necessary for better radiation protection.

ACKNOWLEDGEMENTS

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REFERENCES