Dose distribution and dosimetry parameters calculation of MED3633 palladium-103 source in water phantom using MCNP

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INTRODUCTION

103Pd brachytherapy sources for prostate and breast cancer therapy are usually used (1-3). Radiation oncologists at Toronto Sunnybrook regional cancer centre in Canada (3) have done the first breast cancer treatment in the world using small beads of 103Pd successfully. To calculate the effect of source shield or applicators and dose distribution usually the Monte Carlo codes such as MCNP, EGS4 or GEANT4 are applied.

Theoretical and experimental dosimetric studies have been supplied useful information on the dependence of the brachytherapy source geometry and material (4-7). To define dose distribution function, the radial dose variation, and the dose calculation close to the source in brachytherapy the Monte Carlo method are used. Rivard presented a discretized approach to determining TG-43 brachytherapy dosimetry parameters using Monte Carlo calculations for the MED3633 103Pd source (7). In addition, Meigooni et al. have determined dosimetric characteristics for brachyseed™ 103Pd, model Pd-1 source theoretically and experimentally (5). Corriveau et al. discussed morbidity effect of the time gap between supplemental beam radiation and 103Pd prostate brachytherapy (8).

In the present work, to calculate relative dose in water phantom, MCNP4C code is used (9). Then, the isodose curves and dosimetric characteristics for MED3633 103Pd source have been determined.

MATERIALS AND METHODS

The 103Pd Source

The internal construction and dimensions of the 103Pd source Model MED3633 is illustrated in figure 1. The source contains four resin spheres, each 0.5 mm in diameter, capsulated inside a titanium cylinder nominally of 4.5 mm length and 0.8 mm external diameter. Two 0.5 mm diameter spheres of gold-copper mixture were placed in...
the middle of the source, separating the radioactive spheres into two groups of two spheres. These gold-copper spheres therefore serve as radiographic markers for visualization during and after the prostate seed implantation process, constituting the "mid-markers" design. The photons spectrum emitted per decay of $^{103}$Pd and their intensities are listed in table 1 (7). The source photons' with energies less than 5 keV, and source beta electrons are ignored, due to their negligible chance of penetrating the titanium capsule.

### Method of dose calculation in water phantom

The dose distribution has been calculated around the $^{103}$Pd located in the center of 30×30×30 cm$^3$ water phantom cube (figure 2) by using tally F6:p of MCNP code (9). In order to use variance reduction techniques of MCNP, we have applied F6:p tally in our calculations. The tally in the sphere of 0.1 mm diameter cell was evaluated as dose in the point center of the sphere.

![Figure 1. Schematic diagram of the MED3633 $^{103}$Pd source.](image1)

![Figure 2. a) Scheme of water phantom and $^{103}$Pd source located in the centre of cube, b) the source in large size.](image2)

**Table 1.** The photon spectrum of $^{103}$Pd source, used in the simulation.

<table>
<thead>
<tr>
<th>Photon Energy (keV)</th>
<th>Photons per disintegration (%)</th>
<th>Photon Energy (keV)</th>
<th>Photons per disintegration (%)</th>
<th>Photon Energy (keV)</th>
<th>Photons per disintegration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.074</td>
<td>22.4</td>
<td>23.312</td>
<td>1.94</td>
<td>294.95</td>
<td>0.0028</td>
</tr>
<tr>
<td>20.216</td>
<td>42.3</td>
<td>39.755</td>
<td>0.0683</td>
<td>357.46</td>
<td>0.0221</td>
</tr>
<tr>
<td>20.717</td>
<td>10.4</td>
<td>62.51</td>
<td>0.00104</td>
<td>497.054</td>
<td>0.00401</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

**Monte Carlo dose calculation**

The relative dose curves along the X-axis with 0.1 mm step and along the Y-axis with 0.1 mm step was calculated. Dose at X=2 mm, Y=0 mm point was selected 100 as reference point in percentage depth dose (PDD) scale. Figure 3 shows the PDD variation along the X=1 and 2.5 mm which the effect of source shield is clear in this figure. PDD along Y=0 and 1.5 mm are shown in figure 4. Then, the isodose points by interpolate from relative dose curves were found. The isodose curves for 100%, 75%, 50% and 25% is shown in figure 5. It can be seen easily that $D=D(r, \theta)$, dose distribution depends to $r$ and $\theta$, distance from the center of source and polar angle, respectively. The results for computation of model dependent parameters in the next section are used.
Dose distribution and dosimetry of MED3633 $^{103}$Pd source

Radial dose function, and the dose rate constant and anisotropy function are others obtained dosimetry important parameters, which have been determined to compare our result with those. According to TG43 protocol \(^{(7,10)}\) the absorbed dose can be expressed as:

$$D(r, \theta) = S_k \Lambda G(r, \theta) F(r, \theta)$$  \hspace{1cm} (1)

where $S_k$ is the air kerma strength, $\Lambda$ is the dose rate constant, $G(r, \theta)$ is the geometry factor, $F(r, \theta)$ is the anisotropy function, $g(r)$ is radial dose function, $t$ is time, and $(r_0, \theta_0)$ is the reference point. To use our simulated...
data in treatment planning programs based on TG43 formalism, we have extracted the dosimetry parameters from our simulation expressed as following equation:

\[
\Lambda = \frac{D(r_0, \theta_0)}{S_k}
\]  

(2)

\[
g(r) = \frac{D(r_0, \theta_0)}{D(r, \theta)} \frac{G(r_0, \theta_0)}{G(r, \theta)}
\]

(3)

\[
F(r, \theta) = \frac{D(r, \theta)}{D(r_0, \theta_0)} \frac{G(r, \theta_0)}{G(r, \theta)}
\]

(4)

Upon comparison of \(g(r)\) for the \(^{103}\)Pd source measured or calculated by various investigators \(^4, 6, 7\), in table 2, it is evident that there has been relatively good agreement over all radial distances. Also, the values of dose rate constant \(\Lambda\) obtained by different authors are listed in table 3 which is in accordance with other results. Figure 6 also shows a comparison of \(F(1 \text{ cm}, \theta)\) obtained in this study and the results published by Rivard \(^4\).

**CONCLUSION**

The isodose curves of the MED3633 \(^{103}\)Pd source have been derived from dose calculation by MCNP code. The results show that by the Monte Carlo method dose deposition in high gradient region, near the source, could be calculated accurately. The calculated dosimetry parameters for the

| Table 2. Computational and experimentally obtained \(g(r)\) values against \(r\), reported by various investigators. |
|---|---|---|---|---|---|
| \(r\) (cm) | TLD by Wallace et al. (1999) | Diode by Li et al. (2000) | MCPT code by Li et al. (2000) | MCNP code by Rivard (2001) | MCNP code This work |
| 0.50 | 1.275 | 1.345 | 1.243 | 1.243 | 1.251 |
| 0.75 | 1.132 | - | 1.125 | 1.120 | 1.122 |
| 1.50 | 0.769 | 0.772 | 0.770 | 0.780 | 0.780 |
| 2.00 | 0.580 | 0.551 | 0.583 | 0.603 | 0.587 |
| 3.00 | 0.318 | 0.362 | 0.325 | 0.347 | 0.339 |

| Table 3. The values of dose rate constant reported by different authors. |
|---|---|---|---|---|
| \(\Lambda = 0.70\) | \(\Lambda = 0.721\) | \(\Lambda = 0.677\) | \(\Lambda = 0.672\) |
| MCNP code This work |
| \(\Lambda = 0.669\) |
source agree quite well with their Monte Carlo calculated and experimental measurement values. This study demonstrated a useful approach using MCNP code for dose calculation applicable to many other fields.

REFERENCES

3. The web site: http://www.stillwaterpalladium.com/medicine.html