Monte Carlo and experimental relative dose determination for an Iridium-192 source in water phantom

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INTRODUCTION

Theoretical and experimental studies have been applied for dosimetric parameters determination of the brachytherapy sources (1-3). Usually, Monte Carlo method has been used to define such quantities as the anisotropy dose function, the radial dose function, and the dose calculation close to the source in brachytherapy (4-6).

192Ir source is used widely in brachytherapy to treat localized tumors near body site. Daskalov et al. (7) have done dosimetric modeling of the microselectron HDR 192Ir source by the multigroup discrete ordinates method. Recently, Sureka et al. calculated the relative dose distribution and effective transmission around a shielded vaginal cylinder with HDR 192Ir source using MCNP4B (8). In the present study, MCNP4C (9) code was used to calculate relative dose and anisotropy dose function and radial dose function TG-43 dosimetry parameters of microselectron HDR 192Ir in a water phantom and compared with the measured dose by Gafchromic Rtqa film.

MATERIALS AND METHODS

The internal construction and dimensions of Microselectron HDR 192Ir source is illustrated in figure 1. The source has been manufactured by Nucletron Company (The Netherlands). The simulated source was a cylinder of about 30% Ir and 70% Pt with 21.704 g/cm3 density, encased in a stainless steel. It was assumed that the radioactive material to be uniformly distributed within the 192Ir active core. The decay scheme of 192Ir was available on-line in the Nuclear Data

Keywords: Brachytherapy, dose distribution, Monte Carlo method, MCNP code, anisotropy function, Gafchromic Rtqa film.

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Dose Calculation and Measurement in Water Phantom

Relative dose calculation

The dose distribution was calculated around the $^{192}\text{Ir}$ located in the center of a 30 cm x 30 cm x 30 cm water phantom cube (figure 3) by using tally *F8* of MCNP code. Tally *F8* was evaluated in the point center of a sphere with 0.1 mm diameter cell. First, the relative dose curves were calculated along the X axis with 0.2 mm step and along the Y axis with 0.2 mm step. Dose at X=1.5 mm, Y=0 mm point was selected as the 100% reference point for the percentage depth dose (PDD) scale. Then, the isodose points were by interpolate of PDD curves. Because of source symmetry along the Y axis, dose variation along the X axis had been the same as that of Z axis; so, the isodose curves in XY surface could be extended to isodose surfaces in 3-dimention XYZ space.

Dose measurement

The dose measurement was carried out by using Gafchromic Rtqa film (International Specialty Products Company). This kind of film is designed for routine quality systems management of all modalities of radiotherapy with ease and confidence in 0.02 Gy to 8 Gy dynamic ranges. PDD along X=2.5 mm and Y=10 mm was obtained to compare with Monte Carlo results.

Recently, Tsao et al. have reported the verification of the dose distributions around $^{192}\text{Ir}$ seed sources at radial distances from 0.5...
mm to 6 mm using Gafchromic film. They obtained isodose curve plots in the plane containing the source's longitudinal axis and dose rate plots in the radial direction by this technique. Also, Zilio et al. have reported valuable results of absolute depth-dose-rate measurements for an $^{192}$Ir HDR brachytherapy source in water using MOSFET detectors.

**RESULTS AND DISCUSSION**

Figure 4 shows the PDD variation along the X=0 mm. The effect of source shield is presented clearly in this figure. Figure 5a shows the Monte Carlo and experimental PDD along X=2.5 mm which are in good agreement. Also in figure 5b both results are shown along y=10 mm, in x \([-25\text{mm},25\text{mm}]\) interval are well matched; however, out of this range the Monte Carlo result were estimated to be lower. The discrepancy could have been due to the uncertainty in film positioning during the measurement. The isodose curves for 50%, 10%, 3%, and 1% and a typical PLATO result are showed in figure 6. PLATO brachytherapy software module provides image based planning and 3D visualization as a standard feature. In 1995, the Cleveland Clinic Foundation Taussig Cancer Centre initiated a Nucletron Microselectron $^{192}$Ir remote afterloading system into the brachytherapy service (Microselectron/PLATO Planning System). This system has been utilizing the PLATO dosimetry planning software, which allowed source dwell-time optimization to minimize

**Figure 4.** Monte Carlo result of PDD variation along the X=0 mm.

**Figure 5.** The Monte Carlo and experimental PDD results: (a) along X=2.5 mm and (b) along Y=10 mm.

**Figure 6.** The isodose curves calculated by MCNP (the reference Point: X=1.5mm, Y=0mm) (a), and a typical isodose curves of PLATO (b).
heterogeneity of dose distribution, a notable advance in the field of interstitial brachytherapy. It can be seen easily $D = D(r, |\theta|)$ that dose distribution has been dependent on $r$ and $|\theta|$ distance from the center of the source and polar angle, respectively. The results could be used for computation of model dependent parameters like anisotropy dose function. As it was mentioned before, Pia et al. (5) used the monochromatic spectrum at 356 keV in their simulation; because of energy dependency of attenuation coefficient, dose deposit of monochromatic and real spectrum source was different due to distance from the source. Figure 7 shows the dose variation and relative differences along the $y=0$ for both spectra. Farther from the source, deflection dose reached to 13%, and closer the source, it was 5% due to absorbing of low energy photons near the source and reaching some high energy photons to far distance of the source. These results showed no simplification on spectrum of the source in simulation process may be due to signification error.

**Determination of TG-43 dosimetry parameters**

Anisotropy function and radial dose function are dosimetry important parameters which have been determined to compare the results with those obtained by others. According to TG43 protocol (7, 12), the absorbed dose rate can be expressed as:

$$D(r, \theta) = S_i \Lambda \frac{G(r, \theta)}{G(r_0, \theta_0)} g(r) F(r, \theta)$$  \hspace{1cm} (1)

where $S_i$ is the air kerma strength, $G(r, \theta)$ is the dose rate constant, $\Lambda$ 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. For the use of the simulated data in treatment planning programs based on TG43 formalism, dosimetry parameters was extracted from simulation in the following expressions:

$$g(r) = \frac{D(r, \theta)}{D(r_0, \theta_0)} \frac{G(r, \theta)}{G(r_0, \theta_0)}$$  \hspace{1cm} (2)

$$F(r, \theta) = \frac{D(r, \theta)}{D(r_0, \theta_0)} \frac{G(r_0, \theta_0)}{G(r_0, \theta_0)}$$  \hspace{1cm} (3)

Anisotropy function was an important parameter in comparison with other studies. Figure 8 shows a comparison of $F$ (5 cm, $\theta$) obtained with experimental and Monte Carlo methods by Anctil et al. (13), Baltas et al. (14), Williamson et al. (15) and the results of the present study. A good agreement can be

![Figure 7. The dose variation (a), and relative deflection dose along the Y=0 mm for the real spectrum of $^{192}$Ir and the monochromatic at 356 keV (b).](image)

![Figure 8. Comparison of F(5 cm, $\theta$) obtained with experimental (Exp.) and Monte Carlo (MC) methods by others.](image)
observed between this work and other experimental/Mont Carlo results.

CONCLUSION

Monte Carlo simulation in brachytherapy has been useful to obtain model dependent parameters and to verify PLATO data, since the computational result was more accurate than the analytical PLATO data. Also the results can be used for computing anisotropy dose function. Dose can be calculated accurately by Monte Carlo method near the source because of high gradient dose variation in this region. The present work demonstrates a useful approach using MCNP code in dose calculation that can be applied in many other fields.

ACKNOWLEDGEMENT

The authors would like to thank Prof. G. Furlan, head of the TRIL program at ICTP, Trieste, Italy, for his contribution to this work. Also, A.A. Mowlavi would like to thank the Medical Physicists of Ospedale Maggiore for having a good scientific period with them.

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