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The dose distribution close to an ^{192}Ir wire source: EGS4 Monte Carlo calculations

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Abstract. A Monte Carlo simulation using the PRESTA version of the EGS4 code has been employed as an investigative tool to calculate the absorbed dose in water close to ^{192}Ir wire implants. It has been shown that a treatment planning system, such as GE Target II, using the Sievert integral and the Meisberger polynomial is only able to reproduce the Monte Carlo results at radial distances of 1 mm and farther away. The Sievert integral used with the Meisberger polynomial is proven to be in good agreement with the Monte Carlo generated data at distances between 1 mm and 1 cm.

1. Introduction

Recurrent cancer of the nasopharynx may require a local mould treatment with ^{192}Ir wires. Because of the close proximity of the nasopharyngeal mucosa to radioactive wires, the local dose can be exceedingly high. Most commercial treatment planning computers focus on the gamma-ray spectrum and the absorbed dose under electronic equilibrium conditions (kerma approximation). The contribution from the energetic secondary electrons due to the high atomic number of platinum (Pt) used in the encapsulation cannot be accounted for. These secondary electrons exiting from the Pt encapsulation will cause an enhanced dose rate near the surface of the wire compared with the electronic equilibrium absorbed dose in soft tissue in the same photon fluence.

The algorithm of the GE Target II treatment planning system (GE Target Series 2) employs the Sievert integral (Sievert 1921) and the Meisberger polynomial (Meisberger *et al* 1968). The Meisberger polynomial may not predict accurately the ratio of the kerma in water to the air kerma for radial distances less than 1 cm, where air kerma is the quantity measured using an ionization chamber.

By using EGS4 Monte Carlo simulation, we can find out the absorbed dose in water close to the ^{192}Ir wire source due to the secondary electrons exiting from the Pt encapsulation.

2. Monte Carlo simulation

The Monte Carlo system employed is the PRESTA (parameter reduced electron-step transport algorithm) version of the EGS4 (electron gamma shower) computer code. Detailed descriptions on the structure of the EGS4 code can be found in Jenkins *et al* (1988). For the simulation, the ^{192}Ir wire was modelled by two concentric cylinders with a total length of 150 mm. A cylindrical geometry package from Stevenson (1980) is employed as the HOWFAR subroutine in the EGS4 code. The thickness of the Pt encapsulation of the wire is 0.1 mm and the overall diameter is 0.3 mm. The source core is a mixture of 82% Pt and 18% Ir.

A total of 10^7 histories have been divided into 10 batches for calculation of statistics such as the standard error. The photon spectrum of primary photons of ^{192}Ir has been taken from Amersham International (1982), which contains four main peaks, namely 296, 308, 316 and 468 keV. Figure 1 shows the simulated results of the output photon spectrum exiting from the Pt encapsulation. The total photon transmission is 90.60(0.02)%.

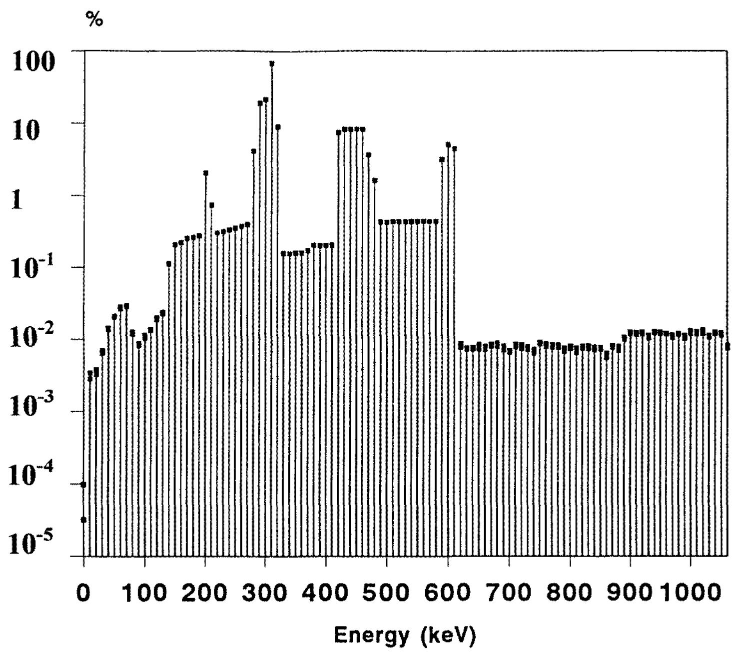

Figure 1. The energy distribution of photons exiting from a Pt encapsulated ^{192}Ir wire, shown as the percentage in a 10 keV interval relative to the total number of primary photons. The thickness of the encapsulation is 0.1 mm and the overall diameter is 0.3 mm. The source core is a mixture of 82% Pt and 18% Ir.

One way to verify our Monte Carlo user code is to compare the results made by Thomason *et al* (1991). These authors modelled the ^{192}Ir source as two concentric cylinders with a length of 3 mm and a total outer diameter of 0.5 mm, having a 0.3 mm diameter core of 90% Pt/10% Ir and a 0.1 mm thick Pt encapsulation (Alpha Omega Industries, Paramount, CA). After modification in source dimensions of our Monte Carlo user code, it can give the total photon transmission of 86.40(0.03)% which is consistent with that given by Thomason *et al* (1991).

One of the beauties of Monte Carlo simulation is its ability to identify the secondary electrons once they are generated from the Pt encapsulation. From figure 2, we see that there are a certain number of the secondary electrons with a mean energy of 216 keV exiting from the Pt encapsulation. Therefore, an enhanced dose rate will be expected at a small radial distance because of these secondary electrons.

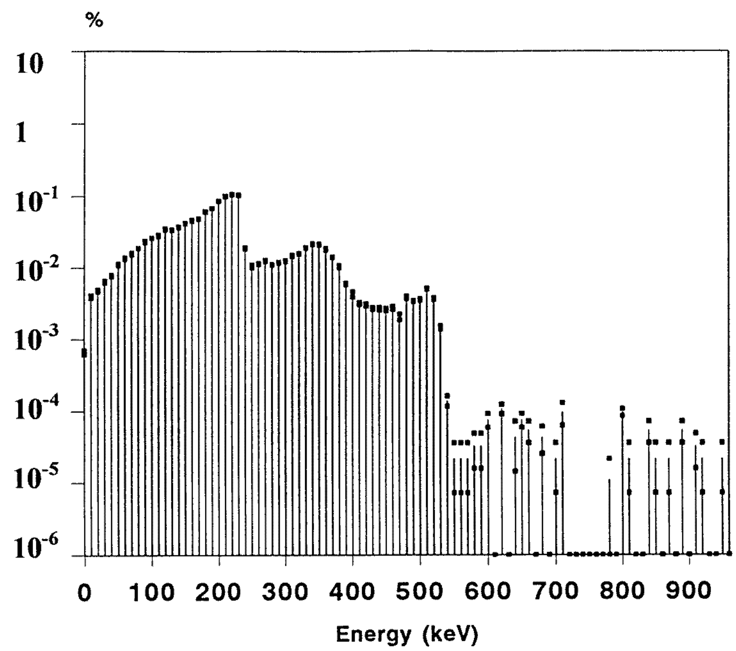

Figure 2. The energy distribution of secondary electrons exiting from a Pt encapsulated ^{192}Ir wire, shown as the percentage in a 10 keV interval relative to the total number of primary photons. The thickness of the encapsulation is 0.1 mm and the overall diameter is 0.3 mm. The source core is a mixture of 82% Pt and 18% Ir.

In calculating the dose distribution in water using the Monte Carlo simulation, a number of water cylinders are constructed around the ^{192}Ir wire source. The thickness of each cylinder is 0.1 mm. In figure 3, the Monte Carlo results of the absorbed dose rate against the radial distance in water has been shown. The total of 10^7 histories run for the simulation give average standard errors of less than 1.5% for all radial distances for the case with and without the secondary electrons from the Pt encapsulation.

At radial distances greater than about 1 mm, both the dose rate including and excluding secondary electrons from the Pt encapsulation coincide with each other. The GE Target II treatment planning system can only reproduce the Monte Carlo results at radial distances greater than about 1 mm (figure 3). However, the results in figure 3 show the fact that the Sievert integral used with the Meisberger polynomial is in good agreement with the Monte Carlo generated data at distances between 1 mm and 1 cm.

3. Experimental test of the Monte Carlo code

Thin TLD (TLD-100, Harshaw) chips are employed to measure the dose distribution of a 15 cm ^{192}Ir wire source (with apparent activity 51.06×10^6 Bq cm$^{-1} \pm 5\%$) in air with and without the insertion of the Perspex (PMMA) cylinder around the source. The TLD chips have dimensions of 3.175 mm $\times$ 3.175 mm $\times$ 0.381 mm. Figures 4 and 5 show the planar view set-ups in measuring the dose distribution with and without the PMMA cylinder. The outer and inner diameters of the PMMA cylinder are 2 cm and 1.62 cm respectively. The PMMA cylinder is long enough to cover the entire wire source. TLDs are hung between the

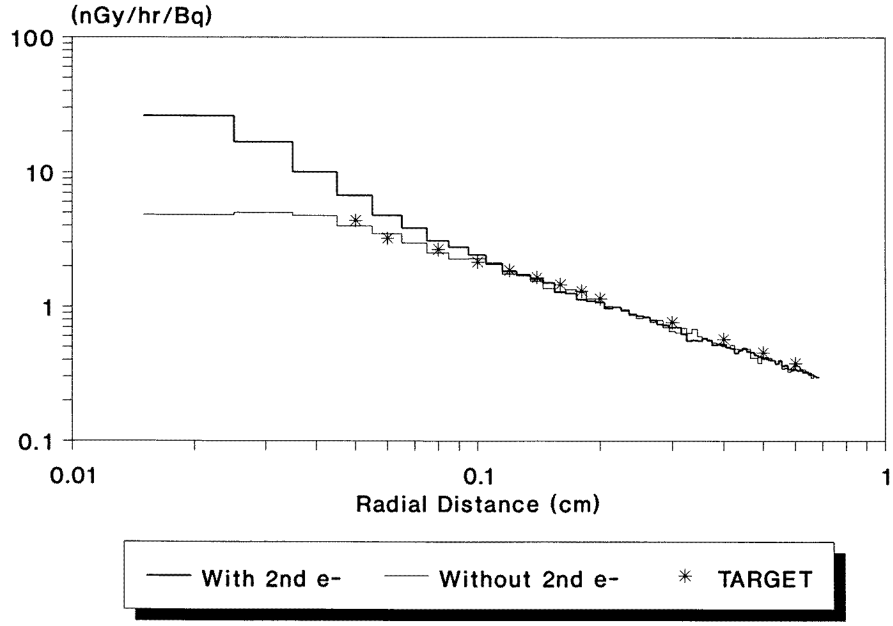

Figure 3. Comparison between the dose distributions in water for the cases with and without secondary electrons generated in the platinum encapsulation. The ^{192}Ir wire has an activity of 3.7×10^7 Bq.

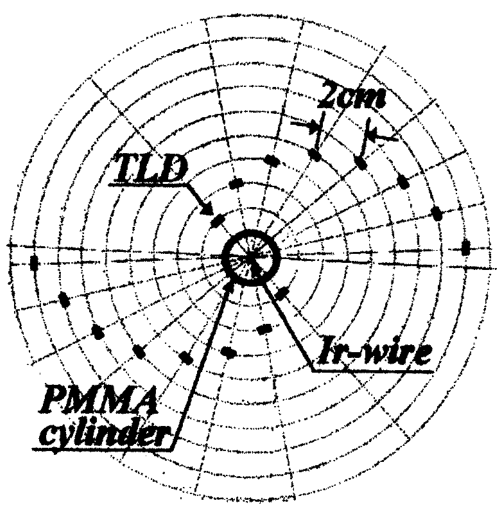

Figure 4. The set-up for the measurement of the dose distribution for the case with the insertion of the Perspex (PMMA) cylinder.

ends of the ^{192}Ir wire source and at radial distances of 2 cm to 9 cm from the wire source, in steps of 1 cm. It is expected that more created secondary electrons will exit from the Pt

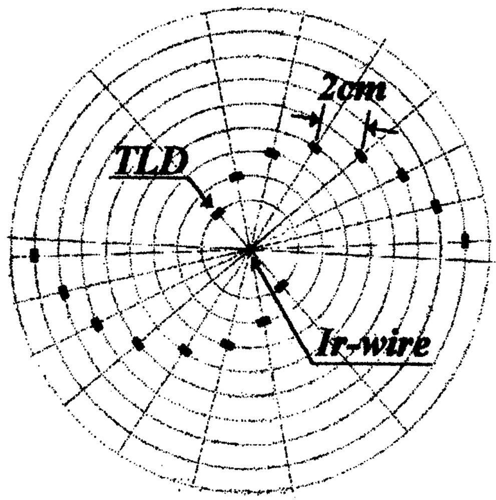

Figure 5. The set-up for the measurement of the dose distribution for the case without the insertion of the Perspex (PMMA) cylinder.

encapsulation than from the PMMA, since most of the secondary electrons exiting from the Pt encapsulation are absorbed by the PMMA cylinder. Therefore, a significant difference can be observed in TL signals between the case with and without the PMMA cylinder.

Table 1. The fractional decrease in TL readings at various radial distances after insertion of the PMMA cylinder.

Radial distance (cm)	Experimental results	Monte Carlo results with standard errors
2	$0.42^{+0.16}_{-0.15}$	0.45 ± 0.01
3	$0.44^{+0.12}_{-0.11}$	0.45 ± 0.02
4	$0.44^{+0.09}_{-0.10}$	0.46 ± 0.02
5	$0.44^{+0.09}_{-0.08}$	0.46 ± 0.02
6	$0.44^{+0.08}_{-0.08}$	0.45 ± 0.02
7	$0.44^{+0.06}_{-0.06}$	0.46 ± 0.02
8	$0.45^{+0.07}_{-0.07}$	0.49 ± 0.01
9	$0.45^{+0.06}_{-0.06}$	0.49 ± 0.02

The fractional decrease in TL signals at each radial distance after the insertion of the PMMA cylinder around the wire source is given in table 1. A rough calculation using attenuation coefficients tabulated by Hubbell (1982) shows that the fraction of photons exiting from the PMMA cylinder is equal to 95.8%. Therefore the large decrease in the TL readings is mainly due to the absorption of secondary electrons exiting from Pt encapsulation in the PMMA cylinder.

For a radial symmetry in the Monte Carlo geometry, a TLD is modelled by a ring of LiF. The thickness of the LiF ring has been set to the thickness of the TLD chips, which is 0.381 mm. Energy is scored within the ring to calculate the absorbed dose. In table 1, we see that the Monte Carlo results of the percentage decrease in TL signals after the insertion of the PMMA cylinder around the wire source are consistent with those measured by experiment.

4. Discussion and conclusions

From figure 3, we see that the GE Target II treatment planing system is able to reproduce the results of the EGS4 Monte Carlo simulation at 1 mm and larger radial distances. The enhanced dose due to the Pt encapsulation within 1 mm radial distances is not important because the tumour size is usually much bigger than 1 mm in radius. Furthermore, if the wires are in a mould, the thickness of the mould is about or even greater than 1 mm.

The actual dose (including the contribution of the secondary electrons exiting from the Pt encapsulation) modelled by the Monte Carlo simulation near the surface of the ^{192}Ir wire source in water is shown in figure 3, which is 26.1 nGy h^{-1} Bq^{-1} in SI units at a 0.1 mm range measured from the surface of the ^{192}Ir wire source. The Monte Carlo results of the dose distribution close to the ^{192}Ir wire source are difficult to obtain from direct measurements in water and the dose enhancement may easily be overlooked by medical physicists and radiotherapists. Since there may be occasions when the dose enhancement close to the wire is important, this work can be useful as a reference.

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