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Dosimetry of Strontium eye applicator: Comparison of Monte Carlo calculations and radiochromic film measurements

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Abstract. Strontium-90 eye applicators are a beta-ray emitter with a relatively high-energy (maximum energy about 2.28 MeV and average energy about 0.9 MeV). These applicators come in different shapes and dimensions; they are used for the treatment of eye diseases. Whenever, radiation is used in treatment, dosimetry is essential. However, knowledge of the exact dose distribution is a critical decision-making to the outcome of the treatment. The main aim of our study is to simulate the dosimetry of the SIA.20 eye applicator with Monte Carlo GATE 6.1 platform and to compare the calculated results with those measured with EBT2 films. This means that GATE and EBT2 were used to quantify the surface and depths dose-rate, the relative dose profile and the dosimetric parameters in according to international recommendations. Calculated and measured results are in good agreement and they are consistent with the ICRU and NCS recommendations.

1. Introduction

Due to fast and worldwide introduction of beta sources, Strontium-90 eye plaque brachytherapy is an established technique for the treatment of ocular melanoma. However, self-absorption and scattering cause difficulty to measure beta-isotope dose accurately [1]. The specific shape of this applicator, size of tumor and type of particles makes the calculation of dose distribution complicated. Indeed, the high dose gradient over short distances (~12 mm), requires using fast and accurate tools to estimate the dose. In the first method, radiochromic films are the suitable detectors for their capability of such spatial resolution and in the other way Monte Carlo methods, seem to be the best solution to obtain an accurate determination of dose distributions.

In this work, GATE (Geant4 Application for Tomographic Emission) Monte Carlo simulations v6.1 platform based on GEANT4 code was used to calculate dose distribution of Strontium ophthalmic applicator in water phantom and compared with measurements obtained with EBT2 radiochromic films [GafChromicTM, ISP Technologies Inc., Wayne, NJ, USA].

Finally; surface dose-rate, relative central axis depths dose-rate, relative central axis dose profile and dosimetric parameters calculated with GATE are compared with EBT2 radiochromic films measurements according to Report 14 of the Netherlands Commission on Radiation Dosimetry [Nederlandse Commissie voor Stralingsdosimetrie] (NCS) and report 72 of the International Commission on Radiation Units and measurements (ICRU) recommendations.

2. Materials and Methods

2.1 Source description

Strontium eye applicator SIA.20 manufactured by (Amersham Healthcare, Arlington Heights, IL) details are given in figure 1. For more details the reader is referred to Reft *et al* [1].

2.2 Monte Carlo calculations

MC code employed in this study is GATE 6.1 running on Lunix-based operating system. The first step in the process was to determine and verify the 90Sr/90Y spectrum (figure 2) by simulating a combined 90Sr and 90Y spectrums. It was run in a spherical water-phantom with a radius of 20 cm by 4x106 photons-electrons combination mode. The source was simulated as an isotropic point source centred in a water-phantom using an energy range of 0.00 MeV to 2.28 MeV [2].

GATE was used to simulate a SIA.20 eye applicator surrounded by a spherical water-phantom of 30 mm diameter and cylindrical detectors as shown in figure 3(a). Relative dose along the central axis of applicator (figure 3(b)) was calculated by summing deposited doses in each detector (1 mm3).

Six million primary electrons were generated depending on the 90Sr/90Y combined spectrum.

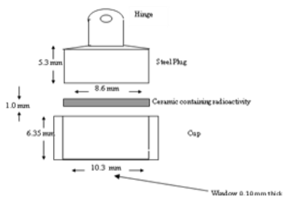

Figure 1. SIA.20 ophthalmic applicator.

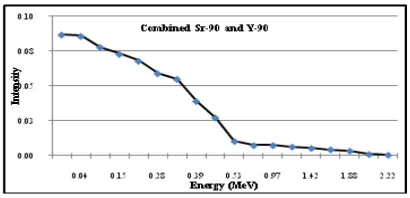

Figure 2. 90Sr and 90Y combined spectrum.

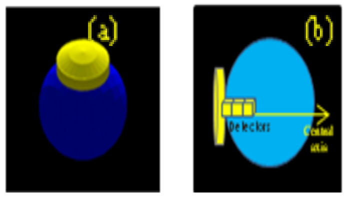

Figure 3. SIA.20 and phantom with GATE (a) and (b) detectors.

2.3 EBT2 Radiochromic film measurements

2.3.1 Film calibration

Seven EBT2 films (lot # A08301202; Expiration: August 2014) of 2x2 cm2 were calibrated with a 6 MeV electron beam using a 3x3 cm2 field (seven dose levels of 0.5 Gy to 10 Gy). Each film was positioned at a 108 mm source axis distance; to eliminate backscatter radiations a PMMA plate of 50 mm was placed underneath the film and another plate of 13 mm was placed in above to obtain a source phantom distance of 95 mm. Unexposed film was used as a zero point. Irradiated films were scanned in transmission mode 24 hours after exposure with an EPSON perfection V750-M scanner (Seiko Epson Corporation, Nagano, Japan). Obtained images (72 dpi and 48 bit RGB) were analyzed with QA FilmPro measuring average optical density (OD) derived from the red channel. Calibration curve of the dose depending on the OD is given in figure 4.

2.3.2 Irradiation procedure of EBT2 films with the eye applicator and dose evaluation

Eight films of 2x2 cm2 were used for SIA.20 doses measuring. EBT2 films were sandwiched in our specific phantom made of polystyrene (~1.05 g/cm3, thickness: 1 mm) and irradiated (Surface dose-rate was 0.53 Gy/s as on 15th Jun 1999) as shown in figure 5, for 30 seconds in the 03rd Feb 2014. The same process of scanning and analysis of films was followed. OD values of EBT2 films irradiated with the SIA.20 eye applicator were translated into dose values by extrapolation points using a third degree polynomial using the dose response curve [4].

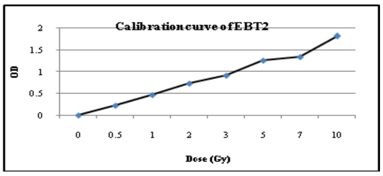

Figure 4. Calibration curve of the EBT2 film.

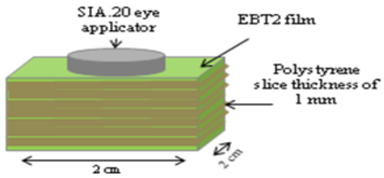

Figure 5. Irradiation of EBT2 films with the SIA.20 eye applicator.

2.4 Quality control (QC) of eye applicator

NCS and ICRU were established a task group to provide recommendations on detectors and procedures for the QC of eye applicators dosimetric parameters. These parameters had the same definition except reference depth, z0 = 1 mm (ICRU) and z0 = 2 mm (NCS). For more details the reader is referred to NCS Report 14 [4] and ICRU Report 72 [5].

3. Results and Discussion

3.1 Comparison of calculated and measured relative depth-dose along the central axis the SIA.20

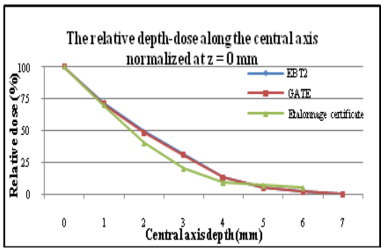

Figure 6. Relative depth-dose rate normalized at z = 0 mm.

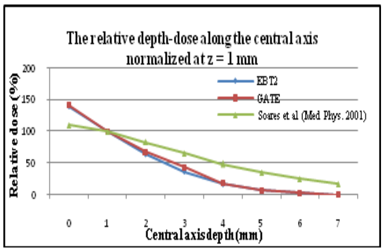

Figure 7. Relative depth-dose rate normalized at z = 1 mm.

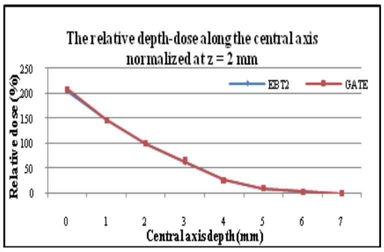

Figure 8. Relative depth-dose rate normalized at z = 2 mm.

Calculated and measured relative depth-dose rate at depth z = 0 mm as shown in figure 6, are in perfect agreement, but show poor agreement with the results provided by the manufacturer [6], with maximum deviations of the order of 63%. Based on experimental measurements the surface dose-rate of the applicator (the day of measurement) equal to 0.42 Gy/s, not 0.38 Gy/s calculated from the calibration certificate; therefore at reception of the applicator the surface dose-rate was 0.6 Gy/s, not 0.534 Gy/s which was provided by the manufacturer.

Figure 7 shows our SIA.20 calculated and measured relative depth-dose rate compared with Soares *et al* [7]. Depth-dose rate was normalized at depth 1 mm. Relative discrepancy between our calculated and measured values is very satisfactory, it doesn't exceed 7%, except 16% for the depth z = 3 mm which may be due to the bad placement of the detector in the simulation. However, relative discrepancies increase with depth between our calculated and measured values on one side and Soares *et al* [7] results other side until almost 100%.

Figure 8 shows the SIA.20 relative central axis depth-dose rate normalized at depth 2 mm for both the calculated and measured. Maximum relative discrepancy at each point doesn't exceed 7 %, which validates our MC simulation code.

3.2 Comparison of calculated and measured relative dose profile of the SIA.20 applicator

Calculated relative dose profiles along the central axis of applicator are in good agreement with measurements. However, relative discrepancies augment with increasing of depth and of perpendicular distance from the applicator central axis, but they do not exceed 17% in the worst case. This comparison demonstrates the good distribution of the applicators' radioactive material.

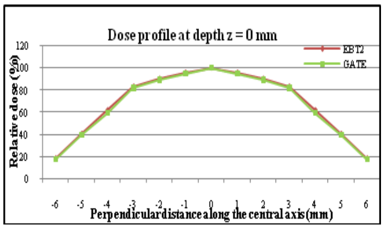

Figure 9. Relative dose-profile normalized at z = 0 mm.

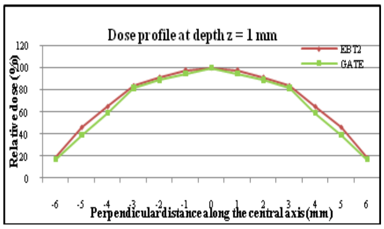

Figure 10. Relative dose-profile normalized at z = 1 mm.

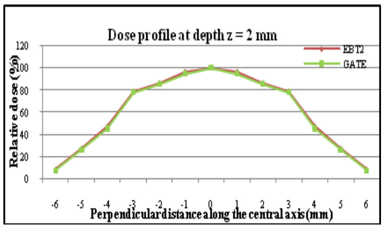

Figure 11. Relative dose-profile normalized at z = 2 mm.

3.3 Quality control of the of the eye applicator: comparison of calculated and measured

Table 1. Calculated and measured dosimetric parameters of the SIA.20 eye applicator.

	EBT2 films		GATE v6.1		Tolerance	
	NCS 14	ICRU 72	NCS 14	ICRU 72	NCS 14	ICRU 72
Average radius (R50)	03.60	04.25	03.70	04.30	/	/
Source non-uniformity (%)	19.00	18.00	18.00	17.00	30.00 ± 1	20.00 ± 1
Source asymmetry (%)	20.99	19.78	19.78	18.57	20.00 ± 1	20.00 ± 1

Calculated and measured dosimetric parameters are of the same order of magnitude. They comply with international recommendations seen previously.

4. Conclusion

GATE platform is an easy and powerful simulation tool for modeling accurate geometries; it is powered directly through command lines, and gives very accurate results. Relative central axis depth-dose rate and relative dose profile calculated with GATE are in good agreement with experimental results obtained with EBT2 films. These results demonstrate a good distribution of the applicators' radioactive material; also that maximum dose is on the applicator central axis. The QA of dosimetric parameters shows that SIA.20 non-uniformity and asymmetry are consistent with ICRU and NCS recommendations.

GATE offers to physicists a good alternative to experimentation i.e., good radioprotection, but the problem with this method is the large simulation time, which requires the use of a calculating grid.

5. References

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