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Test of Significance of Spectrum Choice on the Dose Distribution of High Dose Rate Ir-192 Brachytherapy Source

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Abstract: This study which follows test case 1 of the joint AAPM/ESTRO/ABG MBDCA-WG test cases investigates the impact of spectrum choice on the dose delivered by high dose rate (HDR) ^{192}Ir brachytherapy source placed in a water phantom. Geant4 Application for Tomography Emission (GATE) Monte Carlo Simulation toolkit macro script was written to design the geometry, materials, physics, actors, and radiation source for the simulation. Embedded in the water phantom was the simulated Microselectron HDR ^{192}Ir source. Five different spectra of the HDR^{192}Ir were considered, each defined according to its energy and intensity level. The emstandard_opt4 was adopted for the physics of the simulation process, with DoseActor as the scoring medium.

The results of the simulation with 4 x10^8 run histories revealed that the absorbed varied significantly with spectrum choice. The dose was determined to range from 2.65 x 10^{-7} to 2.07 cGy for Shirley; 1.19 x 10^{-8} and 3.65 cGy for Amersham and 1.59 x 10^{-7} to 2.57 cGy for Glasgow and Dillman. The NNDC spectrum was between 6.82 x 10^{-8} to 2.00 cGy while dose value between 1.36 x 10^{-5} and 1.74 cGy was observed for Duchemin and Coursol. The pairwise comparison of the spectra at 95% confidence level showed that among the five spectra, the pair combinations of NNDC, Shirley and Duchemin and Coursol spectra only were found to have no significant difference with the absorbed dose.

Keywords: GATE, HDR Brachytherapy, Monte Carlo Simulation, Phantom.

1 Introduction

Most common malignancies, including those of the head, neck, skin, and prostate, have long been treated using brachytherapy. It is a type of radiation treatment where a radioactive source is inserted either inside or next to a tumour. Brachytherapy sources are classified low and high dose rate based on the length of radiation exposure time, the energy of the photons released and the radioactive source strength [1- 4]. Unlike the low dose rate (LDR) brachy therapy radiation sources, involving emission of continuous radiation for a period of between 1 and 7 days, utilising biological and physical properties to destroy tumour cells, for brachy therapy with high dose rate (HDR) source, the exercise lasts between 10 and 20 minutes. Radioactive sources for LDR brachytherapy techniques, which are implanted permanently include ^{125}I, ^{131}Cs, and ^{103}Pd while ^{60}Co and ^{192}Ir commonly used when HDR brachytherapy is required are only placed temporarily during treatment.

The use of brachytherapy to achieve a high rate of tumour control not only inhibits cancer growth but also has negative side effects on normal tissues [5]. It is thus critical to investigate the dose distribution of radiation sources in order to design safe and reliable treatment strategies in clinical practice. The 1994 recommendations in the American Association of Physicists in Medicine (AAPM TG-43(U1) task group reports 43 and update dosimetry protocol of the American Association of Physicists in Medicine (AAPM TG-43(U1) on dosimetry protocol have played significant role in the dose calculations of the brachytherapy sources. Dosimetry parameters like air-kerma strength, and dose-rate constant were considered by the AAPM TG-43 and updates for the clinical use of brachytherapy sources [6-8]. However, TG-186 report provided further guidance for using alternative and more reliable approach to dose calculation with the Model-Based Dose Calculation Algorithms (MBDCA). This has provided insights and tools for the medical physicist to establish reference data for the application of MBDCAs for quality assurance programme of individual treatment facility [9].

The existence of high processors and super computers has made the modeling and simulation of radiation treatment easier via Monte Carlo (MC) methods. Among the MC toolkits validated to simulate clinical radiation treatments is the Geant4 Application for Tomographic Emissions (GATE) [10]. The GATE (up to version 9) is a macro-based simulation toolkit of the generic Geant4 MC simulation package. It comprises text files describing the geometry, materials, description of the source and the phantom. The information from GATE simulation includes the parameters of interest in dosimetry like the energy deposited and the dose distribution in the phantom,

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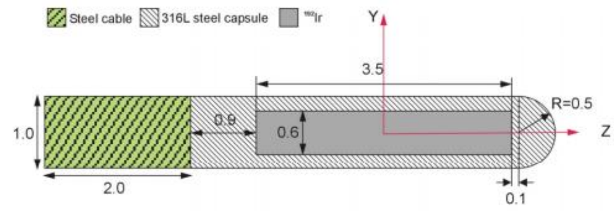
usually water material as obtainable in clinical set-up. For brachytherapy, a volumetric source is simulated with the radiation considered emitted randomly within the radioactive volume. Several spectrum choices are available for investigating dosimetry of some brachytherapy source like ^{192}Ir. Such studies include that of Rivard et al. [11], where Kerma and dose rates in air and water were adopted in the MC investigation of the influence of photon energy spectra from some brachytherapy sources, namely ^{192}Ir, ^{125}I and ^{103}Pd using GEANT4, MCNP5, and PENELOPE-2008 for water and air phantoms. For the spectra considered, no statistically significant differences were observed between the dosimetric parameters within same spectrum. However, there was Water kerma difference of 2%, 2% and 0.7% among different spectrum choice radionuclides ^{192}Ir, ^{125}I and ^{103}Pd respectively irrespective of the radial distance [11]. However, there has not been a report identifying which spectra choice or group of choices of the spectra considered was responsible for the observed difference of the dose and related parameters in water phantom for the brachytherapy sources. This study considers the case 1 of TG 43 among other cases reported by the joint AAPM/ESTRO/ABG MBDCA-WG with the aim to identify the spectrum or group of spectra responsible for the significant difference of the dose (kerma) of the HDR ^{192}Ir brachytherapy source in water phantom, using the same five commonly used spectra for dosimetric studies of the HDR ^{192}Ir as adopted by Rivard et al. [11], namely the Amersham Medical Radiation Sources Catalogue[14], Glasgow and Dillman [15], Duchemin and Coursol[16], Shirley[17] and NNDC[18].

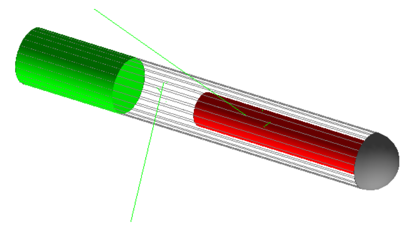
2 Materials and Methods

Monte Carlo Simulation

The simulation in this study follows macro-outlines described in GATE documentations [19] typically: Geometry (This starts with the simulation space called world); Physics list; Source; Actors and Visualisation. The materials in the simulation were as stated in the GateMaterials database file. The geometry of all the volumes were designed and contained in the world, modeled as a 100 cm x 100 cm x 100 cm box having a predefined 51cm x 51cmx 51cm water phantom, since 70% of biological tissue is water. The Physics protocol for the simulation was the emStandard _opt4, packaged to take care of the processes in medical physics applications. The HDR ^{192}Ir was defined based on the compositions and dimension stated by the source manufacturer (Nucletron Company, Netherlands) as analytically reported earlier in Ballester et al. [12]. The source consists of four compartments: capsule cylinder, capsule cap, cable, and active cylinder. The source is a common source globally used for HDR brachytherapy. The composition of the encapsulation and active material are as shown in Figure 1.



a. Analytical description



b. GATE simulated source

Fig. 1: (a): Compositions and dimensions(mm) for the generic HDR ^{192}Ir brachytherapy source [12]

The source is a cylinder of radius 0.3 mm and length 3.5 mm, placed in a water box Phantom dimension (51.1cm x 51.1cm x 51.1cm x 51.1cm) having its origin common to the centre of the world. DoseActor recording the energy deposition (MeV) and the dose (Gy) is attached to 20.1cm x 20.1cm x 20.1cm size of the phantom, translating to 201 voxels in the x, y and z axes.

The Discrete Spectrum source type was used, and the radiation type defined as gamma. Details of the intensity and energy contained in each of the five spectra of the HDR ^{192}Ir considered were as provided in [11]. The 4 x 10^8 number of primary run histories adopted was as reported in an early related study using Geant4 simulation package [18]. For MC simulations, a high number of runs is often required to ensure enough statistics for sufficiently reliable results.

3 Results and Discussion

The graphic visualization of the simulated HDR ^{192}Ir brachytherapy source is presented in figure 1b. Following the size and resolution (voxel) of the water phantom specified [12] for the dosimetry computation using the HDR ^{192}Ir brachytherapy source, the absorbed dose computed in each voxel of the phantom, for the five spectra of the HDR ^{192}Ir is presented in table 1. The absorbed dose delivered to the water phantom was found to range between 2.65 x10^{-7} and 2.07cGy for the spectrum Shirley. The range of the dose for Amersham, Glasgow and Dillman are respectively 1.19 x10^{-8} - 3.65cGy and 1.59 x10^{-7} - 2.57 cGy. While for NNDC, Duchemin and Coursol the dose ranged from 6.82 x10^{-8} - 2.00 cGy and 1.36 x10^{-5} - 1.74 cGy. Also presented in table 1 is the mean dose to the phantom. Both Amersham and Duchemin and Coursol spectra had the same mean dose value of 5.90 x10^{-5} cGy. This was observed as the highest mean dose value. The least mean dose 2.52 x 10^{-5} was from the NNDC spectrum.

Test of Significance

The significance of the spectrum choice on the variation of the absorbed dose was tested with the analysis of variance (ANOVA), at 95% level of confidence. The result (Table 2) showed that spectrum choice significantly impacts the absorbed dose of HDR ^{192}Ir in the water phantom at the chosen level of confidence. The pairwise comparison of the spectra revealed that there exists no significant difference between the pairs of Shirley - NNDC; Shirley – Glasgow and Dillman; and NNDC – Glasgow and Dillman.

Table 1: Absorbed dose of HDR ^{192}Ir brachytherapy source in water phantom

Spectrum	Voxel size	Minimum Dose (cGy)	Maximum Dose (cGy)	Mean Dose (cGy)
Shirley	201	2.6535 x 10^{-9}	2.07	3.12 x10^{-5}
Amersham	201	1.19 x 10^{-6}	3.65	5.90 x10^{-5}
Glasgow & Dillman	201	1.59 x 10^{-7}	2.57	2.82 x10^{-5}
NNDC	201	6.82 x 10^{-8}	2.00	2.52x10^{-5}
Duchemin and Coursol	201	1.36 x 10^{-5}	1.74	5.90 x10^{-5}

Table 2: Showing the Pos-Hoc Test

Pairwise Comparison		Lower Limit Dose*	Estimated Dose	Upper Limit Dose	P-value	Comment
Shirley	Duchemin and coursol	1.4547x10^{-6}	1.3943 x10^{-6}	1.3339 x10^{-6}	0	Significant
Shirley	Amersham	3.3914 x10^{-7}	2.7874 x10^{-7}	2.1834 x10^{-7}	0	Significant
Shirley	NNDC	1.1084 x10^{-9}	5.9292 x10^{-8}	1.1969 x10^{-7}	0.0573	Not significant
Shirley	Glasgow and Dillman	3.0873 x10^{-8}	2.9527 x10^{-8}	8.9927 x10^{-8}	0.6702	Not significant
Duchemin and coursol	Amersham	1.0552 x10^{-6}	1.1156 x10^{-6}	1.1759 x10^{-6}	0	Significant
Duchemin and coursol	NNDC	1.3932 x10^{-6}	1.4536 x10^{-6}	1.5140 x10^{-6}	0	Significant
Duchemin and coursol	Glasgow and Dillman	1.3634 x10^{-6}	1.4238 x10^{-6}	1.4842 x10^{-6}	0	Significant
Amersham	NNDC	2.7763 x10^{-7}	3.3803 x10^{-7}	3.9843 x10^{-7}	0	Significant
Amersham	Glasgow and Dillman	2.4787 x10^{-7}	3.0827 x10^{-7}	3.6867 x10^{-7}	0	Significant
NNDC	Glasgow and Dillman	9.0165 x10^{-8}	2.9765 x10^{-8}	3.0636 x10^{-8}	0.6634	Not significant

* All dose values are absolute and in cGv

4 Conclusion

The study adopted Monte Carlo simulation toolkit to investigate the effect of ^{192}Ir spectrum on the absorbed dose of HDR ^{192}Ir brachytherapy source in voxelised water phantom. Results showed that the choice of the spectrum contributes significant impact on the absorbed dose in water phantom; thus, presenting necessary information, important for consideration when simulating parameters for dosimetric application in brachytherapy optimisation with HDR ^{192}Ir source.

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His pioneer work has been published in numerous prestigious journals, and he has received several accolades, recognizing his contributions to the field. In addition to his research, Mr. Oloyede is an advocate for science education and frequently delivers lectures and public talks to inspire the next generation of scientists

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