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The Caluculation of 3D Saptial Dose Distribution Around a Shielded Vaginal Cylinder with Iridium-192 Source Calculated by using Monte Carlo Code EGS4

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Abstract

According to our previous study on the dose distribution around a shielded vaginal cylinder with a high-intensity ^{192}Ir source by using EGS4 code, the more detailed 3D-simulation model was established in this work. The results obtained by the 3D-simulation model were compared with those measured by ion chamber in previous work and evaluated by the existing treatment planning system. These results show good agreement. Furthermore, the 3D spatial dose distribution around a unit intensity ^{192}Ir source was calculated at each probable position in the vaginal cylinder with 90°, 180°, 270° tungsten shield and no shield cases. Those results save as a database which could be accessed through the graphical user interface developed by IDL^{TM} to display dose distributions in 1D, 2D, and 3D plot under any combination of source intensity at each position, and shielding situation. It demonstrates a prototype of the brachytherapy treatment planning system based on the Monte Carlo EGS4 code.

1 Introduction

^{192}Ir is a widely used source in brachytherapy to treat localized malignancies in nearly every body site and a variety of such source are commercially available. Both theoretical and experimental methods have been widely used to characterize the dose distributions around an isolated source in water medium[1-7] and the heterogeneity correction factors for such a source near localized heterogeneity[8]. An intracavitary source consisting of encapsulated high-intensity (1 Ci) ^{192}Ir is available for using in high dose rate (HDR) single-stepping source remote afterloaders to treat vaginal and cervix malignancy. The vaginal cylinder is one typical set of applicator applied in the treatment of the vaginal lesion. Due to the radiosensitivity of the adjacent organs, e.g. bladder and rectum, severe complication of rectal bleeding may develop for some of the patients. For these patients, a shielded vaginal cylinder (Applicator 084.320 Nucletron Corporation, Columbia MD, USA) was developed to reduce excess dose to the rectum. The previously available commercial brachytherapy treatment planning programs did not take the perturbation into consideration when the presence of high-density material such as tungsten shield. Waterman had measured the planar dose distributions around a high-activity ^{192}Ir and proposed a way to evaluate the dose distributions under the presence of tungsten shield[9]. In our previous study[10], the dose distribution around a shielded vaginal cylinder with an ^{192}Ir source could also be calculated by applying EGS4 Monte Carlo code. The relative isodose distribution calculated by EGS4 on the transverse plane at source location shows good agreement with the measurements obtained by ion chamber and diode detector in water phantom. It demonstrates the reliable and accurate modality to apply EGS4 code for the simulation of this kind of problem. One might take advantage of using EGS4 to calculate the dose distribution in heterogeneous media owing to the capability of Monte Carlo method dealing with three-dimension problem and the flexibility of EGS4 code describing arbitrary 3D geometry models. Hence, the purpose of this work is to apply EGS4 code to calculate the 3D spatial dose distribution around a shielded vaginal cylinder and propose a way to use these results in practical applications. However, it is difficult to implement a real time Monte Carlo calculation for clinical applications because of its time consuming. Therefore, it is more realistic to establish a database which includes the data pre-calculated by EGS4 for the 3D spatial dose distribution around an unit intensity ^{192}Ir source at several positions in the vaginal cylinder with 90°, 180°, 270° tungsten shield and without shield. Furthermore, a visualized user interface was developed by using Interactive Data Language (IDL$^{\mathrm{TM}}$) for accessing this database. Through the interactive graphical user interface, it provides a convenient way to display the 3D spatial dose distribution obtained by EGS4 calculations for any probable combination of source and shielded situations. This work indicates that the database of 3D spatial dose distributions around a shielded vaginal cylinder pre-calculated by EGS4 could be applied to develop a practical treatment planning system. The treatment planning system based on Monte Carlo method could provide some more detailed and accurate dose distribution for the shielded case.

2 Materials and Methods

The EGS4 computer code was used to simulate the 3D-dose distribution around a shielded vaginal cylinder with an ^{192}Ir source. The simulation could be divided into two main components: the ^{192}Ir source, and the shielded vaginal cylinder. The details of each component, including the encapsulation material, the composition and thickness of the applicator wall, and the composition and geometry of shielded vaginal cylinder are described as closely as possible.

The source simulated in this work is the HDR ^{192}Ir source (designed by Nucletron-Oldelft International B. V. and manufactured by Mallinckrodt Diagnostica) is shown schematically in Fig. 1[11]. The cylindrical active ^{192}Ir pellet has a length of 3.5 mm and 0.6 mm in diameter. It is encapsulated in AISI 316L stainless steel sheath with an outer length of 5 mm and 1.1 mm in diameter. One end of the source has a round shape, and the distance form the distal face of the active source core to the physical source tip was 0.55 mm. The energy of the emitted photons from the unencapsulated ^{192}Ir source simulated in this work was listed in table 1[12].

The internal construction and dimensions of the shielded vaginal cylinder (Applicator 084.320, Nucletron Corporation, Columbia MD, USA) of 3.0 cm in diameter upon our simulation are based, are illustrated by Fig. 2. The applicator consists of 15-cm long cylinder plastic shell with an outer diameter of 3.0 cm and 0.5 cm thick wall. It centered on a thin-wall stainless steel tube (0.4 cm o.d.) which serves as pathway for the ^{192}Ir source. There is an air gap between the steel tube and the inner wall of the cylinder. This gap could be filled with 0.8 cm thick tungsten 90°, 180°, or 270° shield. All of these components are held in place along with the central tube by the plastic end cap.

The geometry model of EGS4 simulation was shown in Fig. 3. As it shown, the detailed geometry of the components that were near the tip of cylinder was also taken into consideration. In the EGS4 simulation, the scoring volume for recording spatial dose distribution was divided into two regions, semi-spherical region (10 cm in radius) and the cylindrical region (10 cm in radius and 10 cm height). The space of the semi-spherical region was divided into $50 \times 36 \times 144$ scoring volumes, respectively in radial direction, polar angle, and azimuthal angle. The space of the cylindrical region was divided into $50 \times 40 \times 144$ scoring volumes, respectively in radial direction, axial direction, and azimuthal angle. The number of particles tracked in EGS4 simulation was chosen to keep the statistic deviation of all the results under 5% level.

3 Results and Discussions

3.1 The verification of the 3D simulation model

In our previous study, the dose distribution around a shielded vaginal cylinder was concerned only on the plane where the ^{192}Ir source was. The detail geometry of two ends was simplified in our previous simulation model. In order to evaluate the 3D spatial dose distribution, the 3D-simulation model was established in this work. Hence, this 3D model was verified with the previous results at first. Fig. 4 and Fig. 5 show the relative dose fall-off in the radial direction and the isodose curve on a transverse plane containing the ^{192}Ir source for the unshielded vaginal cylinder respectively. The relative dose was normalized to 0.3 cm away from the cylinder wall. The results evaluated by the 3D-simulation model show good agreement with those measured by ion chamber in our previous work.

3.2 The comparison with the commercial treatment planning system

The 3D-simulation model was compared with the commercial brachytherapy treatment planning system that was adopted by the cancer center of the Veterans General Hospital-Taipei[13]. Fig. 6 shows the dwell time of the ^{192}Ir source at each position for a clinical case, in order to meet the prescribed dose, 500 cGy at 2 cm offset from the center point in radial direction and 3 cm offset from the center point in axial direction. The isodose curve evaluated and plotted by the treatment planning system is also shown in Fig. 6. According to the dwell time of the source at each position, the spatial dose distribution around the vaginal cylinder was also calculated by the 3D-simulation model of this work. The results evaluated by commercial treatment planning system and EGS4 were shown in Fig. 7. These results show good agreement in prescribed dose position in radial direction, but some discrepancy close to the source axis. The discrepancy is due to the existing treatment planning system neglected heterogeneity effect, such as the encapsulated material of source and the guide tube. The effect of heterogeneity and oblique filtration could be taken into consideration by EGS4 simulation without any extra effort.

3.3 The prototype of treatment planning system based on EGS4

One important benefit of using EGS4 simulation is its capability of dealing with three-dimension problems, especially the presence of heterogeneity. However it is difficult to implement a real time Monte Carlo calculation for clinical applications because of its time consuming. It is more realistic to establish a database that includes the data pre-calculated by EGS4 for the 3D spatial dose distribution around an ^{192}Ir source under all probable combination of source position, intensity and shielding situations. As it shown in Fig. 8, each source position and stepping size in the applicator is fixed for the HDR system. Hence, the spatial dose distributions around the cylinder with an unit intensity ^{192}Ir source were calculated by the 3D simulation model of this work at each probable position in the vaginal cylinder with 90°, 180°, 270° tungsten shield and no shield cases. These results were save as a database and could be accessed by the graphical user interface developed by using Interactive Data Language (IDL$^{\text{TM}}$)[14]. Through this interface, it provided an interactive graphical user interface to display 1D, 2D, and 3D spatial dose distribution obtained by EGS4 calculations for any probable combination of source and shielded situations. Fig. 9 shows the interactive dialog for setting up the source positions, intensity and shielding situation. The dwell time and positions mentioned in above paragraph with 180° tungsten shield were input, the 1D radial dose distribution and 2D isodose curve on transverse and vertical plane could be shown by this interface as it shown in Fig. 10. Furthermore, The 3D-isodose volume could be also displayed. Fig. 11 shows the isodose volume (100 cGy) of a single source in the vaginal cylinder with 90° shield. Through this interactive graphical user interface, users can generate and display the results pre-calculated by EGS4 in a few seconds. It seems to be a prototype of our treatment planning system based on Monte Carlo code EGS4 for the shielded vaginal cylinder.

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Table 1 The energy distribution of 192Ir assumed by our EGS4 simulation

Energy (MeV)	yield	Energy (MeV)	yield	Energy (MeV)	yield
0.06683	0.10380	0.30850	0.29300	0.48906	0.00476
0.07563	0.02869	0.31650	0.83000	0.58860	0.04470
0.20138	0.00707	0.41647	0.01456	0.60440	0.08230
0.20580	0.03180	0.46810	0.47700	0.61250	0.05340
0.29600	0.28300	0.48460	0.03130	0.88454	0.00345

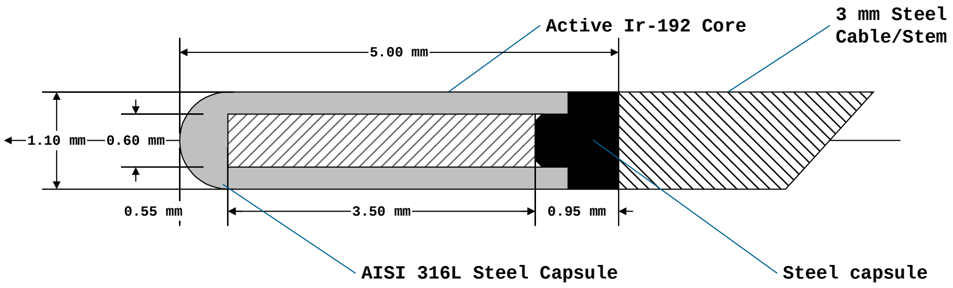

Figure 1: Geometric models of the MircoSelectron HDR ^{192}Ir source.

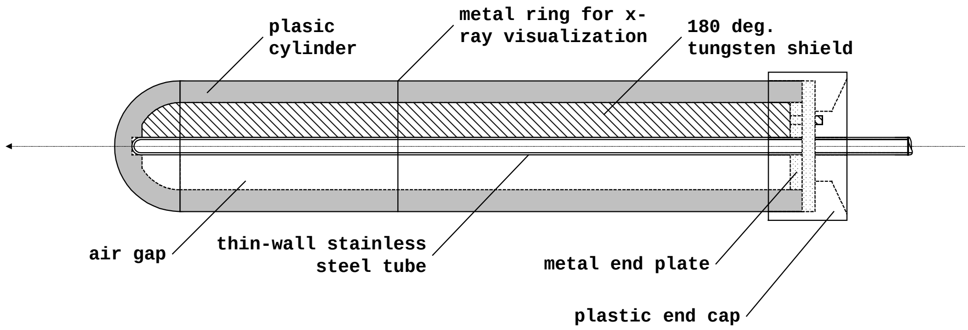

Figure 2: Geometric models of the shielded vaginal cylinder (Applicator 084.320 Nucletron Corporations).

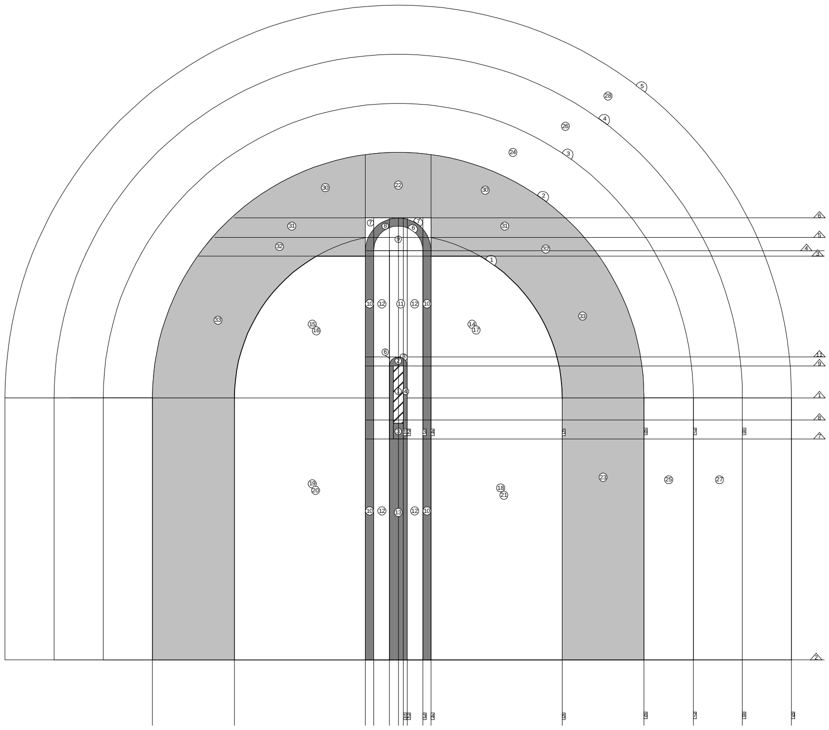

Figure 3: The geometric model of the 3D spatial dose distribution assumed by our EGS4 simulation.

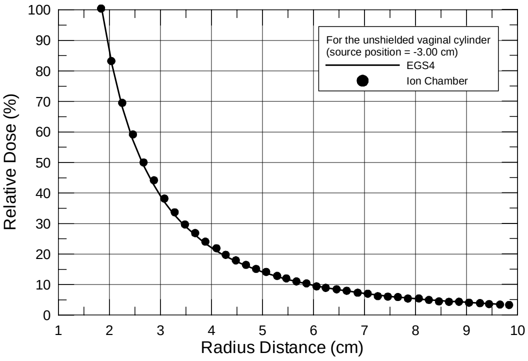

Figure 4: Relative dose fall-off along the radial direction on a transverse plane containing the ^{192}Ir source for the unshielded vaginal cylinder.

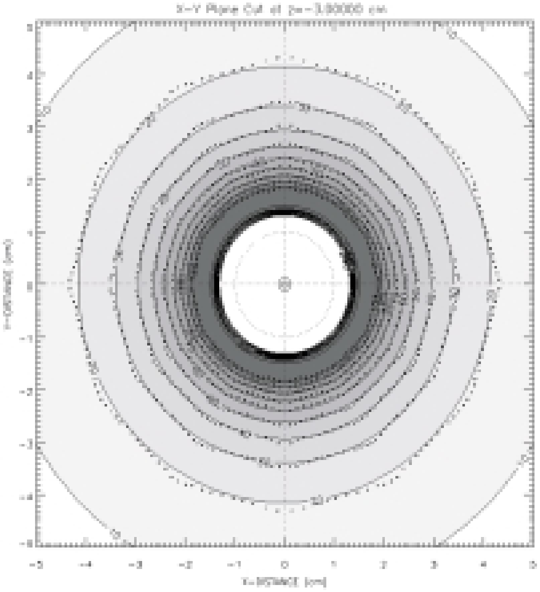

Figure 5: Isodose curve on the transverse plane containing the ^{192}Ir source for the unshielded vaginal cylinder (solid lines are the results obtained by 3D model, dot lines are those measured by ion chamber).

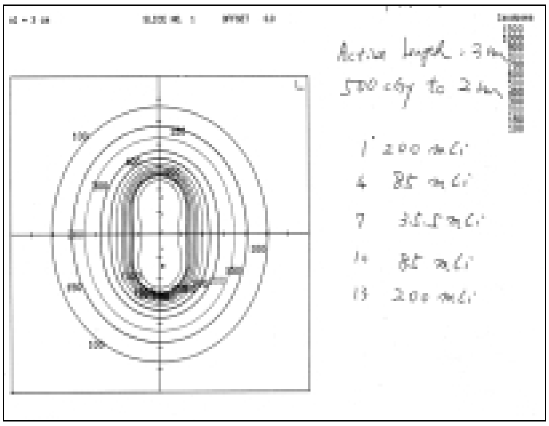

Figure 6: The dwell time and position of ^{192}Ir source in the vaginal cylinder meet the prescribed dose for a clinical case. The isodose curve was evaluated by existing treatment planning system.

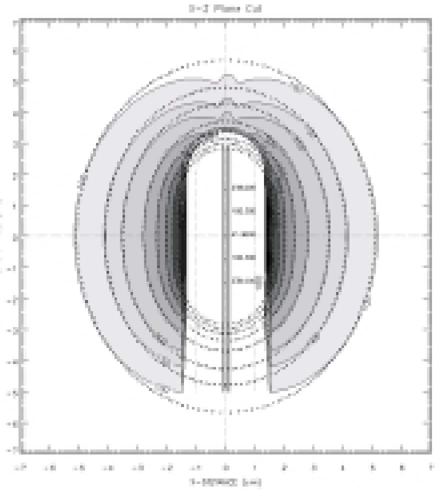

Figure 7: The comparison of isodose curve obtained by 3D simulation model and existing treatment planning system.

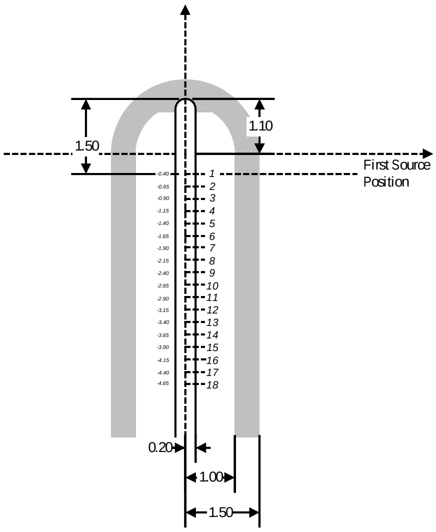

Figure 8: The probable source dwelling positions in the shielded vaginal cylinder for the HDR system.

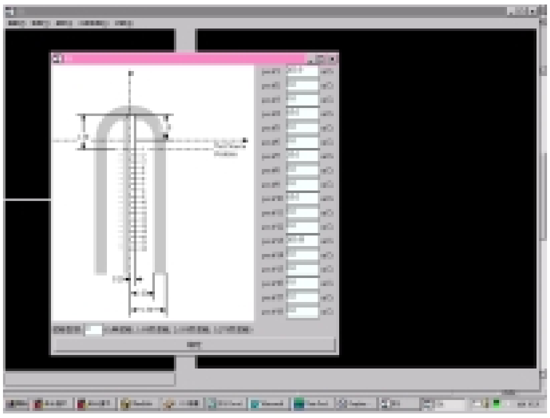

Figure 9: The interactive dialog for setting up the source intensity at each position in the shielded vaginal cylinder and shielding situation.

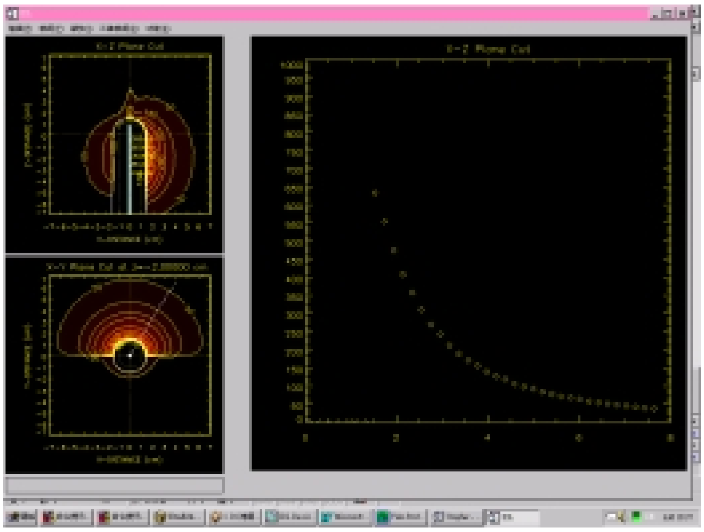

Figure 10: The 1D radial dose distribution and 2D isodose curve on the transverse and vertical plane under a given source arrangement with 180° tungsten shield.

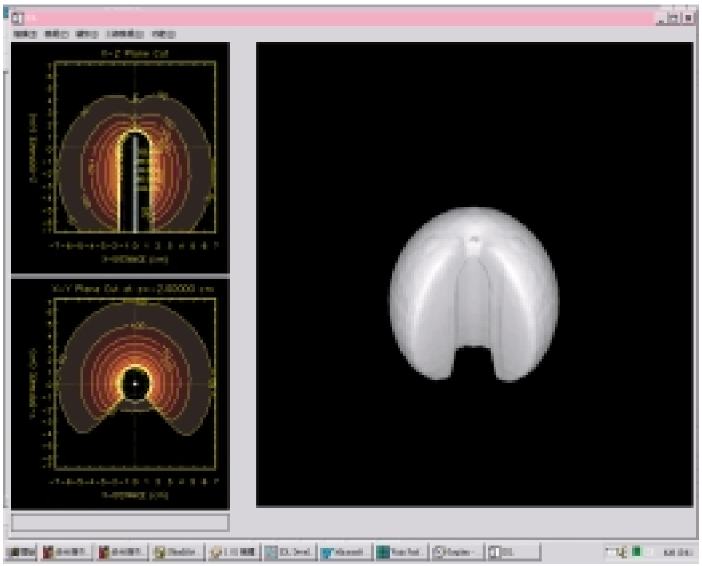

Figure 11: The 3D-isodose volume under a given source arrangement with 90° tungsten shield.