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Original article

Non-Uniform Spatial Dose Distributions Around Co-60 in Human Tissue for Brachytherapy Treatment using Monte Carlo EGS Code

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ABSTRACT

Brachytherapy (BT) uses encapsulated radioactive sources to deliver low (LDR) or high (HDR) dose rates to tissues. The source is implanted interstitial into tissues such as the radioactive needles used in the treatment of tongue carcinoma. These sources must be calibrated to accepted standards. In previous work, we used Monte Carlo Electron Gamma Shower EGS Code for simulating the use of Ir-192 source capsule interstitial in tongue within the oral cavity. In the present work, we extended the simulation to Co-60 source capsule which, for simplification, is similar in structure and surroundings to the Ir-192 one. Radiation Data analysis and spatial Dose distributions are presented. Simulations of non-uniform dose distributions in both the source capsule and the surroundings were presented. Data preparation and examinations of the source capsule details were carried out and compared with the published data. Both depth and radial dose curves are also analyzed. The results showed that Monte Carlo EGS is practically applicable to dose distribution estimate around brachytherapy source applicators. The dose distributions are maximum around the source and fall to minimum rapidly in the near tissue that could be adjusted for the chosen dose value. Comparisons with Ir-192 are one of our objectives in future investigation.

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INTRODUCTION

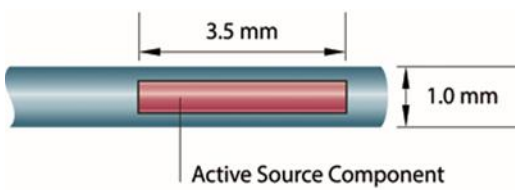
Radioactive source used in high dose rate HDR brachytherapy (BT) for clinical practice needs dosimetric data as recommended by the American Association of Physicists in Medicine, TG43U1 [1]. Experimental measurement of such data may result in large uncertainties because of the rapid fall of the dose at distances near to the source. This limitation can be overcome by accurate Monte Carlo (MC) simulations [2]. There have been many studies comparing these dosimetric data using either experimental or MC studies [3-11].

BT involves the delivery of high dose of radiation to the target volume with sparing to healthy tissues. Low dose rate (LDR) BT is preferably used in the treatment of early-stage oral cancer. The main indications for BT are in the postoperative setting due to the superior dose conformity and better quality of life offered by BT compared to external beam radiation therapy (Teletherapy TT). Postoperative BT can be administered as a monotherapy in early-stage tumors and in combination with TT to treat larger or deeper tumors. BT yields good results for lip carcinoma, tumors with unfavorable localizations and local recurrences in previously irradiated areas. It has been successfully used to treat head and neck cancers. For AAPM report from task group 40 [12], BT procedure should have the ability to independently verify the source strength provided. For source calibration, the recommended quantity for the gamma sources is the reference air kerma rate defined by the ICRU [13,14]. It is the kerma rate to air, in air, at a reference distance of one meter and corrected for air attenuation and scattering. For needles, tubes and other similar rigid sources, the direction from the source center to the reference point shall be at right angles to the long axis of the source. The SI unit of reference air kerma rate is Gys-1. BT is characterized by a steep dose gradient, excellent sparing of surrounding tissues, high doses to the tumor center, and a short overall dose delivery

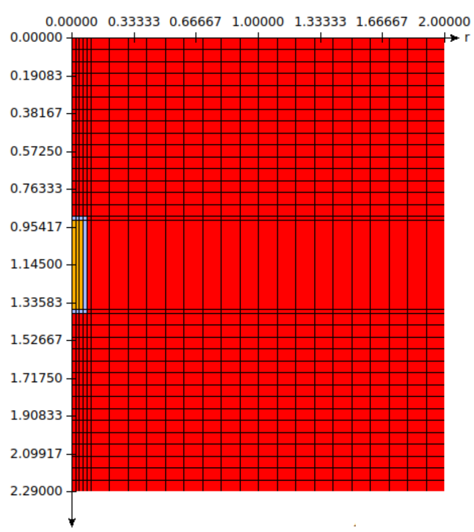
time. This situation prevents accelerated proliferation of tumor stem cells. However, BT has several notable disadvantages, including the invasiveness of the implantation procedure and limitations in terms of the size of tumors suitable for BT (⩽4 cm). Nonetheless, BT remains the most conformal form of radiotherapy, and have a better sparing of organs at risk in oral cancer than intensity modulated radiotherapy.
In previous work, we used Monte Carlo Electron Gamma Shower EGS Code for simulating the use of Ir-192 source capsule interstitial in tongue within the oral cavity [3]. Here, we used Monte Carlo Electron Gamma Shower EGS Code, running on Linux workstation along with GNU suite of compilers, for simulating the use of Co-60 source capsule interstitial in tongue within the oral cavity. Simulations of non-uniform dose distributions in both the source capsule and the surroundings are presented. Data preparation and examinations of the source capsule details were carried out and compared with the published data. Both depth and radial dose curves are also analyzed. The results shows that Monte Carlo EGS is applicable for dose distribution estimates around BT source applicators.

Calculation Method

Spatial and depth dose distributions around a Co-60 source capsule were calculated using the EGSnrcMP with default inputs [15]. The experimental setup for Co-60 needle surrounded by ICRU tissue was simulated. The dose was scored in all media for energy conservation purposes. The stopping power data for the ICRU-37 density corrections were used in the PEGS4 data [16]. The source spectrum was used as energy bins of 25 KeV energy width. The particles were followed, during the simulation, until a cut-off energy AE of 522 keV for electrons and a cut-off energy AP of 10 KeV for photons. The doses were calculated as Gray per history. The materials used in these simulations are Cobalt (Co-60), Platinum (Pt) and Tissue. Fig. 1a shows the construction of source capsule and Fig.1b is the geometrical setup of the source capsule and its surrounding tissue as simulated in EGS.



(a)

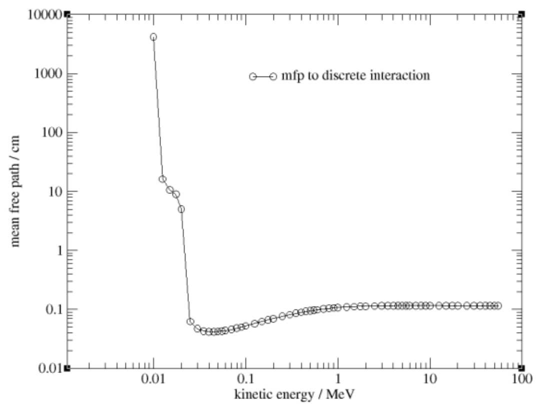


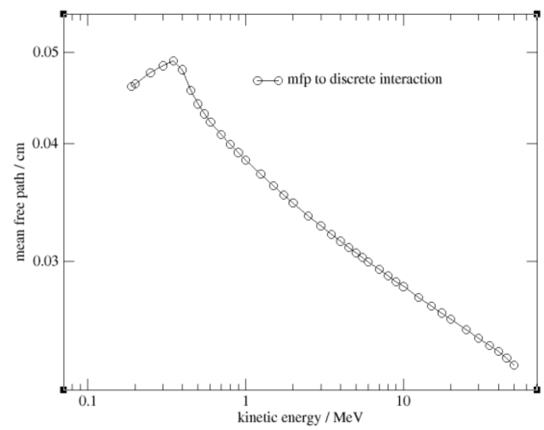
(b)

Figure 1. Construction of Co-60 source capsule (a) and the geometry of dose calculation set-up (b).

Data Preparation and Examination

The radiation data for source capsule media were created by a standalone program PEGS4 code. The data were investigated using EXAMIN code by calculating the collision and radiative stopping power for electrons, the photon mean free path and the relative components of photon cross sections. The ICRU density corrections were used. Fig. 2- 7, shows the comparisons for different media of the source capsule. The created data were compared with the published ones to make sure that the data creation by PEGS4 can be reliable. In previous work, we investigated beta spectrum of Co-60 of different sizes with the cylindrical shapes to check the EGSnrc code capability to simulate the published point source spectrum of Co-60 [17,18].





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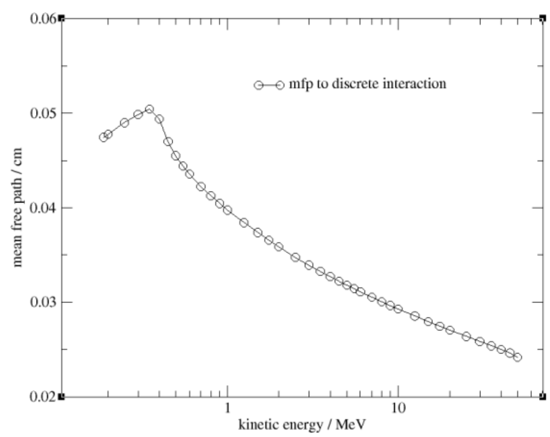
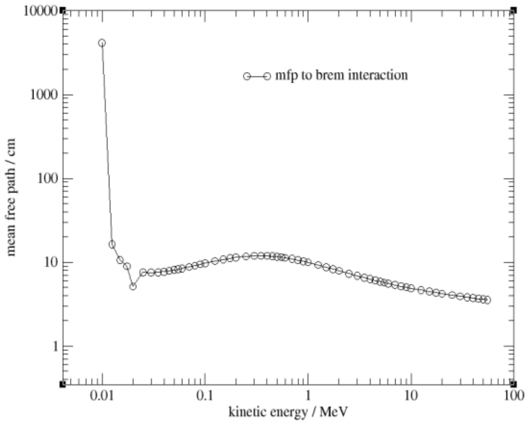


(c)

Figure 2. Mean free path to discrete interaction for Tissue (a), Co-60 (b) and Pt (c).



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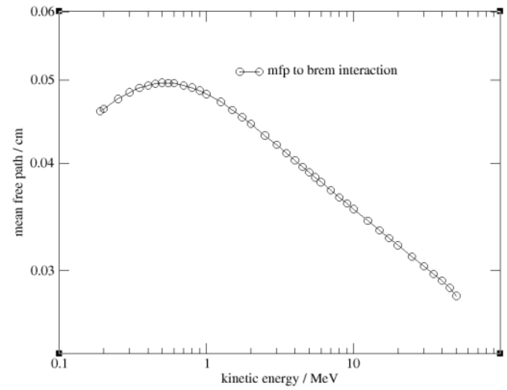

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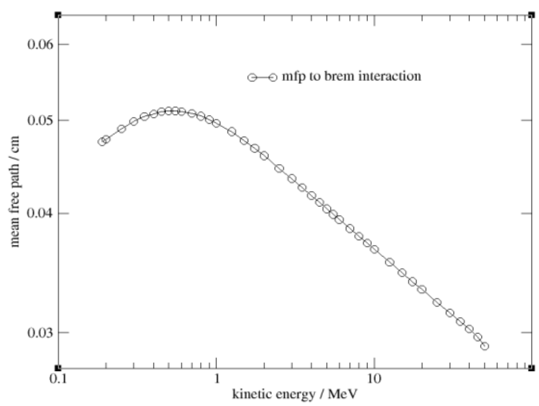

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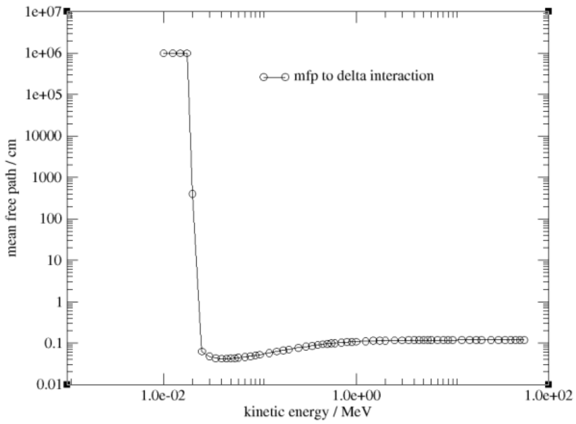
Figure 3. Mean free path to bremsstrahlung interaction for Tissue (a), Co-60 (b) and Pt (c).



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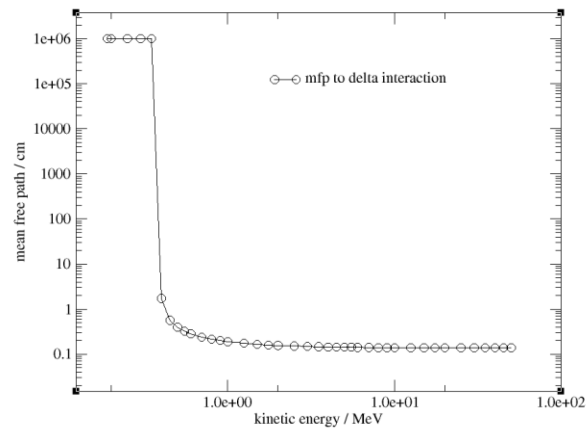

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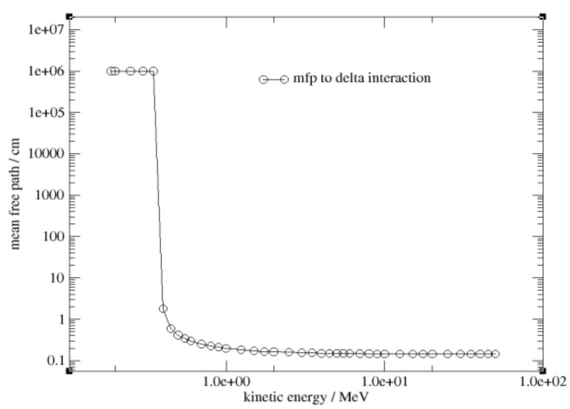
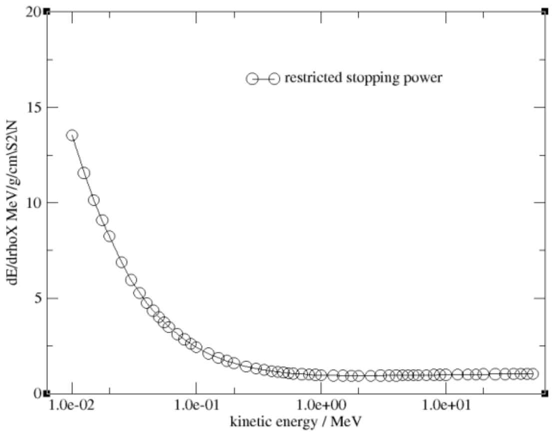


(c)

Figure 4. Mean free path to secondary electron interaction for Tissue (a), Co-60 (b) and Pt (c).



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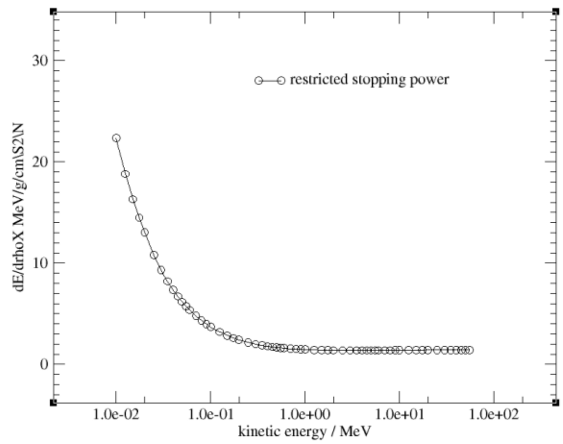

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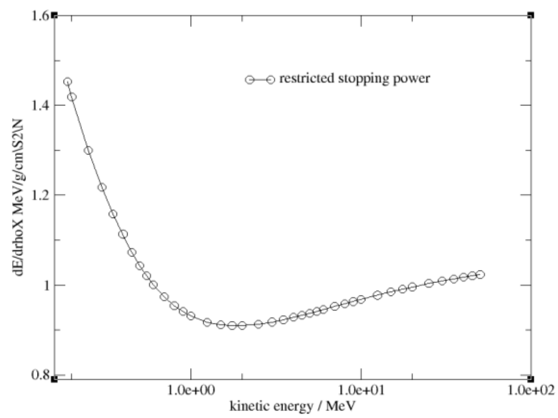
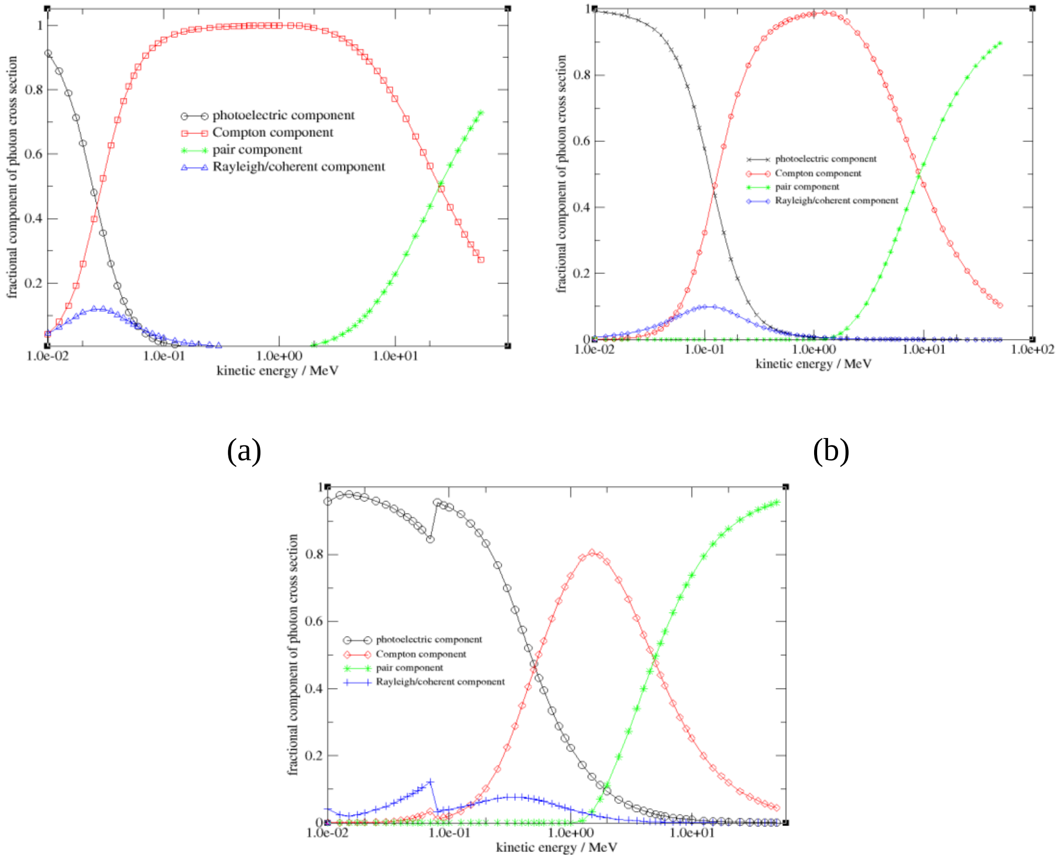


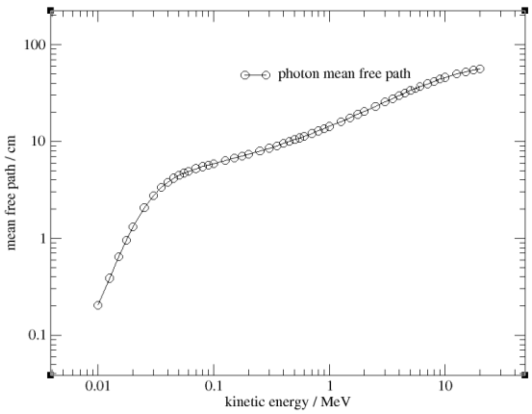
(c)

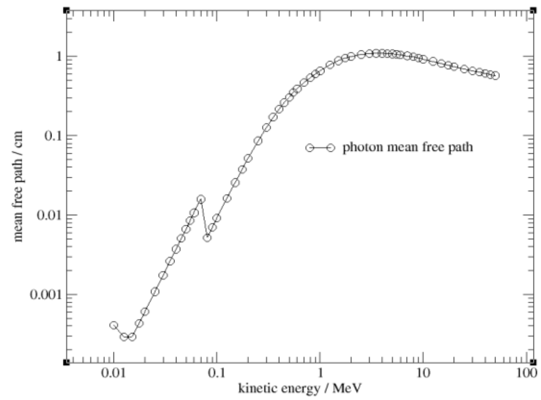
Figure 5. Restricted stopping power of electrons for Tissue (a), Co-60 (b) and Pt (c).



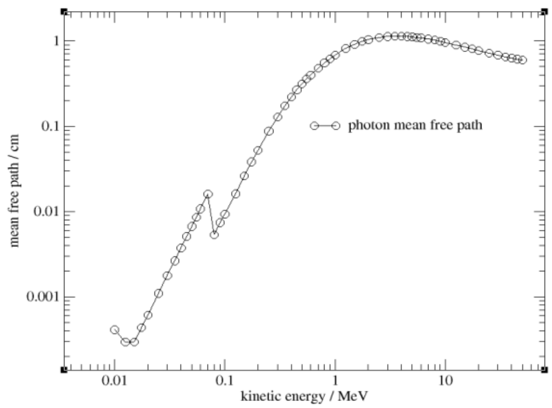
(c)

Figure 6. Relative components of photon interactions for Tissue (a), Co-60 (b) and Pt (c).





(a) (b)

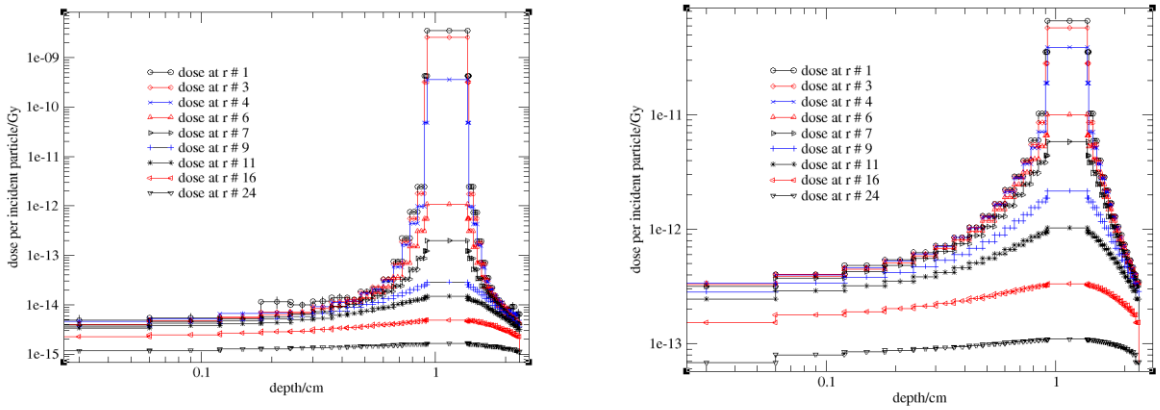


(c)

Figure 7: Photon Mean free path of Tissue (a), Co-60 (b) and Pt (c).

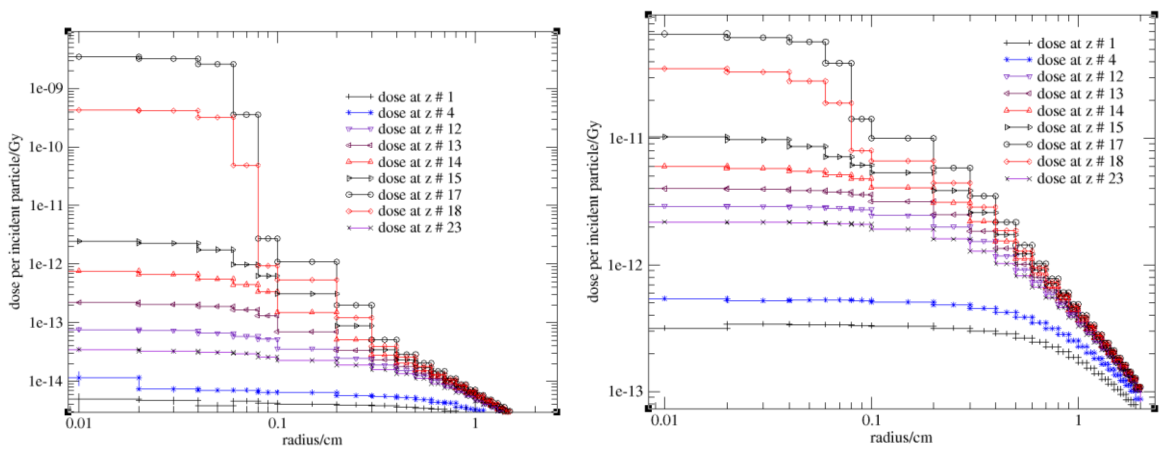
Non-uniform Dose Distributions around Co-60:

The simulated volume was partitioned in cylindrical shape where the central axis of the Co-60 source capsule coincides with the central axis of the targeted volume. This is shown in Fig. 1 where the volume is divided into coaxial rings with radius r and then divided into planes along the central axis in z direction. The radial values for R1 to R23 are, respectively, 0.02, 0.04, 0.06, 0.08, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9 and 2cm. The planes represent depths for either source capsule or its surroundings and their chosen values from Z1 to Z33 are, respectively, 0.06, 0.12, 0.18, 0.24, 0.3, 0.36, o.42, 0.48, 0.45, 0.60, 0.66, 0.72, 0.78, 0.84, 0.90, 0.92, 1.37, 1.39, 1.45, 1.51, 1.57, 1.63, 1.69, 1.75, 1.81, 1.87, 1.93, 1.99, 2.05, 2.11, 2.17, 2.23 and 2.29cm. The source spectra for both beta particle and gamma photons were seeded inside the Co-60 volume and the radiation transports were carried out. Absorbed dose values were scored throughout the whole source-surroundings networks. Fig. 8a shows the depth dose distributions at some radii. For simplification, only some of the whole network is presented here. The dose is maximum within the source diameter and then falls with depth in either side for different radii. Fig. 8b shows the radial dose distributions at some different depths. The dose distributions are maximum around the source and fall to minimum rapidly in the near tissue that could be adjusted for the chosen dose value.



(a) (b)

Figure 8: Depth (a) beta and (b)gamma dose distributions around C0-60 source capsule.



(a) (b)

Figure 9: Radial (a) beta and (b)gamma dose distributions around Co-60 source capsule .

CONCLUSION

Dosimetric properties of Co-60 have been investigated. Both source capsule and the surroundings applicable to high dose rate (HDR) brachytherapy are presented. Data preparation and examinations of the source capsule details were carried out and compared with the published data. Both depth and radial dose curves are also analyzed. The results show spatial dose distribution inside and outside the source in much more details than in practice. Highly localized absorbed dose in the targeted volume can be adjusted to enhance radiation protection of healthy tissue, which is the main advantage of brachytherapy. It is worth noting that the current EGS Monte Carlo simulations for Co-60 source would be valuable for direct comparison with previously published IR-192 radioactive source capsule in future investigation.

Disclaimer

The article has not been previously presented or published, and is not part of a thesis project.

Conflict of Interest

There are no financial, personal, or professional conflicts of interest to declare.

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