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Research Article

Monte Carlo Simulation of Co-60 Teletherapy unit and validation of outcome with dosimetric data published in BJR 25

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Abstract: Monte Carlo simulations of radiation treatment machine head provide practical means for obtaining energy spectra and angular distributions of photons and electrons. In present work BEAMnrc Monte Carlo code is used to simulate megavoltage photon beams produced by Theratron 780-E model radiotherapy unit and to calculate the percentage depth dose & energy spectra of photons and electrons for various field sizes. The unit is realistically modeled, including source capsule, housing and collimator assembly. The Spectrum data & percent depth dose data at SSD 80 cm obtain from the simulation where in close agreement with publish result of Mora et al and BJR 25. The calculated depth-dose curve in a water phantom irradiated by a narrow (5x5 cm2) and a broad (15x15 cm2) Co-60 beam is shown to agree with experimental data at the 4% to 3.5% level. Unlike previous calculations, the results accurately predict the effects of electron contamination on the surface. The variation of electron contamination with field size is also presented, as spectra for various field sizes. For on axis photon energy spectra up to 0.5 MeV energy photon fluence are not significantly different for varying field size. For on axis photon energy spectra above 1 MeV energy photon fluence increases significantly with increasing field size. The increase in photon fluence is due to increase in scatter photons fluence Which is 7% & 9% higher for10x10 cm2 & 15x15 cm2 field size then its value for the 5x5 cm2 field size. For on axis electron spectrum that electron fluence increases with increasing field size. Its value for 15x15 cm2 & 10x10 cm2 field size is 7 & 4 times greater than its value for the 5x5 cm2 field size. The percent depth dose data obtain from the simulation are having a deviation of 4% , 3% & 3.5% for 5x5 cm2,10x10 cm2 & 15x15 cm2 field size.

INTRODUCTION

The knowledge of energy spectra and angular distributions of photons and contaminant electrons emerging from such machines is important for a variety of applications in radiation dosimetry such as Energy spectra enable us to make accurate prediction of dose. They aid us in improving the state of the art of treatment planning by intelligently altering beam characteristics based on available spectral information, and by providing an explanation of underlying principles of a number of radiation dosimetry issues. It includes electron contamination and its effect on surface dose, development of techniques to reduce contamination and Variation of output with field size. Monte Carlo methods provide an accurate means of obtaining the energy spectra and the geometry of the treatment head to a good approximation [1-4]. The accuracy of the technique is limited primarily by the approximations of the theoretical basis of the Monte Carlo program, the accuracy of the cross-section data, and the amount of computer time available to reduce the statistical uncertainties. To confirm the validity of the energy spectra and angular distributions generated by the Monte Carlo programs, one may calculate dose distributions using these data and compare the results of calculations with measured depth-dose data. The Monte Carlo simulation is a powerful and flexible tool for simulating various physical phenomena. Many MC codes, such as EGSnrc & BEAMnrc, FLUKA, GEANT4, and MCNP, have been developed and applied for radiation research. Complete cobalt source was simulated by Mora et al [5] using BEAM code as early as in 1999. Also in 1988 Rogers [6] used EGS to calculate the cobalt source in a limited study, the source size used by Rogers was 2 cm diameter. Subsequently, smaller cobalt sources with higher specific activity were available. In 2004, Al-Basheer [7] has conducted a detailed study of the properties of Theratron telecobalt machine using MCNP code. However, he used a source size of 1.5 cm diameter and 3 cm height applied to Co-60 therapy units. In this work, we used BEAMnrc code to model a Co-60 therapy unit Theratron 780-E to simulate the propagation of photons, the generation of secondary particles and the energy deposition in materials to compare the results with other simulation results and BJR data [8].

METHODS

Monte Carlo Modeling

Geometry of the Theratron 780-E unit

The Theratron 780-E is a typical Co-60 therapy unit. It consists of a source capsule which contains radioactive Co-60 pellets, an immovable primary collimator, an outer set of movable collimators which define the various field sizes of the therapy beam and an overall shield for radiation protection. We realistically model the unit including source, source housing, primary collimator and adjustable multivan collimator assembly. All air gaps between the components are included in our modeling. Fig.1 shows the model of the Theratron 780-E unit used in this study.

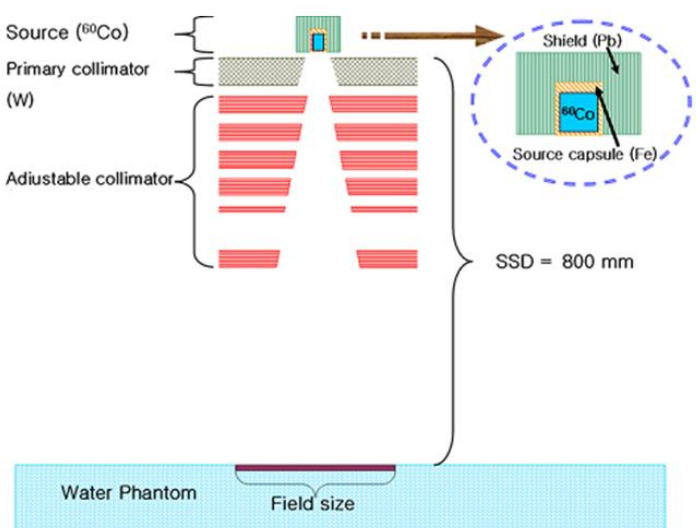


Fig. 1: A schematic diagram showing the Co-60 therapy unit

The capsule

We model a typical capsule size used by Theratron 780-E units with cylindrical geometry about the beam axis. Figure 2 shows a schematic of the source and housing as modeled in our computer simulation. Although we model the Co-60 region as a uniform active material region of cobalt of 2 cm diameter, the actual source is made up of many small pellets. The density is reduced to account for the loose packing and to give the correct overall mass of material. The surrounding heavy metal steel is modeled by an equivalent thickness in g/cm^3 of Fe. A lead wall 2 cm thick is included to simulate the source housing. The Co-60 radiates uniformly 1.25 MeV Radiation beam.

The collimation system

In modeling, we have used the realistic rectangular geometry of the collimator assembly. After the capsule there is a 1.5 cm air gap and then the fixed primary collimator in Fig. 1 which is made of solid heavy metal alloy (90% W, 6% Ni, and 4% Cu) with a thickness of 6.2 cm. The primary collimator is followed by a 0.4 cm air gap and the outer collimator which is of multivan type extends over 19.3 cm. The outer collimator is movable and made up of a series of tungsten or depleted uranium leaves "interlocked" in the *x* and *y* directions. The one simplification in the model is that these are not interlocked but surround the beam on the same layer. Since the primary collimator does not move for different field sizes, its opening is fixed at 1.5 cm in radius at top and is 3 cm in radius at bottom Which allows for an open field of 35x35 cm^2 at SSD=80 cm. the adjustable multivan collimator opening are used to define the varying field sizes at SSD. We have modeled different leaf collimator openings to get field sizes from 5x5 cm2 to 15x15 cm^2 at SSD equal to 80.0 cm. The setting of each leaf of the adjustable collimator structure is modeled in detail for each field size.

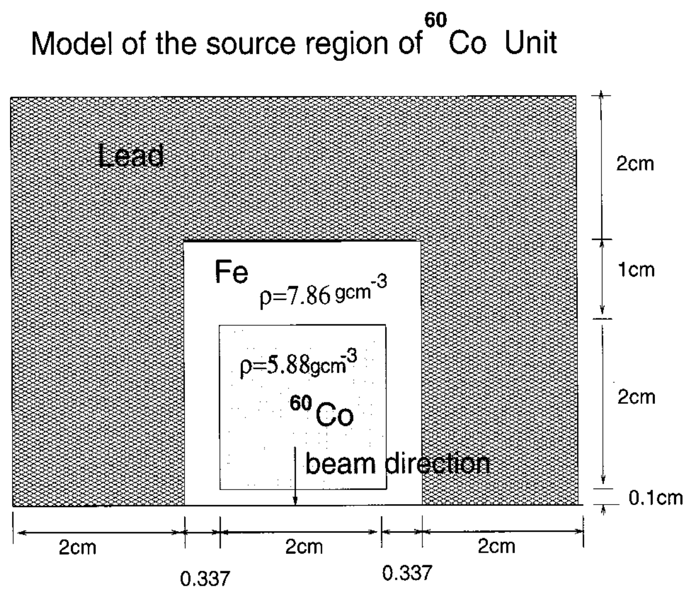


Fig. 2. The model used to simulate the source region including the radioactive material, the surrounded iron capsule and the lead shielding

Monte Carlo calculations techniques

In this section we describe the different stages of the simulation of the Theratron 780-E the principal features of the BEAMnrc code used, the transport parameters of the simulation and the variance reduction techniques applied.

The structure of the calculation

In the simulation of the full therapy unit we have split the calculation into three steps in order to save time. In the first step, which takes the most computing time 1x10^8 photons are initiated uniformly throughout the source material region and have an isotropic distribution. The primary collimator is also included in this step. The output of this step is a phase space file containing the energy, position, direction, charge and history variable for every particle exiting downstream from the primary collimator. The data for 60x10^5 particles reaching the scoring plane before the outer collimator are stored in a compressed format phase space file of 1.2 Gbytes. Since the source and primary collimator do not move during the adjusting of the outer collimator for different openings, it is possible to use this phase space data for the simulation of all field sizes. Thus, this large set of particles is used repeatedly as the input to the next step of simulation. The second step of the calculation simulates the passage of the particles through the adjustable leaf collimator and the air into the SSD plane.

We simulated different openings of the outer collimator to get field sizes from 5x5 cm^2 to 15x15 cm^2 at SSD equal to 80 cm. We have used the variable LATCH which allowed us to store each particle's history during the first and the second step of the beam simulation. Therefore, we were able to determine if a particle was scattered in the source region, primary collimator, adjustable collimator or air slab before reaching the scoring plane. Also the same step was repeated with water phantom placed at SSD for direct BEAMnrc PDD calculation. We transported the particles through a large phantom 30 cm diameter and 20 cm thick. The depth-dose curves are calculated for on-axis scoring regions 2 cm in radius. The data analysis program BEAMDP is used to analyze the phase space data files to extract the energy spectra of all particles reaching the plane at SSD=80 cm, and also the spectra of particles scattered from the source region or from collimators. Statistical uncertainties are determined by breaking all calculations into ten batches and then computing the standard deviation on the mean values of the ten batches.

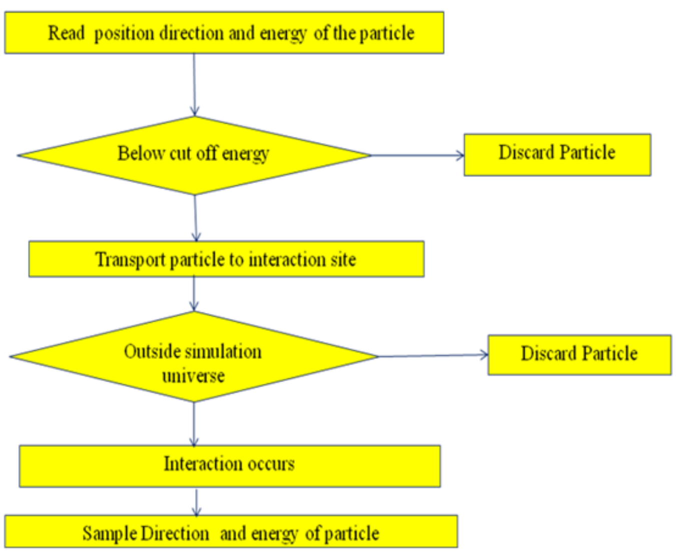
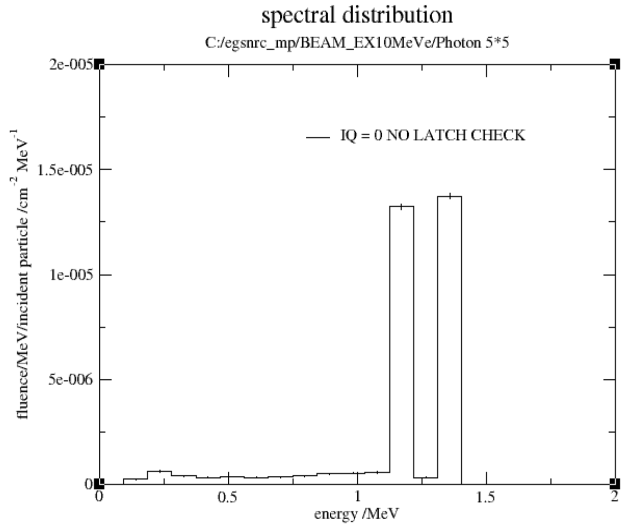


Fig. 3: Range rejection algorithm

Range rejection of particle

Although we break the simulation into three stages and reduced the time required for our calculation with the "adequate" choice of the transport parameters, the transport of all particles originating in the complex geometry of the therapy unit to ECUT is a very time consuming task. Therefore, we applied a variance reduction technique called "range rejection" which is summarized in Fig.3. BEAM stops tracking an particle history if the particle could not get out of the present region with enough energy to reach the scoring plane. This technique saves a significant amount of CPU time. In the first step of the simulation for source capsule and primary Collimator, the global energy cut-offs for particle transport were set to ECUT=0.7 MeV and PCUT=0.010 MeV. However, we bypassed the global ECUT with higher values of ECUT defined for individual regions in order to increase the simulation efficiency.



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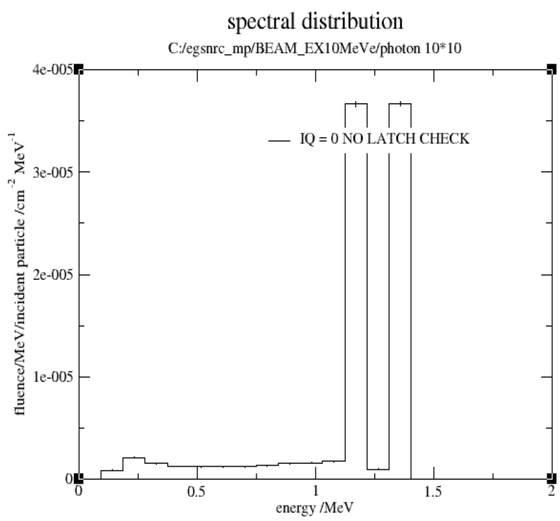

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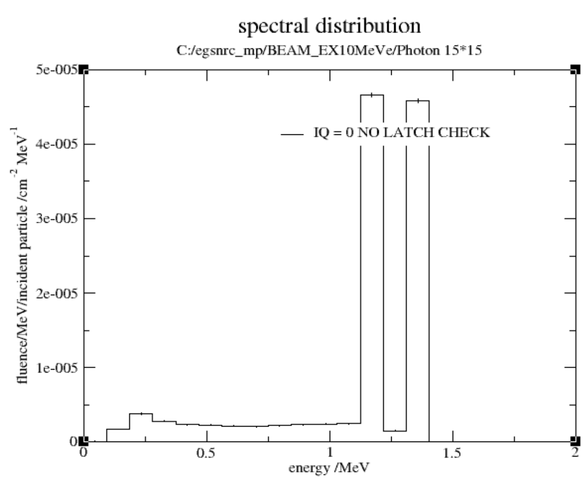
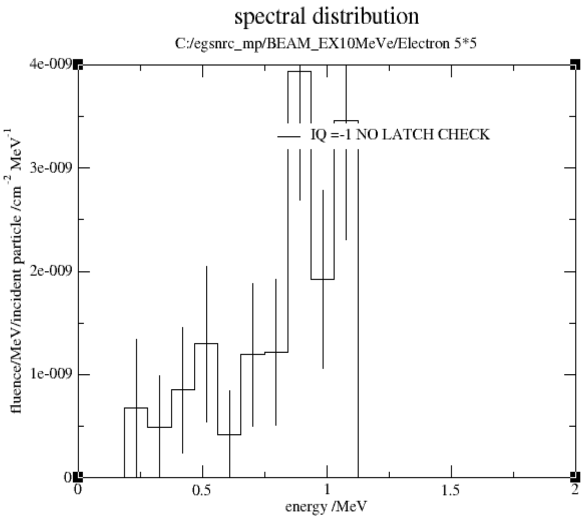
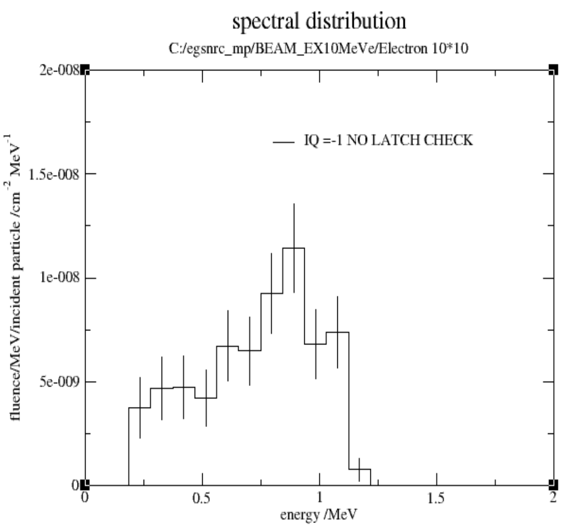


(c)

Fig.4 on-axis photon spectra at SSD=80 cm (a) field Size=5x5cm^2 (b) field size=10x10cm^2(c) field Size=15x15 cm^2



(a)



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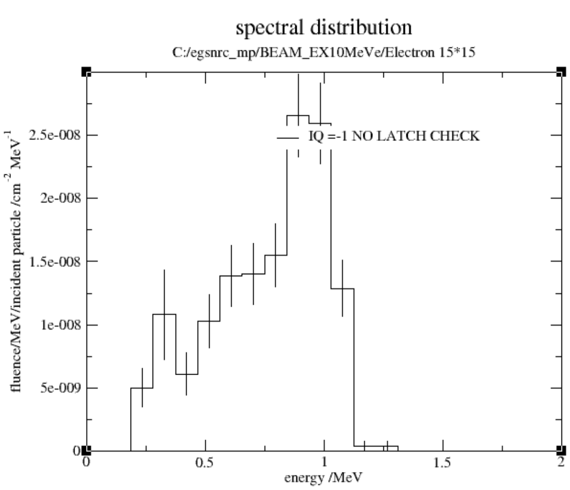


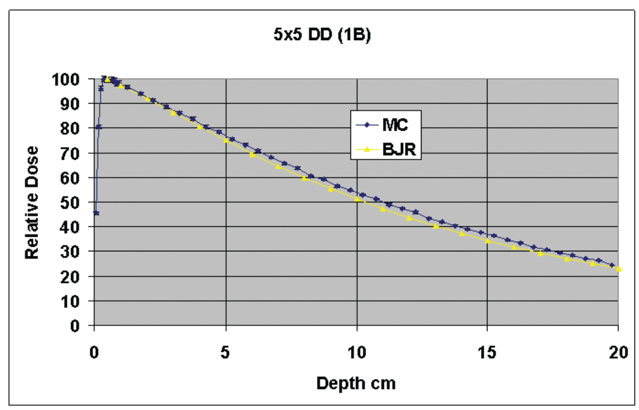
(c)

Fig.5 on-axis electron spectra at ssd=80 cm (a) field Size=5x5cm^2 (b) field size=10x10cm^2(c) field Size=15x15 cm^2

RESULTS AND DISCUSSION

Figure 4 shows on-axis photon spectra obtained by Monte Carlo simulation at SSD=80 cm for field Size 5x5cm^2,10x10cm^2 and 15x15 cm^2. Figure 5 shows on axis electron spectra obtained by Monte Carlo simulation for 5x5cm^2,10x10cm^2 and 15x15 cm^{2}field sizes at SSD =80cm. Figure 6 shows comparison of depth dose data obtained with Monte Carlo simulation using 1 billion histories with the depth dose data available in the BJR 25 [8] for 5x5 cm^2,10x10 cm^2 and 15x15 cm^2 field sizes.

The Spectrum data & percentage depth dose data obtained from the simulation were in close agreement with publish the results of Mora *et al* [5] and BJR 25 [8] .For on axis photon energy spectra up to 0.5 MeV energy photon fluence were not significantly different for varying field sizes. For on axis photon energy spectra above 1 MeV energy photon fluence increased significantly with increasing field size. The increase in photon fluence was due to increase in scatter photons fluence which was 7% & 9% for higher for 10x10 cm^2 & 15x15 cm^2 field sizes than its value for the 5x5 cm^2 field size. For on axis electron spectrum that electron fluence increased with increasing field size. Its value for 15x15 cm^2 & 10x10 cm^2 field size was 7 & 4 times greater than its value for the 5x5 cm^2 field size. The percent depth dose data obtained from the simulation were having a deviation of 4% , 3% & 3.5% for 5x5 cm^2, 10x10 cm^2 & 15x15 cm^2 field sizes.



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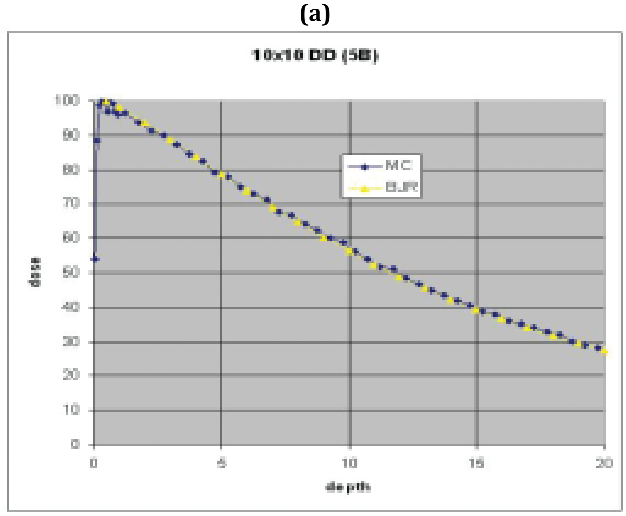

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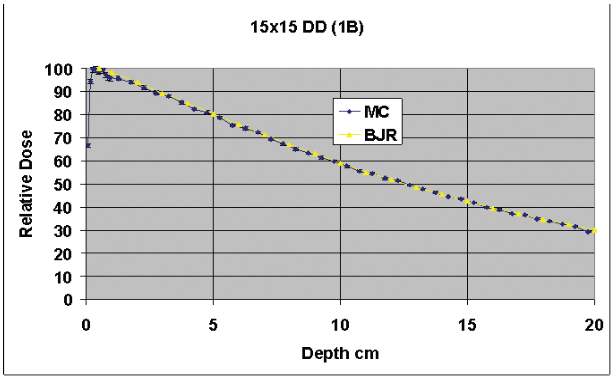

(c)

Fig.6 Comparison of percentage depth dose for ssd=80 with BJR 25 (a) field Size=5x5cm^2 (b) field size=10x10cm^2 (c) field Size=15x15 cm^2

CONCLUSION

We were successful in modeling the Theratron 780-E teletherapy machine with BEAMnrc Monte Carlo code. The simulated values were in close agreement with the data of BJR 25 and other published work. However, it is required to validate the simulated data with the experimentally measured values for the telecobalt unit.

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