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Comparison of MCNP4C, 4B and 4A Monte Carlo codes when calculating electron therapy depth doses

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ABSTRACT

Background: Monte Carlo simulation of radiation transport is considered to be one of the most accurate methods of radiation therapy dose calculation. There are different Monte Carlo codes for simulation of photons, electrons and the coupled transport of electrons and photons. MCNP is a general purpose Monte Carlo code that can be used for electron, photon and coupled photon-electron transport.

Materials and Methods: In this study the MCNP4A, 4B and 4C have been compared when calculating electron beam doses in water. For simulating, the geometry and other parameters were the same for three codes. By choosing two energy indexing algorithm (ITS & MCNP), absorbed doses were scored in water. 10^6 Particles were followed in these three cases.

Results: MCNP4C and 4B gave different results compared to 4A when the ITS algorithm was used in 4B and 4C versions. There was a good agreement between versions 4B and 4C. For the energy spectrum, there were significant differences between these three versions in two planes.

Conclusion: Because of new improvements in electron transport in 4C, this version is reliable for electron transport and also requires a shorter time than the two previous versions. These results, in addition to the practical measurements acquired with MCNP4B by other investigators, suggest that in electron transport the user should use the ITS indexing energy algorithm. *Iran. J. Radiat. Res., 2005; 2 (4): 191-195*

Keywords: *Radiotherapy, electron therapy, Monte Carlo, absorbed dose, energy spectrum.*

INTRODUCTION

Monte Carlo (MC) techniques are becoming more widely used in all medical physics applications. MC simulation of radiation transport is considered a highly accurate method of radiation therapy dose calculation. There are different MC codes for simulation of photons, electrons and the coupled transport of electrons and photons. There are three main families of MC codes frequently used for modeling of electron beams: ETRAN/ ITS (Halbleib 1992, Seltzer 1991), EGS4 (Nelson *et al.* 1985) and PENELOPE (Sempau *et al.* 2001). The MCNP code is based on the ETRAN/ITS electron transport system.

All of these codes are written in the FORTRAN programming language but have differences in the use of physical theory [MCNP Manual]. MCNP offers two energy-indexing algorithms, which refer to two energy grids. By default, the so-called MCNP energy-indexing algorithm is applied, but the user can decide to use the so-called ITS energy-indexing algorithm instead.

In the case of MCNP, there are relatively small number of references. Love *et al.* (1998)

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used EGS4 and MCNP4B to calculate central axis depth doses in water for a 10 MeV electron beam. Jeraj *et al.* (1999) has shown when MCNP is run in the default mode, lower surface dose and deeper penetration has been observed compared with EGS4. When an improved energy-indexing scheme was used, EGS4 and MCNP agreed with each other within the statistical uncertainly of the calculations. There was a good agreement between experimental electron depth dose distributions with EGS4 and MCNP results but a discrepancy of 10% of the maximum dose existed when MCNP4A was used. Wang and Li (2001) reported differences of up to 30% between beta dose distributions calculated using 4B, EGS4 and EGSnrc codes. The results obtained by Cross *et al.* (2001) for a concave Ru-106 eye applicator with MCNP4B showed a difference of more than a factor of 2 with ACCEPT 3.0, one of the ITS 3.0 codes. Schaart *et al.* (2002) observed discrepancies between ITS 3.0 and MCNP4C, in spite of the same electron transport algorithms in both codes.

The MCNP4A code uses ITS 1.0 electron physics, MCNP4B also uses ITS 1.0 or ITS 3.0 for improved electron transport but MCNP4C uses ITS 3.0 electron physics. The main improvements in 4C relevant to electron transport were in density effect calculation for stopping power and Bremsstrahlung production, as well as a new electron library (El03).

The aims of this work were, I) to study the difference between calculated depth doses in water and the energy spectra over three planes calculated using these codes. II) To determine the relative efficiency of these codes in electron transport.

MATERIALS AND METHODS

The geometry used to produce the central axis depth dose curves consisted of a conical electron beam impinging on a rectangular water phantom (figure 1).

The electron beam originated from a point source and diverged into a conical field at 100 cm SSD. The rectangular water phantom had a width of a=20 cm, giving an equivalent cross sectional area of 20×20 cm^2. A smaller concentric cylinder with a radius of r = 1 cm gave a 3.14 cm cross-section and defined the dose scoring region on the central axis. The reason of this geometry design was better variance reduction for speed improvements. For smaller electron ranges the depth of phantom chosen was 10 cm. The smaller cylinder was divided in to 50 slabs. These slabs were 0.2 cm thick to show detail in the build up region and also Rp (the practical range). F2 tally was chosen for scoring the flux over the phantom surface and planes 3 and 5 cm deep. For this, the scoring area was 50 cm^2. These slabs represent a column of dosimeters in water enabling the dose at each depth to be calculated during a single simulation without any correction for the perturbation needed. The geometry was modeled by MCNP4A, 4B and 4C codes by using plane and cylindrical surfaces.

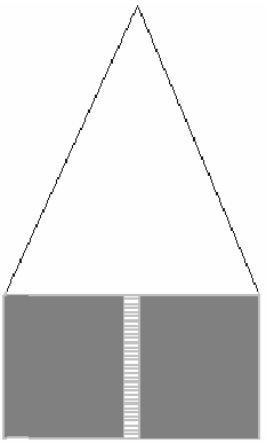

Figure 1. Diagram of the simulated phantom and point source.

Monoenergic electrons with a nominal energy of 10 MeV were modeled. They were set in motion from a point within this cylinder in a direction that defined the Z-axis. The cylindrical geometry described above and an equivalent rectangular geometry was used for each code to compare their efficiency (number of particles, statistical uncertainty...).

MCNP4A and 4B ran under the Windows 98 operating system in a dual processor (2×2GHz, 512 MHz RAM, Athlon CPU) PC. MCNP4C ran under Windows XP operating system on that computer.

All calculations were done in coupled electron-photon mode [MODE P E]. The energy deposited in each of these cells was scored by means of *F8 tally. To obtain the absorbed dose

all of the energy deposited in each cell was divided by the cell mass. The energy spectra of electrons were scored on the phantom surface and planes 3 and 5 cm deep using F2 tally subdivided into 0.1 MeV equidistant energy bins.

For variance reduction, the electron energy Cut-off [Cut: E E] was 0.5 MeV or 5% of the incident electron energy, while photons were transported down to an energy of 100 keV [Cut: P E]. Other variance reduction methods were not used and 10^6 source particles were simulated in each code. The source position was set at 100 cm distance from the phantom surface.

In this work, for each of versions 4C, 4B, two energy-indexing algorithms were used. It is possible to use a so-called ITS-style energy-indexing algorithm, if a special switch on the DBCN card is used.

RESULTS

The results are shown in figures 2 to 7. Figures 2 and 3 show the effect of the choice of energy indexing algorithm on the central axis relative depth dose for codes 4B and 4C. Figure 4 shows relative depth dose curves for all three codes together.

The energy spectra at the three planes are shown in figures 5 to 7. Each plotted point was obtained by dividing the energy bin count by the total number at that plane. For the energy spectrum at the phantom surface (figure 5) all codes show very similar results (within 2%). At greater depths (figures 5 and 6), there are greater differences between the codes. At the 3 cm deep plane, codes 4B, 4C default, are within 1% of each other while 4A gives a 19% greater peak value and 4B and 4C ITS indexing are 16% lower.

Table 1 shows the different computer run times for all codes. The ITS indexing takes a 22% shorter run time compared to the default and 4A has a shorter time compared to 4B. Our results suggest a shorter computation time for 4C compared to the others.

Table 1. Computer Run time for 10^6 particles.

MCNP Codes	Energy index algorithm	Computer run time (minutes)	
4A	Default	687.37	(Computer A)
4B	Default	737.71	(Computer A)
	ITS	576.60	(Computer A)
4C	Default	512.28	(Computer A)
	ITS	396.61	(Computer A)

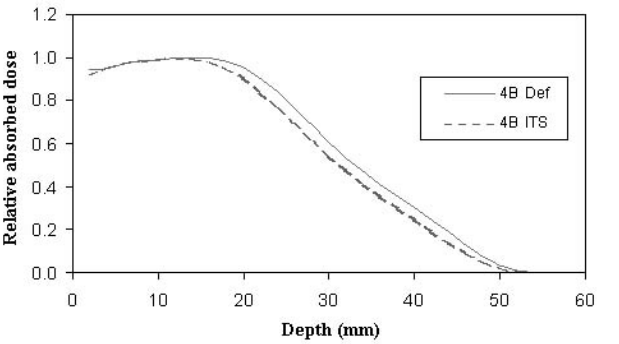

Figure 2. Central axis depth dose curves computed using MCNP-4B.

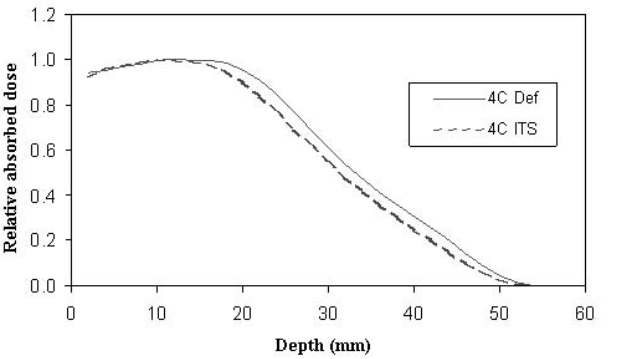

Figure 3. Central axis depth dose curves computed using MCNP- 4C.

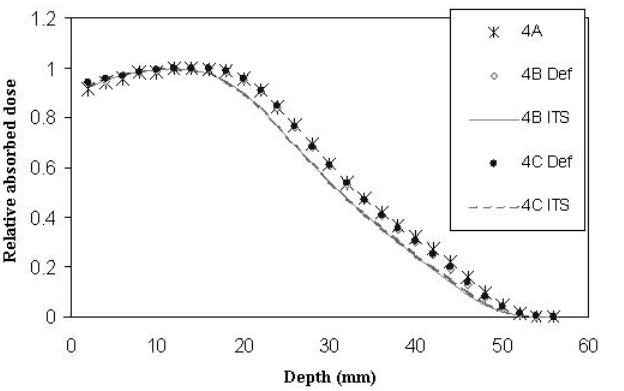

Figure 4. Central axis depth dose curves computed using MCNP-4A, 4B and 4C codes together.

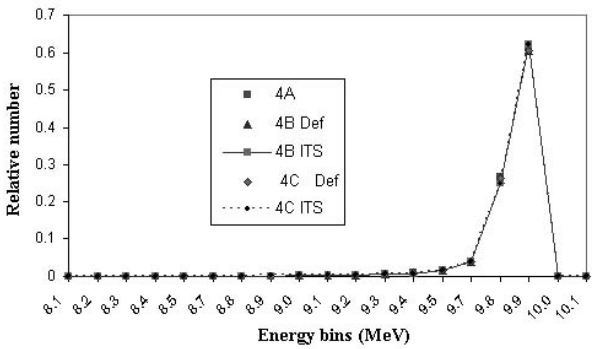

Figure 5. Energy spectrum for MCNP-4A, 4B and 4C codes at phantom surface.

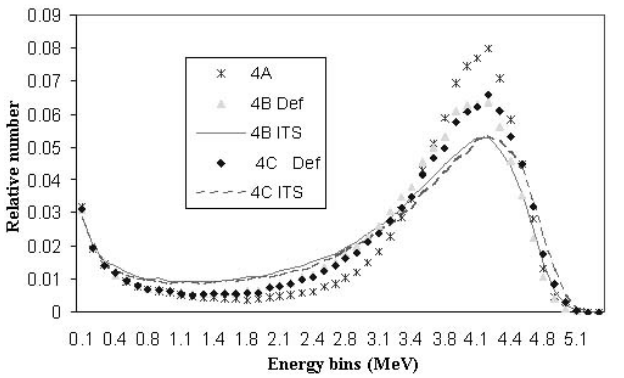

Figure 6. Energy spectrum for MCNP-4A, 4B and 4C codes at 3 cm depth.

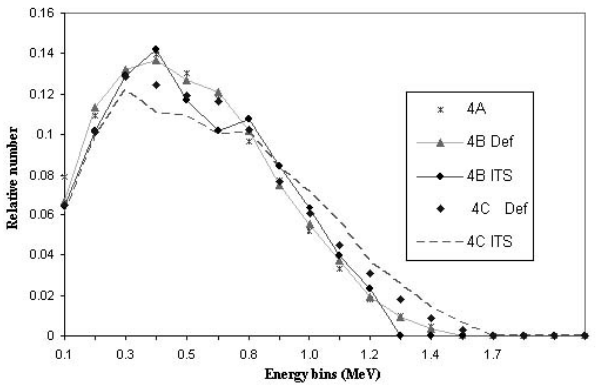

Figure 7. Energy spectrum for MCNP-4A, 4B and 4C codes at 5 cm depth.

DISCUSSION

In our comparison of MCNP4C, 4B and 4A, we have found differences in absorbed dose calculated by 4C (ITS) and 4B (ITS) in comparison with 4C, 4B (MCNP default) and 4A. It was found that absorbed doses calculated by 4C and 4B (ITS) agree with each other, but are different with 4B and 4C (MCNP style). Previous works (Jeraj *et al*. 1999) has shown that the results of 4B (ITS) agree with practical measurements. Therefore we can conclude the results of 4B and 4C in ITS energy indexing also agree with practical measurements. As mentioned by Jeraj, differences in 4A and 4B results may be due to inappropriate sampling of the Landau energy straggling distribution used in older version of ITS, which has improved in ITS 3.0 and MCNP4C. One of the reasons for the different run times of the codes is related to their compilers. Our present 4A and 4B versions use a different compiler compared to 4C. Although, the results for 4C and 4B in ITS style are the same, computer run time for acquiring the same uncertainty is less in 4C than 4B. In addition to the shorter time, 4C has improvements in electron physics that make it a better code for electron transport.

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