Comparison between EGSnrc and MCNPX for X-ray target in 6 MV photon beam

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Abstract. The Monte Carlo codes, EGSnrc and MCNPX, have been specifically developed to study the particles transport in linear accelerator used in radiotherapy. A simple X-ray target 6 MV photon beam geometry was chosen to highlight similarities and differences of particles transport algorithms implemented in these Monte Carlo codes. The purpose of this study was to compare the particles transport in X-ray target 6 MV photon beam using EGSnrc and MCNPX codes. This target has 0.2484 cm thickness consisting of 0.0899 cm Tungsten and 0.1575 Copper. The global cut-off energies used in the simulations for electron and photon were 500 KeV and 10 KeV, respectively. Monte Carlo simulations were performed for 6.4 MeV monoenergetic beam. The parameters used in this simulation were using the DEFAULT setting. The particles fluence, spectral distribution after target and simulation time were analysed in this simulation. The results showed that the spectrum from EGSnrc and MCNPX was not well-matched. There was under 5% difference, especially in the build-up region. Meanwhile, the EGSnrc was 2 to 3 times more efficient than MCNPX code to achieve certain statistical precision. This happened because the differences of transport algorithm and approximation in these MC codes. EGSnrc just follow photons and electrons during simulation, while MCNPX can simulate transport 34 types of particles, including neutrons. It also causes the simulation time difference between these two codes. MCNPX simulation took longer than the EGSnrc. However, in some cases, differences in results as well as simulation time between 2 codes can be ignored.

1. Introduction

The Monte Carlo codes have been specifically developed to study the particles transport in linear accelerator used in radiotherapy [1, 2, 3, 4, 5]. The particle transport is a complicated process depending on the energy and material interact with it. A simple X-ray target 6 MV photon beam geometry was chosen to highlight similarities and differences of particles transport algorithms implemented in these Monte Carlo codes. The X-ray target is one of the important component in photon beam linear accelerator. In order to simulate the particles transport in X-Ray target of 6 MV photon beam, the Monte Carlo codes used in medical physics were adopted; EGSnrc and MCNPX. The methods for tracking particles in the volume of interest used in both of these codes were different.
from each other. Many researchers had conducted some study in benchmarking some Monte Carlo code system package (EGSnrc, PENelope, Geant4 and MCNPX) for many kinds of cases [6, 7, 8, 9]. Steinfelds (2007) found that EGSnrc is much faster than MCNP at modelling primary electrons and MCNP is more versatile than EGSnrc [6].

The objective of this study was to compare the output of X-Ray target of Varian Clinac iX 6 MV photon beam using EGSnrc and MCNPX code system (spectral distribution, statistical uncertainty and simulation time).

2. Method
The X-Ray target 6 MV photon beam was modeled in EGSnrc and MCNP package according to the geometry specifications provided by the Varian Monte Carlo Data package. This package describes the geometry and materials of the target. This target has 0.247 cm thickness consisting of 0.0899 cm Tungsten and 0.1575 Copper [10].

2.1. EGSnrc
The EGS (Electron Gamma Shower) code system is a general purpose package for radiation transport simulation. EGSnrc was one of the code developed by the Ionizing Radiation Standards Group, Institute for National Measurement Standards, National Research Council of Canada. This code is able to simulate electron and photon for particle energies ranging from 1 keV to 10 GeV in homogeneous and inhomogeneous materials [11].

Figure 1 show the sketch of X-ray target modeled using EGSnrc code. The scoring plane sets just below the Copper material. The global cut-off energies used in the simulations for electron and photon were 521 keV and 10 keV, respectively. Monte Carlo simulations were performed for 6.4 MeV monoenergetic beam with FWHM 1.0 cm and field size 5×5 cm². The parameters used in this simulation were using the DEFAULT setting. The scoring plane in EGSnrc was stored in phase space (phsp) files containing the information and identity of particles stored in it (charge, energy, position, direction, etc). BEAMDP data processor was used to analyze this output to obtain particles fluence, angular and spectral distribution.

![Figure 1 Sketch of X-ray target was simulated by EGSnrc code.](image)

2.2. MCNPX
The Monte Carlo N-Particle X-tended (MCNPX) code system was developed by the Los Alamos National Laboratory over the past 30 years [12]. MCNP is a general purpose code that can be used to simulate neutron, photon and electron transport. MCNP has a wide range of capabilities which make it useful for medical physics applications. MCNPX code uses a three-dimensional inhomogeneous geometry and transports photons, electrons and neutrons in the energy range from 1 keV to 100 MeV.

The MCNP input file consist of cell cards, surface cards and surface cards. Specifies of output called F4 tally at the bottom of the target to obtain the spectral distribution. As in the previous
simulation using EGSnrc, the source were performed for 6.4 MeV monoenergetic beam. The sketch of X-ray target modelled by MCNPX was shown in Figure 2.

![Figure 2 Sketch of X-ray target was simulated by EGSnrc code.](image)

The spectral distribution in EGSnrc and MCNPX was compared to analyze how much were the difference between these results, the statistical uncertainty and simulation time. The output particles analyzed in this simulation was photon.

3. Results and discussion

Production of X-rays in target material of linear accelerator (linac) was extremely inefficient. X-ray production in high energy linac photon beam has a higher conversion of electrons into photons. The total number of electrons converted to heat is 99% and only 1% of the electrons were converted to bremsstrahlung photons. Tungsten material has high melting point so it would not melt, despite exposing to very large temperature changes. And the electron interact with the Copper material to produce X-ray bremsstrahlung. X-ray in target was produced by electromagnetic radiation emitted when an electron losses energy as a consequence of coulomb interaction with the nucleus of an atom.

The statistical uncertainty both of the EGSnrc and MCNPX simulations were below 1 %. Figure 3 below shows the angular distribution and fluence (number of photons or electrons per MeV per incident electron on the target) at the scoring plane obtained from EGSnrc code. Only the particles which were inside the defined field were counted.

![Figure 3](image)

Figure 3 (a) The angular distribution and (b) Fluence curve of after X-ray target.

The angular distribution and fluence only scanned in the Y direction. The X and Y direction is similar and identical to each other, so the graphs just scored in one direction. The particles interaction in X-ray target and the products that were scattered have the relative distribution to the beam axis. The
angular distribution is distribution relative to the scattered particles and product of its interaction. Most of photon bremsstrahlung scattered in the wide angle (20 – 60 degree).

Figure 4 Spectral distribution comparison of X-ray target was simulated by EGSnrc and MCNPX code.

The results show that the spectrum from EGSnrc and MCNPX was not well-matched. There was under 5% difference, especially in the build-up region. The spectral distribution chart is a visual representation of the X-ray spectrum produced by a 6 MV photon beam target. This graph shows the relative intensities of X-ray at MeV energy. The 100% peak of EGSnrc and MCNPX spectral distribution was 0.245 and 0.25 MeV, respectively. Meanwhile, the spectrum has the same shape and value in the tail region.

In the simulation process, EGSnrc was more efficient than MCNPX code to achieve certain statistical precision (Table 1). This happened because the differences of transport algorithm and approximation in these MC codes. EGSnrc just follow the photons and electrons during the simulation, while MCNPX can simulate transport 34 types of particles, including neutrons. It also causes the simulation time difference between these two codes. MCNPX simulation took longer than the EGSnrc.

| Parameter               | EGSnrc                  | MCNPX                  |
|-------------------------|-------------------------|------------------------|
| Number of histories     | 1.000.000.000 electrons | 30.000.000 electrons   |
| Simulation time         | 21.66 hours             | 21.22 hours            |
| Statistical uncertainty | 0.0001%                 | 0.13%                  |

4. Conclusions
The X-ray spectrum in the target material of 6 MV linear accelerator (linac) simulated by EGSnrc and MCNPX was identical in tail region but it was not well-match in build-up region. And the EGSnrc was 2 to 3 times more efficient than MCNPX to achieve certain statistical precision in this simulation.

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