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The Influence of Cross-Section Data on the Dose Distributions for Megavoltage Photon Beam

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Abstract: This work aims to study the influence of cross sections data, available in BEAMnrc /DOSXYZnrc Monte Carlo code, on the dosimetric calculations such depth dose and beam dose profiles. A SATURNE43 Linear accelerator has been modeled to simulate a 12 MV photon beam for a square open field of 10×10 cm². Gamma index criteria was used to analyze the MC results and measured ones, which was fixed within 1.5% -1 mm accuracy. The obtained results showed that the depth dose curves and beam profiles are less sensitive to photon and Bremsstrahlung cross section data.

Keywords: EGSnrc; Monte Carlo; cross section; dose distribution.

1 Introduction

Actually, Monte Carlo method becomes widely applied as a powerful tools in radiation therapy for treatment planning calculations. Several codes based on Monte Carlo method, such as EGSnrc [3], MCNP [8] , Geant4 [9], Penelope [11], and Fluka [10] have been developed and applied for dose calculation which use different physical interaction models, cross section data and transport algorithms. EGSnrc is a software toolkit to perform Monte Carlo simulation of charged particle and photon transport through matter. It models the propagation of photons, electrons and positrons with kinetic energies between 1 keV and 10 GeV, in homogeneous materials. EGSnrc-based BEAMnrc allows us to simulate the photon or electron beam through Linac head components, so the default settings in the BEAMnrc code for the EGSnrc parameters should be adequate. However, there are some cases, such as low energy applications, in which the user will want to vary the EGSnrc transport parameters using the EGSnrc inputs. Bremsstrahlung (Brem) cross section and photon cross section are two EGSnrc parameters which have many options that need to evaluate. This study aims to get the least statistical errors when simulating the 12 MV photon beam and to determine the effect of these parameters on the dose distribution.

2 Materials and Method

2.1 Monte Carlo Simulation

BEAMnrc [1] , based-EGSnrc Monte Carlo method [2] , was used to model the treatment head of a Sturne43 Linear accelerator and simulate 12 MV photon beam. The materials and geometrical data of considered Saturne43 Linac head were provided by CEA LIST LNHB (Henri Becquerel laboratory). The experimental dose distributions were calculated within water phantom of 40×40×40 cm^3, for square field size 10×10 cm² defined at 100 cm and SSD equal 90 cm.
Linac head components modeled in this work which include the target, primary collimator, flattening filter and jaws are shown in Figure (1).
Simulations of photon beams carried out by BEAMnrc user code, using ISOURC=19: Elliptical Beam with Gaussian Distributions in X and Y, to generate a full phase space files under the secondary collimators (Jaws). Variance reduction parameters used in this work are include: a directional bremsstrahlung splitting (DBS) (with radius = 10, NBRS=100 and Z= 90 cm), cut-off energy for electrons and photons are 700 keV, 100 keV respectively, ESAVE =1 MeV (Energy below which electron will be discarded in range rejection) [7]. The EGSnrc parameters were set as

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default. All simulations in BEAMnrc were run for 10^6 histories.

The phase space files created by BEAMnrc are used as a particles source in DOSXYZnrc [4] user code in order to calculate the dose distribution within Cartesian geometry. The phase space files were placed directly on the phantom surface. Dose distributions (depth dose and lateral profile) have been calculated into a homogeneous water phantom of external dimension of 40×40×40 cm^3 ,placed at Z = 90 cm from the target. The dose were scored into uniform small regions (voxels) of 0.5×0.5×0.5 cm^3.

VRT parameters such as the particle production threshold and transport energies for electron (ECUT) and photon (PCUT) were 700 and 100 keV respectively. Directional bremsstrahlung splitting (DBS) (with radius =10, NBRS=100 and Z= 90 cm) was defined for reducing the uncertainty. The particles in each phase space were recycled 10 times in order to achieve a statistical 1σ uncertainty less than 0.4 % in all dose points. Default EGSnrc transport parameters are applied in our simulations. The histories number depends on the volume of data stored in the phase space file generated from BEAMnrc.

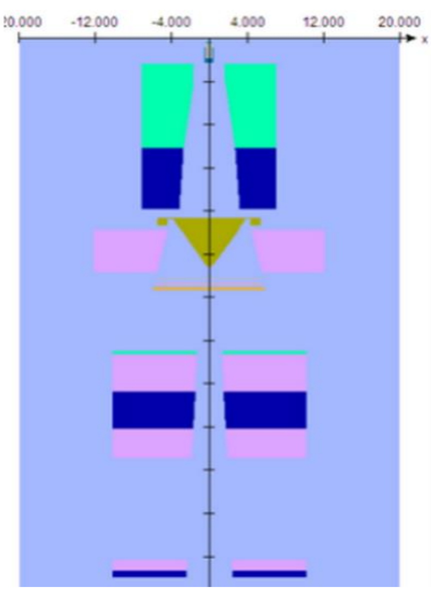

Fig.1: BEAMnrc model of Saturne43 Linac head geometry for 12 MV photon beam.

2.2 Dose Distribution

To test the impact of Bremsstrahlung and photon cross section data on dose distribution, depth dose curves and lateral dose profiles are calculated. In this study, the electron beam parameters as the mean energy, beam width and mean angular spread were 11.8 MeV, 1.5mm and 0.5°, respectively, according to that finding in our recent study [5]. Depth dose curves are calculated along the central axis and normalized to the dose at 10 cm. Lateral dose profiles are calculated on the x-axis perpendicular to the central axis of photon beam and normalized to the dose at 10 cm on the central axis. Both beam profiles and depth dose curves are calculated within homogenous water phantom of volume 40×40×40 cm3.

2.3 Photon Cross Section

Photon cross section packages available in BEAMnrc/DOSXYZ user codes, for coherent scattering, Photo-electric, pair production and triplet production cross sections, are based on “Storm-Israel” (the default), “epdl” and “xcom” which are in the format of log cross section vs. log energy. The Storm-Israel cross-sections are the standard PEGS4 cross-sections. The “epdl” setting will use cross-sections from the evaluated photon data library (EPDL) from Lawrence Livermore. The “xcom” setting will use the XCOM photon cross-sections from Burger and Hubbell [1].

2.4 Bremsstrahlung Cross Section

There are three options for determining the differential cross-section used for bremsstrahlung interactions which are: Brems cross sections= BH (the default), Brems cross sections= NIST and Brems cross sections= NRC option. NIST bremsstrahlung cross-section data which are the basis for radiative stopping powers recommended by the ICRU [1] . The difference between BH and NIST is negligible for energies > 10MeV, but becomes significant in the keV energy range where the NIST data base is preferred. In either case, the total bremsstrahlung cross sections are the same. The NRC cross-sections are the NIST cross-sections including corrections for electron-electron bremsstrahlung from exact calculations in the first Born approximation. The default bremsstrahlung cross section for an electron with a total energy E incident on an atom with atomic number Z, differential in the photon energy k, given by [2]:

$$d\sigma_{brem}(E,Z)/dk = \frac{A'(E,Z)r^2{}_0\alpha Z\big(Z+\xi(Z)\big)}{k}\left\{\left(1 + \frac{E'^2}{E^2}\right)\left[\emptyset_1(\delta) - \frac{4}{3}\ln Z - 4 f_c(E,Z)\right] - \frac{2}{3}\frac{E'}{E}\left[\emptyset_2(\delta) - \frac{4}{3}\ln Z - 4 f_c(E,Z)\right]\right\} \qquad (1)$$

In this current study, these three options are investigated for 12 MV photon beam.

3 Results and Discussion

As mentioned above, both beam dose profiles and depth dose curves were calculated to test the sensitivity of Bremsstrahlung and photon cross section data available in EGSnrc. Dose distributions were simulated for 12 MV photon beam of a SATURNE43 Linac head. The statistical uncertainties (1σ) associated with the simulated of depth dose curve are less than 0.4% for the high dose region and less than 0.6% in the buildup region. The statistical uncertainties (1σ) of the simulated profile are less than 0.4% in the central region and less than 1.5% in the out-off axis regions.

3.1 Bremsstrahlung Cross Section

Figure (2) shows (A) depth dose and (B) build up curves resulting from simulated 12 MV photon beam for NIST, BH and NRC Bremsstrahlung cross section data. From Figure (2), it's clear that the build-up region curve of NIST simulation is greater than others. This result is inconsistent with that reported in the user manual, which states that the difference is negligible for NIST and BH data for E >10 MeV [1] . In this work, we found that the difference is negligible for NRC and BH data for E =12 MeV. After Dmax, three curves are identical with each other, the difference is negligible.

On the other hand, lateral dose profiles resulted from three options show that there are not affected by changes of Bremsstrahlung cross section data, Figure (3). Accurate analyze of these parameters on dose calculations is performed by using gamma index criteria [6], which used to calculate the difference between the simulation results and measured ones. Gamma index results showed that the BH and NRC Brem cross section options give the best matching with measured data.

3.2 Photon Cross Section

Both percent depth dose curves and beam dose profiles obtained from four simulations of different photon cross sections data (xcom, epdl, pegs4 and si) are presented in the following figures (4 and 5).

From figure 4, we notice that the statistical error in buildup region is affected by photon cross section variation. But, buildup region of xcom photon cross section data is smoother than others. Figure (5) shows four beam dose profile curves of different photon cross section data, it's clear that there are a less sensitive to photon cross section variation. A minor influence is appear as shown in inset figure. Both depth dose curves and lateral dose profiles are normalized to the dose at central axis (dose at 10 cm), and compared with measured ones. Then, gamma index will used to analyze the relative difference between them. Gamma index results are summarized in Table (1).

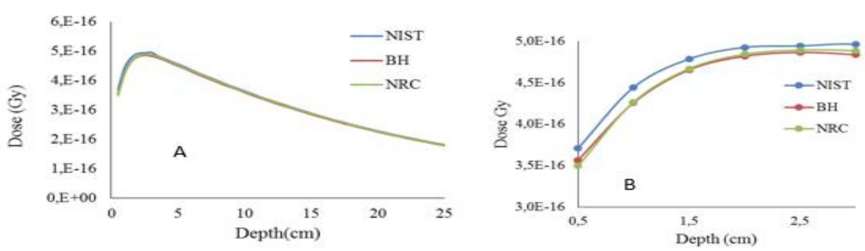

Fig.2: depth dose and build up region curves of 12 MV photon beam as a function of Brem cross sections data.

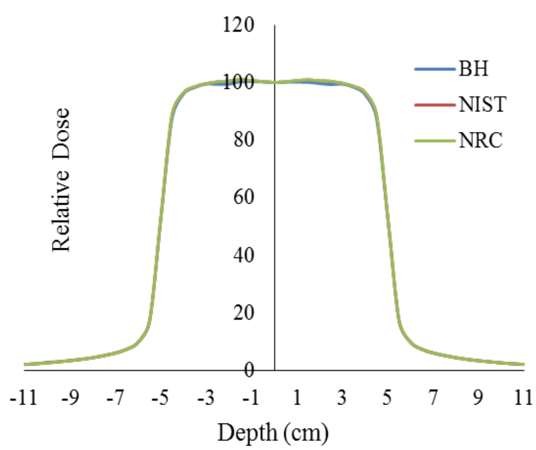

Fig.3: Lateral dose profiles of 12 MV photon beam as a function of Brem cross sections data.

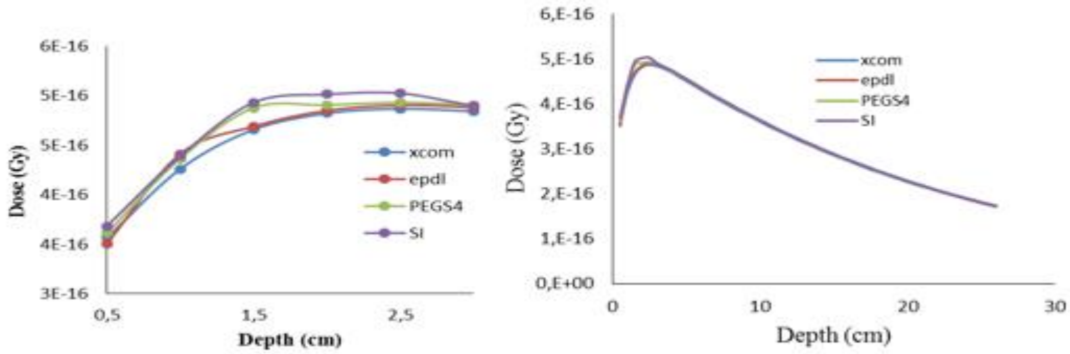

Fig.4: depth dose and build up region curves of 12 MV photon beam as a function of Brem cross sections data.

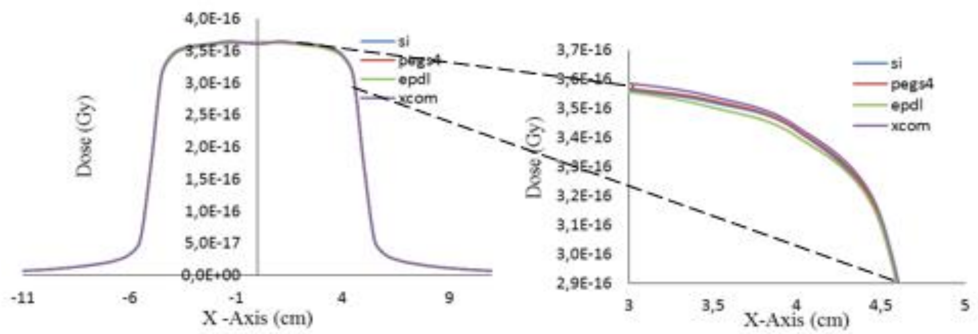

Fig.5: Lateral dose profiles of 12 MV photon beam as a function of photon cross sections data.

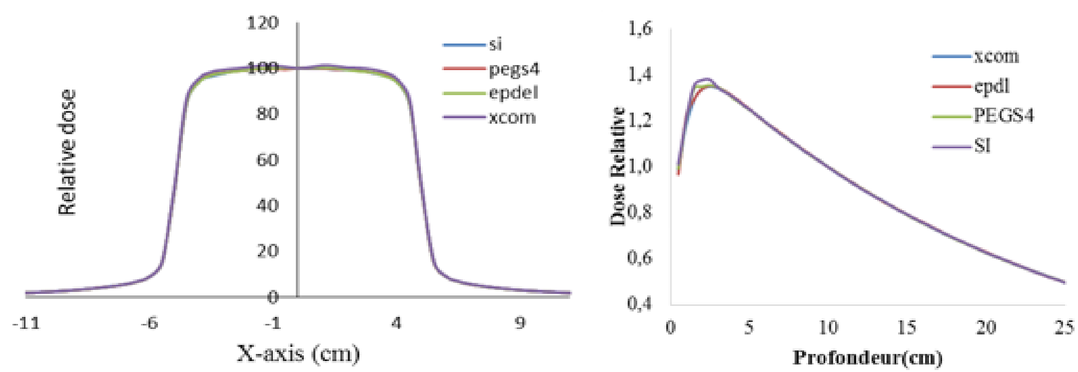

Fig.6: Lateral dose profiles and PDD curves of 12 MV photon beam as a function of photon cross sections data.

Table 1: gamma index test results for four photon cross section data when compared with measured.

photon CS	PDD		Profile	
	<1	<0.5	<1	<0.5
Si	97.9	91.5	86,6	73,7
pegs4	97.9	96.7	86,7	77,7
Epdl	97.9	95.2	84,4	73,2
Xcom	97.9	97.9	91,3	86,7

According to results presented in Table (1), we observe that the best gamma index value corresponds xcom cross section data compared to others especially for beam dose profiles. In general, we can say that dose distributions resulted from Megavoltage are less sensitive on the variation of photon cross sections data available in BEAMnrc and DOSXYZnrc, but we recommended to use xcom library.

4 Conclusions

Two EGSnrc parameters which include Brem and photon cross section are investigated in order to test their impact on the megavoltage photon beam dose calculation. The obtained results show that there is a slight influence of Brem and photon cross section data on the dose distribution. We recommend to test other cross section libraries such as ENDF. Also, must to investigate the sensitivity of cross section data on low and high photon beam energy.

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