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Phase space calculation of 6-MV Elekta compact linear accelerator by GEANT4 simulation

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Abstract

In Monte Carlo simulation of medical electron accelerators with electron beam, the running time of program is high. For reduction of relative error less than 0.01%, instead of the electron source, the photon phase space is introduced. Phase space data includes the energy and angular spectrum of gamma rays are produced by electron beam interaction with target. The purpose of this study is to introduce the phase space of the Elekta Compact linear accelerator using GEANT4 toolkit. Then the total scatter factor (Scp) of Elekta Compact linear accelerator was calculated for phase space validation. Using phase space as a surface source can reduce GEANT4 toolkit execution time and increase accuracy of the dosimetry calculation. Results show that the introduced phase space is a suitable source for the dosimetry calculations of Elekta Compact linear accelerator.

keywords :: Phase space, linac, Elekta, Compact,Scp, GEANT4,

Introduction

Radiation therapy is a treatment that plays a key role in the fight against cancer. This radiation can be applied from outside the patient's body (remote treatment) or by placing radioactive materials in the patient's body (brachytherapy). In remote therapy, linear medical accelerators are used to obtain photons or electrons in the MeV range, as well as proton beams and heavy ions. Photons in this energy range allow the treatment of tumors in body. The radiation fields are formed by a collimator system on the linac accelerator head, creating fields that are formed separately for the target treatment volume. The accelerator head is mounted in such a way that it can rotate around the patient with any desired angle. In this way, the rays can be irradiated from different directions, thus maintaining healthy tissue and important organs and focusing on the tumor tissue [1]. Previous research has shown that Monte Carlo methods are suitable for simulating photon beam transport in linear medical accelerators. Simulation methods can be used to measure the dose distribution in phantoms and patients' bodies. If the data are not accurate in the angular, energy and radial distributions of the photon beams, an error in the dose calculation occurs [2]. The low gain of photons due to the interaction of electrons with target is one of the important factors in causing errors in Monte Carlo calculations [3] and to reduce the error, the number of single-particle calculations must be increased. Increasing the number of single-particle calculations increases program execution time. To solve this problem, phase space is introduced. The phase space files of most accelerators are uploaded by the International Atomic Energy Agency [4]. Previously, different authors have studied the comparison between the results of phase space and the real state using different linear accelerators [5], which reported good agreement between simulation calculations and practical works [6]. In this researh GEANT4 toolkit is used to determine the phase space specification of the 6 MV Elekta Compact linear accelerator. GEANT4 toolkit is a Monte Carlo code that is capable of transporting atomic particles and nuclei in different environments [7]. Geometry and Tracking toolkit (GEANT4) is a simulation software based on the Monte Carlo method that written in C++ software and tracks all kinds of particles and has the ability to simulate magnetic, gravity fields and photons transport in nanoscale. GEANT4 has many libraries with different particle cross sections in different environments [8]. In this method, the spatial, angular and energy spectra of X-ray colliding with the tungsten target are extracted and its information is introduced as phase space. The spectral information of the phase space is defined as the X-ray source in the GEANT4 toolkit of the Elekta Compact linear accelerator for calculation of total scattering factor (Scp) as described in the following.

Experimental

GEANT4 toolkit was used to extract the Elekta Compact linear accelerator phase space. The geometry simulated in GEANT4 is shown in fig 1. The phase space was put as a surface source after target.

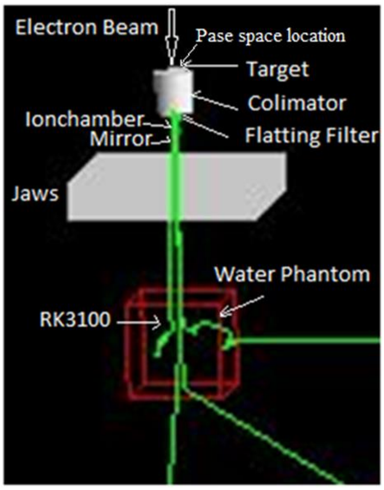

Fig 1: GEANT4 Geometry including the phase space

The accelerator head is composed of the following parts: a) Target: A tungsten cylinder with radius of 2 mm, b) Primary collimator: A tungsten cylinder with height of 10.2 cm and frustum of a Cone. c) Flattening filter: tungsten cone with height of 1.75 cm, d) Ionization chamber: thin cylindrical layers of copper, plastic and air with a total thickness of 1.5 cm and a radius of 3 cm [6], e) Mirror: A Capton cylinder with 45-degree, f) Jaws x and y: tungsten cylindrical shells to adjust the field and f) water phantom with the RK304 detector that is located at 10 cm depth of the water phantom. The source is considered, an electron source with a gaussian energy distribution. Phase space is the characteristics of X ray-source generated by the collision of electrons with the target at the head of the accelerator. These characteristics include the angular spectrum, energy spectrum, and spatial distribution of electrons produced in the target. The geometry of the phase space consists of a surface source with a uniform spatial distribution and includes the angular spectrum and the energy spectrum obtained from the simulation results with the GEANT4 toolkit. To derive the results of the phase space, the angular spectrum and the energy spectrum of the photons produced by the collision of electrons after the farthest target sourface from the source is obtained. The spatial distribution of the photons emitted from this surface is also calculated. The simulation was performed by empolying a 7-core computer, 8 GB of RAM and 2.9 GHz CPU.

Results and discussion

To perform the simulation, the gaussian electron energy distribution of an electron source with an average energy of 6 MeV and a width at half height equal to 3% of the average energy or standard deviation of 0.07 was defined in GEANT4 source. After executing the programe and stopping the electron in target, an X-ray is generated. The X-ray spectrum changes through different parts of the accelerator head due to the absorption of the photons and production of secondary photons due to the photoelectric interaction of photons with matter. The intensity of the produced X-ray decreases and the spectrum becomes weaker at low energies. The produced X-rays can be considered as a photon source. In order to perform dosimetry calculations by electron source with high accuracy, the program must be run for several days. To solve this problem, the phase space of accelerator must be calculated and defined in GEANT4 toolkit. Phase space contains spatial information, energy and angles of the secondary photons reaching the appropriate point inside the accelerator head, which is obtained by programe (Figs 2 and 3). According to the Fig 2, angular distribution of the produced X-rays is a gaussian distribution with standard deviation of 1.33 degrees and a half-height width of 3.12 degrees. Spatial distribution of the emitted photons from the target in different parts of the accelerator were calculated.

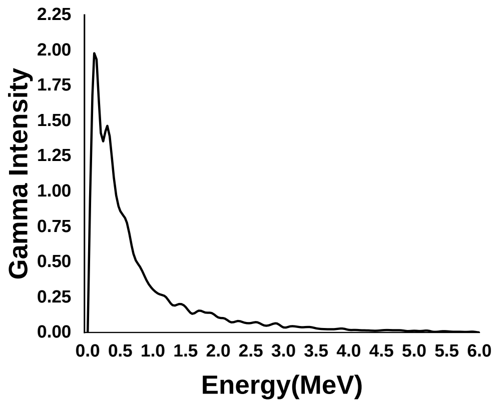

Fig 2 :X-ray spectrum produced in the Elekta Compact linear accelerator.

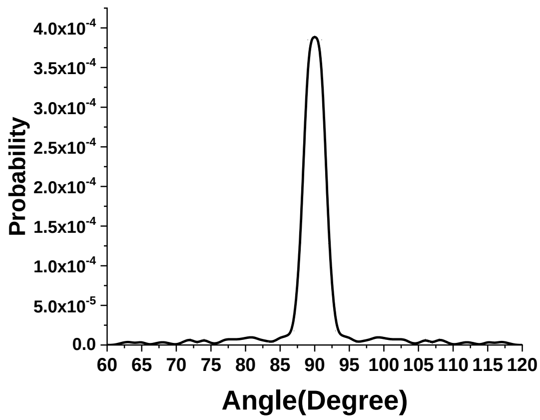

Figure 3 :Angular distribution of the generated X-rays at the head of the Compact model accelerator.

The output data of the surface dose distribution at a depth of 10 cm for 20×20 cm^2 field size in water phantom with and without phase space at the same execution time are shown in Fig 4a and b. As shown in the fig 4b, the data points for dose distribution with phase space are more than another one (without phase space). Therefore, we can decide on the goodness of the phase space used.

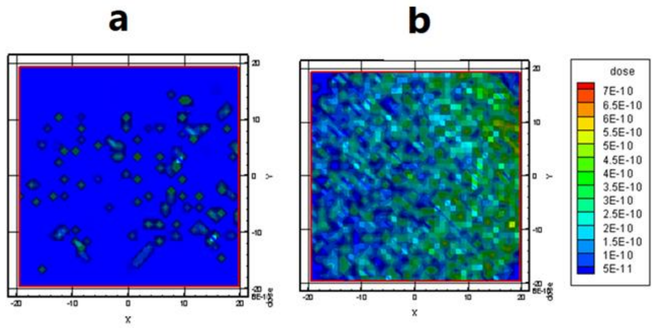

Fig4:Depth dose in 10cm depth for 20×20 cm^2 field size: a) without Phase space b) with Phase space

Conclusions

The purpose of this study is to introduce the phase space of the Elekta Compact linear accelerator using GEANT4 toolkit. For Monte Carlo calculations using the output results of GEANT4 toolkit, the geometry of the Elekta Compact linear accelerator head was simulated then phase space data were extracted and used as a secondary source in GEANT4 simulation. The results of the total scattering factor Scp shown in Table 1. Table 1 data was shown that there are the 96% agreement between the practical and simulation results using the phase space by Geant4 toolkit.

Table 1: Total scattering factor (Scp) simulation results

Field size cm^2	Scp		Agreement level
	With phase space	With practical [9,10]	
10×10	1.00	1.00	100%
25×25	1.23	1.19	96%

As a result, the Elekta Compact linear accelerator phase space can be used as a secondary source in accelerator for dosimetry calculations with the lower run times, higher accuracy and less error**.**

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