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MCNP Dose Calculations in a CT Phantom for Therapeutic External Photon Beam*

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Abstract: In this paper, we have addressed the problem of the radiation transport with the Monte Carlo N-particle(MCNP) code. This is a general-purpose Monte Carlo tool designed to transport neutron, photon and electron in three dimensional geometries. To examine the performance of MCNP5 code in the field of external radiotherapy, we performed the modeling of an Electron Density phantom (EDP) irradiated by photons from ^{60}Co source. The model was used to calculate the Percent Depth Dose (PDD) at different depths in an EDP. One field size for PDD has been examined. A ^{60}Co photons source placed at 80 cm source to surface distance (SSD). The results of calculations were compared to TPS data obtained at National Institute of Oncology of Rabat.

Key Words: Monte Carlo method; Monte Carlo N-particle; electron density phantom; radiotherapy; CT; percent depth dose

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1 Introduction

The radiation therapy is the treatment of the cancer by use of ionizing radiation. The radiation dose is the amount of energy absorbed by the tissues.

In practical radiotherapy, this radiation dose needs to be controlled within an accuracy of few percent; however, the accurate determination of absorbed dose is crucial to the success of radiotherapy[1]. Several methods are available for calculating absorbed dose in a phantom. One of these methods is based on the percent depth dose (PDD) determination. The aim of this work is to calculate the photon central axis PDD variation in Electron Density Phantom (EDP) using a general purpose Monte Carlo N-particle (MCNP) code. This will contribute to the improvement of Monte Carlo simulation in external beam radiotherapy field.

In radiotherapy simulation, models are created in order to predict dose distribution. These models are used as substitution for measurements that are impractical in human body. In this study, we simulate a model of heterogeneous phantom that is frequently used for clinical dosimetry[2]. It is a commercially available system, i. e., the EDP, which incorporates materials to take account of various body tissues compositions.

MCNP is a computational code that can be used in various applications. This code is used for particle transport simulation and modeling the key

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components of radiation therapy[3]. In our study, the MCNP code was employed to determine the dose distributions and the PDD. In external beam radiotherapy, the radiation source is at a certain distance from the patient. The main parameters in photon external beam dose delivery are: (a) depth of treatment; (b) field size; (c) source to surface distance (SSD) in SSD setups or source to axis distance (SAD) in SAD (isocentric) setups; and (d) photon beam energy[4]. The absorbed dose of the incident beam varies with depth. Thus, determining the depth dose evolution along the central axis of the beam is a fundamental step to investigate the dose variation. One way to characterize the central axis dose distribution is to normalize the dose at depth with respect to a reference depth and this quantity is usually expressed as a percentage and is known as PDD[5]. The motivation for this work was the increasing importance of Monte Carlo simulation in external beam radiotherapy. In this paper, we simulate the EDP; the MCNP code was used to calculate dose distribution at different depths in this phantom due to a ^{60}Co spectrum at 80 cm source to surface distance (SSD).

2 Materials and Methods

2.1 Depth dose distribution and PDD

In radiation therapy, the absorbed dose of the incident beam in the patient varies with depth depending on many conditions: beam energy, depth, field size, distance from source and beam collimation system[6]. Thus the calculation of dose in the phantom involves considerations in regard to these parameters and others as they affect depth dose distribution[1].

The PDD may be defined as the quotient, expressed as a percentage of the absorbed dose at any depth d to the absorbed dose at a fixed reference depth d_0, along the central axis of the beam (Fig. 1). PDD is thus:

$$PDD = \frac{D_d}{D_{d_0}} 100 .$$

In this work, we have simulated an EDP by MCNP5/X[7] in which the code was used to calculate the PDD at different depths due to ^{60}Co gamma source located at an SSD of 80 cm. We have tried one radiation field size of 30×10 cm^2. The PDD for this phantom was compared with experimental data of the National Institute of Oncology of Rabat, Morocco.

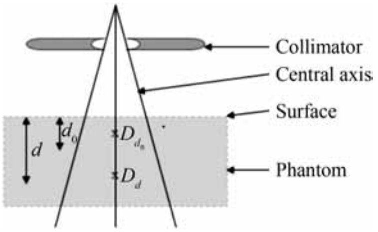

Fig. 1 Sketch illustration for PDD determination.

2.2 The EDP

The CIRS Model 062, EDP[8] adopted in this study is shown in Fig. 2. It is employed to provide two different functions: (a) A tool to assist physicians in documenting the relationship between CT number and electron density for the range of tissue found within the human body[9]; (b) A medical physics tool, used by technologies and physicists in performing quality assurance evaluation[10].

In this work the EDP is used for its medical physics tool function. This phantom has an elliptic shape with a height of 270 mm, a width of 330 mm and thickness of 5 cm for an abdominal scan. It consists of two body parts which are made of soft tissue equivalent epoxy resin. The body size can be small (head) with radius of 90 mm or large (abdomen) and is drilled with 2 concentric rings with radius of 60 and 115.3 mm respectively[11]. Each ring will have 8 holes equally spaced. The phantom has also an additional hole at its centre so it can accommodate a total of 17 inserts. The whole inserts are filled with cylindrical containers which simulate head and abdomen tissues. The EDP includes eight different tissues equivalent inserts as listed in Table 1[12]. The arrangement of the insert materials is shown in Fig. 3.

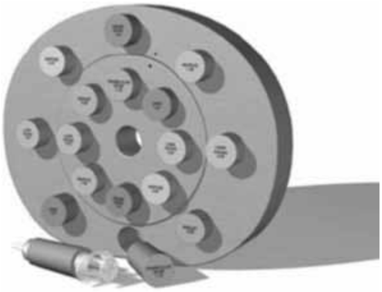

Fig. 2 Physical features of tissue characterization phantom, CIRS Model 62 (CIRS Tissue Simulation Technology, Norfolk, VA).

Table 1 EDP tissues description and densities

Material	Location on Fig. 3	Physical Density /(g/ml)	Relative Electron Density
Syringe water	1	1.000	1.000
Lung (inhale)	2	0.195	0.190
Lung (exhale)	3	0.495	0.489
Breast (50/50)	4	0.991	0.976
Dense bone	5	1.609	1.512
Trabecular bone	6	1.161	1.117
Liver	7	1.071	1.052
Muscle	8	1.062	1.043
Adipose	9	0.967	0.952

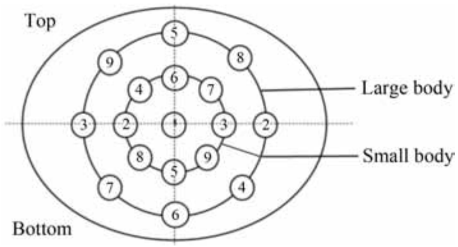

Fig. 3 Arrangement of the inserts within EDP.

In parallel and in cooperation with the National Institute of Oncology of Rabat, Morocco, we have used the computed tomography (CT) scanner to scan the Electron Density Phantom. The CT image of the Phantom was downloaded into the treatment planning system. In this exercise, two types of mediums, homogeneous and heterogeneous were used. In homogeneous medium the phantom is filled only by water whereas the heterogeneous one is formed of tissues.

2.3 Source and collimator modelling

In the radiation external beam photon therapy, most treatments are delivered with a uniform radiation beam on the irradiated field[13]. The collimator is a device used to reduce the cross sectional area of the useful beam of photons or electrons with an absorbing material. In our case it is a conical opening machined in lead block that can be used to limit the beam into a desired size and permits a continuously adjustable field size[14].

The dose calculation accuracy by MCNP is highly influenced by the quality of the collimator and source emission modelling. The source is supposed emitting in limited solid angle defined by the collimator. Four common groups of field shapes are used in radiotherapy: square, rectangular, circular and irregular[9]. In this study we focused our interest on rectangular fields.

The radiation coming from the source is collimated by a collimator of width 10 cm. This collimator is placed on the path of the beam at 35 cm from the source. We used a coupled electron-photon mode for production run. The user cutoff energy was 0.050 MeV. The scoring of energy deposition was accomplished with *F8 MCNP tally which is a track length estimate.

3 Results and Discussion

The MCNP model of the EDP geometry, the source and the collimator are shown in Fig. 4.

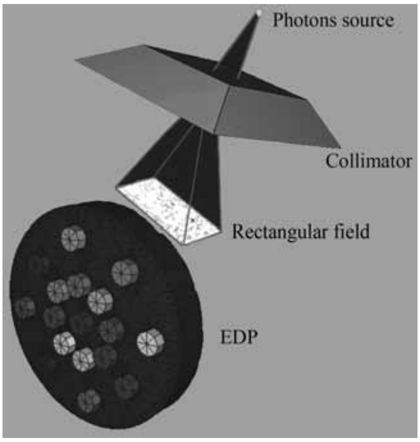

Fig. 4 MCNP model of EDP.

We are interested by calculating the dose deposited in each insert for the two cases. The comparison of the PDD results obtained in our simulations to those provided by the National Institute of Oncology is shown in Tables 2 and 3.

Table 2　Comparison between MCNP calculation and experimental data for homogeneous EDP

Location in the phantom	PDD by MCNP(%)	PDD by TPS(%)	Difference between MCNP and TPS(%)
9-8(large-body)	90	88	2
3-2 (large-body)	58	57	1
7-4(large-body)	34	34	_
4-7(small-body)	71	70	1
2-3(small-body)	56	55	1
9-8(small-body)	42	42	_
5-top	100	100	_
6-top	74	75	1
1	53	54	1
5-bottom	34	37	3
6-bottom	23	25	2

Table 3　Comparison between MCNP calculation and experimental data for heterogeneous EDP

Location in the phantom	PDD by MCNP(%)	PDD by TPS(%)	Difference between MCNP and TPS(%)
9-8(large-body)	52	52.5	0.5
3-2 (large-body)	36	34	2
7-4(large-body)	78.5	80	1.5
4-7(small-body)	65	62	3
2-3(small-body)	51	47	4
9-8(small-body)	40	38	2
5-top	100	100	_
6-top	61	63	2
1	44	43	1
5-bottom	29	28	1
6-bottom	20	18	2

3.1　Homogeneous EDP (water)

In this case the different inserts are occupied by water cylinders of the same density. Table 1 represents a comparison between the measured PDD obtained from treatment planning system (TPS) and that obtained from the MCNP simulation. The mesh tally is generated from an MCTAL file in the MCPLOT tally plotter implemented in the version 2.5 of MCNPX. According to the Table 1 and Fig. 5 that shows a mesh tally of an EDP configuration, we can mention the flowing remarks.

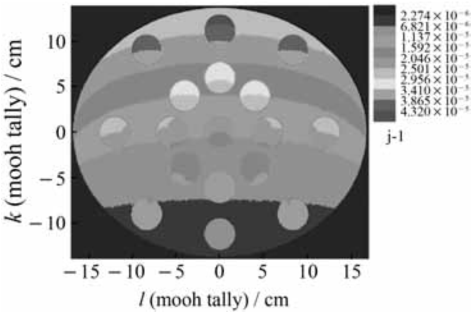

Fig. 5 Mesh tally of an EDP configuration filled with water Units are MeV/cm^3/incident photon.

The PDD decreases with depth. For example, the PDD at locations 5, 6, 1, 5 and 6 (Top toward bottom) starts to decrease from hole 5 (depth 0,5 cm for ^{60}Co) toward 1 (Fig. 5). Moreover, we found that the inserts located at the same level have the same PDD (example of inserts 9-8, 7-4 and 3-2 for both small and large bodies respectively). It is important to point out the small differences between the PDD of TPS and that of MCNP (Table 2) for all points.

3.2　Heterogeneous EDP (tissues)

In this case two parameters influence the PDD, the depth of location and the density of materials. Fig. 6 presents the results of the absorbed dose calculated by MCNP using MESH tally for the PED filled with tissue materials.

We note the following:

(a) For the large body, the inserts 8 and 9 are located at the same level. The insert 8 has a density of 1.062 g/cc but the 9 has a density of 0.967 g/cc, thus the dose is higher in insert 8 than in insert 9.

(b) For the inserts 8 and 9 of the small body, we note the same remark; however their dose is inferior to that in the inserts 8 and 9 of the large body which can be explained by the depth effect.

(c) For the large body, the inserts 7 and 4 are located at the same level. The insert 7 has a density of 1.071 g/cc but the 4 has a density of 0.991 g/cc, thus the dose is improved in insert 7 than in insert 4.

(d) The insert 6 of the small body has a density of 1.161g/cc witch is higher than the density of the insert 7 but it receives a quantity of dose that is inferior. We can explain this by the screen effect where the insert 5 of large body shades the insert 6 of small body.

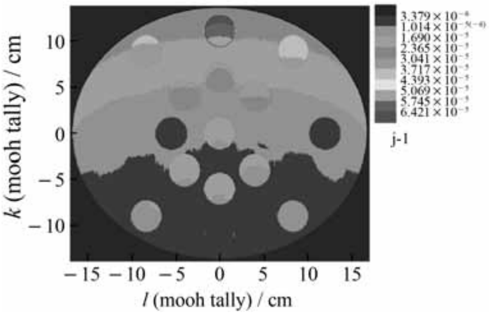

Fig. 6 Mesh tally of an EDP configuration filled with materials Units are MeV/cm^3/incident photon.

(e) The dose level, which is defined as energy deposited per unit volume, of 1.014×10^{-5} (MeV/cm^3/incident photon) in insert 3 is confused with that of the small body; whereas insert 2 has a lower dose level of 3.379×10^{-6} (MeV/cm^3/incident photon) even if they are at the same depth. This difference is due to the large distinction between the densities of the two inserts.

(f) There is a fluctuation at the dose level of 1.014×10^{-5} MeV/cm^3/incident photon which can be explained by: the secondary electrons are generated and ejected in the forward direction. These electrons move along their path and deposit their energy at significant distance away from their site of origin. In this case the electrons continue to move until overstepping the upper edge of the region at the dose level of 1.014×10^{-5} (MeV/cm^3/incident photon) and they are stopped at a certain depth in the last dose level region enhancing thus the dose level on this location. This results in anomalies in the shape of the edge of this region corresponding to the sites of inserts 2 and 3.

(g) The insert 6 of the large body receives a minimal value of the dose; this is due to the depth effect which is conjugated to the screen effect.

4 Conclusion

In this work, dose due to Cobalt photons was calculated within an EDP at various reference depths for a field size 30 × 10 cm^2 by use of MCNP5/X code. The results are compared to TPS data. A good agreement was obtained between the two sets of data. Thus, the present work provides an assessment of ready Monte Carlo tool that accurately and fully describes dose determination in the field of radiotherapy.

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