RAP Conference Proceedings, vol. 6, pp. 97–100, 2021
ISSN 2737-9973 (online) | doi: 10.37392/RapProc.2021.20
RAP-PROCEEDINGS.ORG

COMPARISON OF FOTELP AND MCNP WITH VOXELISED GEOMETRY AND ITS APPLICATION IN RADIOTHERAPY

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Abstract. *For the first time, a comparison of two programs, the European program FOTELP and the American program MCNP, are presented in this research. For this purpose, a numerical experiment with concentric spheres filled with water and a selected electron source of 10 MeV was performed. The deposited energy in concentric spheres was determined, with the radius of the first 0.5 cm and the last 15 cm. The deposited energy was determined, with the discrepancy between these two programs ranging from 0.4 to 17%. The increasing of application Monte Carlo's technique in medicine relies on voxelized geometric shapes that are obtained by voxelization or from CT data. These programs could be used as general-purpose software packages in dosimetry and radiology. Melanoma of the eye was used as an example to illustrate the use of CT data and voxelized geometry in radiotherapy. Domestic program FOTELP (R. Ilić) and derived versions from it, including the package for brachytherapy, is already being applied at the Institute for Nuclear Research, Russian Academy of Sciences, Laboratory for Medical Physics.*

Keywords: *FOTELP, Monte Carlo, MCNP, radiotherapy*

1. Introduction

In medical physics, Monte Carlo (MC) method used in radiation simulation for transport has become universal for the past 50 years. As a result, even though the computing power has increased, the MC packages complexity remained, the MC technique continues to increase in medical physics [1]. In computing the amount and distributions of absorbed energy, this technique is considered the gold standard. The main objective of this paper is therefore to illustrate the potential of the programs in the treatment of eye melanoma [2,3]. ICRP proposed a change of annual dose limit for the eye lens from 150 mSv to 20 mSv (for occupational exposure), which resulted in increased interest in eye dosimetry research [4].

Many improvements in radiotherapy had been observed in dose distribution, optimization, and patient positioning because of the use of Computed Tomography (CT) in the treatment plan. This was achieved by calculating the radiation dose and optimizing it to find out the best dose distribution for the targeted growth which is protecting the normal cells [5].

For radiotherapy studies, CT images can be converted into a voxel model. Voxelization of CT images can be used to calculate the absorbed dose in melanoma of an eye tumor. The dimensions and number of voxels, together with Hounsfield numbers [6], are the basis for the preparation of simulation data.

In order to show how simple geometry can be used to work with more complex geometry, the purpose of this research is to demonstrate real radiotherapy planning using the Monte Carlo programs, which involves phantom transformation to CT. In this paper, two programs, European-domestic FOTELP [7] and American MCNP [8], were used.

2. Material and method-experimental procedure

Most numerical experiments begin with a simplified geometry. Once the performances are acquired, they move on to more complex geometric shapes. However, spherical and planar geometry with layers of material is the most suitable for laboratory experiments.

FOTELP is a Monte Carlo software package that simulates particle tracking and dose delivery. This was used in research in dosimetry, energy protection, finding out energy absorbed in the body parts and the layers of micro-electronics, radiotherapy, and radiation damage object assessment. This program works in the 3-dimensional geometry which consists of an arbitrary field of particles coming from the cause of energy source ranging from 1 keV-100 MeV. Program FOTELP

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uses particle transition from previous to next state of phase space probability which is prepared by program FEPDAT. Program FOTELP simulates time independent and coupled transport of photons, electrons and positrons independent from which of these particles is emitted from the energy source.

FEPDAT code, according to the input data with REAL*8 accuracy, successively runs the subroutine and prepares transition probabilities. To create a database with the inverse distributions or probabilities, each routine performs numerical integration of differential cross-section or distribution. If there was a possibility of creating a database for each process, implementation and control of new models would become easier. The properties of cross-sections and conditions for applying the theory of electron and positron multiple scattering made these procedures very delicate. Integration of differential cross-sections or distribution densities was performed by the adapted Gauss-Legendre formula, while cubic splines were used to approximate distribution densities in the numerical form. In the FEPDAT.INP database the least necessary number of data is input. Using this data, the routines of this code compute numerous constants and required data for the other routines. The FEPDAT.INP file includes the following data. Figure 1 shows an example of input file FEPDAT.INP for water [9,10].

```
  1
276
1.000000   1
  2   1
  1   8
2.000000    1.000000
0.111894     0.888106
0.005000   20.000000   8
  1   1   22
```

Figure 1. File FEPDAT.INP for water.

MCNP (Monte Carlo Neutron Particle) code version 6.2 was used. The MCNP code treats an arbitrary three- dimensional configuration bounded by surfaces of first and second order, and elliptical torus as fourth degree surface. The cross-sections data library for transport of particles is covering the energy range from 10-11 to 20 MeV for neutrons and up to 150 MeV for several nuclides; 1 keV to 1 GeV for electrons; and 1 keV to 100 GeV for photons, while the newest photon library extends the transport to 1 eV.

In MCNP, the variable PAR was used for electron transport, and this variable determines which particle type will source emit, and the default is part=3 and MODE E for electrons. *F8 tally was used to calculate the deposited energy.

Spherical geometry was used to compare the results obtained using the Monte Carlo method in the FOTELP and MCNP programs. Concentric spheres were applied and for that purpose the deposited energy was calculated in the corresponding areas between two adjacent concentric spheres. All spheres are filled with water. The radii of the spheres are: 0.5, 1, 1.5, 2, 2.5 (in cm), and then in steps of 1 cm from 3-15 cm. Outside these spheres, there is a sphere with a radius of 25 cm, filled with air. The whole system is inside the cube with an edge of 30 cm. The space outside the sphere is empty (Figure 2).

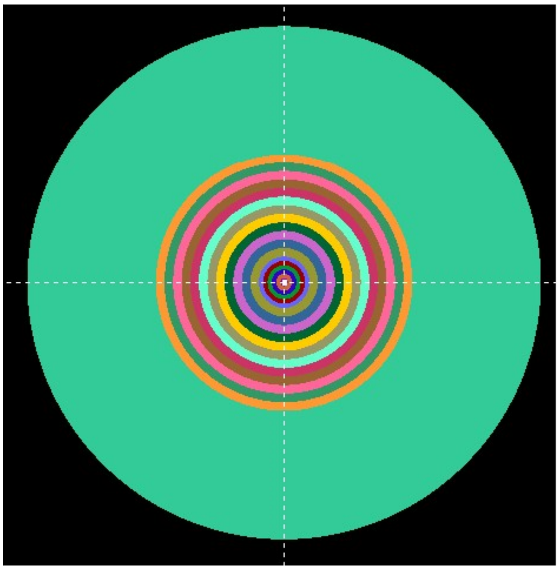

Figure 2. Concentric spheres as a geometric view from FOTELP.

In the CT data, the voxel is defined as a part of space in the form of parallelepipeds of dimensions Dx, Dy, Dz, where also by definition Dx and Dy are the sides of that a parallelepiped along the X or Y axis of a rectangular coordinate system, and Dz the thickness of the slice along the Z axis. The use of voxels in the FOTELP and SRNA [11] programs requires that part of the space be limited so that inside a parallelepiped there is an environment that needs to be irradiated with a particle source. If the source is outside the irradiated area, the mentioned space should cover a part of the air environment. After checking whether the particle on that path has any interaction and simulating these processes, the procedure continues until the end of fate of that particle. At every step where a particle loses energy, that loss is assigned to the current voxel.

This method works with voxel addresses, and with temporary placement coordinate levels of the voxel. This avoids geometry being loaded to those planes that define fixed geometry in other programs so-called CELL. The mentioned FOTELP and SRNA programs use the GEMVOX routine in which temporarily puts only that current voxel in the coordinate system. The consequence is the saving of memory space and that the simulation takes place only with one voxel. The version of the general purpose of the FOTELP code is the FOTELP - VOX code used to calculate the absorbed dose in melanoma of an eye. It uses methods of Monte Carlo in the simulation of particle delivery. This takes place when the particles are transported from the external source via the human body. As a result, there is a 3-dimensional distribution of the absorbed dose. Before this simulation, a person can select between either the photon or electron beam of any shape. The energy on the other side should be above 1 keV to enable the calculation of 3 dimensions dose distribution, the CT data is applied so to describe the anatomy of the patient.

3. Results and discussion

In this paper, spherical geometry was used to compare the results of deposited energy, which were obtained using FOTELP and MCNP. The point, electron source of energy 10 MeV is in the z-axis direction at a distance of 20 cm from the center of the sphere. The particles are emitted in parallel straight direction toward the concentric sphere. The deposited energy in MeV in eighteen water spheres for 10^7 electrons was calculated. The results of the deposited energy are shown in Table 1.

The radii of the spheres are shown in the first column of Table 1, results of deposited energy obtained using the FOTELP and MCNP programs are shown in the second and fourth columns, while the uncertainties of the results are given in the third and fifth columns. The values of deposited energy obtained using the FOTELP and MCNP programs are in the range from 6.25 to 6.78E + 06 MeV, from 7.25 to 6.87E + 06, respectively. The largest discrepancy of 17% is for the first two spheres of radii 0.5 and 1 cm, while in other cases it is less than 7%. The last result refers to the air ring (space between spheres of radius 15 and 25 cm) where the uncertainty is 0.1% for both programs.

Table 1. Results of deposited energy in concentric spheres obtained using FOTELP and MCNP programs.

Radius [cm]	Dep. energy [MeV] - MCNP	Unc. [%]	Dep. energy [MeV] - FOTELP	Unc. [%]
0.5	7.25E+00	3.25	6.25E+00	4.74
1	5.13E+01	3.99	6.20E+01	3.10
1.5	1.48E+02	2.46	1.40E+02	1.60
2	2.78E+02	1.77	2.59E+02	1.24
2.5	4.71E+02	1.35	4.42E+02	1.02
3	6.95E+02	1.15	6.83E+02	0.78
4	2.28E+02	0.7	2.26E+02	0.46
5	3.86E+03	0.54	3.76E+03	0.34
6	5.84E+03	0.44	5.60E+03	0.28
7	8.24E+03	0.37	8.21E+03	0.23
8	1.12E+04	0.32	1.14E+04	0.20
9	1.48E+04	0.28	1.50E+04	0.17
10	2.36E+04	0.22	2.37E+04	0.13
11	2.56E+05	0.08	2.77E+05	0.04
12	1.20E+06	0.05	1.27E+06	0.01
13	2.65E+06	0.03	2.70E+06	0.02
14	4.49E+06	0.03	4.47E+06	0.02
15	6.87E+06	0.03	6.78E+06	0.02
25	2.76E+05	0.05	2.71E+05	0.10

The results of the comparison of deposited energy in concentric spheres are also shown in Figure 3, which confirm the good agreement between these two programs. In this case we did not track secondary particles. The results obtained using both programs are zeros from 10 cm to the center of the spheres.

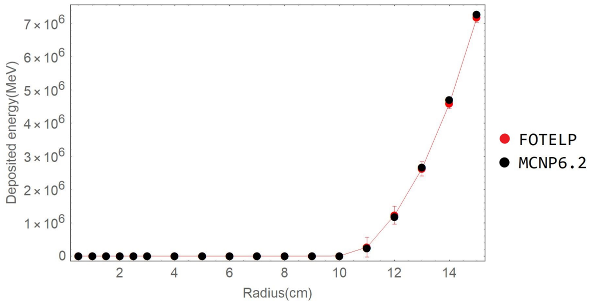

Figure 3. Comparison of deposited energy in concentric spheres for 10 MeV using FOTELP and MCNP codes

Eye melanoma can be great example of how voxelized geometry can be used in radiotherapy. As an illustration of the use of CT data to simulate transport by the FOTVOX program in voxelized geometry, CT data of a patient eye is used.

A beam of electrons is directed at the eye tumor at an angle of θ= 90° and φ = 45° so that it does not touch the pupil of the eye. A CT scan of the patient's head was used, with voxel sizes of 0.5 mm, 0.5 mm, and 1.0 mm. The melanoma was thought to be spherically formed and located at the bottom of the eye. A therapy plan was created using FOTVOX software and a 1 cm radius cylindrical electron beam with an average energy of 10 MeV. A total of 106 electron histories were used in the simulation. The electron dose distribution on a slice of an eye is shown in Figure 4. As an illustration, Figure 4 shows the doses in the X-Z plane along beam axes with colors corresponding to the voxel density for the anatomical image.

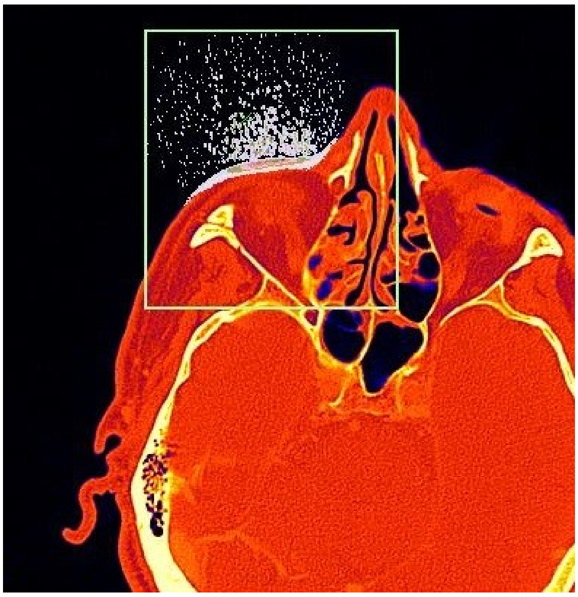

Figure 4. Deposited energy in eye slice obtained by the FOTVOX code by voxelized geometry.

5. Conclusion

The purpose of this paper is to demonstrate the conversion from simple - spherical to more complex geometries in radiotherapy planning.

The deposited energy in concentric spheres was determined, with the discrepancy between FOTELP and MCNP programs which is in the range of 0.4 to 17%.

As the FOTELP software package was developed to simulate transport of photons, electrons, and positrons by the MC method, in this paper, only a part of the possibilities of this software is presented on selected examples. The obtained results of numerical experiments with the FOTELP-VOX program support the expectations that the Monte Carlo technique has entered clinical practice for planning radiotherapy. Our future numerical experiments on complex sources and geometric shapes will be an opportunity to show further possibilities of FOTELP software.

Acknowledgements: *The paper was supported by the Serbian Ministry of Education, Science and Technological Development (Agreement No. 451 03-9/2021-14/200122 and 451-03-9/2021 14/200378). The authors would like to thank Prof. dr Radovan D. Ilic, who introduced us to the technology of Monte Carlo method and enabled the use of all versions of the FOTELP software package. We would also like to thank him for his unselfish professional assistance, persistence, and understanding during the numerical experiments and paper writing.*

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