SPACE PHASE CHARACTERISTICS OF A TYPICAL I-125 BRACHY SEED, MODELLED BY MONTE CARLO TECHNIQUES.

Iulian BĂDRĂGAN[1], Paul STERIAN[2]

Practica clinică curentă necesită ca doza calculată de sistemele de planificare a tratamentului (SPT) să fie verificată suplimantar utilizând o metodă independentă de calcul. Unele dintre aceste metode utilizeaza technici Monte Carlo. In timp ce asemenea sisteme există deja pentru tratamentul cu radiaţie externă, se simte nevoia unui sistem similar pentru cazul implanturilor cu seminţe radioactive.

Lucrarea de faţă se concentrează pe modelarea unei seminţe Brachy I-125 tipice şi prezintă rezultatele obtinute în proces, focusându-se pe schimbarile în spectrul energetic datorate transportului de perticule prin structura seminţei.

The current clinical practice requires double-checking the dose calculations generated by the treatment planning system (TPS) using an independent method. One class of methods employs Monte Carlo techniques. While there are a number of such systems in place designed for external radiation beams, there is a need for a similar approach for treatments using implant seeds.

This work concentrates on the process of modeling a typical I-125 Brachy seed and presents the results obtained along the way, with a focus on the energy spectrum changes due to particle transport through the core and enclosure of the seed.

Keywords: Monte Carlo, Brachytherapy, phase space file

1. Introduction

Radiation has long been one of the tools successfully employed by the medical profession in the fight against cancer. Technology continues to improve every day and new techniques are constantly developed in an effort to overcome the disease. The basic principle however, remains the same – concentrate enough radiation at the site of the tumor, in order to destroy it, while trying to avoid as much as possible damages to the surrownding normal tissue.

Some existing techniques make use of external radiation beams and the most common way to generate them is by using a linear accelerator. One or more such beams are concentrated on the tumor site from various directions, thus maximizing the radiation to the tumor while minimizing it to the normal tissue. By contrast, Brachytherapy uses tiny radioactive sources which are placed inside

[1] Ph.D. Medical Physicist, MCCPM, B.C. Cancer Agency - Abbotsford Centre, Physics Dept., British Columbia, Canada

[2] Prof., Dept. of Physics, University POLITEHNICA of Bucharest, Romania, e-mail: sterian@physics.pub.ro

or in some cases very close to the tumor. One of the most common treatment sites – the prostate – is commonly treated by inserting permanently a number of approximately one hundred I-125 sources, which over a few half-lives deliver enough radiation to destroy the tumor.

A number of software packages have been developed to help planning the details of the implant. For their calculations, they normally employ a standard protocol known as TG43 [1]. However, due to the nature of the disease, additional checks are necessary in order to make sure the radiation dosage is correct, and these second-check calculations have to be independent and accurate. The best methods which fulfill these requirements are those based on Monte Carlo techniques.

This work is part of a broader project which aims to enrich an existing Monte Carlo computing cluster presently used for external beam calculations at the Vancouver Island Cacer Centre with Brachy capabilities. To the author's best knowledge, the project is unique at the time of this writing.

We present the steps taken and results obtained for modeling a typical I-125 Brachy seed and we focus in the end on the energy spectrum changes due to particle transport through seed's geometry.

2. Brief description of the Monte Carlo method

When photon particles are interacting with matter, the most relevant processes in terms of radiation therapy are the photoelectric, Compton and pair production effects. All are subject to statistical probabilities such as interaction probability with pathlength, energy and particle type, scattering angle e.t.c. These probabilities are well known in the literature and were very carefully measured and tabulated. They are extensively used by the Monte Carlo dosimetry.

In Monte Carlo dosimetry, each particle is represented by a set of numbers, storing every moment the characteristics of the particle (position coordinates, direction cosines, energy and type). The software then uses additional information such as the spectrum and the geometry of the radiation source, the geometry and the material composition of the target and the probability tables, to transport an enormous number of particles and score the energy deposited inside the target. The name of Monte Carlo actually is due to the fact that during such a simulation, the program needs to generate random numbers quite frequently in order to explore the probability distributions.

Monte Carlo calculations give the most accurate results due to the fact that they simulate the very physical processes happening inside the target. The number of simulated particles has to be quite large for the results to be statistically meaningfull and this translates into a rather long running time. Gradually, this is becoming less of an issue with the constant increase in individual workstation computing power and the use of high performance computing clusters.

3. Problem definition

A common method to speed routine calculations is to first obtain a model of the radiation source. Typically, this is a file containing a large number of particles which were transported through the source structure until they just got out and were about to enter the target. Afterwards, this file is used as a source and the Monte Carlo code is only sampling from it whenever it needs to transport a new particle through the target. This way, the particle transport through the source itself is bypassed and some significant time is saved. These models are known as phase-space files.

The cluster at Vancouver Island Cancer Centre (VICC) mentioned previously, uses pre-modelled phase-space files for various external beams. In order to be be able to use the cluster for Brachy calculations, we had to derive a phase-space file for the I-125 seed.

4. The Oncura OncoSeed I-125 model 6711

There is a significant number of seed models on the market. We chose for our modeling the one which is actually used for implants at the VICC. A sketch showing the seed geometry and material composition is shown in Fig. 1 [4].

The radioactive I-125 is deposited as a very thin coating on the surface of a core silver cylinder which is further enclosed for patient safety reasons inside a titanium capsule.

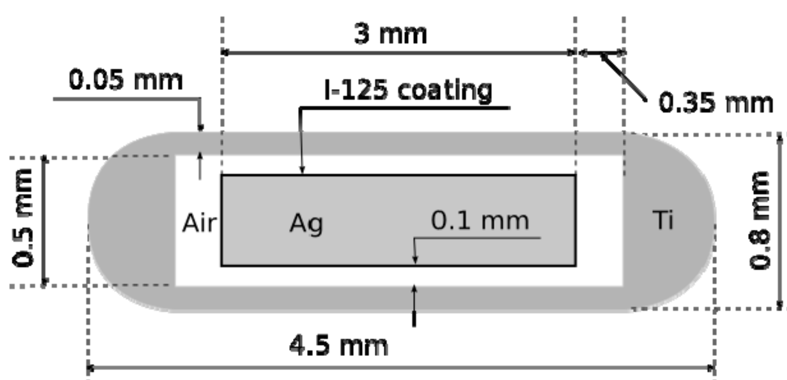


Fig. 1. Schematics of the Oncura OncoSeed I-125 model 6711.

The spectra of I-125 which we used for modeling is listed in Table 1 and further plotted in Fig. 2 [3]. All components are photons.

Table 1

I-125 spectra components used for MC simulation

Energy [MeV]	Weight [%]
0.0038	06.9632
0.0272	17.9245
0.0275	33.4681
0.0310	11.6352
0.0355	30.0090

The average energy of the spectra is 0.0286 MeV, calculated according to equation 1.

$$E_{\text{Average}} = \frac{\sum_{k=1}^{N} \text{Energy}_k \times \text{Weight}_k}{\sum_{k=1}^{N} \text{Weight}_k} \tag{1}$$

where N is the number of components in the spectra.

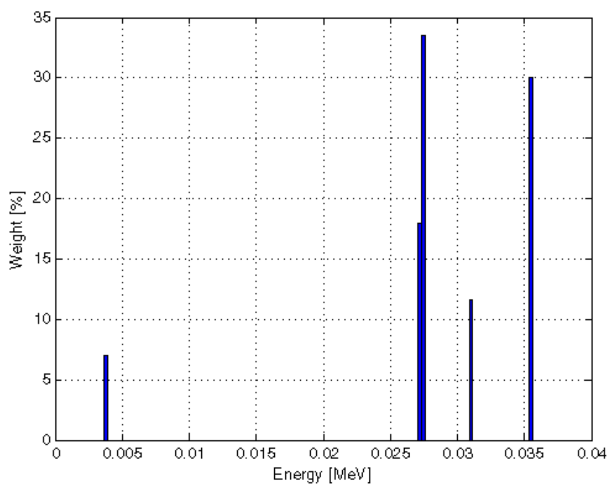


Fig. 2. I-125 energy spectra used for modeling.

5. Details on the EGSnrc transport engine and our user code

For our simulations we used the EGSnrc Monte Carlo system [2, 5]. This package is free for non-commercial use and comes as a bundle of material and physics data and various software routines and tools.

The user has the opportunity to hook into the system by writing his own code which calls the transport routines enclosed inside EGSnrc. Basically the user is in a position to describe the geometry, materials, energy spectra and define the quantities to be scored as output. More details on the coded physics routines and other data can be found in the manuals included with the EGSnrc package.

In order to model the geometry of the seed, we've coded mathematical objects such as planes, cylinders and spheres. Then, we sampled a number of 158,808,000 particles from the I-125 spectra and transported them through the seed structure until either the original particle or a descendent reached the external surface. Once there, we scored the particle in a separate file which is our seed phase space.

However we continued transporting the particles outside the seed until the energy dropped below a predefined value. The outside medium in our simulations was water which is common practice given the fact that the physical density of the prostate is virtually the same as that of water. The reason for continuing with the transport is that we wanted to score the dose deposited in the volume around the seed so we can compare it against standard calculations. An agreement of these values would indicate that our simulation is correct. The dose in medium is defined by equation 2.

$$D\text{ose to a volume} = \frac{\text{Energy deposited in the volume}}{\text{Mass of the volume}} \qquad (2)$$

We used a rezolution of 0.1mm, that is we divided a cube 10cm size centered in the seed, into 0.1mm side cubes and scored the dose in every one of them.

6. Validation against the TG43 standard

The standard used to calculate the dose rate around a Brachy source is described in a document known as TG43. The document defines a number of parameters and tabulates values for them for the most common situations. The values are a compilation of direct measurements and Monte Carlo simulations published in the literature. Equation 3 from the same document, shows how the parameters are used to derive the dose rate in water (dose per time) for any source.

$$\dot{D}(r,\theta) = S_k \times \Lambda \times \left[\frac{G(r,\theta)}{G(r_0,\theta_0)}\right] \times g(r) \times F(r,\theta) \qquad (3)$$

where the significance of the factors is:

$\dot{D}(r,\theta)$: absorbed dose rate; S_k: air-kerma strength

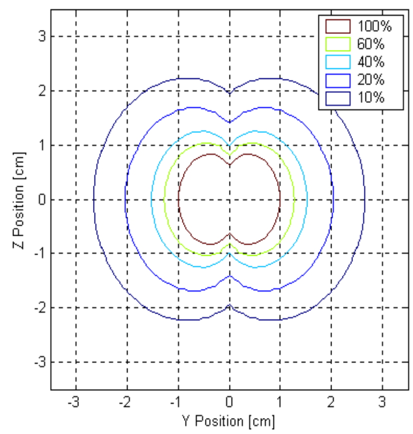
Λ: dose rate constant; $G(r,\theta)$: geometry function

$g(r)$: radial dose function; $F(r,\theta)$: anisotropy function

r: distance from the source center ($r_0 = 1\,\text{cm}$);

θ: polar angle ($\theta_0 = 90^o$)

We've implemented equation 3 with a few routines in Matlab and the results are shown in Fig. 3 as a a collection of isodoses.



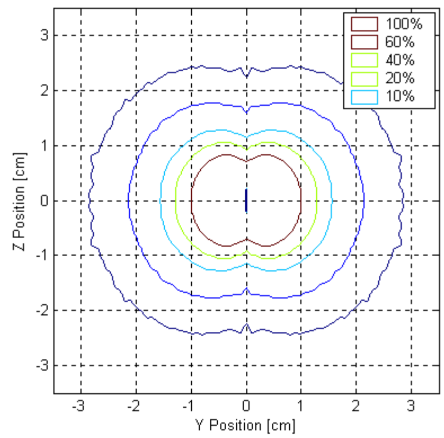


Fig. 3. Isodoses calculated by the TG43 protocol. Fig. 4. Isodoses calculated by Monte Carlo

For comparison, Fig. 4 shows similar results from our Monte Carlo simulation. The similarity is very good at least up to about 1.5 cm distance from the seed. In practice, the adjacent implanted seeds are 0.5cm to 1cm apart from each other and this is where the calculations must agree. For further comparison, Fig. 5 shows a plot of both TG43 and Monte Carlo dose calculations along the central transversal direction. Again, beyond 1.5 cm slight discrepancies begin to show up, but they are not clinically significant. The TG43 calculation uses the data for the parameters defined by Eq. 3, published by Weaver et al.

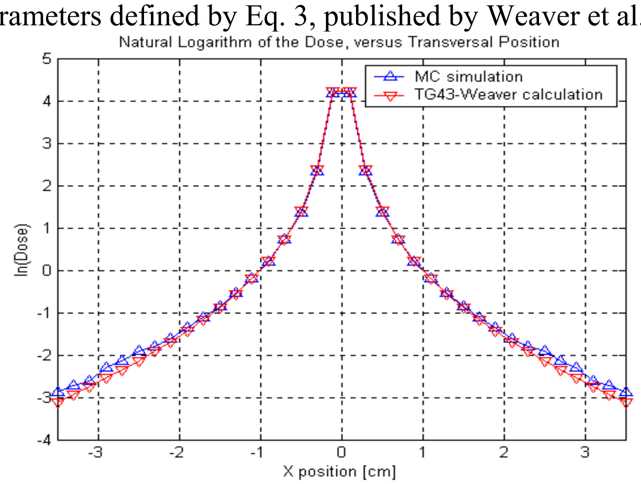


Fig. 5. Comparison of the radial doses scored by Monte Carlo and calculated with the TG43 protocol.

As stated above, these comparisons validate our Monte Carlo model against the standard and implicitly our scored phase space file.

7. The seed phase space file and other details

Out of the 158,808,000 particles simulated, about two thirds get to the surface of the seed and are getting scored into the phase space file. More specifically 106,224,440 particles were scored which is about 66.889% of the total. Of these, about one third (33.44%) are primary particles, which in this context means they interact for the first time at the seed boundary.

Also, it turns out that about 0.3% of the emerging particles are very low energy electrons while the rest are photons. These electrons do not contribute significantly to building the therapeutic dose around the seed so they are not discussed here. Fig. 6 displays a plot of the energy spectra, in which characteristic energies of the silver and titanium are showing as expected, and table 2 lists the top ten spectra energies present in the phase space file.

The average energy of the I-125 Brachy source (phase space file) is 0.0250 MeV, calculated according to Eq. 1 so on the average the energy is attenuated by about 12.6%.

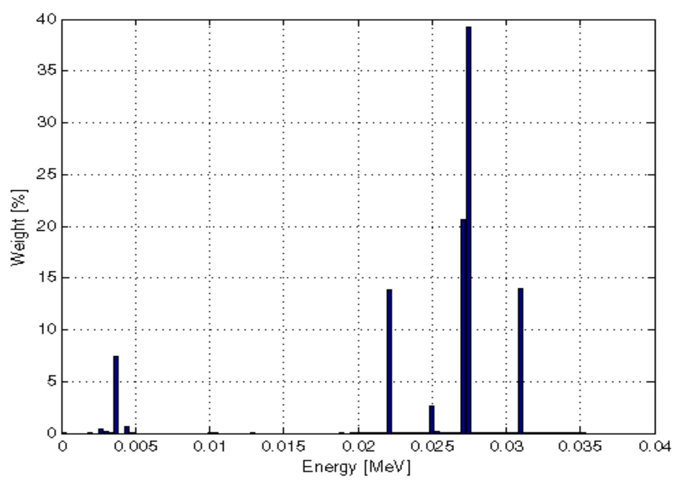


Fig. 6. Seed energy spectrum just outside the titanium enclosure.

Table 2

First ten most significant spectra components

Energy [MeV]	Weight [%]
0.0274	39.2801
0.0271	20.8596
0.0221	13.9962
0.0310	13.6929
0.0037	07.3508
0.0249	02.4731
0.0044	00.6266
0.0027	00.3892
0.0253	00.2529
0.0030	00.1297

8. Conclusions and future work

We have successfully built a Monte Carlo model for the Oncura OncoSeed I-125 model 6711. The scored phase space was validated by straight volume dose distribution comparisons betwen the Monte Carlo values and the TG43 standard. In the process, we've accomplished some insight into a few things such as the energy spectra of the radiation emerging from the seed, particle attenuation, average energy change and the dose distribution in the proximity of the seed, where is virtually impossible to perform direct measurements.

The integration of our phase space file with the existing dosimetric system in Vancouver Island Cancer Centre's computing cluster, requires more work on the programming side such as coding a proper web interface for easy clinical use, other background management scripts such as a means to import the implant seed positions from the TPS and of course a proper amount of tests.

B I B L I O G R A F Y

[1] Report of AAPMM Radiation Therapy Committee Task Group 43, Medical Physics Journal, Vol. 22, Issue 2, February 1995.

[2] http://www.irs.inms.nrc.ca/EGSnrc/EGSnrc.html

[3] ICRP Publication 38: Radionuclide Transformations: Energy and Intensity Emissions - Paperback (Dec 21, 1983), p34, published by ICRP (International Commission on Radiation Protection - http://www.icrp.org/)

[4] http://md.gehealthcare.com/shared/pdfs/pi/oncoseed.pdf

[5] *S. C. Stefanescu,* A generalization of a classical Monte Carlo algorithm to estimate π , U.P.B. Sci. Bull., Series A, Vol. 68, No. 2, 2006, pp.3-13.