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# A dosimetric evaluation using the Monte Carlo method considering geometric variations of the iodine-125 seed for brachytherapy

H. S. Chico[1], L. V. Angelocci[1], C. A. Zeituni[1], C. D. Souza[1], S. S. Sgrignoli[1], and M. E. C. M. Rostelato[1]

[1] *henrique.schico@gmail.com,*
*Instituto de Pesquisas Energéticas e Nucleares, IPEN-CNEN/ SP, Av. Prof. Lineu Prestes, 2242 – Butantã, São Paulo – SP, 05508-000.*

## 1. Introduction

One of the modalities of using ionizing radiation for cancer therapy is brachytherapy, which utilizes sealed sources (seeds) close to or in contact with the target (tumor). The dose to be used is studied through prior treatment planning to understand the distribution of radiation in the target and adjacent healthy tissues. For this purpose, computational methods are widely employed based on the chosen source, type of radiation, and treatment duration. The goal is to determine if the estimated dose for delivery to the patient aligns with the requirements outlined in the planning [1], [2].

According to the Intituto Nacional de Câncer – INCA, in 2023, 341,350 and 362,730 new cancer cases were diagnosed in Brazil for men and women, respectively. Of these cases, 10% to 20% may involve brachytherapy as a treatment. Therefore, as therapeutic methodology becomes more refined and computer systems are improved, it is necessary to investigate the dosimetry of radionuclides [3].

The seed investigated is under development by the Institute of Energy and Nuclear Research at the Center for Radiation Technology and follows a geometry close to the OncoSeed1251 6711 Amershan/GE model. The material that composes it is a titanium tube with a silver core containing radioactive material and solders at the ends. The physical values of the seed are as follows: width of 0.8 mm, total length of 4.5 mm, core length of 3 mm and wall thickness of 0.05 mm, as illustrated in Figure 1 [4].

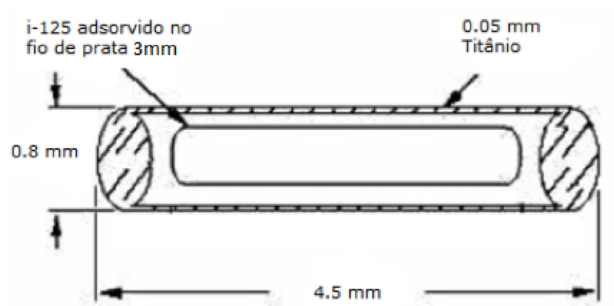


Figure 1. Geometry of the iodine-125 seed.

The production is controlled by a Programmable Logical Controller - PLC. The titanium tube is precisely positioned for the first weld, then repositioned to receive the silver with iodine-125 already fixed, and the second welding is done by laser. The sealing of the tube is performed with the same material that constitutes it. After sealing the source, it undergoes a visual control process and a leak test for approval or rejection. However, there is no protocol for measuring the final length of the seed and the core after its conception. Therefore, an investigative process is needed regarding the final radionuclide dose considering these variations during production [4].

The study and quantification of radiation interactions with matter allows evaluating the amount of energy received by a medium after the incidence of radiation. The absorbed dose can be defined as the amount of energy given (dE) to matter by photons per unit mass (dm). In the International System, the unit of

measurement is joules per kilogram, which can be written as Gy (gray). Meanwhile, Kerma (K) is the ratio of the sum of all kinetic energies (dEtr) per unit mass (dm) [2], [5].
The source dosimetry is extensively studied during its conception. Typically, multiple methods are used to measure the dose to compare results, ensuring reliability to the product. These methods follow the dosimetric formalism presented in Task Group 43 – TG 43, of which Monte Carlo simulation - MC can be used. TG 43 also presents two pieces of information that must be considered: the formalism is only for water as a medium and disregards manufacturing variations [6].
MC can be described as a statistical method in which a sequence of random numbers is used for simulation. In terms of radiation transport, the stochastic process can be seen as a family of particles whose individual coordinates follow the principles of radiation interaction with matter and experimental data collected on the probabilities of interactions. Each particle is evaluated from its emission to its pre-defined cutoff energy, and this evaluation is called the particle's history. The particle's history for these collisions can be simulated by MC assigned to a code, which performs the necessary equations to quantify physical events and understand the probability of these events occurring [7].
The objective of the work was to analyze relevant variations during the conception of the iodine-125 seed for brachytherapy that are not considered by the dosimetric protocol of TG 43. The dose formalism in water from TG 43 was considered. The main interest was to avoid future inconsistencies when this protocol is applied for both experimental and Monte Carlo dosimetry, evaluating the effects of two geometric parameters not normally observed in order to assess whether there is an impact on the final dose rate (variation 1: seed length and variation 2: nucleus length).

## 2. Methodology

The Monte Carlo N-Particle Transport Code – MCNP V6.2 was used, which already incorporates information into its database about the cross-section, the physics describing unexpected events, and combines the tools from version 5 with the extended version's expanded capabilities. Additionally, the User's Manual Code Version 6.2 was strictly followed for code development. To use MCNP V6.2, 100 inputs were written for each physically measured variation [8].
The methodology steps were divided into 2 stages. All simulations used the same radiation spectrum, and $10^9$ particles were simulated for each input code. The formalism was in water, and geometric variations in source manufacturing were considered.
First stage: The 1st input was developed using the nominal seed geometry presented in Figure 1. The output obtained will be discussed in the results to compare them with the outputs of the simulations in the 2nd stage.
Second stage: 100 measurements of the seed length (variation 1) and 100 measurements of the silver core length (variation 2) were performed using a calibrated caliper in millimeters, as seen in Figure 2 (a) and (b).


Figure 2. (a) Physicial measurement of the length of the iodine-125 seed, (b) measuremente of the core.

For variation 1, values ranging from 4.48 mm to 4.69 mm were found, with na average of 4.58 mm. For variation 2, the values ranged from 2.91 mm to 3.03 mm, with na average of 2.97 mm. The obtained values were added to the input, and an input code was written for each obtained measurement, resulting in a total of 200 inputs.

## 3. Results and Discussion

The outputs from the nominal seed and variations was processed using MATLAB software, allowing data interpretation through a matrix system. The reference dose rate profile is visualized in Figure 3 and will be compared to the two investigated cases. The average results of variations 1 and 2 are compared to the reference case by relative difference and standard deviation. The reliability of the MCNP simulation is verified through Type A uncertainty.

As shown in Figure 4a, the variation in the source length affects the dose rate with a relative difference up to 4.48% at points farther from the core. The observed discrepancy may be due to the fact that welds alter the seed's geometry, causing attenuation in thicker regions and less attenuation in areas with less material. The core length shows a relative difference very close to the previous case, within 4.45%, as shown in Figure 4b. In both cases, the most important points are further away from the seed.

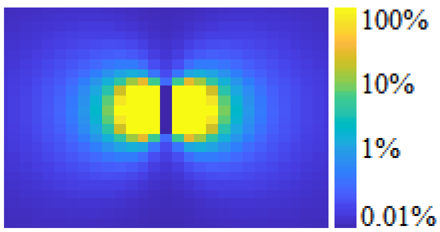


Figure 3. Dose rate profile of the nominal seed.

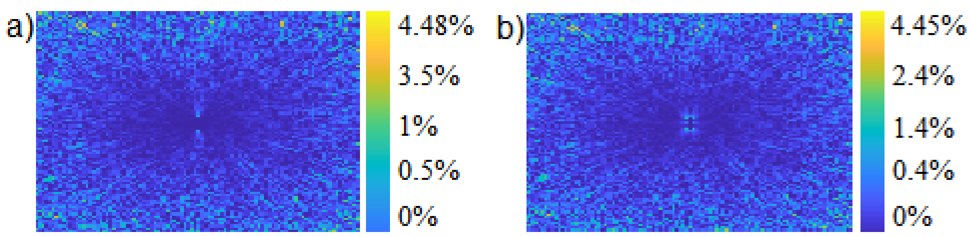


Figure 4. Relative difference of the nominal dose rate profile to the mean for (a) variation in the length of 100 seeds; (b) variation in the length of 100 cores.

Another relevant consideration is the standard deviation between the dose rates of seeds within the same variation. Figure 5 a and 5 b shows that the data dispersion around the mean is low, providing reliability of the simulated codes. The percentage within 0% to 1.6% is negligible. However, if the deviation is significant, its impact on the dose rate profile should be considered by propagating uncertainty, following the recommendations of TG 43.

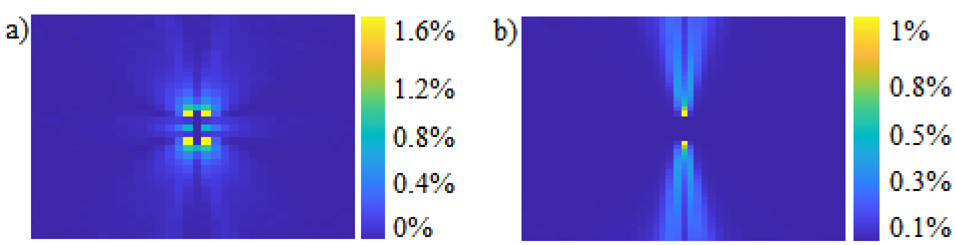


Figure 5. Standard deviation for 100 seeds with length variation (a); and 100 cores with length variation (b).

Type A uncertainty was calculated by MCNP to ensure the reliability of the obtained results. The uncertainty is relatively small, as it did not exceed 0.018% at points farther away, and around the seed, it was at 0.002%. Figure 6 shows that the relative differences compared to the nominal are significant. In addition to the uncertainties, differences of up to 4.48% indicate that the differences derive from the variations made and not a statistical uncertainty

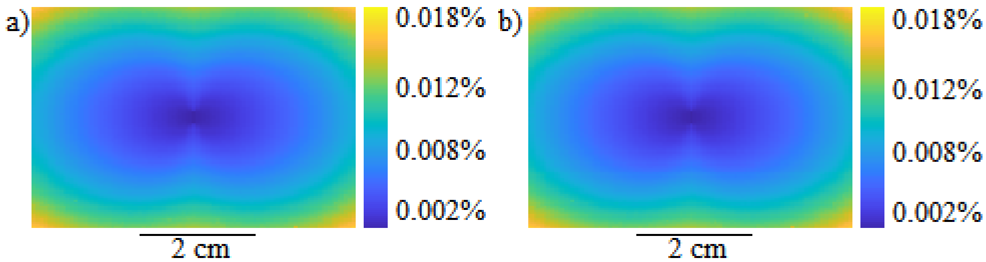


Figure 6. Type A Uncertainty: (a) for 100 seeds with length variation; (b) for 100 cores with length variation.

## 4. Conclusions

The relative difference and standard deviation of the nominal seed contributed significantly to variations in the final dose rate. This must be taken into account in future work because the final dose (variations) is discrepant from the requested (nominal) dose. In this way, it demonstrates that it is necessary to improve the methodology for approving the seed during conception, in such a way that it approaches the reference geometry.

The most significant difference for the variations investigated is at points further away from the seed with values above 4%, while for points close to the seed it was between 1% and 1.4%. Therefore, these values must be taken into consideration during the manufacture of the seed, in order to try to reduce variations so that the final dose is closer to the requested dose.

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