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INDIRECT MEASUREMENT OF RADIATION DOSE RATE FROM BRACHYTHERAPY 125 IODINE SEEDS BY NUMERICAL METHOD: PRELIMINARY COMPARISONS WITH ANALYTICAL CALCULATIONS

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Abstract: Brachytherapy, using radioactive iodine seeds, is a very important and efficient process of cancer treatment. These seeds are small sealed tubes of titanium, 4,50mm long, with the radioactive material inside. The amount of radiation to be imparted on a tumor has to be precisely evaluated, so any calculation process is welcome, beside the normative ones. In this work it is shown a numerical method to compute the exposure rate in the vicinity of the seed, and the results are compared with analytical calculations, in order to make a preliminary evaluation of the method.

Keywords: brachytherapy, 125 iodine, dose rate.

1. INTRODUCTION

In the world, the number of new cases diagnosed was 15,3% of all types of cancer in development countries and only 4,3% in sub-developed countries. The main reason can be the previous diagnosis that has been done in the richest countries. However Brazil is not a developed country, the National Institute of Cancer (INCA) has reached a good index to the richest states (in South Region, the tax is 6,8% and in Southeast region is 6,3%), but worse index in the poorest regions, such North region with 2,2% and Northeast region with 3,4%. The diagnosis rate increases in regions that the Prostate Specific Antigen test was conducted. The mortality caused by prostate cancer has low rate explained mainly by previous diagnosis. The prostate cancer was considered a third age illness, because 75% of cases occur in 65 years old men [1].

One of the treatments used was interstitial brachytherapy with ^{125}I seed, because the procedure has low impact, allowing most patients to return to their normal activities between one or three days after the intervention, with a small or no pain. The other important benefits for the patients are the low impotence rates and few incidents of urinary incontinence.

Brachytherapy is a very important and efficient process of cancer treatment [2,3]. It consists of to irradiate tumors by inserting on it small radioactive sources, called "seeds" (see Figure 1), instead of traditional methods that irradiate the tumors from outside body. It is call "to treat from inside to outside".

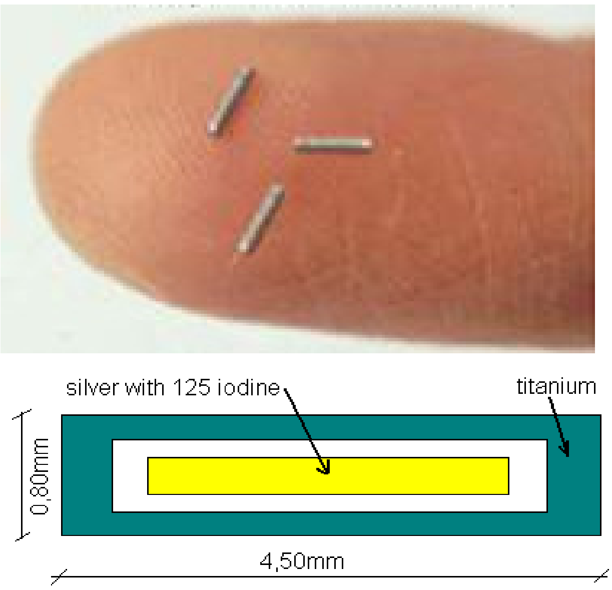

Fig. 1. Above: three brachyterapy seeds on a finger. Below: longitudinal cut of this seed, sketch of the inside. The silver rod has the 125-iodine adsorbed on its surface.

These seeds are small sealed tubes of titanium, 4,50mm long, 0,80mm external and 0,70mm internal diameter, with a silver rod inside. This silver rod has the 125 iodine adsorbed. Effectively, the 125 iodine is the only radioactive source and fits a scab form, around the silver rod. A sketch of the internal side of this seed is shown in Figure 1.

In 1998, the IPEN / CNEN – SP (Nuclear Energetic Research Institute from the National Nuclear Energy Commission), the biggest institute of nuclear technology in Brazil, started a project to develop and produce Iodine-125 seeds. The project must be finished in the end of the next year [4].

One part of this project is the dose evaluation of the seeds and the AAPM (American Association of Physicists in Medicine) recommends that all new products must have the dosimetric characteristics be evaluated at least once. The institute decides to carry on simulation and experimental studies of the dose distribution using an appropriate phantom of which includes absolute dose-rate measurements [5].

This work uses the numerical method next explained which evaluate the dose rate in desired positions close to the seed. This is a new algorithm which will be exhaustively tested before to be used effectively, or be validated. In order to evaluate preliminarily this algorithm, its results were compared with analytical calculations, considering sources of punctual form and as an axis segment. And in the future, this new algorithm will be used to estimate the dose rate and the time need it in the experimental measures.

2. SHORT DESCRIPTION OF ALGORITHM

It was used one numerical and two analytical methods or approaches for the indirect measurement of the exposure rate at certain points close to the seed, see Figure 2.

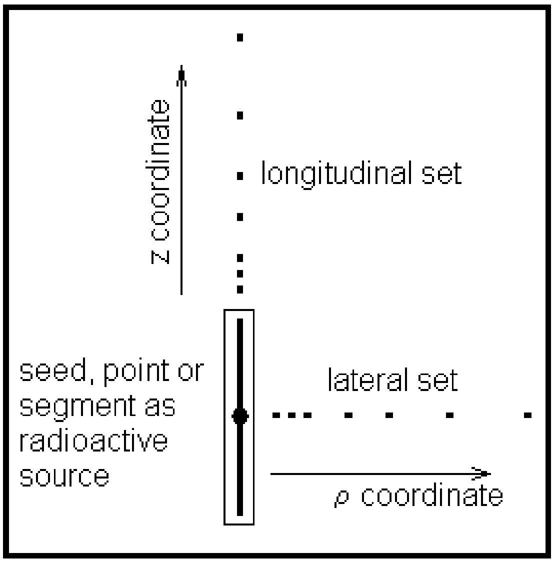

Fig. 2. Two sets of points where dose rate was calculated or simulated

It is important only close to the seed because the photonic radiation generated by the seed has small energies, smaller then 29 keV. This kind of photon has strong attenuation, when passing through materials, even through the air. The process of attenuation is sketched in Figure 3. It is an exponential decay phenomenon and depends on the material and on the photon energy.

The attenuation of some photon beam of intensity I obey the following equation:

$$I = I_o . e^{-\mu . x} \qquad (1)$$

μ is the attenuation coefficient. It depends on the material and on the kind of photon energy. The x term is the thickness of the material where the photon is passing through.

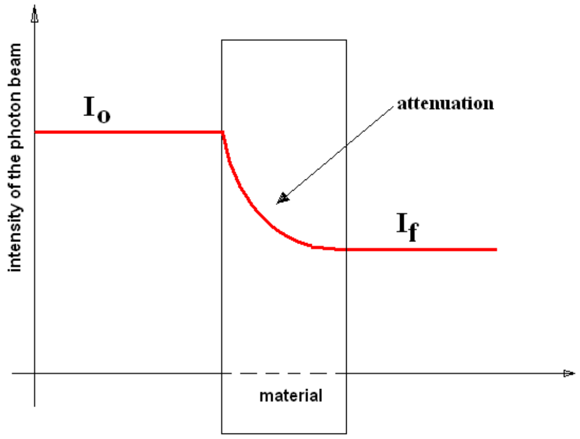

Fig. 3. Sketch of the attenuation of a beam of photons passing through a material from the left to the right side.

Exposure Rate is a quantity related to the *Absorbed Dose Rate*. In simple words, absorbed dose is the energy imparted by the seed to the mass unit of tumor tissue or another kind of material. It has direct use by physicians, but exposure rate is the practical quantity used for calibration purposes. Exposure rate is the total electrical charge (ions) created into the medium by the photonic ionizing radiation per unit mass. The S.I. unit for exposure rate is coulomb per kilogram per second, C/(kg.s). Another traditional and old unit, still in use, is the roentgen per second, R/s. In air, 1R is $2,58.10^{-4}$C/kg . Quantities and units used in Radioprotection, Radiodiagnosis or Radiotherapy are rich fields for Metrology studies.

The numerical procedure consists of finite differences in a cylindrical coordinate system of reference, centered in the middle of the seed, and the z axis coincident with the longitudinal cylindrical axis, see Figure 4.

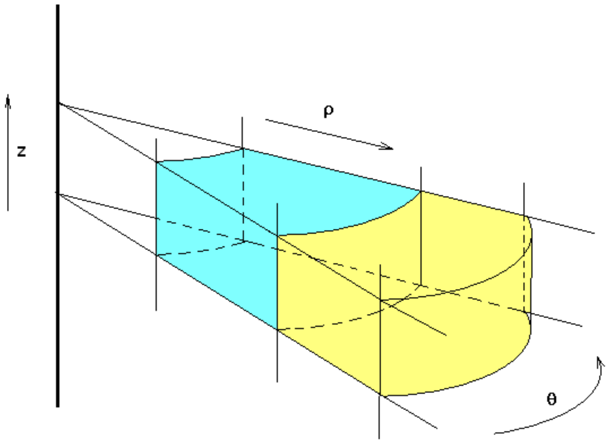

Fig. 4. Representation of two cylindrical finite elements, used by the numerical procedure.

In this preliminary study, the ρ coordinate (distance from the z axis, in a Cartesian system) was discretized in fifteen points, non-uniformly. The θ coordinate (angle from x axis), was discretized uniformly in seventy-two points. And the z axis was discretized in thirty-six points, non-uniformly.

The radiation source (125 iodine) is the surface of the silver rod. It has a cape shape. In the numerical context, this cape is a set of points, in the finite difference picture. Each one of these points was considered as a punctual source of radiation. For a punctual source isolated, the exposure rate at a point distant d from this source is:

$$\overset{o}{X}(P) = \Gamma \frac{A}{d^2} \qquad (2)$$

$\overset{o}{X}$ is the exposition rate; Γ is the radiation constant, peculiar from the 125 iodine gamma radiation emission; A is the activity of the fraction of the source and d is the distance from the source. P is the point of coordinates (ρ_P, θ_P, z_P).

It was considered attenuation from the materials, when radiations beam cross every structure.

One of the analytical methods considers the punctual form of the source and uses the equation 2 but instead of fraction of activity, it was used the total activity of the seed.

The second analytical approach considers the axis segment form of the source. For this geometry, in a point P inside a plane orthogonal to the segment and passing through the middle point of the segment, the exposure rate is calculated by integration and gives the following equation:

$$\overset{o}{X}(P) = 2\Gamma \frac{A_\lambda}{d^2}.\mathrm{arctg}\left(\frac{L}{2d}\right) \qquad (3)$$

A_λ is the linear density of activity; L is the length of the axis segment and d is the distance from the source in the median axis of the segment.

For a point inside the axis of the segment, distant R from the closest end side of the segment, the equation is:

$$\overset{o}{X}(P) = \Gamma \frac{A}{R(R+L)}. \qquad (4)$$

3. RESULTS

By equations 2 (punctual), 3 or 4 (segment), and through the numerical method (computation simulation), it was calculated the exposure rate at two sets of points, shown in Figure 2.

One of these sets contains points distant from the middle of the seed, in an orthogonal or lateral axis. The other set of points are getting far from the seed but through the longitudinal axis.

The algorithm calculates the photon beam attenuation in its "walk" from each one of the source points until the point where the exposure rate are desired to be calculated. In this walk, there are attenuations due to the air, due to the titanium and due to the silver itself.

The results are in Figures 5 and 6, for the sets of points in Figure 4.

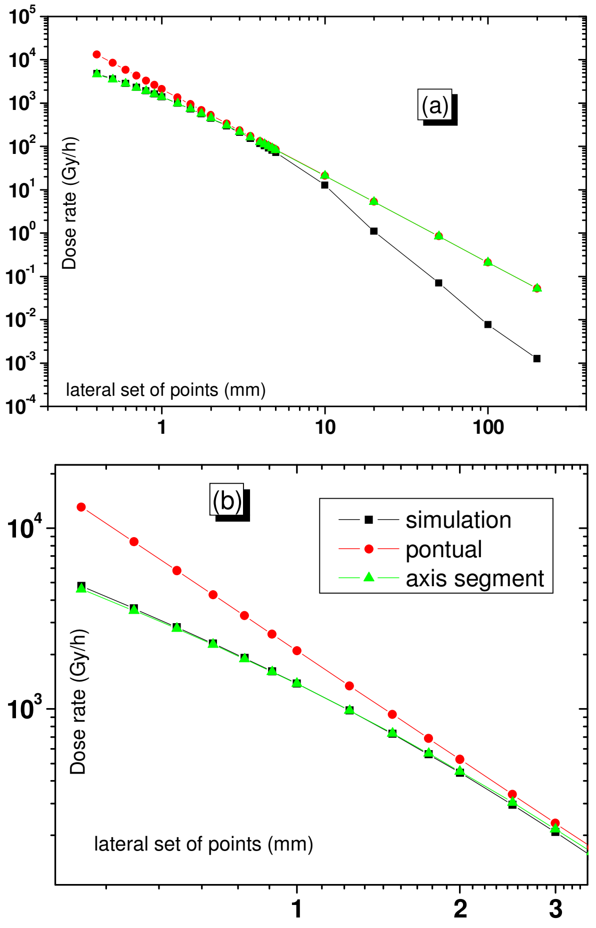

Fig. 5. Dose rate values, in Gy/h, for the points of lateral set. (b) is an enlargement of (a), close to the seed.

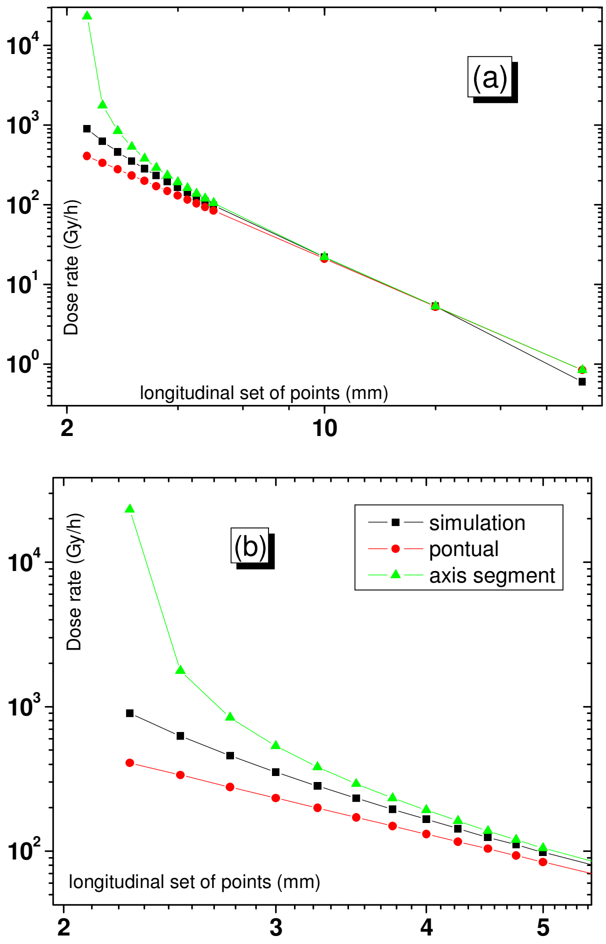

Fig. 6. Dose rate values, in Gy/h, for the points of longitudinal set. (b) is an enlargement of (a), close to the seed.

These results are in Absorbed Dose, although the program output is in Exposure Rate. The unit (and quantity) conversion is straightforward, if the medium is air. Inside a tissue, some correction factor must be applied.

The θ coordinate is irrelevant for these sets and for this preliminary study. It will be important for studies of anisotropy or defects in the seed production. The activity of the seed was 111MBq (3,0mCi; old unit) for every calculation.

The input data are:

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    (lengths in millimeters,
     angles in degrees)

    > point where exposure rate
       will be calculated:

    coordinate ro:....................................... 0,0
    coordinate teta:.................................... 0,5
    coordinate z:........................................ 2,27

    > seed dimensions:

    internal diameter of titanium:............ 0,70
    external diameter of titanium:........... 0,80
    silver diameter:................................. 0,50
    iodine thickness:............................... 0,01
    internal titanium length:.................... 4,30
    external titanium length:................... 4,50
    silver rod length:.............................. 3,00

    > seed activity (mCi):.......................... 3,00

    > attenuation coefficients (mm-1):

    air:....................................................... 4,4856E-5

    titanium:............................................... 2,49

    silver:................................................. 41,7165

    > numerical control parameter:............ 0,01
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These input data are known from tables or handbooks and could be changed, in order to make another studies. The profile of the seed could be changed in internal subroutines of the computational program.

The output of the program is:

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   In the point of  cylindrical coordinates:
     ro =       0,0 mm
     teta =     0,49999997 degrees
     Z =        2,26999998 mm
   or (x,y,z)=( 0,;  0,;  2,26999998) mm

   Exposure Rate =   896,606506 R/h


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4. DISCUSSION AND CONCLUSION

The results show that close to the seed the three ways of calculation have effective differences, as expected by the shape adversity. In longitudinal set, for distances from 9mm to 2cm, every approach has values very close.

In lateral set, the similarity of the approaches happens only from 2 to 8mm. For distances higher then 2cm, in longitudinal set, and higher then 8mm, in lateral set of points, the simulation does not agree with the analytical approaches because there is air attenuation of the radioactive beam.

The extension of this calculations will simulate the dose rate at any point near the seed. This calculation will generate information like that in figure 7.

It was shown preliminary results of a numerical method to compute radiation dose rate from a brachytherapy seed. The results were compared to analytical calculations of dose rates from punctual and axis segment forms of radioactive sources, made by a simple integrations.

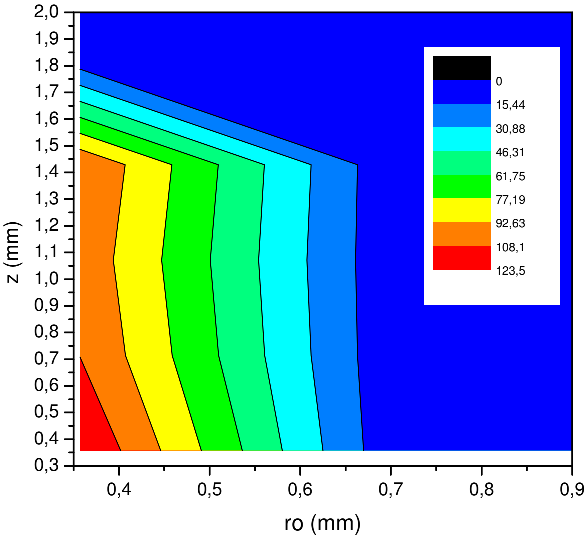

Fig. 7. Isodose curves from a seed. This is a preliminary result, made with too few points.

The results were coherent with expected ones. The work of comparison with experimental results is in progress, as long as calculations with a more density of points in the finite difference.

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