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RADIATION ISODOSE SURFACE DISTORTION AS A SOURCE OF DOSE OR EXPOSURE RATE MEASUREMENT UNCERTAINTY: EXAMPLE IN BRACHYTHERAPY SEEDS

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Abstract – Radiation sealed sources have an emission that could be studied by theirs isodose surfaces. The intersection of a plan with such a surfaces is described by the dose rate contour curves. It is very common to assume that these surfaces have rotational symmetry around the longitudinal axis, and so, the contour curves have mirror symmetries. Here it is shown, by a computational simulation, that if the radioactive material inside de sealed vessel is not homogeneous, the uncertainty in dose rate measurements could achieve high values. This uncertainty value is exemplified in a iodine-125 seed source used for brachytherapy purposes.

Keywords: radiation, sealed source, isodose

1. INTRODUCTION

Sealed sources of radiation are widely used around the world, as in irradiators, gammagraphy devices and brachytherapy seeds, for industrial and medical [1] applications. A very simplified device of this kind is sketched in figure 1. In the inner core, there is the support material, that could be the radioactive material itself, or it has the radionuclide adsorbed on its surface or inside the bulk. This inner core is sealed or shielded, normally by weld, inside a small chamber, of steal or titanium, if biocompatibility purposes are required.

Sealed sources have gamma or x-ray emissions and the other kinds of radiation are shielded by the chamber. The beam emitted is attenuated in its path through the chamber walls.

It is very important to know the dose rate at every position around the seed, in order to establish radiation procedures, medical ones as example. Once known the dose rate three-dimensional function, this could be presented as isodose surfaces, or surfaces where the dose rate is constant. The intersection of these surfaces with a plan is the contour curves, two-dimensional graphics used for dosimetric purposes. The object of this study is these contour curves, where the plan contains the seed longitudinal axis. Contour curves change their shapes if some geometrical or material configuration changes and could be an important source of dose measurement uncertainty if no quality control assure its uniformity. In this study it is shown some changes in dose rate contour curves due to non-uniform distribution of the radioactive material inside the sealed source, that we will call defect.

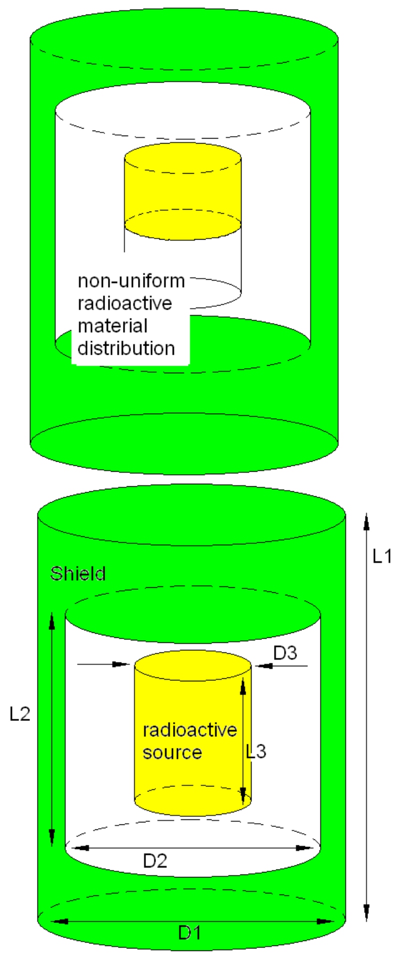

Fig. 1. Sketch of a sealed source or radiation. Up: distribution of the radioactive material only at upper half of the inner rod. Down: homogeneous distribution and indication of lengths valuated at table 1. The cylinder inside is a silver rod, in certain brachytherapy seeds.

2. THEORETICAL CONSIDERATIONS

When a beam of photons passes into an absorbing medium some of the energy carried by the beam is transferred to the medium. In its path, the radiation beam suffers interactions with every material, causing many effects, like scattered photons, high speed electrons creation, bremsstrahlung radiation, ionizations, excitations etc. [2]

The attenuation of a photon beam of intensity I can be expressed by the following equation:

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

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. B is the photon build-up factor. This function takes into account the photons scattered by the material. B depends on photon energy and geometry of the material too. B could be a very complicated function, it has values higher than one and could assume values as much as 10 to 20 in special situations, but it will not be consider in this study and it is proposed a model that assumes the B=1. So, it is only possible to make relative considerations. As the material and geometries of uniform and non-uniform radioactive distribution situations are very similar, these comparisons are valid.

The numerical procedure in reference [3] 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 2.

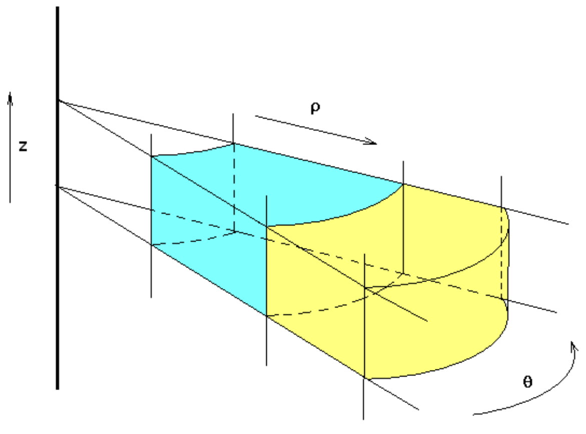

Fig. 2. Two cylindrical finite elements, used by the numerical procedure.

In this study, the ρ coordinate (distance from the z axis, in a Cartesian system) was discretized in sixty points, non-uniformly. The θ coordinate (angle from x axis), was discretized uniformly in twenty points. And the z axis was discretized in one hundred and twenty points, non-uniformly.

The radioactive region is represented by a great number of points (12000) in the surface of the silver rod, inside the chamber. Each of these points is considered as a punctual source of radiation, and the sum of every point has the effective radioactive activity of the source (considered 1mCi in this study). The simulation procedure calculated the dose rate at many desired point around the seed, considering the contribution of every point source of radiation, taking into account the attenuation when the beam pass through different material until reach the desired point of calculation.

3. RESULTS

It was simulated a iodine-125 seed, with dimensions and parameters typically used in brachytherapy medical treatment [4-6]. It was obtained the isodose contour curves. The dimensions and other parameters of the seed are in table 1.

Table 1. parameters used in the simulation. Lengths concern to figure 1.

lengths	(mm)
L1	4,5
L2	3,5
L3	3,0
D1	0,8
D2	0,7
D3	0,5
attenuation coefficient, μ	(mm^{-1})
titanium	2,49
silver	41,72
air	$4,48.10^{-5}$
activity	1,0 mCi

In figure 3 it is shown the resulting contour curves spaced at 10R/h for three different situations. The *roentgen per hour* is a unit of exposure rate quantity, directly related to *dose rate* unit, from the SI system. At all situations the total net activity was the same, 1,0 mCi.

From these graphics, it is clear the drastic distortion of the isodose curves when defects of this kind are present. In the case of lateral distribution, on the opposite side of the rod, the dose is smaller then the bottom limit of the scale used in that graphic (10 R/h).

This distortion is a very important source of uncertainty in measurements of quantities used on radiotherapeutical procedures, like the *anysotropy factor* [7]. In table 2 it is presented results at four points around the radioactive seed for these two defects and for the homogeneous distribution.

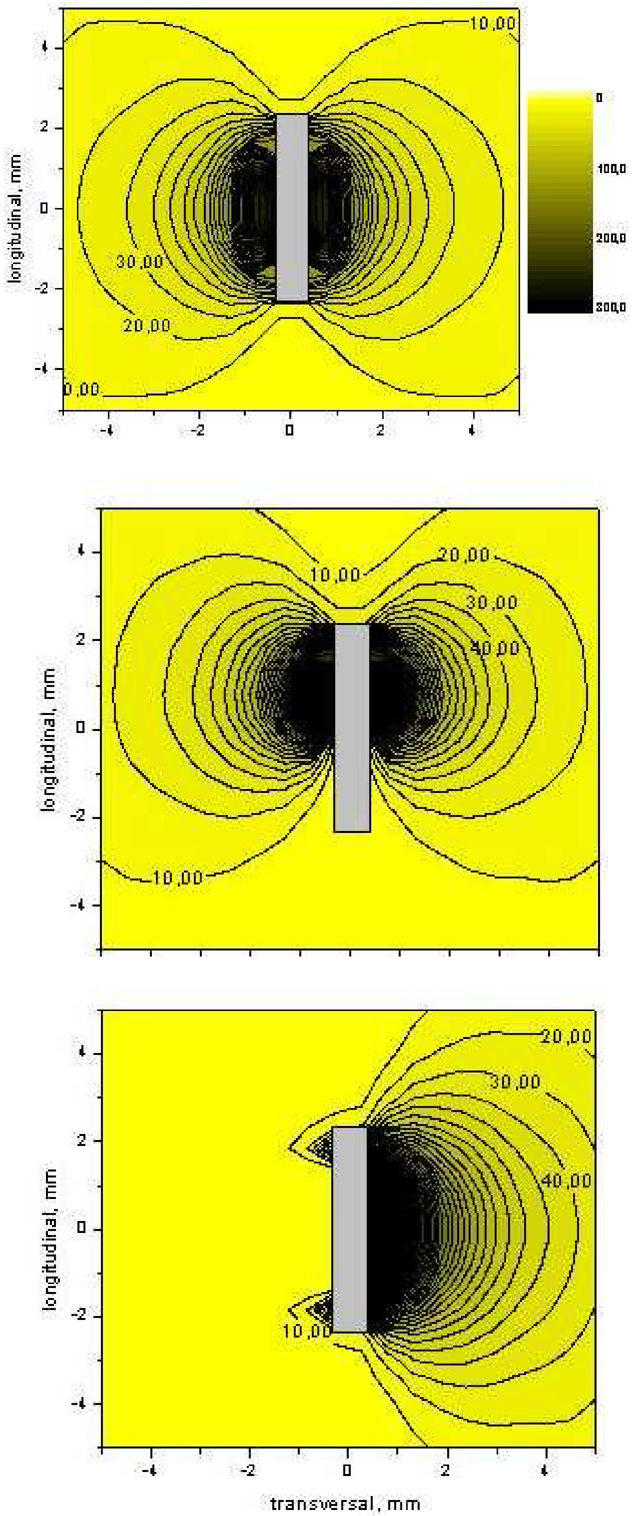

Fig. 3. Contour curves of radiation dose rate emission from a brachytherapy 125 iodine seed, positioned at the rectangle in the center of the images. The quantity is exposure rate, in R/h, directly related to dose rate. The upper case occurs when the radioactive material is homogeneously distributed; the middle and the bottom ones occur when non-homogeneous distribution defects are those shown in figure 4, respectively.

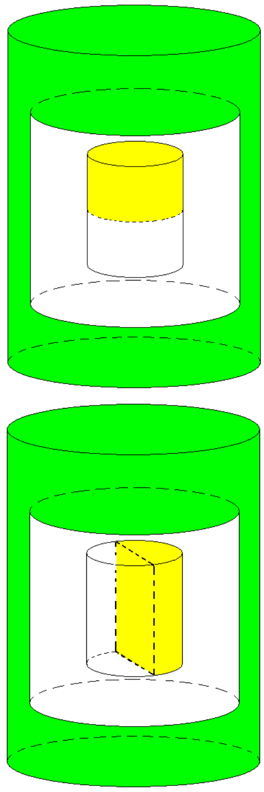

Fig. 4. Indication of the non-uniform distribution of the 125-iodine used in this simulation. In the upper case, the iodine is on the superior half of the rod. In the bottom case, only one longitudinal half of the rod has the iodine. The total amount of iodine is equal inside the chamber for every situation, even on the uniform case.

Table 2. Radiation dose rates (in R/h) at four points around the seed in the homogeneous distribution (H), for longitudinal (LO) and for lateral defect (LA).

points, mm (abscissa; coordinate)	H	LA	LO
(-3,42 ; -0,263)	31,9	0,436	30,5
(3,42 ; 0,263)	31,9	63,3	33,3
(-0,263 ; -3,95)	3,38	3,32	0,00
(0,263 ; 3,95)	3,38	3,45	6,77

For these specific points, there are great differences from the homogeneous distribution to the defects ones.

4. CONCLUSIONS

It is very important to consider the distortion of isodose surfaces as a source of dose rate measurement uncertainty, if no quality control is able to guarantee the uniformity in the radioactive material distribution.

These simple presented examples demonstrate that uncertainties in the amount of dose to be imparted into tissues or surrounding materials of sealed sources are very susceptible to the distribution of the radionuclide inside.

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REFERENCES

[1] International Atomic Energy Agency, IAEA TECDOC-1512, *Production techniques and quality control of sealed radioactive sources of palladium-103, iodine-125, iridium-192 and ytterbium-16*, June, 2006.

[2] H.E. Johns and J.R. Cunningham *(1983), The Physics of Radiology,* ed. Charles C. Thomas, 4ª ed., Springfield.

[3] J. E. Manzoli, P.C.P. Silva, E. S. Moura, C. A. Zeituni, M.E.C.M. Rostelato, "Indirect Measurement of Radiation Dose Rate From Brachytherapy 125 Iodine Seeds by Numerical Method: Preliminary Comparisons with Analytical Calculations", *12th IMEKO TC1-TC7 joint Symposium on Man, Science and Measurement,* pp 203-207, Annecy, France, Sept. 3 - 5, 2008.

[4] D.O. Kubiatowicz "Radioactive iodine seed", Minnesota mining and manufacturing company US Pat. N. 4,323,055. 6 Apr. 1982.

[5] Rostelato, M. E. C. M.; "Estudo e desenvolvimento de uma nova metodologia para confecção de sementes de iodo – 125 para aplicação em braquiterapia". São Paulo, Brazil; 2005.

[6] Williamson, J; Cousey, B.; DeWerd, L.; Hanson, W.; Nath, R.; "Dosimetric prerequisites for routine clinical use of new low energy photon interstitial brachytherapy sources", *Med. Phys.*, 25 (12), pp.2269-2270 (December 1998).

[7] Pirolla, J.L., Manzoli, J.E., Ferreira, C.L., Moura, E.S., Zeituni, C.A., Rostelato, M.E.C.M.; "Distortion on the Two Dimensional Anisotropy Factor of Seeds for Brachytherapy due to Non-Homogeneous Distribution of Iodine 125: a Simulation Study", accepted for presentation at INAC-2009 (International Nuclear Atlantic Conference) - Rio de Janeiro, September 27th to October 2nd .