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Dosimetric study of a brachytherapy treatment of esophagus with Brazilian ^{192}Ir sources using an anthropomorphic phantom

Lucio P. Neves^{a,*}, William S. Santos^b, Ronan Gorski^c, Ana P. Perini^a, Ana F. Maia^b,
Linda V.E. Caldas^a, Gilberto Orenge^c

^a Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear (IPEN-CNEN/SP), Av. Prof. Lineu Prestes, 2242, 05508-000 SP, Brazil

^b Departamento de Física, Universidade Federal de Sergipe, 49100-000 São Cristovão, SE, Brazil

^c Área de Ciências Tecnológicas, Centro Universitário Franciscano (UNIFRA), Rua dos Andradas, 1614, 97010-032 Santa Maria, RS, Brazil

AUTHOR HIGHLIGHTS

- The use of brachytherapy sources was studied for the treatment of esophagus cancer.
- FASH anthropomorphic phantom and MCNP5 Monte Carlo code were employed.
- The doses at lungs, breast, esophagus, thyroid and heart were the highest.
- The data is useful to assess the representative doses of treatments on the esophagus.

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ABSTRACT

Several radioisotopes are produced at *Instituto de Pesquisas Energéticas e Nucleares* for the use in medical treatments, including the activation of ^{192}Ir sources. These sources are suitable for brachytherapy treatments, due to their low or high activity, depending on the concentration of ^{192}Ir , easiness to manufacture, small size, stable daughter products and the possibility of re-utilization. They may be used for the treatment of prostate, cervix, head and neck, skin, breast, gallbladder, uterus, vagina, lung, rectum, and eye cancer treatment. In this work, the use of some ^{192}Ir sources was studied for the treatment of esophagus cancer, especially the dose determination of important structures, such as those on the mediastinum. This was carried out utilizing a FASH anthropomorphic phantom and the MCNP5 Monte Carlo code to transport the radiation through matter. It was possible to observe that the doses at lungs, breast, esophagus, thyroid and heart were the highest, which was expected due to their proximity to the source. Therefore, the data are useful to assess the representative dose specific to brachytherapy treatments on the esophagus for radiation protection purposes.

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1. Introduction

In Brazil, esophageal cancer (Schweigert et al., 2013) is the 6th more frequent among men and the 15th among women (INCA, 2013), the squamous cell esophageal cancer being the most common type, accounting for 96% of all cases. Adenocarcinoma, another type of cancer, has been increasing significantly as well. The treatments currently employed are radiotherapy, chemotherapy, surgery and depending on the case, all techniques are used together. Endoscopic resection is specifically indicated for esophageal cancer at an early

stage. However, this treatment is very rare and surgery is used in most of the cases.

In advanced stages, surgery is used to unblock the esophagus and, besides being an aggressive procedure, there is no improvement in the quality of life of the patients. In this case, other palliative treatments can be used, such as the application of chemotherapy and radiotherapy. The palliative care is also available with an esophageal stent (to prevent narrowing of the esophagus) and brachytherapy (radiation therapy with radioactive seeds).

Several radioisotopes are being produced at the *Instituto de Pesquisas Energéticas e Nucleares* (IPEN) for the use in medical treatments, including the activation of ^{192}Ir sources. These sources are suitable for brachytherapy treatments, due to their low or high activity, depending on the concentration of ^{192}Ir , easiness to manufacture, small size, stable daughter products and the

* Corresponding author. Tel.: +55 11 31339716; fax: +55 11 31339678.

E-mail addresses: lpneves@ipen.br, pereiraneves@gmail.com (L.P. Neves), williathan@yahoo.com.br (W.S. Santos), stan_krum@hotmail.com (R. Gorski), aperini@ipen.br (A.P. Perini), afmaia@ufs.br (A.F. Maia), lcaldas@ipen.br (L.V.E. Caldas), g.orengo@gmail.com (G. Orenge).

possibility of re-utilization. They may be used for prostate, cervix, head and neck, skin, breast, gallbladder, uterus, vagina, lung, rectum and eye cancer treatment. Up to now, there is no dosimetric evaluation over the healthy tissues during brachytherapy procedures of esophagus, employing the sources activated at the IPEN.

In this study, a dosimetric evaluation for brachytherapy was made in the treatment of esophageal cancer with some ^{192}Ir sources activated at the IPEN: a wire and two prototypes of seeds, with different capsule materials. The seeds and the wire were simulated inside a tumor, which was inserted as a sphere with 1.0 cm radius in the middle portion of the esophagus. The wire was inserted passing through the middle of this sphere, and the four seeds were positioned at equidistant positions around the center of the sphere.

This geometrical arrangement was suitable for the dose determination in important structures, such as those in the mediastinum. The dose distribution was evaluated with the use of a Female Adult meSH (FASH) anthropomorphic phantom (Cassola et al., 2010; Kramer et al., 2010), and using the MCNP5 Monte Carlo code (X-5 Monte Carlo Team, 2003) to determine the doses over several structures. This approach has the advantage of determining the doses to several radio-sensitive organs that are far from the treatment volume, which is not possible using the available treatment planning softwares.

2. Materials and methods

In this work, the Monte Carlo MCNP5 code (X-5 Monte Carlo Team, 2003) was employed in order to obtain the doses deposited in several organs from a radioactive source used for a brachytherapy procedure in the esophagus. The doses were evaluated in the following structures: bone-marrow, colon, lung, stomach, breast, gonads, bladder, esophagus, liver, thyroid, bone surface, brain, salivary, skin, heart, and the tumor itself. The output parameter was the **F8 tally* for each of the considered structures. Furthermore, in order to obtain low statistical uncertainties, 1×10^9 histories were simulated.

The information necessary in order to correctly run the simulations is related to the materials, geometry, source spectra, and requested dosimetric quantities. The geometry comprehended the room, patient, and surrounding medium. All room materials and dimensions were simulated in accordance with the description from the building blueprints normally used for brachytherapy procedures. The source spectra were not available from measurements, and therefore, in this work the source was simulated in accordance with its dimensions, including the capsule. The dose rates were evaluated with the following equation, in mGy/h:

$$\dot{D} = 5.7678 \times 10^{-5} \times \frac{\kappa A}{m} \times *F8 \text{ tally} \quad (1)$$

where

- 5.7678×10^{-5} is a constant for unit conversions;
- the photon/decay is represented by $\kappa = 2.363$;
- the activity of the source is $A = 2 \text{ mCi}$ ($7.4 \times 10^7 \text{ Bq}$);
- m is the mass of the organ under consideration.

The adult patient was represented by a female adult human phantom – FASH. The main physiologic data were: height of 162.5 cm and body mass of 60.04 kg. This phantom was developed by the Computational Dosimetry Group of the Nuclear Energy Department from the Federal University of Pernambuco, Brazil (UFPE) (Cassola et al., 2010; Kramer et al., 2010). It was based on a mesh surface using female physiological and anatomical data. It has 140 organs and segmented tissues with dosimetric



Fig. 1. View of the FASH phantom main organs, including the tumor site.

significance, as recommended by the ICRP 89 (ICRP, 2002). The reason to use a FASH phantom is that, besides all important structures on the thorax, there is also the possibility to evaluate the dose at breasts. The main organs and the tumor site of the FASH phantom are depicted in Fig. 1.

The displacement of the internal organs of the chest, compression of the lungs and reduction of the sagittal diameter of the patient on the supine position were considered. In this case, the expected results will be more precise in relation to the results obtained with mathematical anthropomorphic phantoms. In this case, mathematical equations are used to represent the organs and tissues. The room where the brachytherapy procedures are normally undertaken was computationally modelled, and used as a part of the geometrical description on the Monte Carlo code. The walls were made of concrete, using real dimensions and the room was filled with atmospheric air.

The ^{192}Ir wire is made of two concentric tubes, with 0.06 cm of diameter. The nucleus has 0.02 cm in diameter and it is composed of 25.0% of iridium and 75.0% of platinum. The external layer is composed of platinum in order to shield the beta rays. The iridium has a density of 22.65 g cm^{-3} and the platinum 21.45 g cm^{-3} . The prototypes of the seeds have the same proportion of materials, but an external length of 0.415 cm and 0.09 cm of diameter (^{192}Ir). The difference between the seeds remains in the capsuling material: stainless steel and platinum. The configuration of these sources is presented in Table 1.

3. Results and discussion

The virtual phantom FASH was developed with a matrix of dimensions $530 \times 208 \times 1354$ voxels, and each voxel has an edge

of 0.12 cm. The small voxels used on this phantom caused memory allocation failure during the MCNP5 code execution. The solution implemented in this work was to resize the original matrix and use a phantom with sizes $260 \times 104 \times 677$ voxels, with each voxel with 0.24 cm of edge. This new phantom configuration was positioned in the supine position on a bed. This configuration is shown in Fig. 2.

The scheme of the ^{192}Ir seed prototype and the seed distribution inside the tumor are shown in Fig. 3. The positioning of the wire inside the tumor is shown in Fig. 4.

Using Eq. (1) it was possible to determine the doses deposited in the organs with dosimetric importance as recommended by ICRP 103 (ICRP, 2007). The results for the different sources are shown in Table 2 for the wire and the seeds encapsulated with stainless steel and with platinum.

Table 2 shows that some organs, such as lungs, breast, esophagus, thyroid, and heart presented the highest doses, as expected

Table 1
Description of the sources used during the simulations in this work.

| Source type | Size | | Capsule material | Capsule thickness (cm) |
|-------------|-------------|-------------|------------------|------------------------|
| | Length (cm) | Radius (mm) | | |
| Wire | 20.0 | 0.02 | Platinum | 0.02 |
| Seed | 0.203 | 0.02 | Stainless steel | 0.0125 |
| Seed | 0.02 | 0.02 | Platinum | 0.0125 |

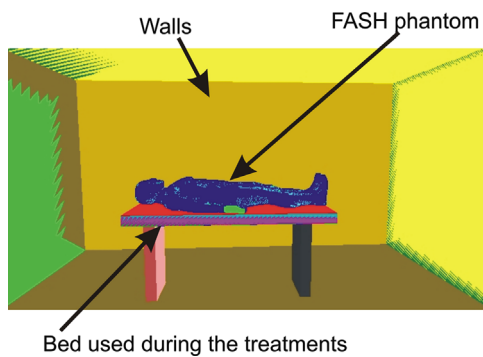


Fig. 2. View of the room with the patient on the supine position.

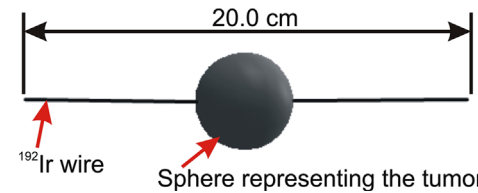
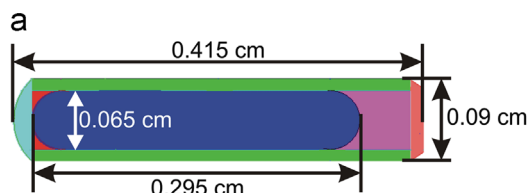


Fig. 4. Scheme of the ^{192}Ir wire distribution inside the tumor.

due to their proximity to the source. Also, the dose depositions were higher for the seeds due to their proximity to the tumor and to the fact that four seeds were considered to be inserted in the tumor. The wire may be an option for cases in which the tumor is spread over the organ. In both cases, this type of treatment is an alternative to the more invasive surgeries, such as esophagostomy.

4. Conclusion

In this work, a dosimetric evaluation for the treatment of esophagus cancer with brachytherapy sources was studied in order to evaluate the doses to the surrounding tissues and to indicate which source type would produce a better dose

Table 2
Dose deposition (%) on several healthy tissues and the tumor using the ^{192}Ir sources.

| Tissues evaluated | Wire encapsulated with platinum | Seed encapsulated with stainless steel | Seed encapsulated with platinum |
|-------------------|---------------------------------|--|---------------------------------|
| Bone-marrow | 0.3 | 1.3 | 1.3 |
| Colon | 0.4 | 0.6 | 1.1 |
| Lung | 14.1 | 75.9 | 77.2 |
| Stomach | 1.5 | 6.4 | 6.2 |
| Breast | 2.4 | 11.3 | 11.5 |
| Gonodas (ovaries) | 0.1 | 0.4 | 0.3 |
| Bladder | 0.9 | 3.2 | 3.1 |
| Esophagus | 184.2 | 356.4 | 340.2 |
| Liver | 3.1 | 9.2 | 8.9 |
| Thyroid | 30.8 | 40.5 | 39.0 |
| Bone Surface | 3.5 | 12.1 | 12.1 |
| Brain | 0.6 | 1.6 | 1.6 |
| Salivary G. | 2.8 | 8.6 | 8.4 |
| Skin | 1.0 | 4.2 | 4.2 |
| Heart | 21.1 | 89.9 | 89.6 |
| Tumor | 100.0 | 100.0 | 100.0 |

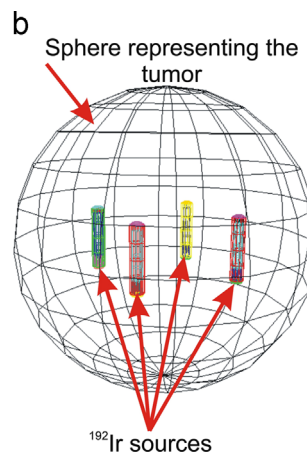


Fig. 3. (a) Prototype of the ^{192}Ir seed and (b) scheme of the seed distribution inside the tumor.

deposition on the tumor. For this approach, three different source configurations, activated at the IPEN, were analyzed: a ^{192}Ir wire encapsulated with platinum, a prototype of a ^{192}Ir seed encapsulated with stainless steel and another prototype of a seed encapsulated with platinum. The doses were evaluated in several organs using a female (FASH) anthropomorphic phantom. It was possible to observe that the doses at the lungs, breast, esophagus, thyroid, and heart were the highest as expected due to their proximity to the source. Therefore, the data are useful to assess the representative dose specific to brachytherapy treatments on the esophagus for radiation protection purposes.

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