DOI: 10.5281/zenodo.3461192

Analysis of different shielding materials for a new Interventional Radiology laboratory: a Monte Carlo approach

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***Abstract* — In this work, the shielding of a new laboratory, located at the *Federal University of Uberlândia* (*UFU*), was evaluated. Several scenarios containing an interventional radiology (*IR*) equipment were simulated, with the purpose of evaluating the effectiveness of wall shielding using different materials. These scenarios were modeled using the Monte Carlo method to evaluate the shielding effectiveness of the walls, using a x-ray spectra of 150 kV. To simulate the workers, public and the patient, six water cylinders were employed. The evaluations were based on the absorbed energy in each phantom and compared with the patient phantom. The results show that the laboratory is safe and does not represent risks for the academic community, presenting all safety parameters for facilities that have radioactive sources.**

Keywords—interventional radiology, Monte Carlo method, shielding, virtual phantoms

I. INTRODUCTION

Interventional Radiology is a minimally invasive technique that is based on fluoroscopy guided image to diagnose or treat an anatomical region. Additionally, surgeries can be replaced by an IR procedure depending on the treatment stipulated by the medical staff and obtain significant results [1]. Given that it is a safer and effective procedure, its use has become more and more frequent in medicine [1, 2]. In Brazil, the *Departamento de Informática do SUS* (DATASUS) registered about 55.034 IR procedures in 2018, which means a growth rate of 19% if compared to 2008 [3].

Besides all advantages, IR may deliver high radiation doses to both patients and Occupationally Exposed Individuals (OEI), mainly due to the duration of the procedure and the dose rates [1, 4-6]. Depending on the dose levels, some biological effects may appear, like epilation, radiation induced erythema or cancer [7-9]. Therefore, the shielding evaluation is a very important step to reduce the radiation doses to workers and public.

To prevent stochastic and tecidual effects, regulations have been created for the protection of OEI, establishing exposure limits and adequate practices, as well as room shielding. Each country has its own radiation protection regulations. In general they follow the *International Commission on Radiation Units and Measurements* (ICRU), which standardizes the procedures for measuring the quantities of interest in IR [4, 10]; or the *International Commission on Radiological Protection* (ICRP), which in its Publication number 85 deals with the risks of the technique in terms of collective dose [11].

In Brazil, the *Brazilian Health Regulatory Agency* (ANVISA) establishes the regulations in radiodiagnosis, through the Portaria SVS/MS nº 453, 1998 [12], but does not differentiate aspects related to interventionist practices [1], like materials and thickness to compose the walls. So, to promote adequate radiological protection, we followed the *National Council on Radiation Protection and Measurements* report 147 [13], which bring the basic principles of radiation shielding calculations for medical facilities using x-rays.

In x-ray facilities, doors and walls must have their thickness carefully calculated to provide radiological protection to both OIE and the public. The shielding capacity of these materials is defined in terms of linear attenuation coefficient and it represents the probability of x-ray photon interaction with the material per unit path length.

Thus, in order to evaluate the project of a new laboratory, to be located at UFU *Physics Institute* (INFIS), which is planned to eventually include an IR equipment, the Monte Carlo technique was used to determine the shielding of the walls, using different materials, such as brick and concrete, to compose the shielding. This technique has become one of the best alternatives available to ionizing radiation dosimetry problems, and it is currently widely used to study the scattered radiation in surgical rooms [14], conventional radiology optimization techniques [15], to evaluate the medical and public exposure in conventional radiology procedures [16] and to calculate dose conversion coefficients for medical the team in IR procedures [17].

II. MATERIALS AND METHODS

We used the MCNPX Monte Carlo code (version 2.7.1) [18] to perform the radiation transport simulations. The computational scenario comprised the space planned to allocate the future laboratory, as well as the equipment and OEI.

To generate the x-ray spectra, the SRS 78 software [19] was employed, using the technical parameters of the x-ray tube IAE, model RTC 1000 HS [20], as anodic angle (12.5º) and tube filtration (0.7 mm Al). We used a tube voltage of 150 kV, which is the maximum voltage available for this tube. The point source was located inside the tube housing, and the beam was simulated with 9 cm × 7 cm, centered in a water phantom cylinder, representing the patient.

In this work, we determined the percentage of deposited energy (D), which was obtained using the *tally F6*, determined in each water phantom, due to the primary and scattered radiation from the x-ray source. The dose percentage was calculated by Equation 1.

$$D = \frac{E_i}{E_3} \qquad (1)$$

where E_i is the energy deposited in the *i-th* phantom and E_3 is the energy deposited in the patient phantom.

In order to evaluate the different shielding materials, four different scenarios were modeled: a scenario with walls of brick and barite, brick and air, brick and concrete, and brick, concrete and air, with the x-ray beam directed as shown in Figure 1 (gray arrow). Despite to mention the material characteristics, the report [13] does not specify the material to be used for shielding in medical facilities or the wall thickness. We chose barite because it is a common composite used in X-ray facilities. The other materials represent those used in wall constructions at UFU.

To evaluate the doses distribution, the cylinder phantoms were positioned in several positions: five inside the room, and one outside the room. The latter was used to compare how much radiation was transmitted through the different shields, as shown in Figures 1 and 2.

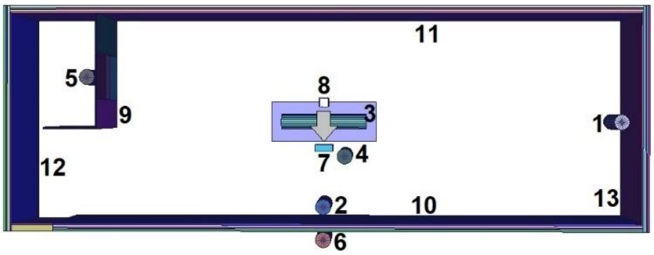

Fig. 1 - Top view of the modeled x-ray facility, showing the distribution of the room. The walls contain brick, air and concrete. The numbers 1, 2, 4-6 represents the OIE in standing positions and number 3 represents the patient lying on the table. Number 7 represents the image amplifier and number 8 the x-ray tube of IR equipment simulated. The gray arrow indicates the primary x-ray beam direction. Number 9 represents lead screen. The numbers 10-13 represent the walls.

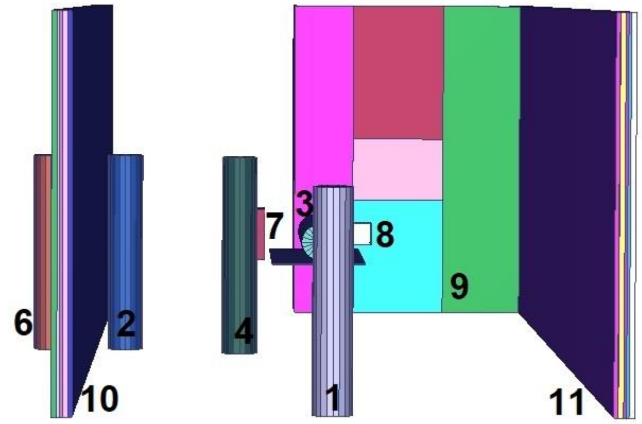

Fig. 2 - Side view of the simulated room. The walls have different layers containing brick, air and concrete.

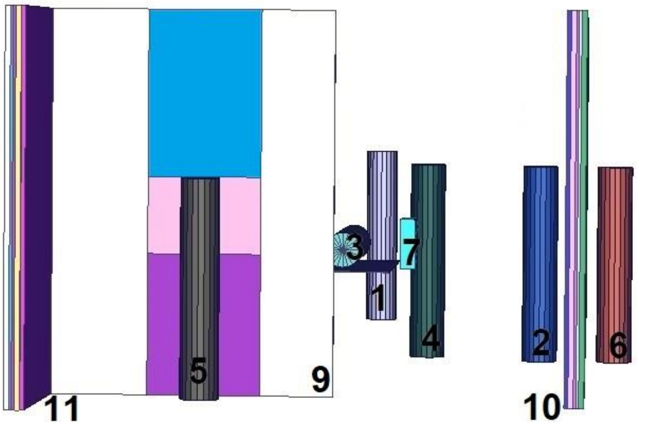

Fig. 3 - Side view of the modulated room, showing the phantom behind the lead protective screen.

Phantoms number 1, 2, 4, 5 and 6 represents the OIE in standing positions. Number 5 represents the OEI behind a lead protective screen. The number 3 represents the patient, lying on the table in all simulations. Phantom number 6 represents an OIE outside the laboratory to compare the energies, and to determine how much radiation is transmitted through the different walls. A total of 1E9 particles were simulated, in order to obtain low statistical uncertainties.

III. RESULTS AND DISCUSSIONS

In this work, we modeled, using Monte Carlo method, a room that contain an IR equipment to evaluate how much radiation pass through the different walls simulated to determine the room safety to the academic public. Table 1 shows the D values, as well as the respective uncertain. From the Table 1, we may notice that the phantom 4 received the highest dose, which was expected since it was the close to the x-ray source and also received the scattered radiation from the patient.

TABLE I - *D* FOR DIFFERENT WALL COMPOSITIONS, FOR A 150 kV SPECTRA

Phantom	**Barite + Brick**		**Air + Brick**		**Brick + Concrete**		**Air + Brick + Concrete**	
	D	***Uncertainties***	***D***	***Uncertainties***	***D***	***Uncertainties***	***D***	***Uncertainties***
1	1.68E-02	0.003	1.69E-02	0.004	1.69E-02	0.004	1.69E-02	0.004
2	1.73E-01	0.001	1.72E-01	0.001	1.72E-01	0.001	1.72E-01	0.001
4	1.92E+00	0.0003	1.92E+00	0.0003	1.92E+00	0.0003	1.92E+00	0.0003
5	2.12E-04	0.03	2.91E-04	0.03	2.93E-04	0.03	2.92E-04	0.03
6	2.24E-06	0.4	9.91E-04	0.02	2.26E-04	0.03	4.80E-04	0.02

The results showed that the deposited energy decreases with increasing distance, as expected. Comparing the cylinders located inside the room, number 5 received the lowest doses, because it that was protected by the lead screen followed by the number 1, because the room's shape is rectangular and it was located as far as possible, within the room, to the x-ray beam. The results also showed that the lead screen was effective to reduce the doses. These results are very similar in all simulations.

Cylinders number 2 and 6, were used to compare the amount of radiation that goes through the wall compositions due to the percent of absorbed energy. Analyzing the results, we can observe that the most effective materials to shield the room was brick and barite, as expected, because its composition (high atomic number and high density) which is adequate to best attenuate the x-ray photons, followed by air + brick + concrete, air + concrete and air + brick, being compatible with the data presented in [13].

The IR procedures consider the primary energy that focuses on the patient and the scattered radiation, transmitted by the patient throughout the room, because the image-intensifier acts as primary beam stop [13]. The patient (cylinder 3), received the primary energy beam, almost the total energy transmitted by the source, being the remaining of the scattered radiation delivered to the other phantoms.

During interventional procedures, the physician uses various projection beams with the aim to better visualize the region under examination [17]. In this work, we positioned the x-ray beam directed to a wall, to measure how much radiation is deposited to OIE outside the room. The energy deposited in each phantom depends on several factors: a) distance between the source and the OIE, b) shielding material, c) occupancy factor, d) number of patients, e) type of area, f) type of radiation (primary or scattered), g) use factor, among others [13].

In general, the time of an IR exam is relatively longer than others radiological exams [21-23], and the doses delivered to the patients and medical team is higher [24-26] because they involve complex procedures, the exam time depends on the medical experience, fluoroscopy time, anatomic region and the nature of lesion [27]. This can cause some damages to the OIE and the public.

This work represents the results of how radiation interacted with the simulated walls and how they can affect the public and the OIE. As we saw, the doses delivered to the phantoms were low, ensuring radiological protection. To estimate how much radiation is delivered to the individuals annually and compare with the norm [12] more studies need to be performed.

IV. CONCLUSIONS

In this study, we evaluate a new radiation laboratory at the UFU Physics Institute, using Monte Carlo simulation. The results served as a basis for the adaptation of the room to the Portaria SVS/MS nº 453/98 and the NCRP 147 report, and they demonstrated that the room is safe, because the radiation doses outside the room are low, mainly for the barite and brick composition.

ACKNOWLEDGMENT

The authors thank the UFU support, as well as the Brazilian agencies: FAPEMIG (Grants nº APQ-02934-15 e APQ-03049-15) and CNPq (Grants nº 420699/2016-3, 421603/2016-0 e 168947/2017-0).

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DOI: 10.5281/zenodo.3461192

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