Design, construction and characterization of a portable irradiator to calibrate installed ambient dose equivalent monitors

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Abstract. Calibration of installed dose monitors measuring the ambient dose equivalent, $H^*(10)$, should be done periodically according to portuguese national law. To be able to realize this calibration LMRI (Metrology Laboratory for Ionizing Radiation) constructed a portable irradiator made of lead with a ^{137}Cs source. The dosimetric characterization of the irradiator was made, either experimentally or using the MCNPX code. The influence of the wall where the monitors are installed was studied by Monte Carlo simulations and correction factors applied to the $H^*(10)$ were determined.

1 Introduction: According to Portuguese law, radiation protection dose monitors measuring the quantity ambient dose equivalent $H^*(10)$, should be checked periodically, with a periodicity of two years. These monitors can be portable or fixed (installed) on the wall of the facility, hospitals or any other facilities, and for these situations they are usually checked *in situ*. So, for this purpose, the LMRI constructed a portable irradiator made of lead and equipped with a ^{137}Cs source, which is the reference radiation for calibration purposes of these radiation protection devices according to IEC 60532 [1]. The design of the irradiator considered two parameters of contrary sense, its weight and the dose at its exterior surface. The weight is an important parameter, because its use requires that it is hand-held. After its construction the radiation field was characterized and the dosimetry was made. Finally, the influence of the wall where the monitors are usually fixed has been studied by Monte Carlo and correction factors determined.

2 Design of the irradiator: The ^{137}Cs source used [2], has an air kerma rate at 1m (10 cm) distance of 14 µGy/h (1.4 mGy/h) and an estimated activity of 0.18 GBq at the reference date. The dimensions of the irradiator were calculated taking into to account the dose limit of 20 mSv/year. This dose should consider the number of working days with the irradiator. This implies the reduction of the ambient dose equivalent from 1.68 mSv/h to 0.085mSv/h at 10 cm of the surface of the irradiator. The methodology for the calculus was based on the iterative method presented by Turner [3]. The source has the spherical shape and it is involved in an acrylic material as it is shown in figure 1A, the design of the irradiator with a cylindrical shape, made of lead should have the minimum thickness of the walls of 3 cm. Its several parts are shown in the figure 1B and the schematic design is shown in figure 1C.

Figure 1. A - The ^{137}Cs source with the spherical shape (in grey) inside the acrylic covering. **B** - The several components of the irradiator. 1- Main body, 2-Removable cover, 3- Cylinder of lead, 4-Lid. **C** - The schematic design of the main body of the irradiator with the source.

3 Characterization of the irradiator: The characterization of the irradiator was made first, considering radiation protection optimization and secondly the radiation beam properties.

3.1 Radiation protection characterization: To access to the ambient dose equivalent, the equipment used was a Babyline 31. The dose was measured along various directions (see fig.2) at several distances from the irradiator. During these measurements the removable cover was in place. The results obtained are shown in figure 3.

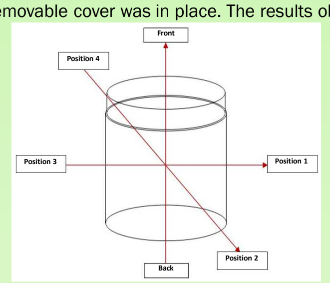

Figure 2. The axis where measurements were done.

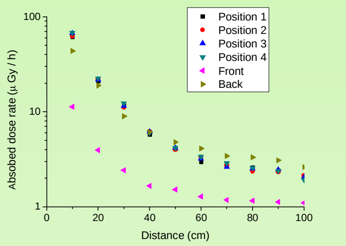

Figure 3. Absorbed dose as a function of the distance to the irradiator for several axis.

Due to the cylindrical symmetry, the values on 4 first axes are very similar and its average value for 10 cm distance is 64.6 µGy/h ± 3.1 µGy/h. The corresponding ambient dose equivalent is 78.0 µSv/h ± 4.0 µSv/h. This value shows a good agreement with the value estimated (85 µSv/h) from the calculus for the design of the irradiator.

3.2 Radiation beam characterization: The study of the radiation beam profile was done by experimental and Monte Carlo simulation methods. For experimental measurements was used the PTW 23361 ionizing chamber. It is a vented sensitive volume of 30 cm³, a diameter of 31 mm and a length of 51 mm. The Monte Carlo simulations studies were made using the MCNPX code, version 2.7.0. Experimental and Monte Carlo simulation results were obtained for 3 distances from the irradiator, 20 cm, 30 cm and 40 cm. The results, presented in figure 4, obtained with the Monte Carlo code and its agreement with the experimental values allows concluding that the methodology used for the simulation is valid. In figure 5 it is shown three profiles for 20 cm, 30 cm and 40 cm.

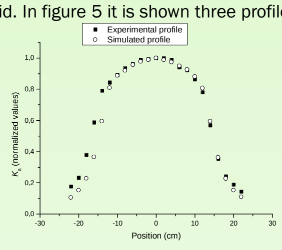

Figure 4. Experimental and simulated profiles for 30 cm distance.

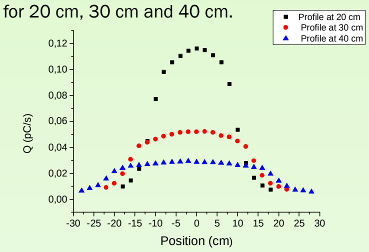

Figure 5. Experimental horizontal profiles of the beam for distances of 20 cm, 30 cm and 40 cm.

4 Dosimetry: The dosimetry was done using two different volume chambers, a smaller chamber with 30 cm³ sensitive volume and a 1 litre ionization chamber. To determine the $H^*(10)$ value the following equation was applied:

$$H^*(10) = M \times N_{PT} \times N_{Ka} \times CC$$

where M is the chamber measurement, N_{PT} is the correction factor for reference pressure and temperature, N_{Ka} is air kerma calibration coefficient of the chamber and CC is the conversion coefficient of Ka to $H^*(10)$ for energy of 0.662 MeV.

For Monte Carlo simulations, the input includes the ionizing chamber and the irradiator without the cover. The calculated quantity is air kerma, using the tally F6. Applying the CC the quantity $H^*(10)$ is obtained. The results of the dosimetry are shown on figures 6 and 7.

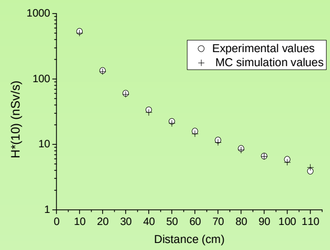

Figure 6 Experimental and Monte Carlo simulations results relatives to the ionizing chamber PTW 23361.

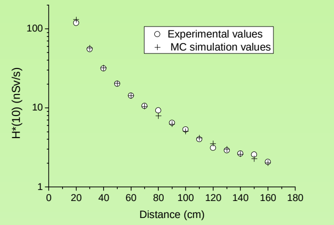

Figure 7. Experimental and Monte Carlo simulations results relatives to the ionizing chamber PTW 32002.

The agreement between the two set of values for both situations is good. Both sets of values are adjusted by the function $y = ax^b$. For figure 6, the b values are -1.970 and -1.986 for function adjusted to the Monte Carlo values and experimental values, respectively and for figure 7 the b values are -2.023 and -1.916 for Monte Carlo and experimental values, respectively. The law of the inverse of square root is also followed very closely.

5 Study of the influence of the wall supporting the monitor: Most of the times, these installed monitors are fixed to a wall. This wall can influence the measurements because the backscatter radiation which can reach the detector. In order to quantify this influence a Monte Carlo study was realized using only the smaller chamber. The wall has surface with an area of 2 m × 2 m and a thickness of 20 cm. Two densities were considered. The density of 2.3 g/cm³ and the density of 1.5 g/cm³. The chemical composition is the same. Relative difference between the results with and without the wall are shown in figure 8.

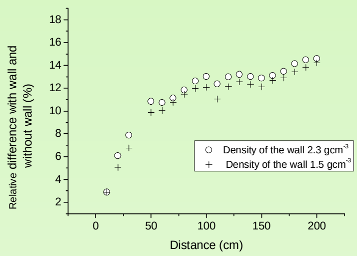

Figure 8. Influence of the wall in the dosimetric Monte Carlo results.

For the distances considered the geometry with the wall always shows higher values as expected For higher density wall, at 10 cm distance the difference between the case with wall or without wall, is 2.9% and at 200 cm distance the difference is 14.6 %. For the lower density wall the results are very similar showing differences of 2.4% and 12.2% for the same distances. This increase in the value of $H^*(10)$ with the distance is due to the increase of the area of the wall directly reached by the photons emitted by the source thereby leading to a greater contribution of scattered radiation reaching the detector.

6 Conclusions: The design and construction of an irradiator for *in situ* metrological control of installed radiation protection monitors measuring the ambient dose equivalent was done. The dose at 10 cm distance from the irradiator was established in a very conservative way and it is very close to the expected value. The profile determinations show the variation of the FWHM with the distance and validates the methodology used for the Monte Carlo simulation studies. Dosimetry was done using two ionizing chambers. The results are different at a distance of 80 cm which can be justified by the different contribution of the scattered photons reaching the detector. Finally, the influence for the presence of a wall behind the monitor was studied and corrections factors were determined. They can increase the $H^*(10)$ values until 15 %.

The irradiator is ready to perform the *in situ* metrological control of installed ambient dose equivalent monitors.

References: [1] International Standard, IEC 60532. Radiation protection instrumentation – Installed dose rate meters, warning assemblies and monitors – X and gamma radiation of energy between 50 keV and 7 MeV. Edition 3.0. 2010. [2] ISO 4037-1:1996, X and gamma reference radiation for calibrating dosemeters and dose rate meters and for determining their response as a function of photon energy – Part 1: Radiation characteristics and production methods. [3] Turner, James E., Atoms, Radiation, and Radiation Protection. Second Edition. John Wiley & Sons, Inc. 1995

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