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Radiological protection for newly built experimental setup with low energy X-ray beams

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Introduction

The self-construction of experimental systems using ionising radiation needs to determine an effective dose or equivalent dose [1]. The threshold values for both doses are determined by legislation in Poland [1]. Depending on these parameters, workers exposed to radiation are divided into two categories A (effective dose is greater than 6 mSv per year) and B (effective dose is from 1 to 6 mSv per year) [1]. Additionally, self-constructed experimental system together with dose measurements should be reported to the National Atomic Energy Agency (NAEA) in Poland to obtain permission to perform experiments using this kind of equipment [1]. A self-designed and -constructed experimental system utilizing low-energy X-ray and situated at Jan Kochanowski University in Kielce, Poland has permission from NAEA no. D-19526 of 23.09.2015 and the dose measurements of ambient equivalent dose was done by the Regional Sanitary and Epidemiological Station in Kielce, Poland. However, the ambient dose equivalent is a certain approximation of the effective dose [2]. For this reason, measurements were made to directly define the effective dose. In these measurements a μSPEC500 semiconductor detector (Ritec Ltd., Latvia) was used to determine the effective dose from the measured spectra in different points of the experimental setup.

Methods

Experimental setup

Experimental setup for radiobiological studies is localised at Jan Kochanowski University in Kielce, Poland [3]. The system contains of an X-ray tube (C-tech tube, no. 9430 922 00291, PANalytical, Holland) and a generator (no. PW 3830, PANalytical, Holland). The maximum values of voltage and intensity were set as 60 kV and 50 mA, respectively. The holder for biological material was situated at a distance of 50 cm from the X-ray tube inside a protective box (Fig.1) in an irradiation chamber (Fig.2). Radiological protection was ensured by the construction of anti-radiation shields, which they include:

- ❑ self-designed and made a protective pipe that was situated behind the X-ray tube (Fig.1) and was built with two plastic pipes of different diameters and between them was located lead (Pb) (4 mm in thickness) and aluminum (Al) (2 mm in thickness). Additionally, the end between two axially positioned tubes inside the protective box was glued with a lead sheet (4 mm in thickness) to protect against the backward dispersion of X-rays.
- ❑ the protective box which was built with wooden plates covered with Pb (2 mm in thickness) and copper (Cu) (0.5 mm in thickness). Additionally, the box had a door in the front to change biological material closed within a Petri dish. Behind the door inside the box, additional stable and sliding protective plates were located to protect the door (Fig.1). The stable plate was made with Pb (2 mm in thickness) covered by Cu (0.5 mm in thickness). The sliding plates were made with Pb (2 mm in thickness) surrounded on two sides by Al (1 mm in thickness). Before irradiation of the Petri dish, these plates were sliding and the door was tightly closed using latches.
- ❑ additional plates of Pb (2 mm in thickness) and Al (2 mm in thickness) were located (Fig.1) around the whole experimental setup. These plates had the following dimensions: height = 50 cm and, width = 50 cm.

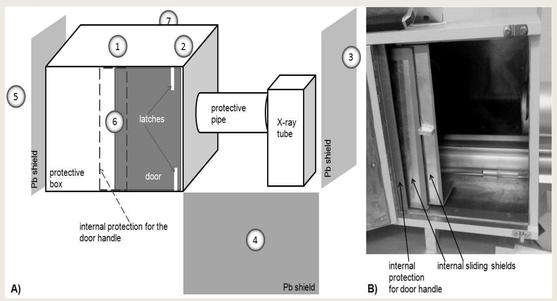


Fig.1. The schema of the experimental setup (part A), where measurement points of spectra are marked from 1 to 7 (part A), and the view of the internal sliding shields when the door is opened (part B).

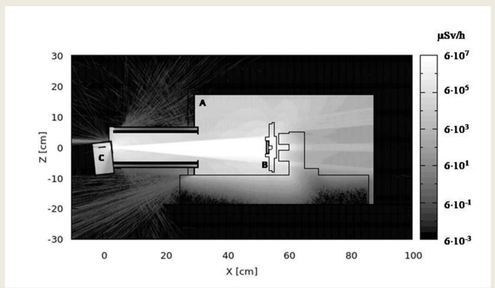


Fig.2. Total effective dose in the experimental setup calculated by Monte-Carlo simulation, where A is the irradiation chamber, B – the Petri dish holder and C- the X-ray tube.

Results

Detector calibration

The μSPEC500 detector was calibrated using a ^{241}Am source that emitted a 59.5 keV X-ray line [4]. Fig.3 shows the spectrum of ^{241}Am registered by μSPEC500.

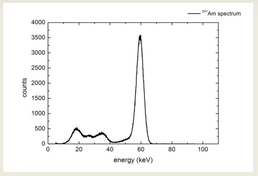


Fig. 3. The spectrum of X-rays radiation emitted by ^{241}Am and registered by μSPEC500.

Absorbed dose in water calculated at different points of experimental setup

Absorbed dose in water (D) was calculated using equation [5]:

where E is energy of individual photons registered in the spectrum and subscript max means maximum energy, is fluence and, is the mass-energy absorption coefficient for water from the dataset in Hubbell and Seltzer [6].

$$D = \int_0^{E_{max}} E \frac{d\Phi(E)}{dE} \left(\frac{\mu_{en}(E)}{\rho}\right) dE$$

Effective dose rate

Effective dose rate (E) was calculated using equation [7]:

$$E = \sum_T w_T w_R D_T$$

where *D* is absorbed dose, *w* is weighting factor, *T* is tissue and *R* is radiation. The *w* factors are equal to 1 for the whole body and for X-ray radiation [7].

Total effective dose per year

The total effective dose was calculated taking into account the registered dose rates around the experimental setup presented in Table 1 (points from 1 to 6). In this case, the total effective dose was equal to 2.7 mSv/h. Fig.1 shows points where measurements of spectra were registered .

Table 1. Effective dose rate in measurement points.

Number of measurement point (Figure 3)	Effective dose rate (μSv/h)
1	0.6
2	0.5
3	0.1
4	0.6
5	0.5
6	0.4
7	0.4

Effective dose in Monte-Carlo simulation

The code Fluka 2011 version 2c.4 [8] available at Świerk Computer Centre, Poland was used to create Monte-Carlo simulations. The full geometry of the real experimental system (Fig.1) without additional external lead plates (i.e., Pb shield) was mapped in the simulation program and the total effective dose rate (μSv/h) was determined around the entire experimental system and inside the irradiation chamber with Petri dish holder. Fig. 2 shows Monte-Carlo calculation results.

Conclusions

Total effective dose rate was determined around the self-constructed experimental system with low energy X-ray radiation. Measurements of this value and Monte-Carlo calculations using Fluka simulation software were done in different points around the experimental setup. Based on these values, one can conclude that this newly built structure with ionising radiation meets requirements the laws and regulations of radioprotection because the total effective dose determined around the experimental system is less than 6 mSv per year.

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