

Towards the estimation of the scattered energy spectra reaching the head of the medical staff during interventional radiology: A Monte Carlo simulation study

Zagorska A¹, Bliznakova K², Buchakliev Z³

¹ Department of Medical Physics and Biophysics, Medical University, 1 G. Sofiisky str, 1431 Sofia, Bulgaria

² Department of Electronic Engineering and Microelectronics, Technical University of Varna, Bulgaria

³ SSDL-Sofia, National Centre of Radiobiology and Radiation Protection, 3 G. Sofiisky str, 1431 Sofia, Bulgaria

E-mail: zagorska.anna@gmail.com

Abstract. In 2012, the International Commission on Radiological Protection has recommended a reduction of the dose limits to the eye lens for occupational exposure. Recent studies showed that in interventional rooms is possible to reach these limits especially without using protective equipment. The aim of this study was to calculate the scattered energy spectra distribution at the level of the operator's head. For this purpose, an in-house developed Monte Carlo-based computer application was used to design computational phantoms (patient and operator), the acquisition geometry as well as to simulate the photon transport through the designed system. The initial spectra from 70 kV tube voltage and 8 different filtrations were calculated according to the IPEM Report 78. An experimental study was carried out to verify the results from the simulations. The calculated scattered radiation distributions were compared to the initial incident on the patient spectra. Results showed that there is no large difference between the effective energies of the scattered spectra registered in front of the operator's head obtained from simulations of all 8 incident spectra. The results from the experimental study agreed well to simulations as well.

1. Introduction

In recent years there is an increase practice of interventional radiology, which results in increasing doses at unshielded parts of the body of medical specialists. In 2012, the International Commission on Radiological Protection has recommended a reduction of the dose limits to the lens of the eyes for occupational exposure [1]. With respect to these new limits, investigations of different parameters affecting radiation protection to medical staff in interventional procedures are necessary. The overall goal of a project that is running in the Department of Medical Physics and Biophysics, Medical University, Sofia is to estimate the dose distribution within the lens of the eye of the operator's head. This paper presents the results from the first phase of this study with purpose to examine the impact of



additional filtration to the scattered spectra around the X-ray unit, in particular at the level of the head of the medical staff at a position close to the X-ray unit.

2. Materials and methods

2.1. Simulations.

Figure 1a shows the computational phantoms designed for the purposes of this study. The 'patient' was chosen to be part of the Mathematical MIRD type hermaphrodite phantom, resembling a torso – elliptical cylinder, simulated from water, with the following dimensions: length of 70 cm, width of 40 cm and thickness of 20 cm [2]. Legs and patient's head were not included in the patient model, since their contribution to the scattered X-ray field is negligible in the irradiation conditions studied.

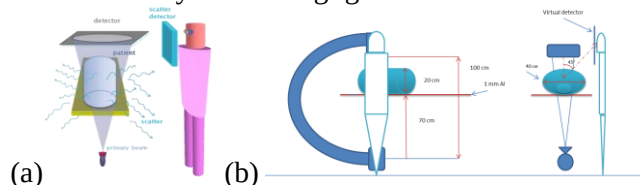


Figure 1. Simulation scenario: (a) schematic presentation of the phantoms used in the study and (b) simulated acquisition geometry.

The 'patient support coach' was modelled as a rectangular slab with dimensions of the rectangle equal to 100 cm and 60 cm, with thickness of 1 mm and composition set to aluminum (Al). The 'operator' was modelled as shown in figure 1a. The height of the examiner was consistent with the height of a standard sized human phantom – 176 cm [3]. The geometry used for the simulation of the interventional procedure is shown in figure 1b. Specifically, the focus-to-image detector distance was set to 100 cm, focus-to-table distance was set to 70 cm, while patient-to-scatter detector distance was equal to 20 cm. The X-ray source was modelled as a point source. Incident beam area on the detector was set to 400 mm² (200 mm x 200 mm). In addition to the designed system, a virtual detector with size of 500 mm x 500 mm, named scatter detector, was modelled and positioned in front of the operator's head in order to account for all scattered radiation reaching the operator's eye at a distance from the centre of the patient phantom to the centre of the scatter detector equal to 57 cm. The initial incident spectra were calculated for 70 kV tube voltage, 12° angle tungsten target, 3 mm and 4.5 mm Al inherent filtration with an additional copper filtration (Cu) (0.1 mm, 0.3 mm, 0.6 mm, 0.9 mm) according to IPEM 78 [4].

Further, to simulate the photon transport from the source through the designed system, as shown in figure 1a, the Monte Carlo module from the XRayImagingSimulator was used [5]. Only photons, reaching the scatter detector were recorded. The following detail information was concerned: photon energy, position and direction. This information will be used during the second phase of the project to evaluate the dose distribution within the eye lens of the operator. During simulation, the Kerma approximation was utilised, which is acceptable for photon energies below 200 keV, considered in this study [6].

2.2. Laboratory test.

To verify the results from the simulation studies, a laboratory test was carried out at the X-ray bench of the Secondary Standard Dosimetry Laboratory, Sofia. The 'patient' was simulated with a slab phantom with dimensions 300 mm x 300 mm x 150 mm [7]. An Al plate of 1 mm thickness was placed between the phantom and the X-ray tube to simulate the patient support coach, similarly to the geometry designed with the XRayImagingSimulator. Tube filtration and voltage were the same as

these used in simulations. Ionizing chamber was situated at a position corresponding to the centre of virtual scatter detector to measure scattered air kerma (K_a). Electrometer Unidos10002 with Extradin ionizing chamber of 30 cm³ volume, traceable to SSDL-Sofia, Bulgaria was used. Exposure and measurements were performed for all simulated filter combinations.

2.3. Data Analysis.

The overall average statistical uncertainty was calculated as $(\bar{E}) = \sqrt{\frac{1}{N} \left[\frac{1}{N} \sum_{i=1}^N e_i^2 - \bar{E}^2 \right]}$, where $\bar{E}$ is the mean energy of the photons reaching the scatter detector, $e_i = \sum_j e_{ij}$, where e_{ij} denotes the energy of the j^{th} photon of the i^{th} history; the number of histories N varied between 7.10^6 and 4.10^7 . Calculated overall average statistical uncertainties for all cases were less than 1%. All data processing and visualizations were realized in Matlab 8.1 [8]. First Half value layer (HVL_1) of the scattered spectra, as well as the air kerma (K_a), mean and effective energy were calculated. Data for $\frac{\mu_{en}}{\rho}$ of dry air were taken from NIST [9]. Calculated K_a from scattered spectra for all filter combinations was normalized to filter combination of Al3Cu0.1 and Al4.5Cu0.1, respectively.

3. Results and Discussion

Figure 2a,b show the calculated scattered spectra, obtained from simulation study with 3 mm Al, 4.5 mm Al and different Cu filters and registered at the scatter detector in comparison with the primary spectra.

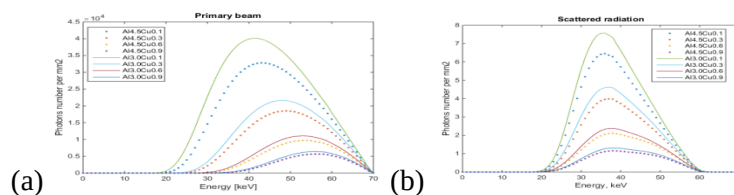


Figure 2. Comparison between primary beam and scattered radiation: a) primary beam spectra and b) simulated scattered spectra for 70 kV and different copper filters.

The shape of the spectrum depends on the voltage applied to the X-ray tube (kV), the angle, and the amount of inherent and added filtration in the X-ray beam. Aluminum filtration removes the low-energy end of the bremsstrahlung spectrum, which would otherwise be absorbed in the superficial tissues of the patient without contributing to the scattering process towards the operator's head. In practice an additional filter of copper is used to further harden the spectrum [10].

Calculated mean energy, HVL_1 and energy at maximum photons for primary beam and scattered radiation as well as effective energy of the simulated scattered spectra are summarised in table 1.

Table 1. Results from processing calculated data from primary and scattered spectra

Filtration	Primary beam			Scattered spectrum			
	HVL_1 , mm Al	Mean energy, keV	Energy at maximum photons, keV	HVL_1 , mm Al	Mean energy, keV	Energy at maximum photons, keV	Effective energy, keV
Al3Cu01	4.04	44.5	41.5	2.12	35.0	36	29
Al3Cu03	5.56	48.8	49.0	2.12	35.9	37	29
Al3Cu06	6.79	52.4	53.5	2.12	36.8	38	29
Al3Cu09	7.51	54.6	55.5	2.31	37.5	39	30
Al4.5Cu01	4.45	45.7	43.5	2.12	35.2	36	29
Al4.5Cu03	5.79	49.5	49.0	2.12	36.0	37	29
Al4.5Cu06	6.91	52.8	53.5	2.12	37.0	38	29
Al4.5Cu09	7.59	54.9	58.0	2.12	37.6	38	29

The results show that the mean energy of primary spectra varies between 45 keV and 55 keV with respect to the filtration while the respective mean energy of scattered spectra is in the range of 36 keV - 39 keV.

Calculated values of HVL_1 of different scattered spectra are similar. While the HVL_1 of the primary beam increases with additional filtration, the HVL_1 of the scattered spectra remains in the range of 2.1 mm – 2.3 mm Al. The effective energy of the scattered beam is calculated to be 29 keV-30 keV, not depending of the additional filtration.

In overall, good coincidence between results from laboratory tests and simulations is observed. Figure 3a,b summarise the results from the laboratory tests against simulations.

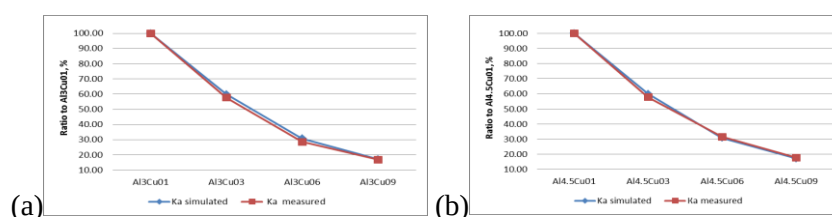


Figure 3. Normalised readouts of ionising chamber and calculated K_a for different filter combinations: (a) Al 3 mm, (b) Al 4.5 mm.

Results show that for filter combinations with 3 mm Al simulated and experimentally calculated K_a diverge from 2 % to 7 %, while for filter combinations with 4.5 mm Al this discrepancy was between 3 % and 4 %.

4. Conclusion

This simulation study showed that for the studied tube voltage of 70 kVp and filter combinations, there is no large difference between the effective energy of the calculated scattered spectra registered in front of the operator's head. Simulation results agreed well with experimental ones. Presently, simulations are running with other tube potentials and different X-ray tube positions. The photon distributions registered in front of the operator head will be used to study the distribution of the absorbed dose in the operator's lenses.

5. Acknowledgements

This work was granted by Medical University – Sofia under Project 12D/2014, Contract 23D/2014. The authors express sincere gratitude to clouds services by Oblak.bg for granted infrastructure to perform simulations.

6. References

- [1] International Commission on Radiological Protection. Statement on tissue reactions approved by the commission on April 21. 2011. ICRP; 2011
- [2] MIRDO Pamphlet № 5, 1978 Society of nuclear medicine
- [3] ICRP (International Commission on Radiological Protection), 2003. ICRP Publication 89: Basic Anatomical and Physiological Data For Use In Radiological Protection
- [4] Cranley K et al, 1997 IPEM Report 78: Catalogue of Diagnostic X-ray Spectra and Other Data (cd-rom ed.) The Institute of Physics and Engineering in Medicine (IPEM), York, UK
- [5] Bliznakova K, Kolitsi Z, Pallikarakis N, 2004, A Monte Carlo based software tool for radiotherapy investigations Nucl. Instr. Meth. B 222 pp. 445-461
- [6] Siiskonen T, Tapiovaara M, et al, 2007, Monte Carlo simulations of occupational radiation doses in interventional radiology, The British Journal of Radiology, 80, 460-468
- [7] International Organization for Standardization. X and gamma reference radiation for calibrating dosimeters and dose rate meters and for determining their response as a function of photon energy. Calibration of area and personal dosimeters and the measurement of their response as a function of energy and angle of incidence. 1999. ISO 4037-3
- [8] Academic MATLAB® license No. 980068
- [9] NIST, 2012 (<http://physics.nist.gov/cgi-bin/Star/compos.pl>).
- [10] International Commission on Radiation Units and Measurements, 2005. Patient dosimetry for X rays used in medical imaging. ICRU report 74. Bethesda, MD, U.S.A.