CALCULATION OF AVERAGE CONVERSION COEFFICIENTS FOR AIR KERMA TO EFFECTIVE DOSE FOR DIAGNOSTIC X-RAY BEAMS

M.A. Frota¹, A. X. Silva² and A. Kelecom¹

¹ Laboratório de Radiobiologia e Radiometria - Departamento de Biologia Geral
Universidade Federal Fluminense, Outeiro de São João Batista, s/n
Caixa Postal 100.436 - 24001-970 Niterói RJ, Brasil
marcofrota@vm.uff.br or egbakel@vm.uff.br

² [PEN/COPPE – DNC/Escola Politécnica] CT/UFRJ
Universidade Federal do Rio de Janeiro
21945-970 – Ilha do Fundão – C.P. 68509; Rio de Janeiro, RJ, Brazil
ademir@con.ufrj.br

ABSTRACT

This work aims to calculate the average conversion coefficients from air kerma to ambient dose equivalent, \( H^{*}(10)/K_{\text{air}} \), and effective dose, \( E/K_{\text{air}} \), for 50 kVp, 100 kVp and 150 kVp X ray beams used for medical diagnostic, after transmission through barriers of lead. The X ray qualities used were those recommended by the Birch and Marshall for primary diagnostic X rays. Several lead layers were irradiated with 50cm × 50cm primary beam spectra. The transmitted spectra were calculated to obtain the conversion coefficients for beams found in radiodiagnostic services. The calculations were done using the MCNPX code and voxel model FAX. The values obtained were compared with data derived from the literature. In addition, conversion coefficients for X ray qualities after penetration of lead layers were studied to get data which might be of interest in shielding of diagnostic rooms.

1. INTRODUCTION

Ionizing radiation is actively present in the life of man, who may be exposed in several ways to natural or artificial sources, such as cosmic rays, terrestrial radiations, ingested or inhaled radionuclides, travels by airplanes, radiopharmaceuticals, X-rays, nuclear reactors, nuclear atmospheric tests and accidental contaminations. The well-known and dangerous effects resulting from ionizing radiation make necessary a careful control in order to maintain expositions beneath acceptable limits. Radioprotection is responsible to avoid or to reduce, as far as possible, the occurrence of eventual harmful effects caused by ionizing radiation in workers and population in general. Obviously, quantification and determination of the dose absorbed by the human body through direct experiments with radiation may not be carried out. Hence, computational simulations and the use of an exposition model that mimics the human body exposed to radiation are the best alternative tools. Usually the results of such simulations are expressed as conversion coefficients, ratios between doses absorbed by radiosensible organs and tissues and measurable quantities. Thus if simulated conditions correspond to e real situation, routine dose measurements may be interpreted in terms of absorbed dose multiplying the radiometric instrument record by the corresponding conversion coefficient. The primary calibration quantities are not equivalent dose ones. Conversion coefficients of the calibration quantities must be determined (in terms of air Kerma), for the quantities of interest in Radiologic Protection, such as the Effective Dose \( E \). Data adopted by ICRP74[1] have been calculated aiming to investigate the behavior of \( E \) in the case of external irradiation with monoenergetic photons from 10 keV to 10 MeV. Figure 1 shows that
Figure 1. Comparison between conversion coefficients $E/K_{air}$ for monoenergetic photons up to 10 MeV obtained by MCNP [2] and those recommended by ICRP74, for both AP and PA irradiation geometries.

The conversion function, following ICRP, is strongly dependent from the photon energy between 30 keV and 200 keV, where diagnostic X-ray equipments operate.

This work aims to calculate the conversion coefficients for effective dose normalized in terms of air kerma, $(E/K_{air})$, for realistic X-ray spectra found inside radiodiagnostic rooms. The following steps were carried out: (1) calculation of X-ray spectra transmitted through lead layers of increasing thickness, compatible with those used to shield the rooms where radiodiagnostic X-ray equipments are installed and (2) determination of conversion coefficients in terms of air kerma for the effective dose $(E/K_{air})$, for both AP and PA irradiation geometries and (3) comparison of obtained values with literature data.

2. METHODS AND CALCULATIONS

The MCNPX code for particles transport used in the present study combines the MCNP4C version with the LAHET (Los Alamos High-Energy Transport) code used for calculations of transport and interaction of nucleons, pions, muons, light ions and anti-nucleus in complex geometries [3]. The MCNPX can simulate the transport of photons, electrons, neutrons, protons and charged particles in material medium over a broad energy band [3]. In this work, the code was used to simulate photon transport through media such as: air, equivalent tissues and lead layers (shielding used in intervention radiological installations), to obtain the transmitted spectra and the estimation of doses in organs of the FAX voxel simulator [4]. Figure 2a shows the three primary spectra characteristics of X-ray equipments at potentials of 50 kVp, 100 kVp e 150 kVp, obtained from the “Catalogue of Data for Diagnostic X-ray”, published by the Hospital Physicists Association BIRCH [5]. Determination of spectra transmitted through lead layers was achieved by simulation, with the MCNP code, of a 50cmx50cmx5cm box with a lead plate placed at the middle (attenuator material) with a thickness increasing by 0.1 mm from 0.1 to 1.0 mm, as depicted in Figure 2b. The irradiation beam, produced by a planar collimated source, reaches perpendicularly the attenuator material; transmitted beam is measured at the external surface of the box, after the attenuator material.
Figure 2. (a) Primary spectra at 50, 100 and 150 kVp; (b) X-ray beams reaching attenuator material, in the Y direction.

For each transmitted spectrum, the $H^{*}(10)/\Phi$ and $E/\Phi$ conversion coefficients were calculated. At this step, the mean doses absorbed by organs of the FAX voxel simulator [6] were calculated for a simulated irradiation of the whole body using a flat beam (56.88 cm long and 163.08 cm high) of photon spectra of energies between 50 keV and 150 keV. To obtain the equivalent doses normalized by fluency ($H/\Phi$), the values of deposited energies should be multiplied by a factor of $1.486 \times 10^{-9}$ Gy cm$^2$. The latter results from the following steps: (a) conversion of deposited energy from MeV into joule; (b) calculation of the absorbed dose (Gy) dividing the energy, expressed in joule, by the mass of considered organ (kg); and (c) calculation of the fluency in Gy cm$^2$ multiplying the absorbed dose by the area of the flat source (cm$^2$). To calculate the mass of the organ one multiplies the number of voxels by the volume of each one (0.046665 cm$^3$, as the voxel edge measures 0.36 cm). Multiplying the volume by the density of the tissue, obtained from the *International Commission on Radiation Units and Measurements* (ICRU 44)[7] one gets the mass of the tissue in kg.

3. RESULTS AND DISCUSSION

We here report the results of the conversion coefficients for photons spectra of 50, 100 e 150 keV in the AP and PA geometries, after they cross lead layers of thicknesses from 0.1 to 1.0 mm. The values of the conversion coefficients are compared with the values obtained from mathematical simulators available in the literature. Figures 3a and 3b represents the conversion coefficients for the effective dose normalized in terms of air kerma ($E/K_{air}$) in the AP and PA irradiation geometries, for the X-ray spectra transmitted through lead barriers obtained in this work, and those obtained using the mathematical phantom, and of $H^{*}(10)/K_{air}$ for photon spectra of 50 keV. The conversion coefficients in Figure 3a display a more neat behavior in the AP projection rather than in the PA one, for both simulators. This may be explained by the proximity of most organs of the body in this projection (AP). However, it is possible to observe that in both projections the operational quantities, $H^{*}(d)$ overestimates in all os points the risk limiting quantity. This behavior is repeated in the other X-ray spectra, under potentials of 100 kVp and 150 kVp.
Figure 3. Comparison between the values of conversion coefficients $H^{*}(10)/K_{\text{air}}$, $E/K_{\text{air}}$ [using voxel (■) e mathematic phantoms (○)] for the spectrum at 50 kVp transmitted by lead layers of increasing thickness, in the (a) Antero-Posterior (AP) and (b) Postero-Anterior (PA) projections.

Table 1 reports the conversion coefficients mean values for the operational quantity $[H^{*}(10)/K_{\text{air}}]$ and for the risk limitation quantity $[E/K_{\text{air}}]$, for the primary beams at 50, 100 and 150 kVp, in the AP and PA projections, and for the beams transmitted through lead barriers. Results are compared with recommended values from the literature [1]. Comparing the AP e PA irradiation geometries, it may be concluded that the AP irradiation presents the highest for conversion coefficients in terms of air kerma. This can be understood since the organs with higher weight factors are localized superficially to this geometry (stomach, ovaries and breasts). The PA geometry shows a behavior similar to the AP one. One of the goals of this work was to investigate discrepancies between effective dose values obtained from MCNPX and literature data. The different series of data available from literature, however, were in general based on different Monte Carlo codes e different kinds of anatomical models. To investigate the effect of the model in voxel, data were compared with values from the literature [1] that are based on several mathematical models.

Table 1. Mean conversion coefficients, $[H^{*}(10)/K_{\text{air}}]_{\text{m}}$, $[E/K_{\text{air}}]_{\text{FAX}}$ e $[E/K_{\text{air}}]_{\text{mMIRD}}$, AP and PA projections.

<table>
<thead>
<tr>
<th>Tension (kVp)</th>
<th>$[H^{*}(10)/K_{\text{air}}]_{\text{m}}$ (Sv/Gy)</th>
<th>$[E/K_{\text{air}}]_{\text{FAX}}$ (Sv/Gy)</th>
<th>$[E/K_{\text{air}}]_{\text{mMIRD}}$ (Sv/Gy)</th>
<th>ICRP74&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Transmitted</td>
<td>Primary</td>
<td>Transmitted</td>
</tr>
<tr>
<td>50</td>
<td>0.98</td>
<td>0.98</td>
<td>1.19</td>
<td>1.19</td>
</tr>
<tr>
<td>100</td>
<td>1.37</td>
<td>1.37</td>
<td>1.59</td>
<td>1.59</td>
</tr>
<tr>
<td>150</td>
<td>1.53</td>
<td>1.53</td>
<td>1.60</td>
<td>1.60</td>
</tr>
</tbody>
</table>

a = monoenergetic beam
Table 2 reports the ratios \([H^*(10)/E]_{\text{mMIRD}}\) e \([H^*(10)/E]_{\text{mFAX}}\) for primary X-ray beams at 50, 100 and 150 kVp, transmitted through lead barriers, in the AP and PA projections, found no interior inside medical diagnostic rooms. Although uncommon, discrepancies higher than 30% can be observed between the conversion coefficients.

<table>
<thead>
<tr>
<th>Tension (kVp)</th>
<th>([H^*(10)/E]_{\text{mMIRD}}) Primary</th>
<th>Transmitted</th>
<th>([H^*(10)/E]_{\text{mFAX}}) Primary</th>
<th>Transmitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>3.29 1.63 2.26 2.21 10.5 1.83 3.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1.79 1.26 1.56 2.22 3.66 1.35 1.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>1.57 1.23 1.54 1.19 1.64 1.23 1.68</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Such differences originate from the variation between both models MIRD and FAX in the localization (stomach), size (thyroid), depth (esophagus) and distribution (bones) of the organs. These parameters directly cause the observed discrepancies between both anatomical models. One observes also that increasing the thickness of the barrier, the conversion coefficients values tend to stay constant.

4. CONCLUSIONS

In this work, conversion coefficients were calculated in terms of air kerma for the effective dose, \(E/K_{\text{air}}\), for the usual spectrum energy of X-ray equipments that operate at 50, 100 and 150 kVp, as used in radiodiagnostic.

The calculation methodology developed here was efficient to simulate exposition models found in practice. The MCNP code allowed to simulate irradiating conditions including the interaction of the incident radiation field with lead attenuator barriers and to obtain dose estimations in organs and tissues, using a mathematical anthropomorphic simulator.

The results reported in Table 1 show that the quantity \(H^*(10)\) overestimates the quantity \(E\) all along studied the voltage range studied in both projections.

The results reported in Table 2 show that the ratio \([H^*(10)/E]_{\text{mMIRD}}\) overestimates the effective dose by a factor of 3.2, when \([H^*(10)/E]_{\text{mFAX}}\) also overestimates the limiting risk quantity by a factor of 10.5 in the PA projection. Thus, since \(E\) is the quantity that has been limited, due to connectivity with occupational risk, the barriers should be designed in agreement with this quantity, on the contrary, they might be insufficient.
ACKNOWLEDGEMENTS

The authors wish to thank the Profs. Helio Yoriyaz of IPEN/CNEN and Richard Kramer of Departamento de Engenharia Nuclear of UFPE, Brazil.

REFERENCES