EXIT SPECTRA FROM THE PATIENT IN DIAGNOSTIC RADIOLOGY: MONTE CARLO SIMULATION STUDIES

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INTRODUCTION

Differential absorption of the beam of X-ray, as it passes through the patient, results in the creation of the radiographic image. To optimise the radiographic image ,the photon energy response of the screen/film system has to match the spectral properties of the radiation beam emerging from the patient. The exit spectrum consists of two components: 1) transmitted without interactions with the body, which contains the usefull diagnostic information, and 2) Compton scattered. The analysis described in this work is based on mathematical phantoms developed at GSF (Gesellschaft fur Strahlen und Umweltforschung) (1). Monte Carlo technique applied to the GSF anthropomorphic heterogeneous has been realized in our laboratory (2). They are similar to the GSF phantoms but contain some variations in elemental composition of organs and tissues. The linear attenuation coefficients for each organ and tissue calculated from White and Fitzgerald (3) have been introduced in our mathematical models. In this work a detailed analysis of exit spectra is presented by means of male and female mathematical human phantoms (Adam and Eva). The technical parameters for two typical radiographic techniques have been reproduced. Transmitted and scattered radiation spectra impinging on radiographic plane have been also simulated. Calculations have been carried out for external irradiation of the phantoms with monochromatic and distributed photon energy.

THE MATHEMATICAL PHANTOM

The heterogeneous mathematical phantoms presented in this work are very similar to GSF Adam and Eva. They comprise 24 internal organs each of which is characterized by quadratic equations. Volumes and masses of organs of the two sex-specific adult mathematical phantoms are based on average values given by ICRP 23 (4). The phantoms have different dimensions with 19 regions of different composition and density. For each organ and tissue percentage by weight of 51 elements and specific gravity from ICRP 23 have been considered. Organs tissues and contents that are not well specificated in ICRP 23 have been assumed as soft tissue. They are : breast, uterus, ovaries, gall bladder, urinary bladder and the contents of intestine and stomach. In the phantoms all skeletal components such as compact bone and active bone marrow are homogeneously distribuited in the skeleton.

RESULTS AND DISCUSSION

The results consist of an accurate analysis of the intensity and the quality of radiation that is responsible of the image forming process during a diagnostic X-ray examinations. To this aim the irradiation geometrical conditions of the radiological examination were accurately simulated. The theoretical spectra incident on the phantoms were taken from HPA Report (5) with costant potential and total filtration of 2.5 mm Al. For each examination two different components of radiation transmitted on image detector system were analyzed: 1) the radiation that passes through the phantom without interaction ("transmitted") and 2) the scattered radiation ("Compton"). The first produces the diagnostic informations of the image , the second causes its impairing. Figure 1 shows the Compton spectra produced from monochromatic photons of 50 keV and 80 keV in abdomen AP projection for Adam and Eva. No appreciable difference can be noticed on the radiation qualities due to the different dimensions of the two phantoms. In figure 2 transmitted spectra are shown for 90 kV incident radiation in lungs AP projection. A wide energy range of the incident spectrum (15-35 keV) is not usefull to produce the image and contributes mainly to the dose. In the conditions described above and to obtain a more general analysis of correlations between incident photon energy and transmitted spectrum on radiographic plane were carried out only calculations with monochromatic photon energy. Furthermore was developed a procedures , starting from the informations obtained from monochromatic energies to obtain the transmitted and Compton spectra produced by any incident distributed photon energy . To calculate the transmitted spectra a simple polynomial interpolation was applied to Monte Carlo results for monochromatic energies. The calculation of Compton spectra was more complicated because every monochromatic energy produces a distributed spectrum on image detector system as shown in figure 1. A method called "decrement method" was applied. It relates each energy Ed of Compton spectrum to monochromatic energy Em by the equation: $Ed = Em - \Delta E$ where ΔE is the decrement that increases with 1 keV step. This method takes into account the particular energy distribution of Compton spectra in which the numbers of events increases with Ed. Interpolating by polinomial expressions the numbers of the events of energy Ed obtained from a discrete number of monochromatic energies for each decrement ΔE it is possible to obtain the following mathematical expression:

$$N_c\left(E_j - \Delta E_k\right) = \frac{N(E_J)}{N_0} \sum_{i=0}^{9} A_i(\Delta E_k)\, E_J^{(i)}$$

where E_j and $N(E_j)$ are the energy and the number of monochromatic photons j emitted from the X-ray source respectively. N_c is the number of Compton photons at energy $E_j - \Delta E_k$ and $A_i(\Delta E_k)$ are the polynomial coefficients. N_o is a normalization costant. The result of the procedure applied to 90 kV spectrum in a lungs AP examination is shown in figure 3. The procedure allows to obtain a good accuracy fitting the values of Compton spectrum, obtained from the simulation of a distributed energy emission of the source. Finally figure 4 shows the complete result of intensity and radiation quality on image detector system for the transmitted and Compton photons obtained applying the procedure described above.

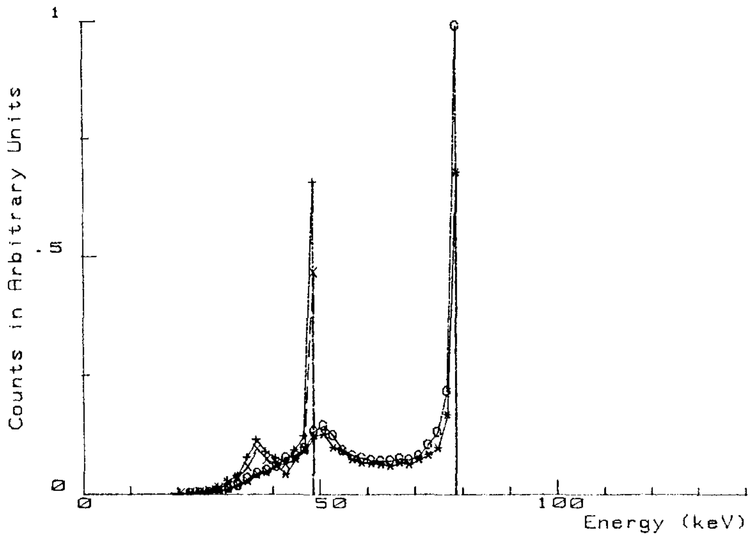

Fig.1 Simulation of Compton spectra produced from monochromatic photons of 50 keV and 80 keV in abdomen AP projection.

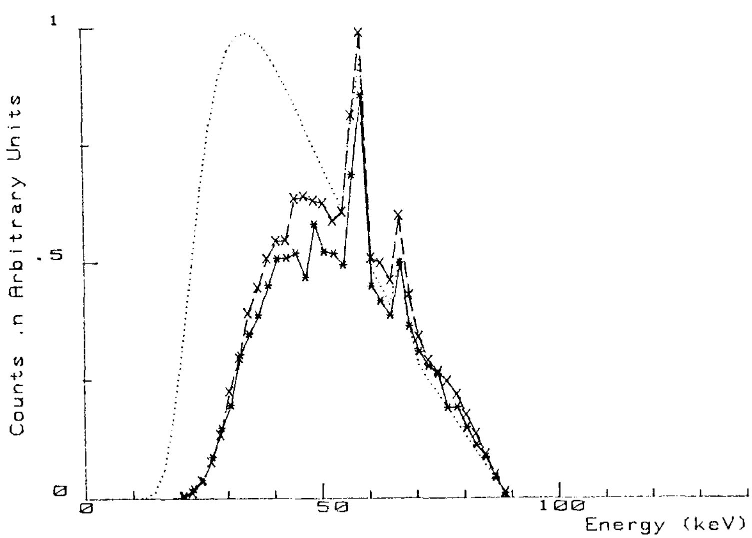

Fig.2 Transmitted spectra for 90 kV incident radiation in lungs AP projection for Adam (asterisc) and Eva (cross) compared with the incident photon spectrum (dot).

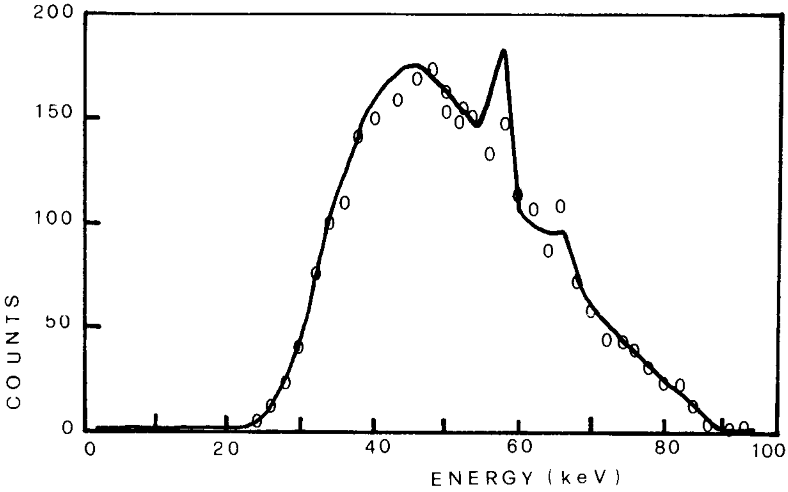

Fig.3 Projection: Lungs AP 90 kV.
Comparison between Compton spectra obtained with Monte Carlo simulation (circle) and applying the decrement method (full line).

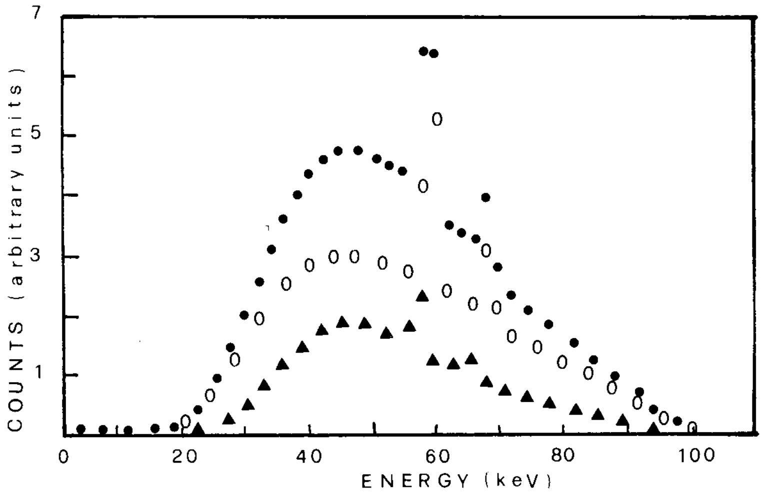

Fig.4 Projection: Lungs PA 100 kV.
Transmitted (circle), Compton (triangle) and total spectra (dot) obtained applying the decrement method.

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