MONTE CARLO CALCULATIONS OF DOSE EQUIVALENTS FOR HIGH ENERGY ELECTRONS USING THE MIRD-5 HUMAN PHANTOM

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Abstract

For radiation protection from high energy electrons such as those from LINAC, absorbed doses and dose equivalent in human organs were calculated by using the EGS4 monte carlo simulation code and MIRD-5 mathematical human phantom. Effective dose equivalents were also calculated for the AP and PA geometrical irradiation conditions in the incident electron energy range of 0.1 to 200MeV. The conversion factors from the incident particle fluence to the tissue dose equivalent as well as to the effective dose equivalent were obtained for electrons and compared with those for photons and neutrons. The H_{1cm} in ICRU sphere was also simulated.

The simulation has shown the conversion factors of effective dose equivalent amounts to be on the same order of magnitude as for photons in the energy range higher than 1MeV. Furthermore in the range above 10MeV, stochastic effects from electrons become more significant than from photons of equivalent energies. The ratio of the effective dose equivalent to H_{1cm} becomes larger than unity above 20MeV for AP condition and above 35MeV for PA condition, respectively.

Introduction

For effective radiation protection, it is necessary to specify the degree of irradiation in numerical terms. ICRP(International Committee on Radiation Protection) has recommended the system of numerical specification based on the dose equivalent(H_T) in various organs of an individual and the weighted sum of the dose equivalents in some of the organs - the effective dose equivalent(H_E)[1]. These are essentially unmeasurable and, as a result, they must be estimated from the measurable radiation field quantities such as the particle fluence. In practise, various conversion factors, such as H_T or H_E per unit particle fluence, were calculated by using the human phantom and ICRU sphere, which is a equivalent material of human soft tissue. In the case of photons(0.1 to 10MeV) and neutrons(2.5×10^{-8} to 14 MeV), ICRP has recommended conversion factors from the unit particle fluence to H_T and H_E[2]. However in the case of electrons, it has not yet recommended such factors. Instead, ICRP has shown the maximum dose equivalent and the dose equivalent at the depth of 1 cm of a semi-infinite slab of 30 cm thickness whose composition is the same as that of an ICRU sphere. For beta rays from isotopes those energies are likely lower than 2MeV. So that the depth in tissue of interest for radiation protection purposes is no more than a few millimeters. For such low energy beta ray, conversion factors from absorbed dose in air to tissue dose equivalents of skin were recommended[3].

In the progress of LINAC applications, radiation protection from high energy electrons of more than 2MeV has become a great priority. For electrons of energy above 2MeV, it would be necessary to consider the dose equivalent to organs lying deeper than the skin. In the present study of electron irradiation, we have calculated the organ dose equivalents and effective dose equivalents for the AP and PA geometrical irradiation condition using the EGS4 monte carlo simulation code[4] and MIRD-5 mathematical human phantom.

Monte carlo simulation

The monte carlo simulation code employed in this work is the EGS version 4, developed at Stanford Linear Accelerator Center(SLAC). EGS has been successfully employed by others in the field of medical physics to study such phenomena as the electron contamination of photon beams. Like any other monte carlo code, EGS follows each individual electron and photon particle until it either escapes from the system geometry or its energy falls below a user specified cutoff energy. A photon cutoff energy of 0.01MeV and an electron cutoff energy of 0.521MeV (including the electron rest mass energy) are used in this work. During the course of particle transport, energy loss, interaction type, energy and angle of the emerging particle from an interaction are sampled by EGS from appropriate probability distributions and other relevant physical data.

The mathematical anthropoid phantom used in this work is a hermaphrodite phantom and is derived from MIRD Pamphlet No.5(revised)[5]. It has also Lewis' oesophagus. Fig.1 shows the anterior view of the MIRD phantom. The phantom consists of three types of tissue - lung, skeletal, and other soft tissue. Elemental composition of different tissues of the phantom and their masses were determined by using the reference data. To obtain the effective dose equivalent absorbed dose calculations were made for bone, lungs, red bone marrows and every other organ to which the radiation weighting factors are assigned.

Results and Discussion

The EGS code was run for each calculation with 10^5 electron histories for AP exposure and with 10^4 for PA exposure. We have simulated the energy deposition in every organ (61 organs) defined in MIRD phantom in the electron energy range of 0.1 to 200 MeV. For examples, Figs.2, 3, and 4 have shown the conversion factors for lung, thyroid, and testes, respectively. From those figures, it has been shown that the values of conversion factors for electrons attain the same order magnitude as those for photons and neutrons near 5 MeV, the effect of which depends on the composition of organs and their location in the phantom. Fig.2 shows an example for which the conversion factor for electrons has increased with respect to energy more rapidly than those for photons and for neutrons. Also it exhibits a more sudden saturation. Such a energy dependency of the conversion factor for electrons was common in other organs as well.

Effective dose equivalent per unit fluence for electrons are shown in Fig.5. The increase of the effective dose equivalent with increasing energy is due to the increase of the electron range. The value of the conversion factor for electrons exceeded that for photons above 10 MeV and showed saturation at almost the same values as neutrons. Fig.6 showed the ratio of the effective dose equivalent to the H_{1cm} in ICRU sphere. The

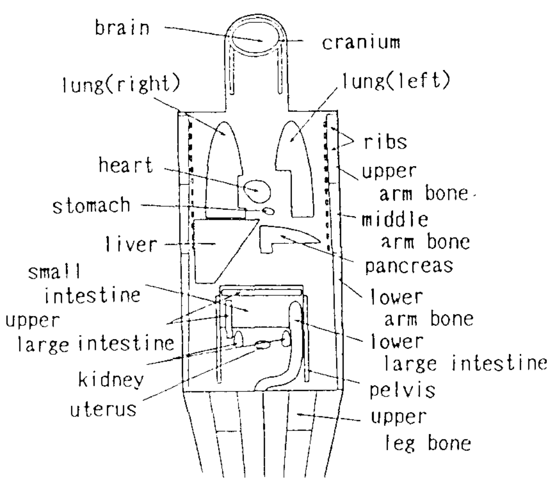

Fig.1 Anterior view of the principal organs in trunk of the MIRD phantom

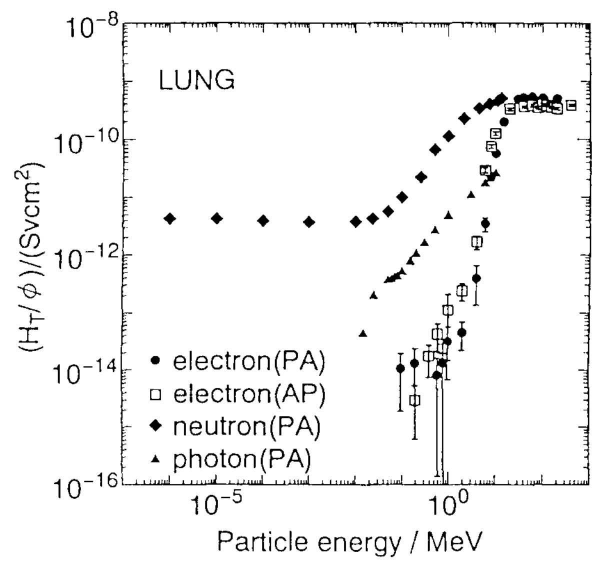

Fig.2 Dose equivalent(H_T) to the lung per unit fluence(ϕ) in the MIRD phantom irradiated by monoenergetic particles. Exposure geometries:AP, broad parallel beam from front to back(anterior-posterior); PA, broad parallel beam from back to front(posterior-anterior). The data for electrons : this work; For neutrons and photons : ICRP Pub.51.

figure shows that the ratio becomes larger than unity above 20MeV for AP exposure and 35MeV for PA exposure.

References

[1] ICRP Publ.26

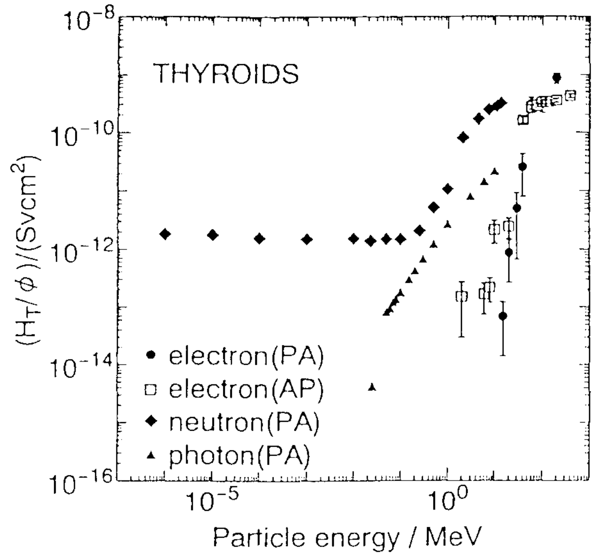

Fig.3 Dose equivalent(H_T) to the thyroid per unit fluence as a function of energy; geometries and symbols, and the data source explained in the caption to Fig.2

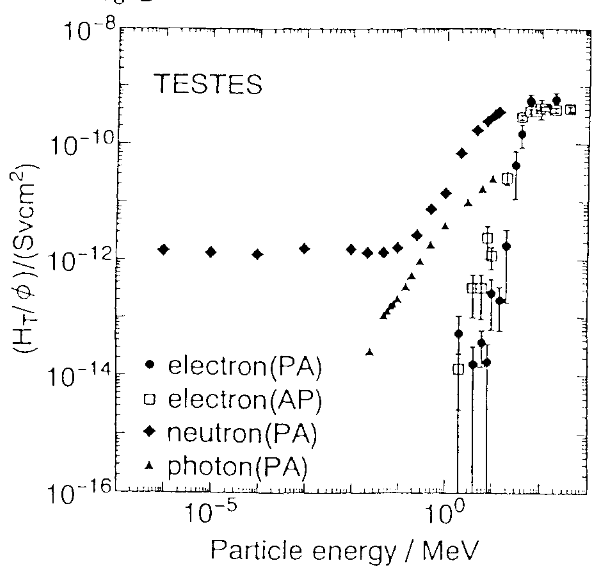

Fig.4 Dose equivalent(H_T) to the testes per unit fluence as a function of particle energy; geometries and symbols, and the data source explained in the caption to Fig.2.

[2] ICRP Publ.51
[3] Rad. Prot. Dosim., 14, 337(1986)
[4] W.Nelson et. al., SLAC Report-265(1985)
[5] W.S. Snyder et.al., NM/MIRD Pamphlet No.5(revised),J.Nucl.Med. 19 Supplement:5-67(1987)

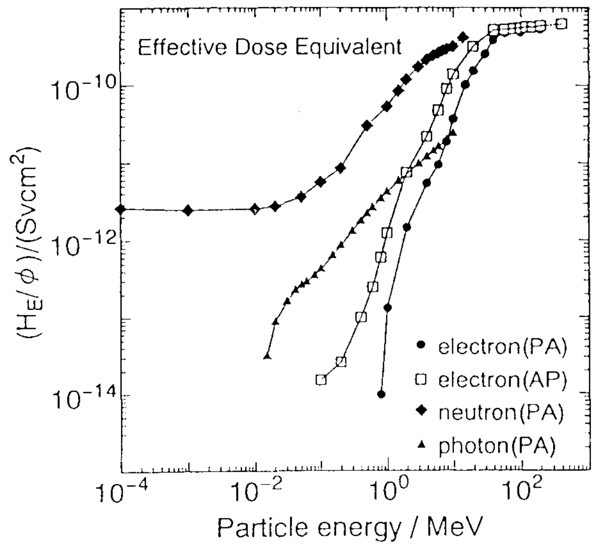

Fig.5 Effective dose equivalent(H_E) per unit fluence as a function of particle energy. Geometries and symbols, and the data source are explained in the caption to Fig.2.

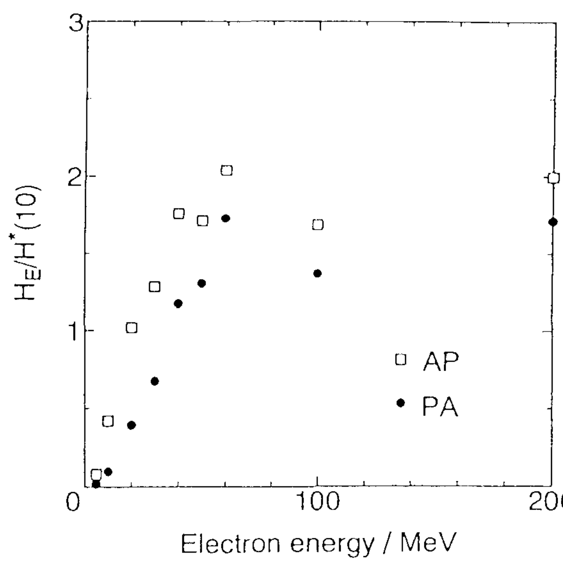

Fig.6 The ratio of Effective dose equivalent to the H_{1cm} [$H^*(10)$] in ICRU sphere as a function of electron energy. Geometries and symbols are explained in the caption to Fig.2