PHOTON & ELECTRON INTERACTION PROPERTIES OF ICRP REFERENCE MAN

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1. INTRODUCTION

The latest report of the ICRP Task Group of Committee 2 on Reference Man (1) contains a comprehensive tabulation of the concentrations of 51 elements in 81 organs, tissues and tissue components. The document replaces an earlier report of Committee 2, published in 1959 (2), which listed 44 elements found in 36 organs and tissues, but excluded the important C, H, N, O concentrations. The new document corrects these omissions and also includes useful data on specific gravities, organ masses and water/fat/protein contents for the systems considered.

This paper describes certain important deficiencies discovered with the new elemental compositions and outlines the mathematical procedures adopted to calculate partial and total photon and electron interaction data. The results of an analysis of the photon data (3) are discussed, together with some preliminary results of the analysis of the electron data.

2. TISSUE COMPOSITIONS

With the large quantities of data presented in the report it is, perhaps, not surprising that anomalies exist. By summing the masses of the elements quoted for each tissue and comparing the summation to the total mass given, it is apparent that twelve tissues have mass deficiencies in excess of 20%. Consequently, the data for gall bladder, G.I. tract (oesophagus), larynx, lymph nodes, pituitary, skeleton (bone), skeleton (trabecular), skin (epidermis), skin (dermis), thymus, trachea and urinary bladder were rejected. Generally the mass deficiencies are due to the elements C, H, N or O being omitted, but for the skeletal materials elemental calcium is not quoted.

Of the remaining 69 systems, 41 have mass errors in the range 0-2%. Seven organs and tissues, included in the calculations, have mass errors between 5% and 20%.

3. CALCULATION PROCEDURES.

Partial and total mass attenuation and energy absorption coefficients for 33 energies in the range 10 keV - 100 MeV were calculated (3) using the elemental cross sections of Hubbell (4) and Storm and Israel (5). Data were derived using the conventional 'mixture' rule, by summing over the 51 elements considered in the ICRP tabulation. Rad/roentgen conversion factors were calculated using the elemental composition of air given by ICRU (6). In addition, photoelectric K, L_1, L_2, L_3 absorption edges (5) for the 38 elements present with atomic numbers in excess of 30 were considered. These elements, ranging from gallium (Z : 31) to uranium (Z : 92) contribute data via absorption edges at energies above 10 keV.

Electron collision mass stopping powers were calculated for the same 33 energies from the formulae presented by Berger and Seltzer (7) and Kim

(8). Radiation mass stopping powers were derived from elemental data (7, 9) and the application of the 'mixture rule'. The c.s.d.a. ranges were calculated using a smoothing cubic-spline algorithm (10) to fit the total mass stopping power data and using the Clenshaw-Curtis (11) method for the integration of the standard range relationships (7). Mass angular scattering powers were derived from calculated elemental data (12) and the use of the 'mixture rule'.

4. RESULTS

4.1 Photons. Tabulations of photon interaction data were obtained for all of the 69 accepted Reference Man tissues and organs. Detailed analyses of these tables have shown that the tissues and organs may be divided into two classes, A and B.

CLASS A contained the 'high attenuation' systems and was arbitrarily taken to include those with specific gravities >1.2 and/or mass attenuation coefficients at 10 keV $> 0.600 m^2/kg$. This group included total body, teeth and the skeletal materials.

CLASS B contained the 'low attenuation' systems with specific gravities $\leqslant 1.2$ and/or mass attenuation coefficients at 10 keV $\leqslant 0.600 m^2/kg$. CLASS B tissues were divided into three sub-groups, B(I), B(II) and B(III).

B(I) was arbitrarily taken to include those 'fat-like' tissues containing $\geqslant 75^{w}/_{o}$ fat. Adipose and yellow marrow were in this category.

B(II) contained tissues with $< 75^{w}/_{o}$ fat and water contents. Skin, pancreas, liver and heart were classified B(II).

The 'water-like' tissues, B(III), were taken to be those with $\geqslant 75^{w}/_{o}$ water. Some 39 systems, including blood (plasma), G.I. tract, spleen, testes and thyroid were in this group.

CLASS A tissues showed a large spread in their attenuation and absorption data. For example, the low energy attenuation coefficients for teeth (enamel) was nearly seven times that for total body. Large differences ($\sim$ 30%) were also noted between the interaction data for skeleton (cortical bone) and similar coefficients calculated (4) for the composition of compact bone given by ICRU (6).

Thirteen of the B(II) tissues were found to have interaction data within 9% of those for aorta, while 35 of the B(III) tissues were found to be within 6% of the data for testes (3).

The only significant absorption edge was found for thyroid, when an increase of 7% in the total interaction data was observed at 33.2 keV due to the K-edge of iodine.

4.2 Electrons. Preliminary tabulations of stopping powers, angular scattering powers and ranges have been produced for the accepted tissues and analyses of the results initiated.

For the complete set of tissues, the collision stopping powers were found to increase by some 60% from the minimum values recorded for the 'high (photon) attenuation' tissues. Radiation stopping powers and angular scattering powers showed a corresponding increase of 40% and 90-100% respectively over the minimum values which were recorded for the 'low (photon) attenuation' tissues.

The tissue groupings developed specifically for photons may be applied successfully to the electron results, but the division of CLASS B tissues into sub-groups appears to be inappropriate for stopping powers. The 62 tissues in the three CLASS B sub-groups exhibited a 20% variation from the minimum values, while 54 were found to have data within 7% of those for muscle (skeletal).

For mass angular scattering powers the variations from the minimum values recorded for CLASS A and CLASS B tissues were 50-60% and 30-40% respectively. These results appear to indicate that all, or part, of the CLASS B sub-groups should be retained for this process.

5. SUMMARY

The latest Reference Man document provides a useful set of elemental concentrations for the calculation of both photon and electron interaction data. All of the important interaction parameters have been calculated for 69 organs, tissues and tissue components and an attempt has been made to organise the results into rational groupings. The enhanced absorption properties of liver, spleen and thyroid reported earlier by ICRU (13) were not observed, and significant differences in the results for cortical bone compared to earlier estimates were recorded. For routine Health Physics calculations the data for one or two representative tissues within each group should give adequate results, but more stringent research applications might necessitate the use of data for specific tissues.

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