SELECTION OF SUITABLE LIQUIDS AND SOLIDS FOR A PHANTOM FOR INTERNAL DOSIMETRY MEASUREMENTS

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1. INTRODUCTION

The absorbed dose to various body organs from internally deposited radionuclides has two components, the β-/γ-dose from activity deposited in the organ itself and the γ-doses from activity deposited in all the neighbouring organs. Average dose equivalents in different target organs per transformation in a source organ can be determined either by Monte Carlo photon transport calculations or by point kernel calculations. Limitations of the computational methods as well as of the mathematical model of the human body call for experimental validation of internal dose calculations. Uncertainties of physical data such as tissue compositions may be of minor importance compared to the overall uncertainty but need to be experimentally demonstrated.

2. TISSUE EQUIVALENT MATERIALS

For internal dose measurements in phantoms, the phantom material and the tissue it simulates should have identical responses to both photons and electrons. Therefore, the photon mass-attenuation and mass-energy absorption coefficients, μ/ρ and μ_{en}/ρ, as well as the electron mass-stopping power, S/ρ, should all be identical for the two materials over a wide energy range [1]. As equal volumes of the two materials should have the same mass, the mass density, ρ, should also be identical.

New tissue substitutes for 9 tissues have been evaluated, both theoretically and experimentally [1]. One of these substitutes, "total soft tissue", is close to the composition of the total soft tissue given by the ICRP [2]. The mass density is 1.03 g/ml and the composition in per cent by weight is: H(10.49%), C(23.33%), N (2.58%), O(62.80%), Na(0.11%), Mg(0.01%), P(0.13%), S(0.20%), Cl (0.13%), K(0.20%), Ca(0.02%). The ratios of μ/ρ, μ_{en}/ρ and S/ρ for the substitute to those of real tissue are equal to 1 in the energy range of 0.01-100 MeV, and the tissue is recommended as a suitable phantom liquid in which the organs could be submerged. Consequently, the "total soft tissue" liquid was used in these experiments.

Because of the low density of a human lung (0.25-0.30 g/ml in the median respiratory state) a liquid cannot be used as lung substitute. For these experiments, a preliminary substitute was prepared from two different types of porous granules, VERMICULITE and LECA, both produced from geological minerals. The grain sizes ranged from 0.3-3 mm and their mass densities were measured to be 0.10 and 0.40 g/ml, respectively. The two materials were mixed in an approximately equal volume ratio giving a mass density of 0.26 g/ml. Unfortunately, the content of H, C, and N is negligible; a chemical analysis gave the following elemental composition: H (0.3%), O(46.7%), Na(0.68%), Mg(4.4%), Al(10.1%), Si(25.0%), K (2.9%), Ca(0.72%), Ti(0.54%), Fe(5.8%). The effective atomic number $\bar{Z}$ has been calculated as 13.8, which is a factor of 2 higher than for both soft tissue and air.

In the energy range of 0.1-2.0 MeV the ratio of μ/ρ, μ_{en}/ρ and S/ρ for the lung tissue substitute to those of soft tissue were calculated to be 1.10, 1.12 and 1.20, respectively. As the elemental composition of lung tissue + blood + air is similar to soft tissue [2], the absorption and scattering properties of the lung tissue substitute for photons and electrons are rather poor compared to real lung tissue, especially for the electrons.

3. EXPERIMENTAL WORK

An experimental programme for determining the radiation doses absorbed in target organs from radionuclides deposited in different source organs will be carried out with a newly constructed phantom [3]. To determine the importance of tissue substitute compositions in the phantom, experiments with both γ- and β-emitting nuclides have been made.

The γ-dose rates were measured in cylindrical "organs" submerged

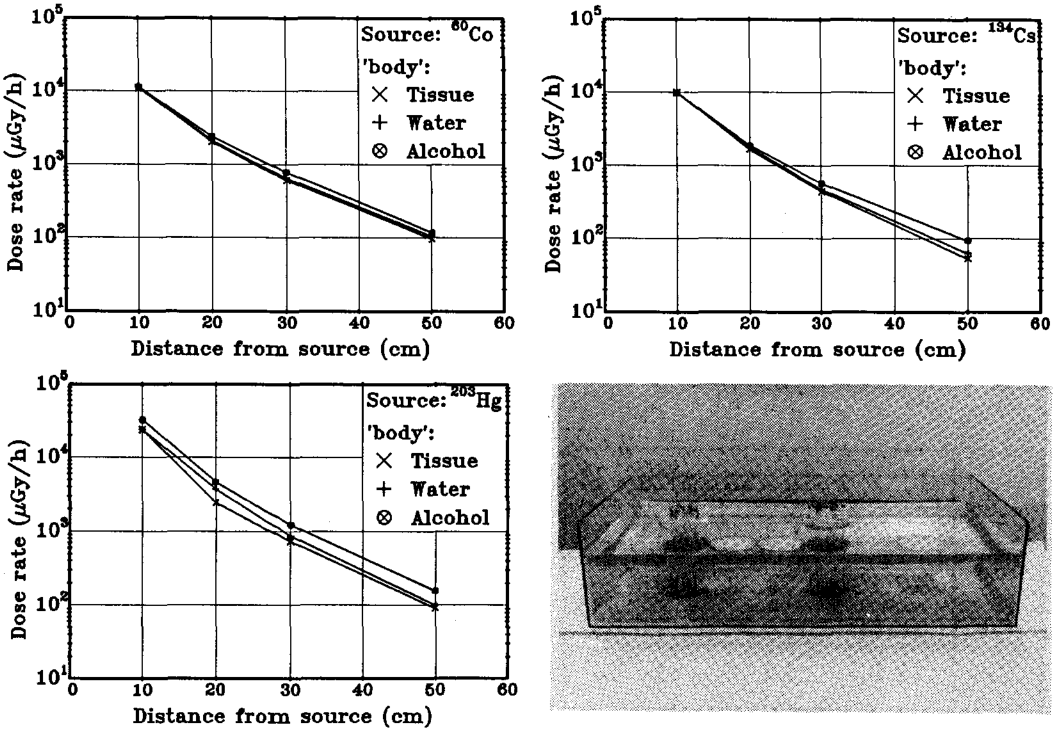

Figure 1. Measured γ-dose rates and the experimental setup.

in three different "body" liquids, namely alcohol, water, and the tissue equivalent liquid. An aquarium of dimensions 80 cm x 30 cm x 20 cm contained the liquid and represented a body. Two water filled cylinders with 10 cm diameter and 13 cm height represened a source and a target organ. The target cylinder was supplied with 13 vertically mounted tubes containing a total of 39 LiF TLD-700 dose meters. The centerline distance between the target and source could be varied from 10 to 50 cm. The target organ dose rates were represented by the average value of the readings from the 39 target dose meters.

Three different nuclides, ^{60}Co, ^{134}Cs, and ^{203}Hg, representing a photon energy range from 279 keV to 1332 keV were successively dissolved in the water in the source cylinder. The activities of the nuclides were chosen so that the dose rate was approximately 100 μGy/h at a source-target distance of 50 cm.

Figure 1 shows the results of the target dose rate measurements and the experimental set-up. As can be seen, the results for alcohol differ considerably, up to 80%, from those of the water and tissue for all three nuclides. At large source-target distances (50 cm) the difference between the target dose rate in water and in "total soft tissue" is 9% for ^{60}Co, 17% for ^{134}Cs, and 10% for ^{203}Hg.

Pure β-emitters ^{32}P ($E_{\beta max}$ = 1.71 MeV), ^{204}Tl ($E_{\beta max}$ = 0.763 MeV), and ^{35}S ($E_{\beta max}$ = 0.167 MeV) were successively dissolved in water, the soft tissue equivalent liquid, and the lung tissue granule. The lung granule was soaked with water containing the nuclide, and after drying the absorbed activity was distributed homogeneously in the granule.

The β-dose rates were measured in cubic "organs". Glass bowls of dimensions 12 cm x 10 cm x 8 cm were filled with the three organ materials. TL dose meters were placed in a special holder and covered with mylar foil of 0.8 mg/cm^2 thickness to avoid contamination of the dose meters. MgB_4O_7:Dy dose meters in which 3% graphite was imbedded were used, representing a nearly infinite thin dose meter, so that correction for attenuation in the dose meter was necessary only for ^{35}S [4]. The correction factor was 1.7. A correction for attenuation of β-particles in the mylar foil was also made for ^{35}S.

Nuclide	Dose rate (mGy/h * l)		
	Water	Tissue	Lung
^{35}S	27.13	24.21	146.71
^{204}Tl	16.52	14.92	79.28
^{35}P	19.02	18.02	116.32

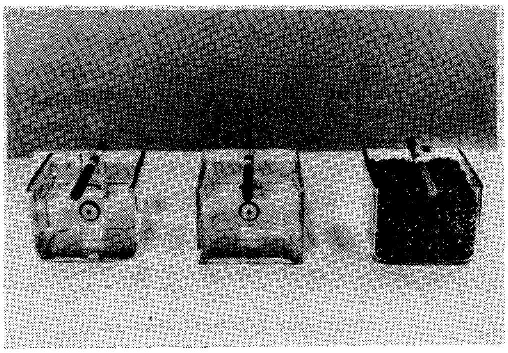

Figure 2. Measured β-dose rates and the experimental setup.

Figure 2 shows the result of the measurements and of the experimental set-up. The dose rate ratio $\dot{D}_{tissue}/\dot{D}_{water}$ normalised to source volume varied between 0.89 and 0.94, and the dose rate ratio $\dot{D}_{lung}/\dot{D}_{water}$ between 4.8 and 6.1.

4. DISCUSSION AND CONCLUSION

With 1 liter target and source "organs" submerged in a 50-liter "body" containing different liquids as substitutes for soft body tissue, γ-dose rate ratios $\dot{D}_{liquid}/\dot{D}_{water}$ were measured at different source-target distances up to 50 cm. For the total soft tissue equivalent liquid this ratio was measured at the largest distance to 0.91 (0.88) for ^{203}Hg, 0.85 (0.93) for ^{134}Cs and 0.92 (0.95) for ^{60}Co, respectively. For alcohol the ratio varied from 1.2 to 1.6. The figures in parentheses are the corresponding ratios calculated by the point kernel method. The measurements were carried out in two identical arrangements, and the difference between the two sets of results were in all situations less than 3%. Based on these measurements, it is concluded that for γ-radiation water is a rather good substitute for soft tissue, and that internal γ-doses for a given source-target geometry can be measured with an uncertainty less than 10% compared to a more correct soft tissue composition.

A homogeneously distributed β-emitting nuclide in a source organ will result in a β-dose rate to all the organ tissue that is proportional to the volume concentration (Bq/l) divided by the organ mass density if edging effects are neglected and the organ dimensions are greater than the β-particle range in the organ material. The β-dose rate ratio for two organs with the same nuclide concentration but with different densities will accordingly be equal to the reciprocal mass density ratio. The β-dose rate ratios $\dot{D}_{tissue}/\dot{D}_{water}$ and $\dot{D}_{lung}/\dot{D}_{water}$ were measured within 1-liter source organs containing soft tissue liquid, lung tissue granule and water to be 0.89 (0.93) and 5.4 (3.8) for ^{35}S, 0.91 (0.93) and 4.8 (3.8) for ^{204}Tl and 0.94 (0.93) and 6.1 (3.8) for ^{32}P, respectively. The figures in parentheses are the reciprocal mass density ratios. The measurements were repeated several times with small scattering between the results. The mass density for the soft tissue liquid was measured to be 1.08 g/ml, i.e. greater than the theoretical value of 1.03 g/ml, apparently due to an unnoticed evaporation loss of alcohol from the liquid during earlier measurements. It is concluded that water is also a good substitute for different tissue equivalent liquids for measurement of internal β-doses, and that mass density is the decisive parameter for the absorbed β-dose. The measurements on the lung granule show that factors other than the mass density may influence the absorbed β-dose. Further measurements on other granule materials with a more realistic elemental composition are required to determine these factors.

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