CONSTRUCTION OF A HETEROGENEOUS PHANTOM FOR INTERNAL DOSIMETRY MEASUREMENTS

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1. INTRODUCTION

Intake of radionuclides could result both from routine work with radioactive materials and from accidents. For medical purposes, intakes of radionuclides are administered in both diagnostic and therapeutic treatments. Therefore, there is a need to evaluate the internal radiation doses received by the body organs from intakes. As measurements of internal doses are almost impossible to make in practice, internal dosimetry today is, to a large extent, based on calculations.

The current method of internal dose calculations is described in pamphlets from the MIRD (Medical Internal Radiation Dose) Committee [1]. The MIRD-method is based on calculations of the ratio of the energy absorbed by a target organ to that emitted by a source organ. The phantom used in these calculations - the Snyder-Fisher Phantom - is a heterogeneous phantom approximating the adult human body.

Some years ago the ICRP (International Commission on Radiological Protection) [2] published limits for the intake of radionuclides based on a method very similar to the MIRD-method.

Although there are limitations and uncertainties associated with internal dose calculations, little effort has been made so far to verify the calculations experimentally. Therefore, the present study has been undertaken with the goal to build a phantom more close to a "standard man" than the MIRD-phantom and use this phantom for measuring the Specific Effective Energy SEE(T←S) absorbed in selected target organs from radionuclides distributed homogeneously in specific source organs.

2. BASIC THEORY

One of the basic parameters in the field of radiological protection is the committed effective dose equivalent, H_{50}. To calculate H_{50}, it is necessary to determine the committed dose equivalents in a number of target organs T from the activity in a given source organ S, $H_{50}(T \leftarrow S)_i$, for radiation type i:

$$H_{50}(T \leftarrow S)_i = U_S \cdot SEE(T \leftarrow S)_i$$

where

U_S is the number of transformations of the radionuclide in the source organ S over a period of 50 years after the intake

$SEE(T \leftarrow S)_i$ is the specific effective energy in $MeV \cdot g^{-1}$ per transformation for radiation type i (modified by the quality factor) absorbed in the target organ T from each transformation in the source organ S

$SEE(T \leftarrow S)_i$ is given by:

$$SEE(T \leftarrow S)_i = \frac{Y_i \cdot E_i \cdot AF(T \leftarrow S)_i \cdot Q_i}{M_T}$$

where:

Y_i is the yield of radiations of type i per transformation of the radionuclide

E_i is the energy of radiation i

$AF(T \leftarrow S)_i$ is the fraction of energy absorbed in the target organ T per emission of radiation in the source organ S

Q_i is the quality factor for radiation type i

M_T is the mass of the target organ

For an intake of a given radionuclide, a target organ can be irradiated by several source organs giving the committed dose equivalent to the target organ as:

$$H_{50,T} = \sum_S U_S \sum_i SEE(T \leftarrow S)_i$$

The value of U_S is the time integral over 50 years of activity of the radionuclide deposited in that organ:

$$U_S = \int_0^{50} q(t)dt$$

depending on both the biological retention and the physical half-life of the radionuclide.

3. CONSTRUCTION OF A HETEROGENOUS PHANTOM

Human organs from the body of a 180 cm, 75 kg male were used for the moulding process. The person did not die of a disease in any of the used organs, leaving these as reasonably representative of an adult male. The following organs were used:

- lungs
- kidneys
- liver
- thyroid
- pancreas
- spleen
- stomach
- bladder

All organs were saturated with a mixture of formalin and alcohol thereby keeping their original shape. The stomach and bladder were both filled with gypsum.

A negative form of each half of an organ was moulded by Sadocover 488, a 2-component polyethane surface coating material. A positive model of a half organ was moulded by filling the negative form with Sadocast 521, another 2-component polyethane casting material. After hardening, this second material is easily machined and polished to prepare a completely smooth surface. A heated sheet of 2-mm Acryl-plast material was placed at the top of the positive model, and with a vacuum technique a plastic shell identical in shape to the original half organ was produced. Because of the size of the trunk, head, and limbs it was necessary also to make negative vacuum forms of the casting material from the positive models.

The two plastic shell halves were then glued together leaving a hollow replica of the original organ. Several thin plastic tubes were inserted through each organ for the placement of TL dose meters. A hole in the side of the organ, closed with an O-ring tightened plug, makes it possible to fill the organ with liquid.

The positions of the organs were determined from anatomical atlases. The organs were fixed within the body in an easily replaceable way. Figure 1 shows different steps in the moulding process and Figure 2 the final phantom.

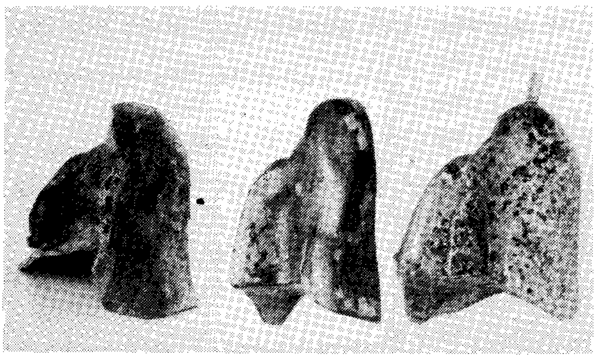

Figure 1. Moulding process for the production of a hollow replica of the right lung. From left to right: real lung, positive model of a half lung, and hollow replica of lung filled with granule.

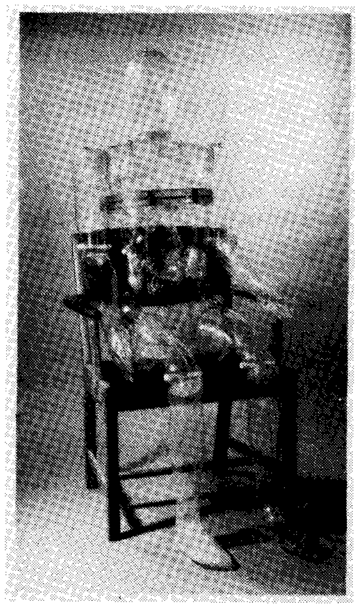

Figure 2. Phantom for internal dosimetry measurements.

4. EXPERIMENTAL PROGRAMME

An extensive experimental programme will be undertaken to determine the Specific Effective Energy SEE(T←S) absorbed in the target and source organs of the constructed phantom that will represent man more closely than the MIRD-phantom. Radionuclides of importance in health physics at nuclear installations and laboratories as well as nuclides used in nuclear medicine will be used. The organs and the body will be filled with liquid except for the lung material which will be simulated by a granule [3]. The activity of the nuclide will be dissolved in the organ liquid and successively placed in all the source organs. For the lungs the granule will be soaked with liquid containing the radionuclide and then dried.

Two dosimetric methods can be used to measure the organ dose: small TL dose meters that measure the doses at several selected points within the organ or a volumetric dose meter with TL powder mixed in organic materials molding a solid dose meter with the same shape as that of the organ.

Both methods have their advantages and limitations. The measurement of dose at selected points within the organ is easily performed and gives the dose distribution in the organ directly. The total organ dose, however, has to be calculated from the point measurements. The volumetric dose meter gives the total organ dose directly, but not the dose distribution, although possible by measuring the response from sub-volumes of the organ. The difficulty here is to obtain a uniform mixture of TL powder and organic material and to recover all the TL powder from the mixture for the dose reading process.

In this study TL dose meters of the size 1 mm x 1 mm x 0.5 mm will be placed inside the thin plastic tubes passing through the organs to measure the γ-dose. The β-dose in the source organs will be determined in a separate arrangement where TL dose meters are submerged in the organ tissue liquid or granulate having linear dimensions large compared to the range of the β-particles [3].

The measured values of SEE(T←S) will be compared to the corresponding values in ICRP publication no. 30 [2].

REFERENCES

[1] W.S. Snyder, M.R. Ford and G.G. Warner, Soc. Nucl. Med., MIRD Pamphlet No. 5 (1978).

[2] Annals of the ICRP. ICRP Publication 30 (1979).

[3] Bente Lauridsen and Per Hedemann Jensen, Selection of Suitable Liquids and Solids for a Phantom for Internal Dosimetry Measurements. 7th International Congress of IRPA, Sydney, April 10-17, 1988