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DETERMINATION OF SUPERFICIAL ABSORBED DOSE FROM EXTERNAL EXPOSURE OF WEAKLY PENETRATING RADIATIONS

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ABSTRACT

The methods of determining the superficial absorbed dose distributions in a water phantom by means of the experiments and available theories have been reported. The distributions of beta dose were measured by an extrapolation ionization chamber at definite depthes corresponding to some superficial organs and tissues such as the radiosensitive layer of the skin, cornea, sclera, anterior chamber and lens of eyeball. The ratios among superficial absorbed dose D (0.07) and average absorbed doses at the depthes 1,2,3,4,5 and 6 mm are also obtained with Cross's methods. They can be used for confining the deterministic effects of some superficial tissues and organs such as the skin and the components of eyeball for weakly penetrating radiations.

Keywords Water phantom, Superficial absorbed dose, Eyes, Dose limits, Weakly penetrating radiations, Safety standards, Extrapolation chamber, Skin dose

1 INTRODUCTIONS

The recommended annual limits of effective dose and equivalent dose to the lens of eye for workers and members of public have been decreased in 1990 Recommendation of the International Commission on Radiological Protection (ICRP Publication 60)[1] as compared with the ICRP Publication 26 (1977)[2] (See Table 1).

Different tissues or organs vary in their responses to ionizing radiations. Among the rest the most radiosensitive tissues and organs are ovary, testis, bone marrow and the lens of eye. Threshold doses for some deterministic effects resulting changes in function in these tissues and organs are shown in Table 2. For workers the annual equivalent dose limit is 150 mSv in a year applied to the lens of the eye and 500 mSv in a year applied to the skin average over any 1 cm^2. For individual members of the public the Commission has adopted an arbitrary reduction factor of leading to annual limits of 15 mSv for the lens and 50 mSv over any 1 cm^2 of skin.

The quantity of interest in radiation protection is equivalent dose, H_T, in each tissue or organ (T). This is the quantity to which the Commission's annual dose limits

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for deterministic effects basically apply. The restrictions on effective dose are sufficient to ensure the avoidance of deterministic effects in all body tissues and organs except the lens of the eye and skin. Thus they will not necessarily be protected against deterministic effects. Therefore the equivalent dose limits to the lens of the eye and skin are excluded from computation of effective dose and are provided separately when considering the protection for individuals against ionizing radiations.

Table 1

Comparisons of Recommended dose limits in the Recommendations of ICRP 60 and ICRP 26

Types of exposure	Applications	Recommended dose limits / mSv · a^{1}	
		ICRP 26	ICRP 60
Occupational	Effective dose (whole body)	50	20 (average over defined periods of 5 years)
	Annual equi. dose in the lens of the eye	300	150
	the skin	500	500
	the hands and feet	500	500
Public	Effective dose (whole body)	5	1
	Annual equi. dose in	50 (any tissue or organ)	
	the lens of the eye		15
	the skin		50
	the hands and feet		—

Table 2

Estimations of the threshold for some deterministic effects in the adult human testis, ovaries, lens of eye and bone marrow (From ICRP 41)[3]

Tissue and effect	Total dose equivalent received in a single brief exposure / Sv	Total dose equivalent* / Sv	Annual dose rate* * / Sv · a^{-1}
Testis			
temporary sterility	0.15	No application	0.4
permanent sterility	3.5—6.0	No application	2.0
Ovaries sterility	2.5—6.0	6.0	>0.2
Lens of the eye			
detectable opacities	0.5—2.0	5	>0.1
visible impairment (cataract)	5.0	>8	>0.15
Bone marrow depression of hematopoiesis	0.5	No application	>0.4

* Received in highly fractionated or protracted exposure

* * Received yearly in highly fractionated or protracted exposure for many years

The superficial individual absorbed dose D_p (0.07) and directional absorbed dose D'(0.07) for weakly penetrating radiations are usually measured in radiation protection practices[4—6]. The objective of the paper is to establish the relationships between the average absorbed dose to the lens of eye and the two quantities by two means for external exposure.

2 DETERMINATION OF THE ABSORBED DOSE DISTRIBUTIONS IN A WATER PHANTOM

2.1 Considerations in theory

The quantities of interest in radiation protection are the equivalent doses in each tissue or organ (H_T). In the circumstance of external exposure from weakly penetration radiations the radiation weighting factors are taken to be unity. Therefore the equivalent dose equals to the average absorbed dose over tissue or organ of interest in numerical value.

For protection of tissues and organs the measurement or estimation of average absorbed dose is basic link in practices. However, it is immeasurable directly. Its values are only obtained by extrapolating the dosimetric quantities with some models.

In general, there are two approaches to beta dosimetric problem for external exposure, i.e. computation and experiment.

Some theoretical calculations are based on following ways:

a. Absorbed dose distributions around a isotropic point source in an infinite homogeneous medium provide a basis for calculation of beta doses from any spatially distributed source in the medium[7].

b. Point source functions for monoenergetic electrons in several media have been tabulated by Spencer[8] and Berger[9].

c. General solutions of Age-diffusion theory and transport theory for beta ray dosimetry are capable of tackling the problem[10,11].

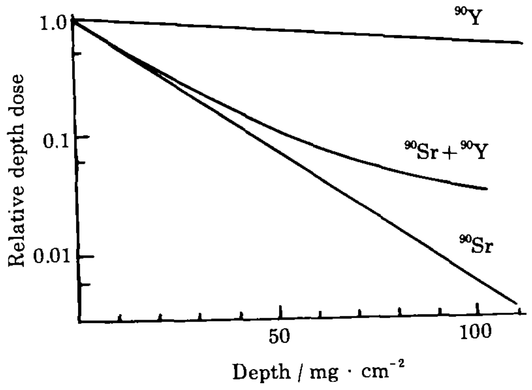

Fig.1 Dose contributions from respective ^{90}Sr, ^{90}Y and ^{90}Sr+^{90}Y

These treatments are confined to an assumption of electrons slowing down continuously. They exclude the contributions from γ-, x-rays or bremsstrahlung and Auger electrons, and apply only to infinite homogeneous media. They are also inapplicable for absorbed doses at an interface. From Loevinger's semiempirical relationships[7] it is obvious that absorbed dose of a point source at an interface ($r = 0$) will necessarily be divergent. Besides, theoretical models hardly ever take into account many anatomical and physical factors in practices.

As an example of calculation the percentage doses contributed from individual strontium and yttrium spectrum unfiltered to their total absorbed dose at different depthes were obtained using the solutions of Age-diffusion theory. It is proved that the absorbed doses delivered by ^{90}Sr and ^{90}Y respectively are inequable each other anywhere except at about 65 mg/cm^2 (see Table 3 and Fig.1).

Table 3

Percentage doses contributed from ^{90}Sr and ^{90}Y respectively to total dose

Depth / mg · cm^{-2}	^{90}Sr	^{90}Y	Depth / mg · cm^{-2}	^{90}Sr	^{90}Y
0	0.95	0.05	40	0.75	0.25
3	0.94	0.06	60	0.55	0.45
7	0.93	0.07	70	0.43	0.57
10	0.92	0.08	80	0.32	0.68
20	0.88	0.12	100	0.16	0.84

2.2 Considerations in experiment

Penetration of electrons in a medium is completely determined by two reasonably well-known quantities, the stopping power (dE/dX) and mass attenuation coefficient μ_{en}. So the interactions of beta radiations with tissues are more similar to water than other materials. In order to imitate these tissues of interest a physiologic saline (0.9 %) phantom contained in a topless and bottomless cylinder made of polystyrene was adopted except in so far as a piece of thin film act as the bottom. A correction has been applied to account of its attenuation.

A uniform radiation field of broad beams was realised by a strontium+yttrium plane source filtered by 100 mg/cm^2. In this instance, the absorbed doses mainly come from ^{90}Y.

The average absorbed dose at defined depthes up to 6 mm where some of important tissues and organs lie in (see Table 4) were measured by means of an extrapolation ionization chamber made of tissue equivalent material[12]. The lens of eye and skin lie in respectively the depthes 3 and 0.07 mm recommended by the ICRP.

Table 4

Depthes recommendated by the ICRP where some important tissues and organs lie in

Tissue or organ	Depth / mg · cm^{-2}
Radiosensitive layer of the skin	7
lens of the eye	300
gnode	1000
bone marrow	2000—3000

Besides, the cornea, sclera and lens were separated anatomically from a fresh eyeball. Then their attenuations for ^{90}Sr+^{90}Y radiations have been determined.

3 MEASUREMENT RESULTS

3.1 Absorptions and equivalent thicknesses of eyeball components for ^{90}Sr+ ^{90}Y radiations are shown in Table 5.

3.2 Average absorbed doses to water phantom at defined depthes of interest where the tissue and organ lie in were measured. The relative depth doses are shown in Fig.2. The ratios of average absorbed doses at some depthes relative to superficial absorbed dose at 0.07 mm are obtained and listed in Table 6 along with the results obtained by other authors. Items 1—5 are computational values utilizing Cross's[15] Tables. Item 6 is the experimental values, and items 7 and 8 come from Friedell[13] and Snaroff[14].

Table 5

Percentage attenuations and corresponding thicknesses of eyeball components for $^{90}Sr+^{90}Y$ radiations

Component name	Absorption / %	Equivalent thickness / mm (water)
Cornea	0.42	0.72
Sclera	0.31	0.49
Lens	0.78	2.5
Anterior chamber	0.90	3.0
	0.95	4.0

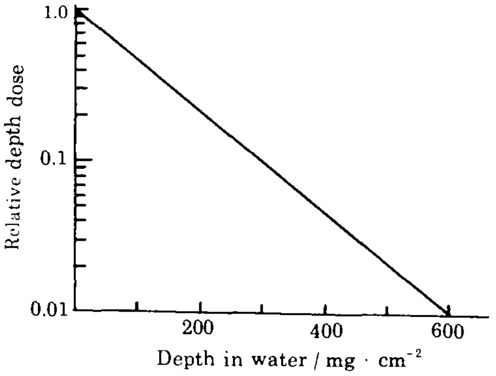

Fig.2 Relative depth dose distributions of a $^{90}Sr+^{90}Y$ source filtered by 100 mg / cm^2

Table 6

Ratios of absorbed doses at various depthes related to superficial absorbed dose for some radionuclides

Nuclide	T	E_{max} / MeV	$\bar{E}$ / MeV	D(0.07)	D(1)	D(2)	D(3)	D(4)	D(5)	D(6)
^{204}Tl	3.78y	0.776	0.243	1.00	0.047	—	—	—	—	—
^{32}P	14.3d	1.718	0.695	1.00	0.273	0.103	0.037	0.0092	—	—
^{24}Na	15h	1.39	0.54	1.00	0.215	0.059	0.012	0.0013	—	—
^{106}Ru	1.01y	3.54	—	1.00	0.42	0.26	0.188	0.141	0.094	0.061
$^{90}Sr+^{90}Y$	28.5y	2.274	—	1.00	0.198	0.10	0.053	0.027	0.007	0.042
Present experiment				1.00	0.46	0.24	0.10	0.048	0.022	0.011
Ref.[13]				1.00	0.41	0.19	0.09	0.04	0.01	—
Ref.[14]				1.00	0.50	0.25	0.15	0.6	0.028	—

3.3 Radiation effects depend on the depth which the tissue and organ of interest lie in. Considering that several components exist in front of the lens and eyeball can be stretched out and drawn back as well as individual discrepancy, the absorbed dose at the front surface of the lens is about 3 %—7 % of superficial absorbed dose D(0.07) and 0.6 %—1.5 % at behind the lens.

4 CONCLUSIONS

It is shown that the results of present work have a satisfactory agreement with experiments of other authors[11,14]. The discrepancy between theoretical calculation and experiment is due to the fact that a practical filtered spectrum was used in the experiment. The restriction on facial skin dose is sufficient to ensure the avoidance of deterministic effects in the lens of eye for some weakly penetrating radiations. In radiotherapeutic exposure, the absorbed doses to tissues are in general very much higher and both the dangers of the exposure and the benefits of the treatment can be assessed more quantitatively. But sometimes, for example, the therapeutic dose of vernal catarrh is about 18—169 Gy. The radiations play no useful part for the lens of eye and are merely adventitious. At the time the absorbed dose constraint must be applied for controlling exposure. Thus the lens of eye should necessarily be protected against deterministic effects.

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