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Organization of Personnel Dosimetry

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INDIVIDUAL MONITORING OBJECTIVES

Individual monitoring means the making measurements by equipments carried on the person of workers or measurements of the quantities of radioactives materials in their body or in excreta and the interpretation of such measurements.

- **-Estimating the <u>Effective Dose</u> or the <u>Equivalent Dose</u> in significantly exposed tissues of people working with ionizing radiations**
- **-Furnishing information of the actual radiation protection condition in the workplaces**
- **-Providing data useful for reviewing optimization programmes**
- **-Helping for the confirmation of classification of workplaces**
- **-Detecting variations in working condition and irradiation facilities**
- **-Furnishing informations in case of accidental exposures**
- **- Furnishing data useful for epidemiological investigations**

TYPES OF INDIVIDUAL MONITORING

- <u>Monitoring for external irradiation</u>

Fairly simple and usually sufficiently cheap and without heavy commitment of resources.
It should be generally used for all people who are occupationally exposed

- <u>Monitoring for internal contamination</u>

Monitoring of ingestion and inhalation of radioactive materials is much more difficult and complex.
It should be generally used only for people working in controlled areas where it is effectively expecting significant intakes

DESIGNING A MONITORING PROGRAMME

To achieve an adequate level of protection and costs of the monitoring programmes, two basic conditions must be considered:

- Technical parameters
- Identification of people requiring individual monitoring

<u>Technical parameters</u>

- expected level of dose or intake in relation to the relevant limits
- likely variations in the doses or intakes
- complexity of measurements and interpretation procedures for internal contamination

<u>Identification of people</u> requiring individual monitoring

A basic need in designing a programme of individual monitoring is to indentify the individuals for whom it must be provided.

To this aim the ICRP has introduced a system of classification of working conditions, based on the <u>possibility</u> of reaching a selected dose value of exposure

<u>Working condition A</u>

Condition where the annual dose <u>might exceed</u> three-tenths of the relevant annual limits.

For this condition, in contrast with B, the compliance with the dose limits cannot be achieved or demonstrated without routine individual monitoring

<u>Working condition B</u>

Condition where <u>it is most unlikely</u> that the annual dose will exceed three-tenths of the relevant annual limits.

Individual monitoring may sometimes be performed as a method of confirmation of the good level of the radiation protection conditions

Criteria for classifications of working condition

Work. Condit. A

- Works with substantial radiation sources not enclosed in fully interlocked shields
- Works where experience has shown that individual doses are almost always low but may sometimes rise to three-tenths of the annual limits

Work. Condit. B

- Works with sources of sufficiently low activities (for gamma sources around less than 15 MBq.Mev, 0.4 mCi.Mev, and about ten times lower for beta sources with Emax>0.3 MeV)
- Works with adequately shielded sources and interlocks to prevent any exposure other than through the shield
- Works not involving radiation sources and taking place outside controlled areas even though it may involve occasional access to controlled areas

REFERENCE LEVELS

A reference level is a pre-determined value for any of the quantities used in radiation protection which will require a certain action to be taken if the measured value exceed this pre-defined level.

RECORDING LEVEL

Is a formally defined value for effective dose or intake above which the result of a monitoring program is of sufficient interest to be worth keeping. (recommended value for monthly indiv. monit. = 1/10 (20 mSv /12) = 0.16 mSv or lower)

Using recording level, any data smaller than the recording level should be treated as zero for assessing the annual dose or intake for the purpose of radiation protection.

INVESTIGATION LEVEL

Is a pre-established value for effective dose or intake usually set in relation to a single measurement above which the result is sufficiently important to justify other additional investigations (recommended value for one month monitoring = 3/10 (20 mSv /12) = 0.48 mSv or lower)

INTERVENTION LEVEL
Is a pre-established value for effective dose or intake such that if this value is not exceeded it his highly improbable that intervention, to correct an apparently unaccepatble situation, will be required.

Individual monitoring for external radiation

Effective dose and equivalent dose in tissues (PRIMARY QUANTITIES) are not directly measurable. Individual monitoring should be performed by measuring other quantities (OPERATIONAL QUANTITIES) that can be related with sufficient accuracy to the Primary Quantities.

Operational Quantity (ICRU39;ICRU47):
PERSONAL DOSE EQUIVALENT , $H_P(d)$
Dose equivalent in soft tissue below a specified point on the body at an appropriate depth d, expressed in mm.

- skin	d= 0.07 mm	$H_P(0.07)$
- eye	d= 3 mm	$H_P(3)$
- deep organs	d= 10 mm	$H_P(10)$

Also $H_P(d)$, defined in the body, is NOT DIRECTLY MEASURABLE.However these quantities can be adequatley represented by the corresponding dose equivalent at a depth d on the appropriate radius in the ICRU sphere (a 30 cm diameter tissue-equivalent sphere with density of 1 g cm^{-3} and mass composition of 76.2% oxygen,11.1% carbon and 2.6% nitrogen)* Figg. 1-2. According to more recent ICRU recommendation, a more simplified slab phantom of Perspex 30x30x15 cm can be used for dosimeter calibration and type testing (Fig.3) * Hydrogen 10.1%

Relation between $H_P(d)$ and Effective Dose

The relation between these Quantities has been established by ICRU.
The relation between "effective dose equivalent" and $H_P(10)$ and H'(10) are respectively shown in Fig.4 and Fig. 5 for different photons irradiation conditions and for two locations of dosimeter (front and back)
The relation between Exposure and Effective Dose and Effective Dose Equivalent (free in air) are shown in Figg. 6-7.

Categories of dosimeters

BASIC DOSIMETER

Dosimeter designed to estimate the operational quantities $H_P(d)$ in radiation protection, without additional informations.
For the majority of individual monitoring a simple basic dosimeter will be satisfactory.
(ex. TL dosimeter)

DISCRIMINATING DOSIMETER

Dosimeter that in addition to the estimation of the operational quantities provide additional information on the irradiation conditions, like type, energy and direction of the radiation.
This dosimeter may be useful in rare cases for workers regularly receiving doses approaching the dose limits in complex radiation fields.
(ex. film dosimeter or multi-element TL dosimeter)

EXTREMITY DOSIMETER

Dosimeter designed to be worn on an extremity (hand, forearm, foot etc.) when this extremity may become the limiting organ or tissue.
It is usually worn in addition to a basic or discriminating dosimeter. (ex. TL dosimeter)

DIRECT READING DOSIMETER

Dosimeter which can give an immediate indication of the dose or dose rate evaluated.
Usually recommended when radiation fields are not sufficiently known and high dose rates may be encountered.
(ex. electronic dosimeter)

Calibration of Personal Dosimeter in terms of $H_P(d)$

Operational procedure

Irradiation, using ISO gamma and x reference radiations, of the dosimeter on an appropriate phantom, as shown in Fig. 3, using conventional radiation fields known in terms of primary quantity (absorbed dose or kerma in air), measured without the phantom. Using suitable conversion coefficients published by ICRU and/or other Institutions (ex. Tab. 1), this quantity must be converted in the involved Operational Quantity $H_P(d)$ which will be related to the reading of the dosimeter.
The angular responses required by the dosimeter for the different photon energies are shown by the graphics of Fig. 8

REQUIREMENT FOR PERSONAL DOSIMETERS

ACCURACY

This parameter should be intended as the difference betwwen the quantity measured with the practical dosimeter and that obtained with an ideal dosimeter.
The uncertainties acceptable are a function of the involved dose values.
When annual doses are approaching the relevant limits , the uncertainties should not exceed -33% or +50% at the 95% of confidence level, and -50% or 100% at the 95% of confidence level when annual doses are lower than 1/5 of the relevant limits
(4 mSv for $H_P(10)$ and 100 mSv for $H_P(0.07)$)
This condition may be represented using a continous function of dose level, as shown in Fig. 9.

The overall uncertainty S is obtained by a quadratic combination of systematic and random uncertainties.
The limit of -33% and +50% at 95% confidence level is respected if :
$1.96\,|S| < 0.5\ (0.33+0.50)$ $\qquad S<0.21$

It is convenient to separate the uncertainty related to energy and angular response by the remaining uncertainty sources.

$$\sqrt{S_R^2 + S_0^2 + S_{E,\phi}^2} \leq 0.21$$

S_R = total random uncertainty
S_0 = total systematic uncertainty evaluated at normal incidence (0°)
$S_{E,\phi}$ = resultant uncertainty related to the energy and angular response

In the case of :

$S_R = 0.1$ and $S_0 = 0.1$

we have :

$S_{E,\phi} = 0.16$

So the corrisponding allowable limits for the combined uncertainties related to energy and angular response will be :

$\pm 1.96 \ S_{E,\phi} = \pm 0.31$

Main sources of systematic uncertainties

- Energy and Angular Response
- Non-linearity of response
- Fading
- Calibration errors
- Response to other types of radiations (i.e. beta)
- Effects from exposure to light

Main sources of random uncertainties

- Differences among detector sensitivities
- Fluctuations of working conditions of the instruments used for reading the dosimeters.

REQUIREMENTS FOR ENERGY AND ANGULAR RESPONSES

These two characteristics are correlated and are frequently the main sources of error of personal dosimeters. To obtain a single source of uncertainty related to these two parameters the following procedure is considered satisfatory.

For each energy it should be determined the directional responses of the dosimeter at 0°, 20°, 40° and 60° angles of incident radiation. Only the mean value R(E) of these responses can be taken into account, considering that some kind of similar average over different angles of incident radiation will occur in practice.

$$R(E) = (R_{E,0} + R_{E,20} + R_{E,40} + R_{E,60}) / 4$$

with $R_{E,\varnothing} = (H_{E,\varnothing})_M / (H_{E,\varnothing})_T$

$(H_{E,\varnothing})_M$ = measured dose value

$(H_{E,\varnothing})_T$ = conventionally true value

The uncertainty related to the angular response at energy E may be taken equal to $| 1 - R(E) |$

To have an acceptable energy and angular response, the following condition for <u>all range</u> of interested energies E should be fulfilled:

$$| 1 - R(E) | \leq 1.96\, S_{E,\phi}$$

If $S_R = 0.1$ and $S_0 = 0.1$, then it is required :

$$| 1 - R(E) | \leq \pm 0.31$$

DOSIMETRIC TECHNIQUES FOR INDIVIDUAL MONITORING

Thermoluminescence (TL) detectors

Electrons and holes are trapped in irradiated TL detectors, that emit light under thermal stimulation.
After the readout, the dosimetric information is loosed.
Advantage : detectors nearly tissue-equivalent
Such detectors, placed under an appropriate flat absorber equivalent to 10 mm of tissue, will constitute a dosimeter having an energy and angular response in terms of Hp(10) close to the ideal. For example the energy response of LiF-in-teflon detector shielded with 700 $mgcm^{-2}$ of plastic is flat within ±15% from 40 keV to 1.25 MeV
For measurement of Hp(0.07) from beta radiation, the main deficiency is that the sensing element is too thick.
Minimun detectable Hp(10) depends on TL detector and TLD reader and ranges from 0.02 mSv to 0.001 mSv.

Phographic films

After irradiation with ionizing radiations and chemical development, the optical density of a film is a function of the absorbed dose.
This type of detector provide a convenient permanent record.
Photographic films are far from tissue equivalent (at low energies, around 40 keV, 20-50 times more sensitive than at 300 keV), and one or more filters(Cu,Sn,Pb etc.) are required to improve their energy response.
By combining the optical densities under several filters, a energy response within ± 20% in terms of Hp(10) (for normal incidence) may be obtained from 15 keV to 1.25 MeV.
However it is rather difficult to ensure the correct energy response for different angles of incidence of the radiation, particularly for low-energy photons, and the directional response depends strongly on the filters used. Using 4 different filters a constant energy response ±38 % from 0° to 60° has been obtained.
Minimun detectable Hp(10) is in the range 0.1 mSv to 0.2 mSv.

Photoluminescent (PL) detectors

Rods or discs of silver-activated glasses containing phosphates of elements such as Al,Li,K and Ba.
Stable color centers are created in irradiated PL detectors, that fluoresce under UV stimulation.
The dosimetric information is maintained after the readout of the PL detector.
The detectors may be annealed by thermal treatment at about 400 °C.
The energy response in terms of Hp(10) depends on the atomic number of elements in the glass.
"Low-Z" glasses are 3.6 times more sensitive at 50 keV than to 1.25 MeV and must be corrected by appropriate filters.
A flat energy response within ± 15% from 12 keV to 660 keV in terms of Hp(10) may be obtained using appropriate filters (compensated dosimeter).
The directional response depends on geometry and dimension of PL detectors ; with a thin, flat detector may be obtained a directional response within ±35% for incidence up to 60° and energies above 12 keV.
Minimun detectable Hp(10) around 0.4 mSv.

Ionization chambers

Small cylindrical, plastic-walled ionization chambers, frequently equipped of a quarz fibre electrometer (pensil chambers) have normally a photon energy response around ±15 % in terms of exposure from about 40 keV to 1.25 MeV.
The energy response in terms of Hp(10) of such a dosimeter worn on the trunk differs from the unity by about the same amount.
However these dosimeters, worn with their axis parallel to the body surface, do not have the correct angular response for measuring Hp(10) (error increases as energy decreases)

Semiconductor detectors

Si diodes, used in direct-current mode, need the use of approriates filters to have an accepatble (± 30%) energy response in terms of Hp(10) for photons from about 50 keV to 1.25 MeV.
The directional response of such a dosimeter is more critical and it will depend strictly on the thickness and geometry of the filters.

Referencss

1) ICRP Pubblication N. 26 (1977) - " Recommendation of the International Commission on Radiological Protection"

2) ICRP Pubblication N. 35 (1982) - " General Principle of Monitoring for Radiation Protection of Workers"

3) ICRP Pubblication N. 51 (1987) - " Data for Use in Protection against External Radiation"

4) ICRP Pubblication N. 60 (1990) - " 1990 Recommendations of the International Commission on Radiological Protection"

5) ICRU Report N. 39 (1985) - " Determination of Dose Equivalents resulting from External Radiation Sources"

6) ICRU Report N. 40 (1986) - " The Quality Factor in Radiation Protection "

7) ICRU Report N. 43 (1988) - " Determination of Dose Equivalents from External Radiation Sources " Part 2

8) ICRU Report N. 47 (1992) - " Measurement of Dose Equivalents from External Photon and Electron Radiations "

9) EUR 5287 - Commission of the Europena Communities (1991) - " Technical Recommendation for Monitoring Individuals Occupationally Exposed to External radiation "

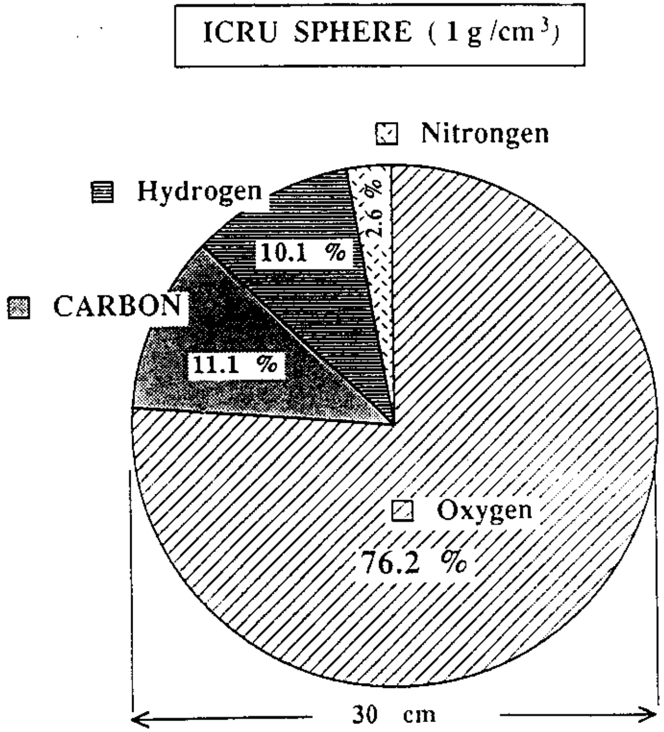


Fig. 1

CONDITION FOR CALIBRATION IN TERMS OF

INDINVIDUAL DOSE EQUIVALENT

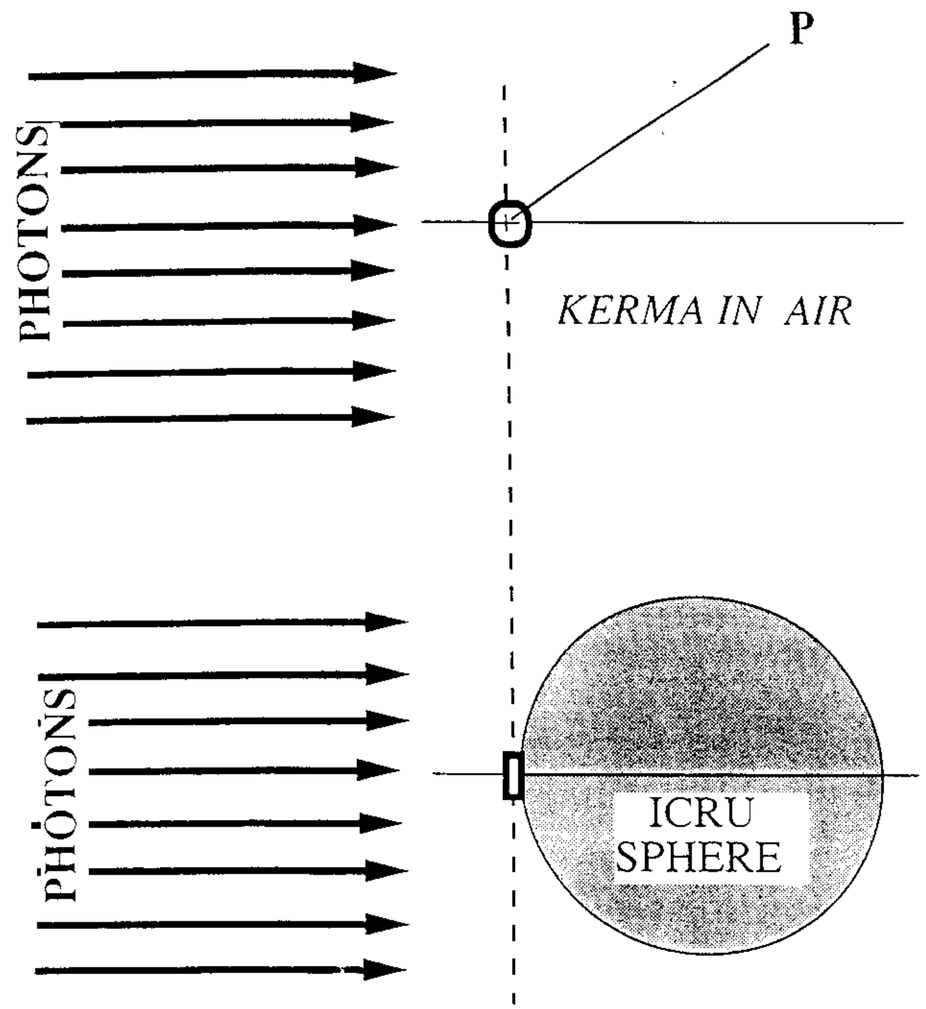
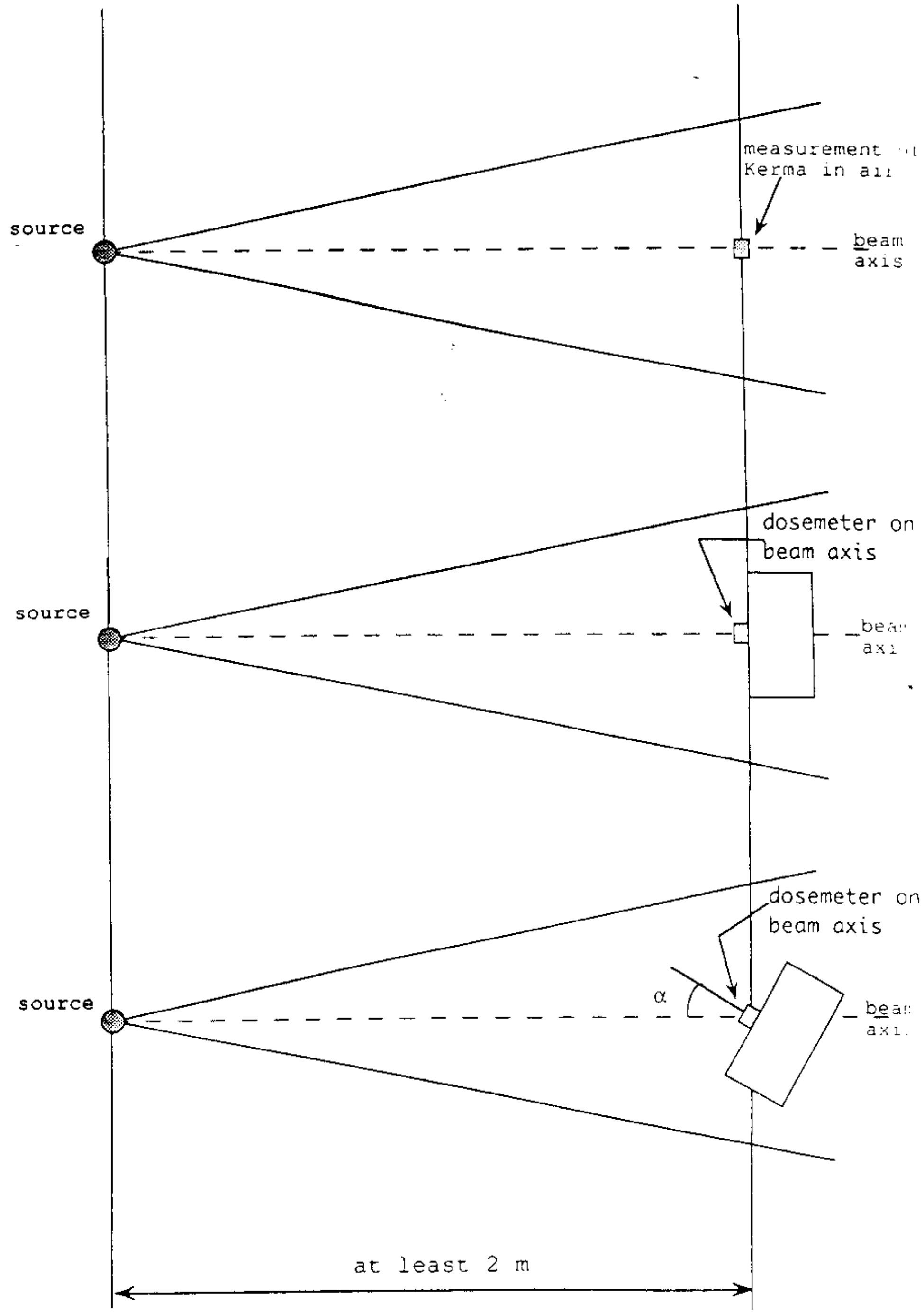
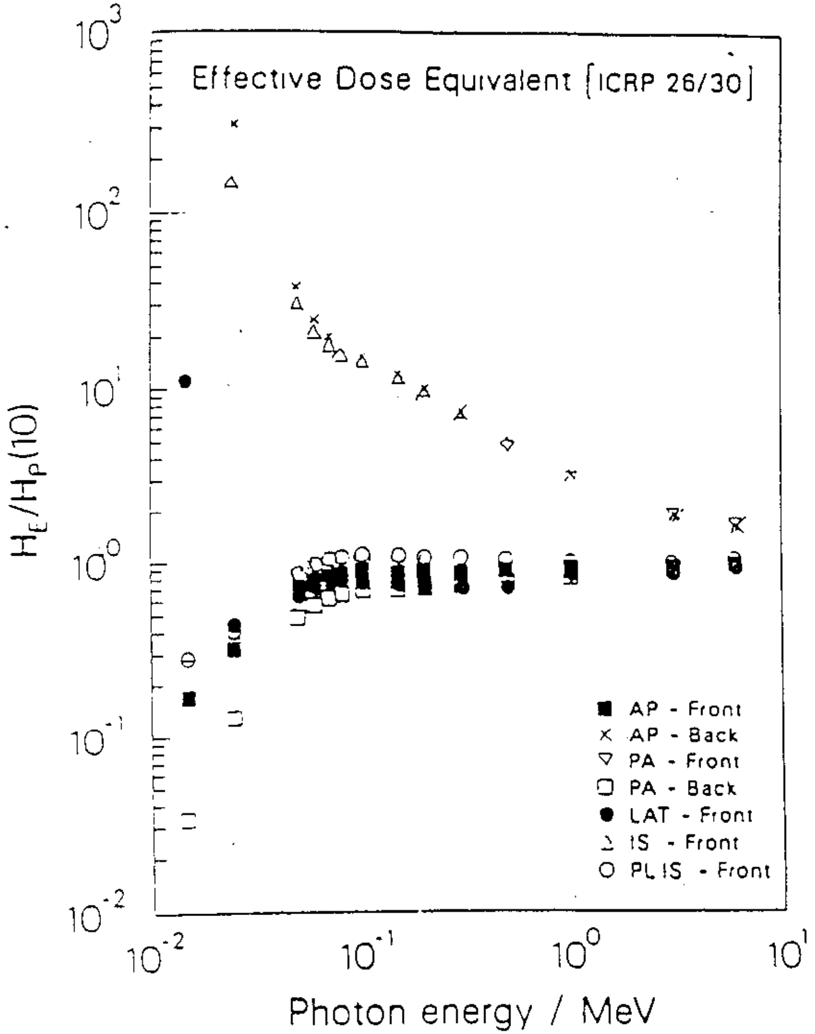


Fig. 2



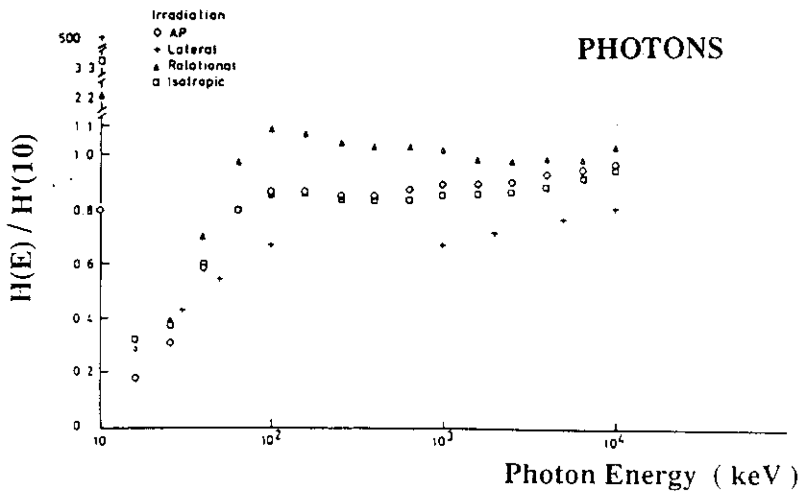
CALIBRATION CONDITIONS OF A PERSONNEL DOSIMETER

Fig. 3

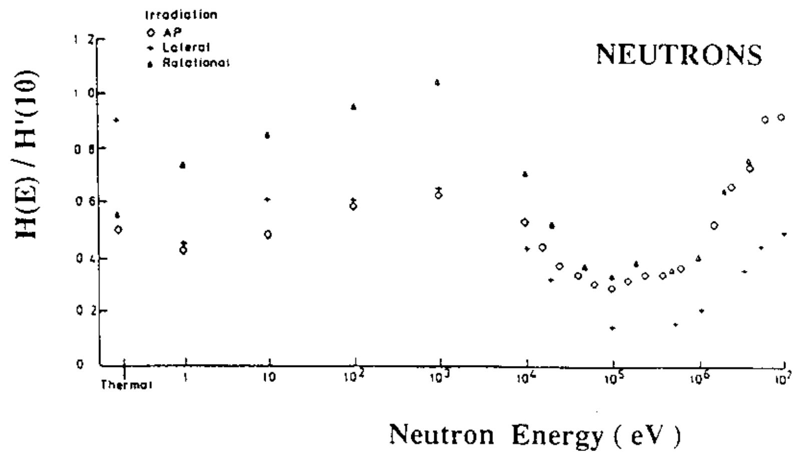


Ratio between Effective Dose Equivalent $\underline{H}(E)$ and Individual Dose Equivalent $\underline{H}_p(10)$ for various irradiation geometry and for two locations of the dosimeter , front and back of the body.

Fig. 4

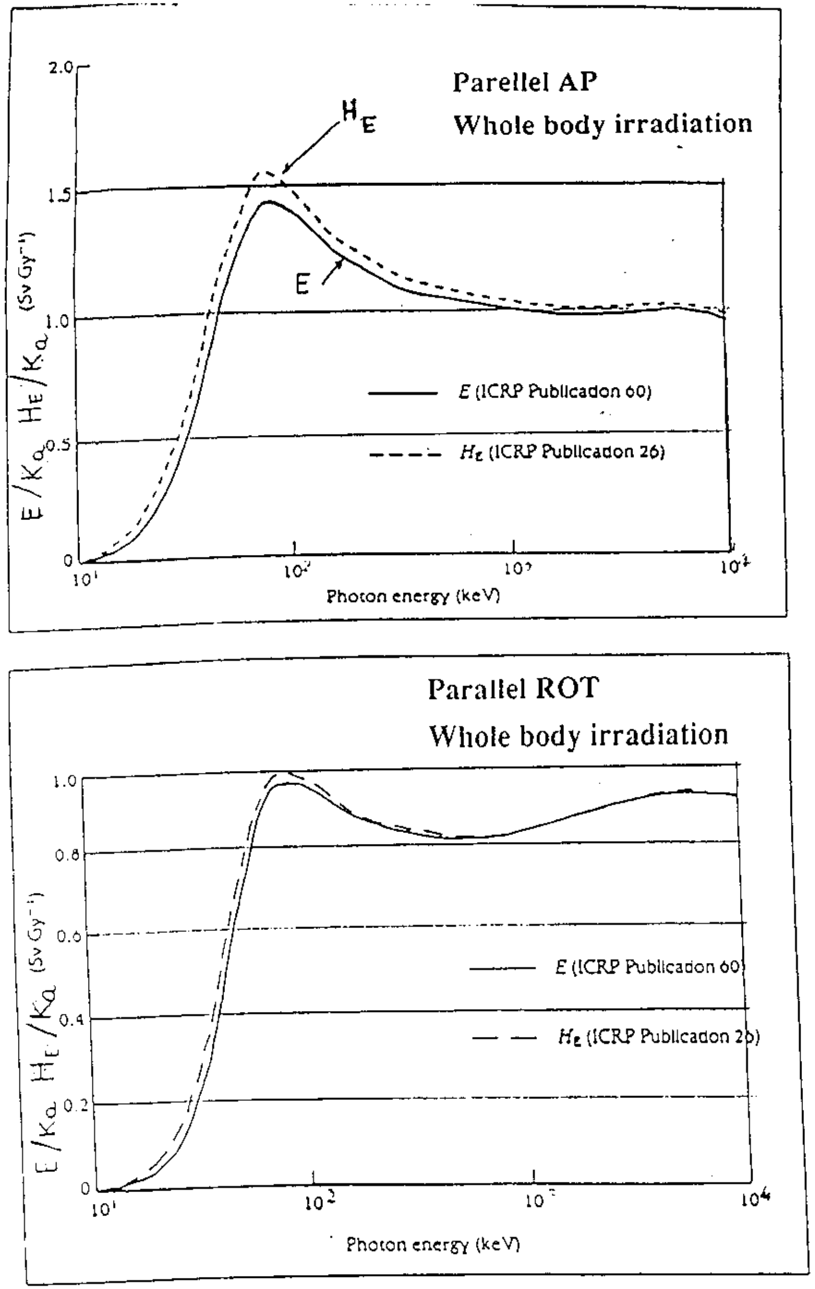


Ratio of H(E) / H'(10) versus photon energy for various irradiation geometries



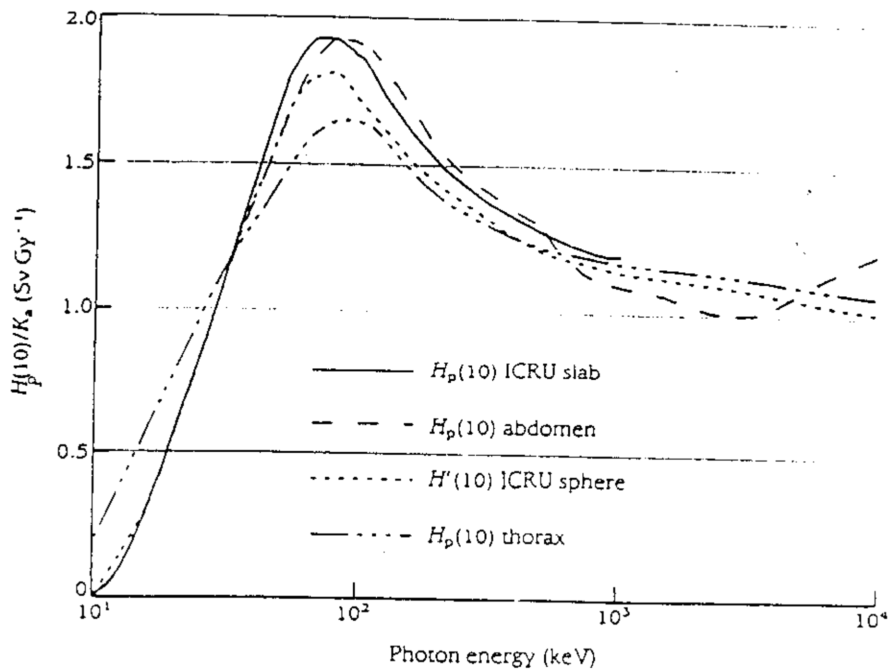
Ratio of H(E) / H'(10) versus neutron energy for various irradiation geometries

Fig. 5



Relation between EFFECTIVE DOSE EQUIVALENT $\underline{H_E}$ (ICRP26) and EFFECTIVE DOSE E (ICRP60) normalised to air kerma

Fig. 6



Conversion coefficients between air kerma and individual dose equivalent Hp(10) in the AP irradiation geometry (for ICRU sphere, ICRU slab 30x30x15 cm and anthropomoriphic phantom)

Fig. 7

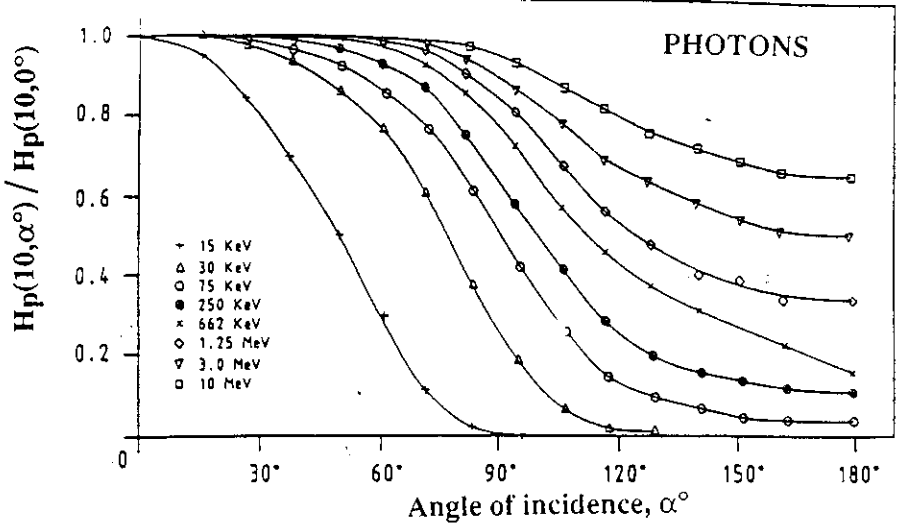
Conversion coefficients-Sv/Gy(Kair) for the ISO phantom (tissue equivalent material 30x30x15 cm) for ISO reference radiations.

Mean Energy keV	$H_p(10,\alpha)$ $\alpha = 0°$	$\alpha = 20°$	$\alpha = 40°$	$\alpha = 60°$	$H_p(0.07,\alpha)$ $\alpha = 0°$	$\alpha = 20°$	$\alpha = 40°$	$\alpha = 60°$
9.88	--	--	--	--	0.951	0.946	0.941	0.919
17.4	0.449	0.420	0.342	0.184	1.01	1.01	1.00	0.987
23.1	0.778	0.757	0.678	0.484	1.09	1.08	1.08	1.06
25.2	0.879	0.861	0.782	0.583	1.12	1.12	1.11	1.09
30.9	1.15	1.13	1.04	0.830	1.25	1.24	1.22	1.17
33	1.22	1.20	1.10	0.89	1.29	1.28	1.26	1.23
48	1.68	1.64	1.53	1.26	1.57	1.56	1.52	1.42
65	1.89	1.86	1.74	1.46	1.72	1.71	1.66	1.54
83	1.87	1.85	1.74	1.48	1.71	1.71	1.66	1.56
100	1.80	1.78	1.69	1.45	1.67	1.65	1.62	1.53
118	1.72	1.71	1.63	1.41	1.61	1.60	1.58	1.50
161	1.57	1.55	1.49	1.34	1.49	1.49	1.48	1.43
205	1.48	1.47	1.42	1.30	1.42	1.42	1.41	1.39
248	1.42	1.42	1.38	1.27	1.37	1.38	1.37	1.36
662	1.21	1.21	1.20	1.20	1.21	1.21	1.22	1.23
1250	1.15	1.15	1.15	1.15	1.15	1.15	1.16	1.20

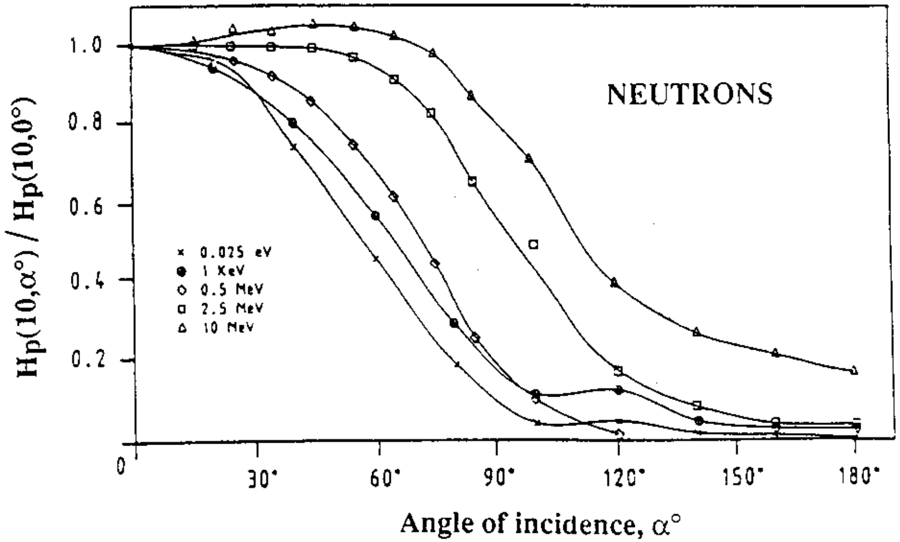
Conversion coefficients-Sv/Gy(Kair) for the ICRU sphere (tissue equivalent material 30x30x15 cm) for ISO reference radiations.

Mean Energy keV	$H'(10,\alpha)$ $\alpha = 0°$	$\alpha = 20°$	$\alpha = 40°$	$\alpha = 60°$	$H'(0.07,\alpha)$ $\alpha = 0°$	$\alpha = 20°$	$\alpha = 40°$	$\alpha = 60°$
9.88	--	--	--	--	0.93	0.92	0.90	0.87
17.4	0.45	0.43	0.34	0.21	0.99	1.00	0.99	0.97
23.1	0.78	0.77	0.69	0.53	1.07	1.08	1.07	1.04
25.2	0.89	0.87	0.80	0.64	1.11	1.11	1.10	1.08
30.9	1.13	1.09	1.03	0.88	1.21	1.21	1.19	1.16
33	1.18	1.14	1.08	0.93	1.24	1.24	1.22	1.19
48	1.56	1.53	1.46	1.28	1.47	1.45	1.42	1.39
65	1.74	1.70	1.63	1.46	1.59	1.56	1.53	1.50
83	1.71	1.67	1.62	1.47	1.58	1.57	1.54	1.51
100	1.64	1.62	1.57	1.44	1.55	1.54	1.52	1.49
118	1.58	1.55	1.52	1.41	1.50	1.49	1.47	1.46
161	1.44	1.43	1.42	1.33	1.39	1.39	1.39	1.40
205	1.37	1.36	1.35	1.29	1.34	1.34	1.35	1.36
248	1.34	1.32	1.31	1.26	1.31	1.31	1.32	1.34
662	1.18	1.19	1.18	1.17	1.19	1.19	1.20	1.23
1250	1.14	1.14	1.13	1.13	1.16	1.16	1.18	1.20

Tab. 1

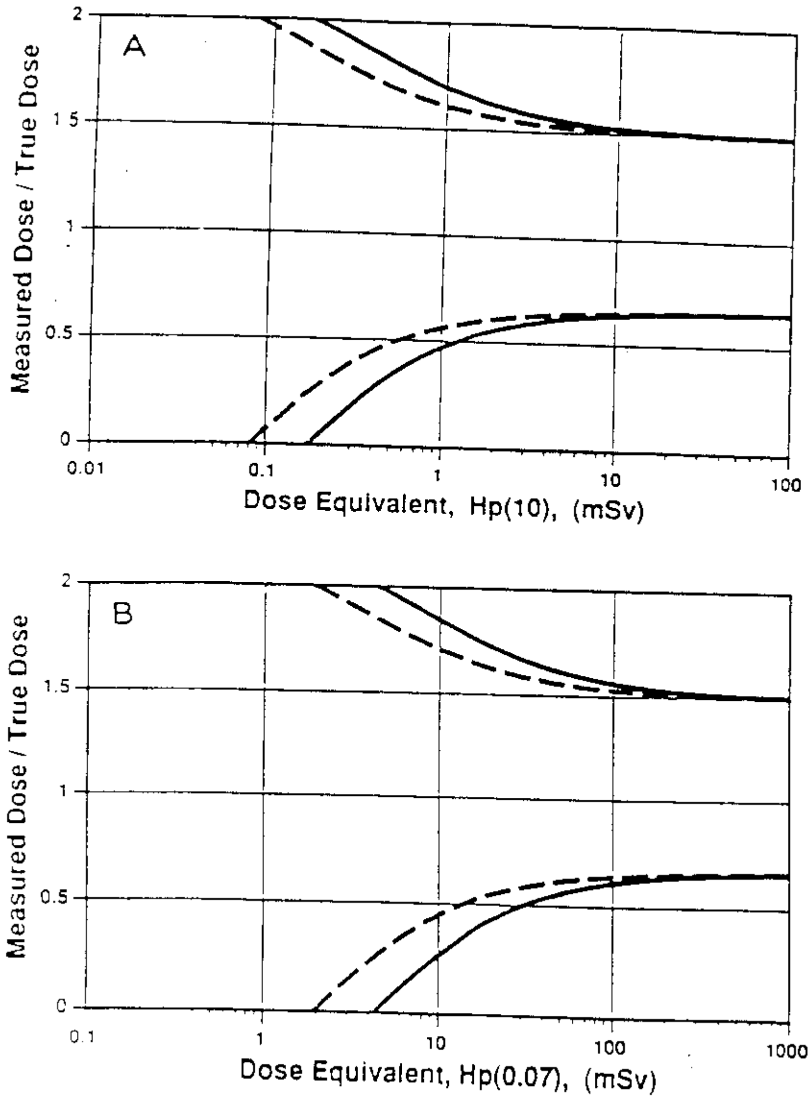


Ratio of $H_p(10,\alpha°)$ to $H_p(10,0°)$ against angle of photon radiation incidence



Ratio of $H_p(10,\alpha°)$ to $H_p(10,0°)$ against angle of neutron radiation incidence

Fig. 8



Allowable upper and lower limits for the ratio:
Measured dose/Conventional true dose as a function of dose level.
A. Limits for $H_p(10)$; B. Limits for $H_p(0.07)$
Full lines monthly monitoring periodes
Broken lines: bi-weekly monitoring periods.

Fig. 9

APPENDIX

Ionizing Radiation Quantities

Absorbed Dose (D) Gray

Energy absorbed per unit of mass

$$D = \frac{d\bar{\varepsilon}}{dm}$$

d $\bar{\varepsilon}$ = average energy imparted by ionising radiations to the matter in a volum element

d **m** = mass of the matter in this volume

EQUIVALENT DOSE (H_T) Sievert

Absorbed dose averaged over a tissue or organ **T**, weighted for the type and energy of the radiation **R** incident on the body

$$H_{T,R} = w_R D_{T,R}$$

w_R = radiation weighting factor

$D_{T,R}$ = average absorbed dose from radiation R in the tissue or organ T

When the radiation field is composed of types and energies with different values of w_R, the absorbed dose must be subdivided in blocks for each value of w_R, and then summed to obtain the total equivalent dose :

$$H_T = \sum_R w_R D_{T,R}$$

EFFECTIVE DOSE (E) Sievert

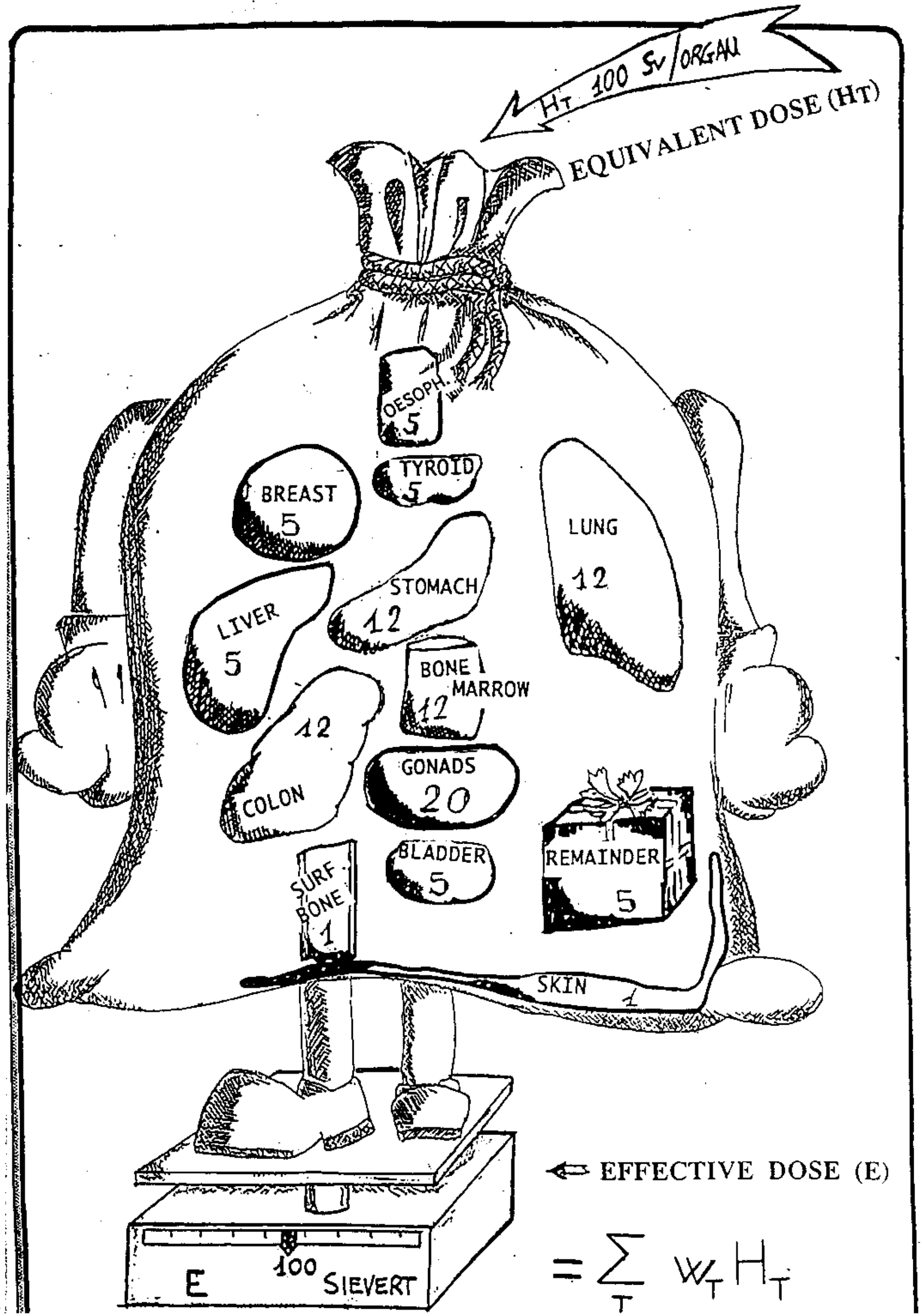
Effective dose E is the sum of the weighted equivalent doses $\mathbf{H_T}$ in all the tissues and organs of the body, produced by internal and external irradiations.

$$E = \sum_T w_T H_T$$

w_T = weighting factor for the organ or tissue T
H_T = equivalent dose in tissue or organ T

$$E = \sum_T w_T \sum_R w_R D_{T,R}$$

N.B. A <u>uniform</u> Equivalent Dose over the whole body gives an Effective Dose <u>numerically equal</u> to the value of that uniform Equivalent Dose



DOSE EQUIVALENT (H) Sievert
ICRP 26 (1977)

Absorbed dose at a point in the organ or tissue **T**, multiplied by a quality factor **Q** related to the type and energy of the radiation field in the interested point and by others factors **N** which could modify the potentially harmful effects of a given absorbed dose.

$$H = D\,Q\,N$$

The quality factor **Q** ranges from 1 for photon and beta radiation to 10 for neutrons and 20 for alpha radiation

OPERATIONAL QUANTITIES

Area Monitoring

Ambient Dose Equivalent H*(d)
at a point (*for penetrating radiation*)

H*(d) at a point in a radiation field is the dose equivalent that would be produced by the corresponding expanded and aligned field in the ICRU sphere at a depth d, on the radius opposing the direction of the aligned field.

For strongly penetrating radiation a depth of 10 mm is frequently employed. For weakly penetrating radiation, a depth of 0.07 mm for the skin and 3 mm for the eye are employed.

Directional dose equivalent H'(d,α)
at a point ***(for weakly pen. radiations)***

H'(d,α) at a point is the dose equivalent that would be produced by the corresponding expanded field in the ICRU sphere at a depth d, on a radius in a specified direction α .

For weakly penetrating radiation d= 0.07 mm (skin);3 mm (eye)
For strongly penetrating radiation 10 mm

Individual Monitoring

Personal dose equivalent Hp(d)

Hp(d) is the dose equivalent in soft tissue below a specified point on the body at an appropriate depth d (mm)

Hp(10) = strongly penetrating radiation

Hp(0.07)=weakly penetrating radiation, skin

Hp (3) = weakly penetrating radiation, eye

The calibration of the dosimeter is generally performed under simplified conditions on an appropriate phantom.

COMMITTED TISSUE EQUIV. DOSE $H_T(\tau)$ (Sievert)

For a single intake of activity at time t_o:

$$H_T(\tau) = \int_{t_o}^{t_o+\tau} \dot{H}_T(\tau)\, dt$$

$\dot{H}_T(\tau)$ = relevant equivalent dose rate in a organ or tissue T at time **t**

t_o = time of intake

τ = time period over which the integration is performed

In specifying $H_T(\tau)$ τ is given in years .

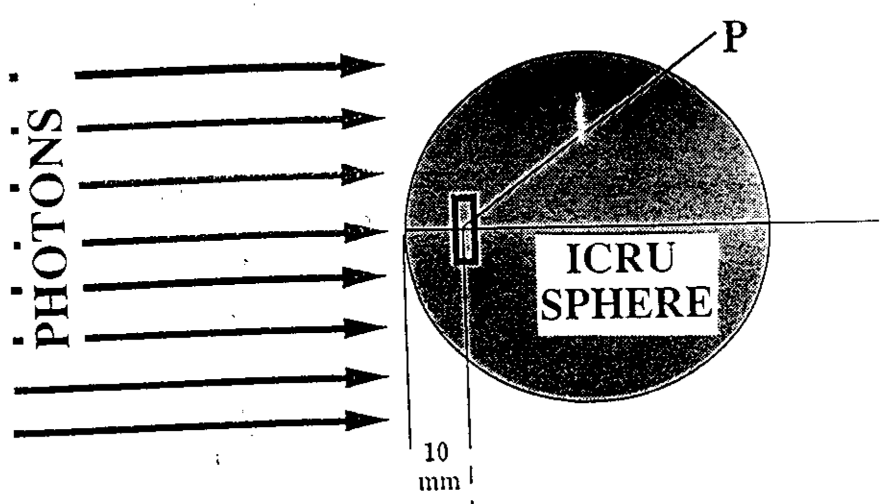
When the period τ of integration is not given, a period of 50 years is implied for adultus or a period of 70 years for children

COMMITTED EFFECTIVE DOSE $E(\tau)$ (Sievert)

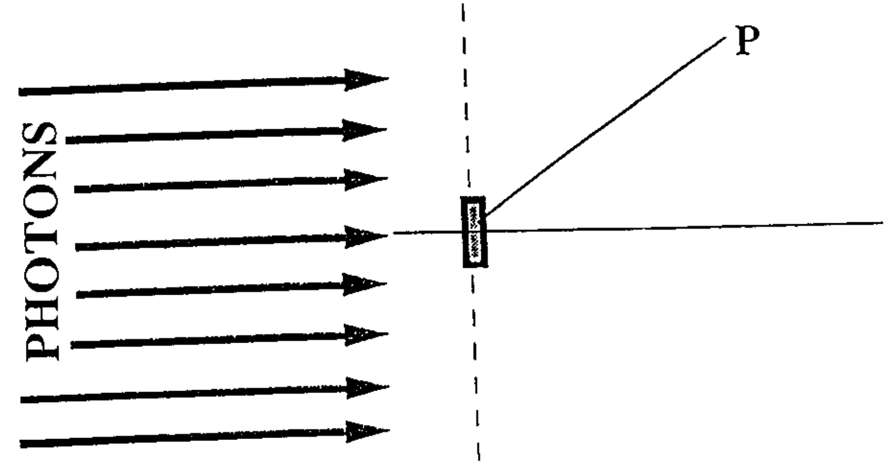
$$E_{(\tau)} = \sum_T w_T H_{T(\tau)}$$

(τ) numbers of years over which the integration is made

AMBIENT DOSE EQUIVALENT



AIR KERMA



DIRECTIONAL DOSE EQUIVALENT
(Photons E< ≈15 keV Electrons E< ≈ 2.5 MeV)