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NEW TRENDS IN RADIATION PROTECTION DOSIMETRY *

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Introduction

Radiation protection dosimetry is without any doubt the branch of dosimetry where the most imponent changes have been introduced during these last few years. Therefore only developments in this field will be examined here.

The problem of operational quantities for external exposure

As it is well known the ICRP recommended in its Publication 26 (1) a system of dose limitations in which primary limits are defined in terms of:

i) dose equivalent to organs and tissues in order to prevent non-stocastic risks;

ii) effective dose equivalent to prevent stocastic risks.

The effective dose equivalent H_E is a weigthed sum of dose equivalent H_T in a number of given tissues and organs:

$$H_E = \Sigma_T \; w_T \; H_T \qquad 1.$$

where w_T is a weigth factor related to the tissue or organ T, obtained on the basis of radiological risk estimates. The recommended values of weigth factors w_T are listed in Table 1.

Table 1. - Recommended value of w_T.

Tissue	wT
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

Because both dose equivalent to various organs and effective dose equivalent are unmeasurable, secondary limits are also recommended for operational quantities. In the same publication 26 in case of external exposure the secondary limits refer to deep and shallow dose equivalent index.

We shortly remind that shallow dose equivalent index represents the maximum of dose equivalent in the first 1 cm shell of the ICRU sphere excluding the surface layer of 0.07 mm thickness, whereas the maximum in a 14 cm diameter core is called deep dose equivalent index. Dose equivalent index is the greatest of the two values (2).

These two quantities, however, were soon recognized as inadequate as some of their characteristics were found to be unacceptable from a metrological point of view.

In a first time, the angular anisotropy of these quantities was pointed out, in contrast with the "isotropy" of instrument response. In fact, while an instrument calibrated in an unidirectional radiation field will still give the same response, for the same fluence, even when exposed in an isotropic field (apart from differences not relevant here), the maximum dose equivalent in the ICRU sphere will be different in either case.

Later, a further disadvantage of dose equivalent index was noticed: its non-additivity with respect to the components of the radiation field in angle, in energy and time (3).

The consequences of this latter aspect are obviously unacceptable in radiation protection. For instance integral measurements performed over the same period could give different results depending on the reading frequency.

Undoubtedly shallow and deep dose equivalent index are conceptually inadequate quantities , although the proponent International Organizations (ICRU and ICRP) where never willing to admit it.

Thus, during these last years, a great number of studies have been carried out in order to determine new and more adequate operational quantities, generally on the basis of calculation codes of ever increasing sophistication.

The ICRU proposal

The ICRU proposed in its Report 39 (4) four new operational quantities for external exposure:

i) "Ambient dose equivalent", $H^*(d)$, and "Directional dose equivalent", $H'(d)$, for environmental monitoring;

ii) "Individual dose equivalent, penetrating", $H_p(d)$, and "Individual dose equivalent, superficial", $H_s(d)$, for personnel monitoring.

In either case two quantities are considered, one of which is appropriate for strong penetrating radiation and the other one for weakly penetrating radiation.

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

It is worth specifying that in the "expanded field" the fluence and its angular and energy distribution have the same values throughout the volume of interest as in the actual field at the point of reference. In the "aligned and expanded" field the fluence and its energy distribution are the same as in the expanded field but the fluence is unidirectional.

The depth recommended by ICRU for monitoring in terms of ambient dose equivalent is 10 mm.

In short, one shall measure the dose at 10 mm depth in the ICRU sphere exposed to the aligned and expanded field as above specified and not rather to the actual field.

Likewise the directional dose equivalent at a point in a radiation field 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 specific direction. The depth recommended by ICRU for monitoring in terms of H'(d) is 0.07 mm, corresponding to the thickness of the skin dead layer.

The quantities recommended for individual monitoring, $H_p(d)$ and $H_p(s)$, represent the dose equivalent in soft tissue below a specified point on the body, at depths appropriate for strongly and weakly penetrating radiation, respectively. The recommended depths are also in this case 10 mm and 0.07 mm.

This complicated solution to the problem of operational quantities is likely to present one advantage only: they are defined taking into account the characteristics of existing instruments. This should allow to apply them easily in practice.

However, it must be noted that ICRU has defined the new quantities in order to "supplement" and not to "replace" the index thus refusing to recognize their conceptual inadequacy. Therefore, index are still belonging to the large family of quantities that could be used at present in radiation protection.

It should be also remembered that the solution proposed for environmental monitoring is an elaboration of an analogous IEC proposal (5) which was proved effective for beta and gamma rays of energy up to 4 MeV with the exception of high energy beta rays.

Moreover the use of ambient dose equivalent produces unacceptable overestimates of effective dose equivalent in quasi-isotropic fields. ICRU itself recognizes that in this case more complex measurements will be needed.

Limitations of applicability may also be pointed out concerning personnel neutron dosimetry in the range of medium energies, where the recommended quantities will sometimes underestimate effective dose equivalent by a factor 3 or 4. It must be admitted, however that in such energy range the lack of appropriate detectors constitutes a problem by far more warrying than that of the quantities to be used.

Those interested are suggested to consult directly the ICRU Report for a more complete discussion of the new quantities and of their limitations.

ICRP did not yet officially express an opinion about this matter. The new quantities seem anyway to be compatible with the recommended dose limitation system despite the insufficiencies discussed above.

In fact, if a comparison is made between the ICRU quantities and the equivalent dose index in various experimental conditions we find that, limited to photons and neutrons of energy up to 20 MeV, incident unidirectionally and isotropically onto the ICRU sphere, the ratio of $H_{I,d}$ to H*(10) is very close to 1. Some differences are observed between $H_{I,s}$ and H' (0.07) but only at low energies (below 10 keV).

The same conclusion can be drawn from a direct comparison of H*(10) with the effective dose equivalent. In the same cases reported above H*(10) gives a conservative estimate of H_E, with some exceptions at low energies, where H' (0.07) becomes relevant.

Moreover, it must be observed that, following the ICRP recommendations (6), individual monitoring is not required for workers in Working Condition B (recommended limit 15 mSv/year), while when the limits are exceeded, the appropriate quantity remains the absorbed dose (7). It is evident that the range of utilization of the new quantities appears to be narrow indeed.

Operational problems

We find now convenient, as an example, to mention the operational problems concerning the measurement of ambient dose equivalent, the quantity best studied at present.

In order to calibrate the instrument the conversion coefficients between measurable physical quantities (exposure, air kerma, fluence etc.) and the new quantity have to be known. The response of the chosen instrument should comply with the conversion curve, usually calculated by Monte Carlo methods.

Once a set of standard conversion coefficients is adopted, a detector will be selected along with various absorber and scattering materials in order to tailor the instruments to the desired response.

Fig. 1 shows the curve of conversion coefficients from air kerma to ambient dose equivalent for beta and gamma rays.

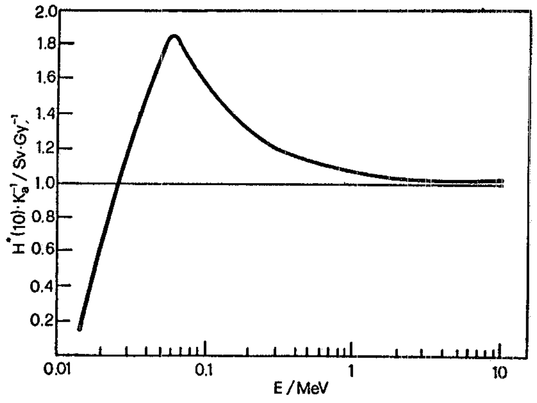

Fig. 1. - Provisional conversion coefficients from Air kerma to Ambient dose equivalent (adapted by 11).

Most existing instruments can easily be adapted to measure of the new quantity and only small modifications will be necessary. Some of them may be adequate after appropriate scale and range change alterations.

A typical example can be drawn from a paper presented at the last IRPA Conference (8) where conversion of a GM tube to measure dose at 10 mm depth in the ICRU sphere is discussed. The energy response of this detector with respect to that quantity is shown in fig. 2, curve a.

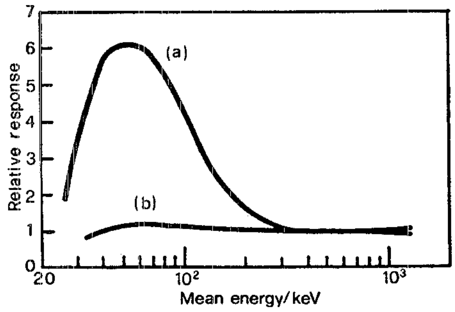

Fig. 2. - Energy dependence of response of a GM tube ZP 1310: a) without any filters; b) with the filter described in the text (adapted by 8).

To flatten down the curve, the authors investigated various combinations of different materials. They concluded that the best absorber should be of a mixture of Sn-CeO_2 and Gd_2O_3 (lanthanide elements) powders with mass ratios for the metals of 1 :3 :3. From this mixture a small cylindrical hull divided into two equal parts was prepared by adding plastic glue to the powders. Between the two parts of the hull various PMMA rings of different thicknesses could be inserted. By the filter arrangement shown in fig.3 the detector response changes as shown in fig. 2 curve b.

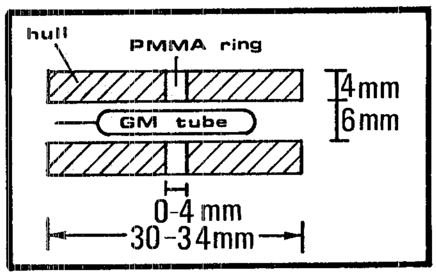

Fig. 3. - Arrangement of GM Tube ZP 1310 for measurement of dose at 10 mm depth (adapted by 8).

Regarding neutrons, provisional conversion coefficients between neutron fluence and ambient dose equivalent as a function of neutron energy are given in fig. 4. Some values are also reported in Table 2. Note that at 1 keV the new conversion coefficient is lower by nearly a factor of two with respect to the corresponding ICRP 21 factor (9), while for neutron energies above 10 keV the new factors are about 20% higher.

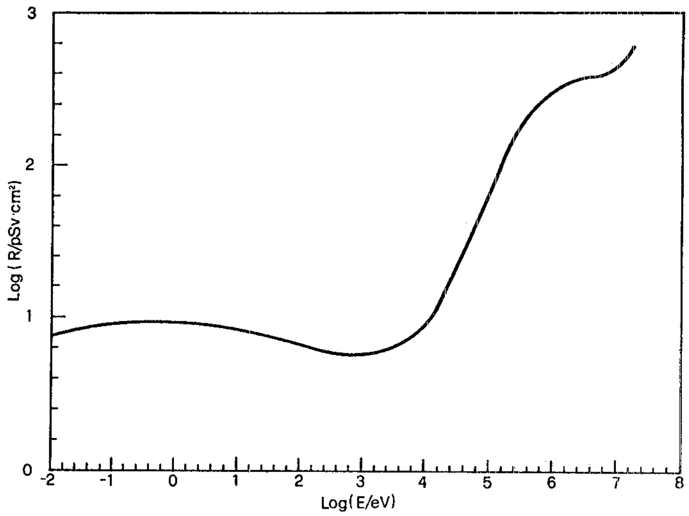

Fig. 4. - Ambient dose equivalent per neutron fluence as function of neutron energy (adapted by 11).

Table 2. - Ambient dose equivalent per unit neutron fluence.

Neutron energy (eV)	Conversion Coefficients (pSv cm2)
2.5×10^{-2} (Thermal)	8.28
1	9.56
10	8.52
100	6.78
10^3	5.65
10^4	9.05
10^5	66.50
5×10^5	237.298
10^6	314.02
2×10^6	364.02
5×10^6	392.184
10^7	447.87
2×10^7	588.81

However, the values reported above must be scaled down by a factor of 2 due to the recent ICRP decision (10) to increase by a factor 2 the neutron quality factor throughout the whole energy spectrum.

In practice procedures will be substantially the same as in the past. As a matter of fact, the problems in neutron dosimetry have always been solved empirically. The Andersson-Braun rem-counter is a typical example.

The neutron energy response in terms of H* (10) of one of the most known rem-counter, the Studsvik 2202 D, is shown in fig. 5. Overestimates at energies near 1 keV can be noticed. Indeed, they are not very different from those occurring at present using the same instrument for dose equivalent measurements.

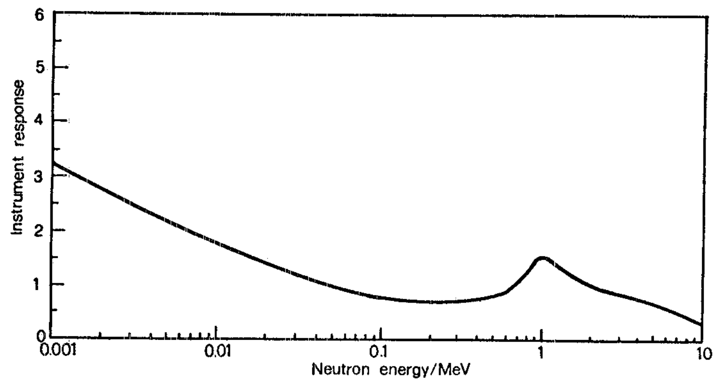

Fig. 5. - Response of a commercial rem-counter (Studsvik 2002D) in terms of ambient dose equivalent to the various energies (adapted by 11).

Although new equipment design would be required for ambient dose equivalent determination, the Studsvik 2002 D already can be used for operational measurements of the new quantity.

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