IS THE DOSE EQUIVALENT INDEX A QUANTITY TO BE MEASURED?

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PRIMARY RADIATION PROTECTION QUANTITIES

EFFECTIVE DOSE EQUIVALENT

With its Publication 26 /1/, ICRP limited the risk of stochastic radiation effects in man by setting a limit to the annual effective dose equivalent

$$H_e = \Sigma\, w_j H_j \qquad (1)$$

which is a weighted (w_j) sum of average dose equivalents H_j in particular tissues. Of course, H_e cannot be determined by routine radiation protection measurements, the chief obstacle being the intricate geometrical shape and the intrinsic structure of the human body as well as the necessity to determine dose equivalent distributions in many tissues. Yet it should be emphasized that H_e is unequivocally defined by eq. (1) in any radiation environment irrespective of its variation with time or of the movement of the exposed person.

SECONDARY OR OPERATIONAL RADIATION PROTECTION QUANTITIES

DOSE EQUIVALENT INDEX

Hence, for practical measurements operational quantities must be introduced which approximate H_e. If such an operational quantity is to be applicable to whole body irradiation by all kinds of ionizing radiations it must be defined in an anthropomorphous phantom, simulating the trunk of the human body, as e.g. in a neutron field secondary radiations originating in the irradiated person contribute substantially to H_e. A simple phantom sufficiently anthropomorphous for radiation protection in many situations of external irradiation is the 30 cm diameter sphere composed of soft tissue as introduced by ICRU /2/. The definition of the maximum dose equivalent in this sphere as a possibly operational quantity, which is termed dose equivalent index H_I, was then obvious.

Eventually, ICRP /1/ took up this idea and stated that with external exposure to penetrating radiation the limitation of the deep dose equivalent index $H_{I,d}$ i.e. the maximum dose equivalent in the inner 28 cm diameter core of the sphere /3/, would afford at least as good a level of protection as the limitation of H_e. For simplicity's sake, only the unrestricted dose equivalent index H_I as introduced above will be considered in the following.

EFFECT OF IRRADIATION HISTORY

Whereas the introduction of the dose equivalent index certainly simplifies calculations in a given stationary radiation field, ambiguity arises when the dose equivalent to a moving person is to be estimated, as the 30 cm sphere has no inherent coordinate system and hence cannot be oriented in space. Likewise, when the radiation field varies with time with the spere remaining fixed, the dose equivalent index H_I is generally not the time integral of the dose equivalent index rate $\dot{H}_I$,

$$H_I \leq \int_0^T \dot{H}_I(t)dt \tag{2}$$

as the location of the dose equivalent rate maximum in the sphere may vary with time:

- H_I is non-additive with respect to its components in time.

EFFECT OF IRRADIATION GEOMETRY

This peculiarity of the dose equivalent index also shows up in the superposition of various angular components. Let $d\vec{\Omega}(d\Phi/d\Omega)$ be the differential fluence of incident particles with directions whithin the solid angle element $d\vec{\Omega}$. Then the corresponding differential maximum dose equivalent will be $d\hat{H} = d\vec{\Omega}(d\hat{H}/d\Phi)/(d\Phi/d\Omega)$. As the maxima produced by various angular components may occur at different locations within the sphere, the relation

$$H_I \leq \int_{4\pi} \frac{d\hat{H}}{d\Phi}\frac{d\Phi}{d\Omega}\, d\vec{\Omega} \tag{3}$$

is valid for the resulting maximum H_I:

- H_I is non-additive with respect to its components in solid angle.

Relation (3) allows the maximum uncertainty in H_I coming from this kind on "non-additivity" to be estimated. For radiation of fluence Φ incident unidirectionally to the sphere, this is also the maximum fluence at the surface of the sphere, and numerically equal to dN/dF, the number of particles per surface element passing the surface of the sphere at that point where the particles hit this surface element dF perpendicularly. For radiation of the same fluence Φ incident isotropically to the sphere, the maximum fluence at the surface is only $\Phi/4$ at any point of the surface of the sphere, if the sphere fully shields the incident radiation[1]. This means that also the number of particles passing the surface per surface element dF is $(1/4)dN/dF$. In those cases where the sphere only partly shields the incident radiation, the anisotropy factor

$$k_\Omega = H_I / \int \frac{d\hat{H}}{d\Phi}\frac{d\Phi}{d\Omega}\, d\vec{\Omega} \tag{4}$$

is between 1/4 and 1 (cf. /4/).

EFFECT OF RADIATION ENERGY

Similarly, the location of the dose equivalent maximum in the sphere depends on the energy or energy distribution in the incident radiation. Again, the dose equivalent index resulting from various energy components in the incident radiation will generally not be the sum of the dose equivalent maxima corresponding to these components:

$$H_I \leq \int \frac{d\hat{H}}{d\Phi}\frac{d\Phi}{dE}\, dE \tag{5}$$

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[1] This is illustrated by recalling that in the unidirectional case, the total number of particles incident to the sphere of radius r is $N = \Phi\pi r^2$. In the isotropic case this number N is to be distributed equally over the whole surface $4\pi r^2$ which leads to a "shielded" incident particle fluence $\Phi\pi r^2/(4\pi r^2) = \Phi/4$.

- H_I is non-additive with respect to its components in energy. According to Harvey /4/, the factor

$$k_E = H_I / \int \frac{dH}{d\Phi} \frac{d\Phi}{dE} dE \tag{6}$$

ranges between 0.7 and 1.

The maximum uncertainty in H_I coming from the non-additivity of angular and energy components is then characterized by the extreme values

$$\check{k} = \check{k}_\Omega \cdot \check{k}_E = 0.175 \text{ and } \hat{k} = 1, \text{ the ratio of which is}$$

$$\hat{k}/\check{k} = 5.7 \tag{7}$$

INSTRUMENT PERFORMANCE AND CALIBRATION

These considerations lead to two essential requirements for an instrument intended to measure H_I:

- The instrument must exhibit the full scattering and absorption properties of the 30 cm dia. sphere;
- The dose equivalent distribution must be explored throughout the entire sphere in order to locate the resulting maximum.

Notwithstanding the fulfilment of these requirements there is no simple and unique way to derive H_I from dose equivalent index rate measurements. The uncertainty mentioned above will subsist. In practice, however simple instruments with a single fixed detector will be used. Whereas it should be possible in principle to construct an instrument to indicate H_I for a range of incident radiation energies in a fixed irradiation geometry, e.g. unidirectional incidence, the calibration performed under these conditions is not transferable to other irradiation geometries. The maximum deviation is given by expression (7). Yet, a measurement which may be uncertain to a factor of 5, loses its sense.

OTHER OPERATIONAL QUANTITIES

Among possible candidates for operational quantities, which do not show the shortcomings of H_I are,

- Dose equivalent ceiling $\hat{H}_c = \int d\hat{H}$ (cf. /4/) which is the sum of dose equivalent maxima in the sphere for all radiation components;
- Average dose equivalent $\bar{H}$ in the sphere;
- The dose equivalent H_d in a specified depth at a particular location in the sphere.

That operational quantity H_o for which the ratio H_e/H_o is least energy dependent should be most suitable. As H_e is additive with respect to all its components, the same should apply to any quantity H_o. The three mentioned above fulfil this condition. As results of calculations and experiments to answer these problems are still scarce, fig. 1 can give only a few examples for photon radiation based on ref. /5/. It is to be noted that none of the scalar quantities mentioned above can give full information on H_e, since H_e depends among other things on the orientation of the exposed person in the radiation field and on its variation over the occupied space.

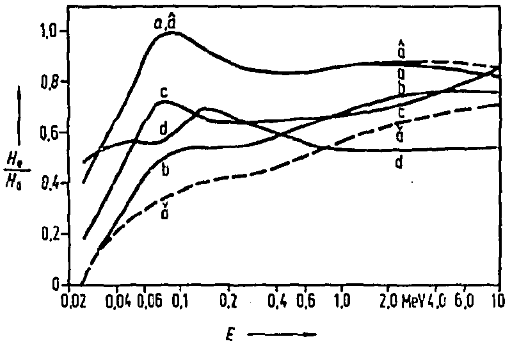

Figure 1. Ratios H_e/H_o of effective dose equivalent H_e to various operational quantities H_o (cf. /5/).
Curve a: $H_o \equiv H_{I,d}$ deep dose equivalent index, irradiation geometry (IG): parallel beam (PAR) rotating perpendicularly to vertical axis of the human body (ROT)
Curve ă: " minimum value of $H_e/H_{I,d}$ } IG: from PAR
Curve â: " maximum value of $H_e/H_{I,d}$ } to ROT
Curve b: $H_o \equiv H_{I,d}^{PAR}$ Reading of an isotropic detector calibrated by means of a parallel beam to indicate $H_{I,d}$; IG: ROT
Curve c: $H_o \equiv H_I$ (unrestricted) dose equivalent index; IG: ROT
Curve d: $H_o \equiv 2\overline{H}$ Average dose equivalent in the 30 dia.sphere;IG:ROT

The curves for the minimum (ă) and maximum (â) values of the ratio $H_e/H_{I,d}$ indicate its range for various exposure conditions from parallel beam incidence perpendicular to the vertical axis of the body to a parallel beam rotating around this axis. The solid curves give various ratios for the rotational beam. Obviously, the ratio $(H_e/\overline{H})/2$ (curve d) shows the least variation with incident radiation energy. It should be pointed out that the absolute value of the ratios is not of great consequence, as a conservative estimate of H_e can always be achieved by applying an appropriate scale factor or by introducing secondary limits to the respective operational quantity.

Future investigations should include the fully isotropic case, extend the range of incident energies and in particular consider kinds of radiations other than photons. Quantities of vector or matrix character should be explored in order to estimate H_e to a closer approximation.

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