THE "INDEX QUANTITIES" OF THE ICRU

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Abstract

In its last report on radiation quantities and units (ICRU Report 19, 1971) the International Commission on Radiation Units and Measurements (ICRU) has defined the Absorbed Dose Index (D_I) and the Dose Equivalent Index (H_I) for employment in radiation protection. The explanatory statements provided by the Commission are rather brief and it appears that some misconceptions have arisen with regard to these quantities.

It will be the purpose of this paper to present the reasons for the introduction of these quantities and to examine their utility as well as their limitations.

Radiation protection is based on a broad range of sciences and dedicated to the task of protecting man from a potentially dangerous agent that has a variety of forms and acts in manifold ways. In view of both the scientific nature and the practical importance of the subject it is essential that precise terminology be employed.

The interactions between the various ionizing radiations and the bodies of individuals exposed to them are usually quite complex and it is unavoidable that various approximations be made in practical health physics. This results in assessments that often have comparatively wide margins for error. This is quite understandable and as a rule also entirely acceptable, but substantial uncertainty in the numerical values of various quantities need not be accompanied by ambiguity concerning the quantities themselves.

"Dose" is perhaps the most important word in the vocabulary of radiation protection. Yet it has been, and still is, being employed in a variety of meanings. This may in part be due to the fact that the unmodified term has not been officially associated with a definite physical quantity and that the quantity under discussion is often evident from the context. Thus, a "dose" of 10 rads is obviously an absorbed dose, a "dose" of 10 rem is plainly meant to be a dose equivalent and a "dose" of 10 roentgens must be an exposure. There is perhaps some merit to the contention that in such instances the precise name of the quantity involved is redundant and that insistence that it be completely specified is pedantry. However, if SI units were to be used the name of the unit for dose and dose equivalent would be the same.

When absorbed dose and kerma are confused substantial errors can ensue. Thus, it has been customary to relate radiation epidemiological data to what are termed "dose", "air dose" or "first collision dose" when the quantity under consideration is in fact tissue kerma in free air. There have been evaluations of the "RBE" of neutrons relative to gamma rays (as in comparisons of leukemogenic effects in Hiroshima and Nagasaki) that are based on the ratios of the kermas of gamma radiation and neutrons that produce equal effect. This is erroneous because in penetrating to the blood forming organs, neutrons are more strongly attenuated than gamma rays. Consequently the RBE must be higher than the kerma ratio.

There has been much confusion concerning the meaning of the term "dose" when it has been employed to characterize radiation fields "free in air." The absorbed dose at some point in air can only be energy absorbed per unit mass of air at that point. It should be noted that even this quantity need not be solely determined by the interaction between radiation and air since, for instance, structural material in the vicinity might be a source of secondary charged particles that reach the point of interest. It follows that the absorbed dose depends not only on the atomic composition of the material at the point of interest, but also on the composition and geometrical arrangement of the matter surrounding it. Attempts to define a "tissue dose in air" or "first collision dose" in terms of the absorbed dose in a "small" mass of tissue located at the point of interest are therefore ambiguous unless the magnitude of the mass is specified. In general as this tissue mass is increased the charged particle spectrum traversing its center will change from initial values characteristic of the surroundings to those characteristic of tissue, but in addition the primary radiation will also be attenuated. This subject is analyzed in some detail in Part II of ICRU Report 19.[1]

Kerma and exposure can often be effectively utilized to characterize ambient levels of indirectly ionizing radiations since they are defined in terms of a vanishing interacting mass. These quantities can be useful at radiation energies below a few MeV's because they are sometimes not too different from the maximum dose in a human body located at the point of interest. What is commonly termed the "dose" registered by an area monitor is frequently either tissue kerma or tissue kerma multiplied by some backscattering factor which might again be uncertain, since its value must depend on the degree of isotropy of the radiation. At energies in excess of hundreds of MeV neither kerma nor exposure are meaningful because of the very large range of secondary charged particles and because of the complexity of interactions (particularly nuclear interactions).

It is of course, always possible to characterize the radiation field in terms of the distribution of particle fluence with respect to three variables which are (a) the nature of the particles, (b) the energy and (c) the direction; however, this information is usually very difficult to obtain and its practical applications are often involved.

In summary:

1) The only single valued (as opposed to spectral) quantities that can be meaningfully employed in radiation protection to characterize ambient radiation levels in "free air" are exposure for x- and gamma rays, and kerma for all indirectly ionizing radiations. The utility of these quantities tends to lessen at higher radiation energies, but even in the lower energy range further information (such as the angular distribution of the incident radiation) is desirable.

2) There exists no suitable quantity for directly ionizing radiations.

A few years ago the International Commission on Radiation Units and Measurements (ICRU) having recognized the lack of suitable quantities defined (1) what have become known as the "index" quantities, which meet the following requirements:

1) They are closely related to the maximum absorbed dose or the maximum dose equivalent in a human body if it were centered at the point of interest. In the majority of practical cases it is these quantities which need to be determined. There are, of course, instances where other doses or dose equivalents are of greater interest as for

instance in local irradiation of extremities.

2) Their value is unambigously defined regardless of directional properties of the radiation field.

The absorbed dose index, D_I, and the dose equivalent index, H_I, are respectively the maximum values of absorbed dose and of dose equivalent in a 30 cm diameter sphere which is centered at the point of interest and consists of tissue equivalent material of specified composition. Except for highly unusual situations (such as traversal parallel to the body axis by a beam of extremely energetic heavy ions the maximum dose or dose equivalent in a 30 cm sphere is not less than that in a human body at the same location.

The ICRU has omitted the definition of the time rate of change of these quantities but such an extension follows quite naturally. Thus, one might quantify the hazards to personnel in a fallout field in terms of a map containing information on the absorbed dose index rate. The statement that at the control console of an accelerator the dose equivalent index rate is X millirem per hour implies that if an operator were to be located there, a dose equivalent rate of X millirem per hour will not be exceeded in any part of his body. If the accelerator building is surrounded by a fence that is located along a line which is defined by an annual value of the dose equivalent index of 500 millirem, compliance with current radiation protection regulations is ensured regardless of occupancy factors.

In situations illustrated by these examples the term "dose" has been employed with the same meaning as that of the index quantities. However, as explained above it has also been used to indicate tissue kerma in free air or other less clearly defined concepts and this has led to uncertainties. If one is dealing with a unidirectional beam of 1 MeV neutrons the absorbed dose index is 50% larger than tissue kerma in free air. In the case of isotropic incidence of low energy γ radiation the magnitude of either index can be less than half as large as the kerma.

Because they are defined in terms of maximum values in an extended region centered at the point of interest, the index quantities have somewhat unusual characteristics. For example, the maximum absorbed dose in the sphere will usually be near its surface rather than at its center and outside of the limits of a sharply collimated beam the value of either index can be large at positions (i.e. locations of the center of the sphere) where there is very little radiation. Also, the index quantities are not defined for locations that are less than 15 cm from solid structures (e.g. a shielding wall). The reason is, of course, that there would be no room for a real or conceptual sphere of tissue equivalent material. However, placement of a human body in such locations would be similarly impossible. Finally, it should be pointed out that for mixtures of different radiations the maximum absorbed doses or maximum dose equivalents occur at different locations in the sphere with the result that summation of the indexes for the components of the mixture results in a conservative upper limit. It should be stressed that the objective of defining the index quantities was to provide a clear and unambiguous specification of the radiation field for practical purposes. They are neither intended nor suitable as a basis for the formulation of radiation protection standards.

Although D_I and H_I are in principle determined by exploration of a spherical phantom of 30 cm diameter, such a procedure should rarely be necessary in practice. Information on the radiation field will usually be adequate to assess the value of these quantities on the basis of measurements involving conventional ionization chambers or other dosimeters with reasonable corrections made for such factors as backscattering or wall attenuation.

It is my hope that this presentation has adequately indicated the need for the formulation of the index quantities and that they will be accepted as useful adjuncts to the other quantities employed in radiation protection.

[1] Radiation Quantities and Units. Report 19 of the International Commission on Radiation Units and Measurements.