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THE NEW OPERATIONAL QUANTITIES FOR RADIATION PROTECTION

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Abstract — Philosophies and quantities for radiation protection have often been subjected to changes, and some of the developments are traced which ultimately led to recent proposals by ICRU. Development in the past has largely been towards clarification and generalisation of definitions. The present changes, however, reflect a more fundamental issue, the transition from the limitation system to the assessment system in radiation protection. The index quantities were suitable tools to ascertain compliance with the limitation system of radiation protection. The new quantities proposed by ICRU are suitable estimators for effective dose equivalent, which is an essential quantity in the assessment system of radiation protection. A synopsis of the definitions is given.

INTRODUCTION

The history of radiation protection is also the history of a succession of different quantities – or units, as they used to be called before the ICRU came into existence. In the first decade of the century radiation dose was specified in terms of certain pills of yellow-green changeable colour, whose chemical composition was carefully concealed. Later, the 'pastille unit' of Holzknecht and the subsequent one of Sabouraud were succeeded by less picturesque but not always less enigmatic quantities. As a rule, the concepts of radiation protection tended, and still tend, to retain elements of vagueness on different levels.

Quantities can suffer from confusion, caused by technical deficiencies in definitions and by the degradation of definitions when they are put to practical and impractical uses. More important are problems that arise from the very concepts and philosophies of a branch of science. It may be appropriate, before presenting a new set of quantities, to indicate briefly some of the ambivalences of the latter type in radiation protection, and to relate them to the definitions now chosen.

TRANSITION FROM THE LIMITATION SYSTEM TO THE ASSESSMENT SYSTEM

When ICRP classified the effects of ionising radiations into two types[1], it took account of a real difference with important implications for the practice of radiation protection. The choice of the designations "stochastic" and "non-stochastic" may not have been entirely fortunate, and there may also be instances – e.g. certain prenatal effects – where the classification remains doubtful. Nevertheless, the distinction can help clarify the aims of radiation protection.

Initially, radiation protection was merely concerned with the non-stochastic effects of high doses of ionising radiations. It was, therefore, natural to introduce a system of dose limitations with the intention of excluding any harmful effects of ionising radiations. Later, hereditary damage and radiation cancerogenesis were recognised as risks of ionising radiations that could never be excluded with absolute certainty. Therefore, a different philosophy was conceived, which does not aim to eliminate risks, but to reduce them to levels that are deemed acceptable. Any optimisation must, of course, have the twofold aim of keeping the probability of harmful effects in an individual small, and of minimising – in a practicable manner – the total risk in an exposed collective of persons. Therefore, in such a system, one aims not only at the limitation of the exposure of individuals, but also at an assessment of overall exposure. Rossi has recently given an account of the two principal systems in radiation protection, which he refers to as the limitation and the assessment systems[2].

Dose equivalent was introduced as a quantity for the limitation system. It was defined to apply to any specified point in an exposed body, and no detailed advice was given, where the relevant points of measurement in the body would have to be chosen, if compliance with regulations had to be ascertained. The most conservative and the common interpretation was, that the dose equivalent had to be kept – with some reasonable averaging over small volumes – below specified limits at any point in an exposed person. In practice this led to difficulties, at least under certain circumstances. If a small detector measured absorbed dose or dose equivalent in an unknown radiation field, the result of the measurement would apply to the detector or to structures of comparable geometry, but it could not necessarily be related to values of dose that would be produced at various points in a human body positioned at the location of the measurement. ICRU then introduced the index quantities[3] which are closely related to the maximum dose equivalent in a human body. The dose equivalent index is the maximum dose equivalent occurring in a spherical phantom that is centred at the point of interest. Artificial as this concept may have appeared at the time, it was in fact merely a natural extension and an explicit statement of common pragmatic procedures; instruments had long been designed with the intention of determining a dose which included buildup and backscatter due to the body*. In common cases an actual exploration of the ICRU sphere was, of course, neither recommended nor required; the index quantities merely served to define formally the quantity that was previously used or aimed at intuitively.

A few years ago, when the assessment system superseded the limitation system, inadequacies of the prevalent practice began to be felt. Ostensibly, the criticism was directed at the index quantities, but inherently – and apart from a general desire for simplicity in measurement – it was motivated by a trend towards operational quantities that were less conservative and more closely linked to the assessment system of radiation protection, which requires realistic estimates rather than mere upper bounds of factual values.

The effective dose, i.e., the effective dose equivalent, H_e, introduced as a weighted average of the dose equivalents to the organs of a person[1], is – except for minor technical deficiencies of the definition – a suitable, well-defined and by now widely accepted quantity. It is sometimes asserted that H_e is not directly measurable. However, this qualification is sufficiently loose to apply, depending on the conception of a "direct measurement", to any quantity. In fact, H_e is difficult to determine with high accuracy, but it rarely requires such a determination. In practice, crude estimates of the effective dose are usually sufficient. Various instruments or computations can provide such estimates. However, the need for simplifications and approximations can not obviate the need to base measurements and design criteria for instruments on rigorous definitions and clearly stated conventions. It was, therefore, felt desirable to develop certain concepts and quantities that could be used in radiation protection practice and that could serve as estimators of the effective doses, or of potential effective doses, in persons.

An ICRU Report Committee, chaired by T. E. Burlin and sponsored by G. Cowper and D. Harder, has covered the groundwork that led to the present recommendations. From this extensive study two further committees of the ICRU and the Main Commission have then distilled definitions which were intended to be sufficiently simple and clear to speak for themselves[5]. Under the assumption that this aim has been reached, they are here cited with a few comments in abbreviated form.

DEFINITIONS OF THE NEW QUANTITIES

The new quantities for environmental (area) monitoring are compromises between authenticity and abstraction. For conceptional simplicity and for practicability of measurement they are defined as point functions, i.e., their values at a specified point depend only on the radiation field at this point. Nevertheless, they are related to an extended, remotely anthropomorphic phantom – the ICRU sphere. To resolve this apparent contradiction, the somewhat artificial concept of an *expanded field* is required; it is the uniform radiation field that agrees with the actual field at the specified point.

The principal quantity for area monitoring is, moreover, designed to be independent of the angular distribution of the radiation field, which requires the further abstraction of an *aligned, expanded field*. This is the uniform, unidirectional field that has the same fluence distribution as the expanded field.

Using these two auxiliary concepts, one can define a quantity for the environmental monitoring of penetrating radiation:

> The *ambient dose equivalent*, H^*, at a point in a radiation field, is the dose equivalent produced by the aligned, expanded field in the ICRU sphere 10 mm below the point of normal incidence.

For individual monitoring of penetrating radiations one can use a partly analogous quantity:

> The *individual dose equivalent, penetrating*, H_p, is the dose equivalent in soft tissue 10 mm below a specified point on the body.

In certain circumstances, a depth different from the recommended value of 10 mm may be chosen for H^* or H_p; it must then be indicated.

H^* and H_p can serve as estimates, usually conservative, of the effective dose if properly

*Even with the early dosimetric methods, which hardly met present metrological standards, the presence of the body had to be crudely simulated, although this procedure was still purely empirical: "When in the holder, the pastille . . . should have a piece of metal as a backing, if its indications are to be accurate"[4].

applied. For most penetrating radiations they can also serve to ascertain compliance with the limits for organ doses.

For weakly penetrating radiations, where the skin (or the lens of the eye) may be the limiting organ, one requires additional quantities:

The *directional dose equivalent*, H′, at a point in a radiation field, is the dose equivalent produced by the expanded field in the ICRU sphere at a depth of 70 μm on the radius in a specified direction.

This quantity can be used for environmental monitoring, and the corresponding quantity for personal monitoring of weakly penetrating radiation is entirely analogous:

The *individual dose equivalent, superficial*, H_s, is the dose equivalent in soft tissue 70 μm below a specified point on the body.

With the quantities H′ and H_s, there too may be circumstances, where a depth different from the recommended value is chosen; it must then be indicated.

CONCLUSION

H* and H_p serve as estimators of the effective dose that either would be produced in a person at the monitored location or was produced in the person monitored with the individual dosemeter.

H* is independent of the directional distribution of the radiation field. To account for the worst case, usually frontal irradiation, the definition must, therefore, be inherently conservative. Large values of H^*/H_e occur, particularly, for neutrons between 100 keV and 1 MeV. This could be a reason to reconsider the recommended depth for H*. Nevertheless, the degree of conservatism is for H*, at least for unidirectional fields, less than that of the index quantities. In certain instances H* could even slightly underestimate the effective dose.

The relation between H_p and the effective dose depends, of course, on the proper placing of the personal dosemeter. By only using a single dosemeter one monitors, in effect, merely the frontal half-space of the person. Additional precautions may, therefore, be required to ensure that no irradiations remain undetected. From this point of view, it is somewhat undesirable that the definition of H_p implies reduced response to lateral incidence for certain radiations. For this reason a modified definition was considered which could lead to a more nearly isotropic response over the frontal half-space. However, it was then felt that commonsense flexibility in the implementation of the definition will suppress undesirable, formalistic, extra steps that might be taken to reduce the effective acceptance angle of a personal dosemeter. If a dosemeter responds properly to frontal irradiation, its suitability will not be reduced if its lateral response happens to be somewhat larger than is required by the definition.

Little needs to be said about the quantities H′ and H_s. Their definitions are effectively equivalent and they require identical calibration procedures in the case of weakly penetrating radiations. H′ may also be of interest for larger values of d and would, in this case, be largely equivalent to H_p. However, an instrument used to measure H′ would then – in the same way as an instrument for H* – demand built-in characteristics that represent the spherical phantom stipulated in the definition. Personal dosemeters require only part of such characteristics, since they are worn on the body and calibrated on its surrogate, the ICRU sphere.

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