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Abstract

In its Report 39, the International Commission on Radiation Units and Measurements (ICRU), has defined four new quantities for the determination of dose equivalents from external sources: the ambient dose equivalent, the directional dose equivalent, the individual dose equivalent, penetrating and the individual dose equivalent, superficial. The rationale behind these concepts and their practical application are discussed. Reference is made to numerical values of these quantities which will be the subject of a coming publication from the International Commission on Radiological Protection, ICRP.

Keywords (chosen by the author)

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6

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Proposed Recommendations of ICRU and ICRP on the Determination of Dose Equivalent

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ABSTRACT

In its Report 39, the International Commission on Radiation Units and Measurements (ICRU), has defined four new quantities for the determination of dose equivalents from external sources: the ambient dose equivalent, the directional dose equivalent, the individual dose equivalent, penetrating and the individual dose equivalent, superficial. The rationale behind these concepts and their practical application are discussed. Reference is made to numerical values of these quantities which will be the subject of a coming publication from the International Commission on Radiological Protection, ICRP.

INTRODUCTION

We always strive for simplifications. This is why, in radiation protection, physicists have always tried to describe the hazard of a radiation field by one single number even for very complex irradiation conditions. Thus, more and more complex quantities have been introduced to describe the radiation field and its interaction with the human body. This year, the ICRU has defined four new quantities believed to form a coherent system, the use of which should lead to simple interpretation of occupational exposures.

In my lecture, I will start with the problems involved in deriving appropriate quantities, and the solutions which have been suggested through international consensus. I will end up with the recommendations which are just now emerging from the ICRU and the ICRP. Finally I will discuss the practical consequences of these recommendations.

PROBLEMS OF CHARACTERISATION AND THEIR SOLUTIONS

MANY RADIATIONS. To simplify, we want to use one same quantity for many types of radiations, since mixed fields are commonly occurring: alpha, beta, gamma, neutron and other radiations. The well known solution has been to use a quality factor that corrects for the differing degrees of hazard associated with different radiations.

MANY TYPES OF BIOLOGICAL INJURY. Figure 1 shows dose-response relationships for many types of injury that may follow irradiation. Some types exhibit a threshold, such as the induction of death or of hypothyroidism in children, and the threshold dose may vary over a large range. Others may not have a threshold, and for instance the overall risk of induction of fatal cancer may be much lower than the risk of mental retardation due to fetal irradiation, for the same radiation dose. Instead of describing the dose to all organs, it is sufficient to describe the doses to a few groups of organs, since dose limits have been ordered in two main groups, relating to non-stochastic and stochastic injury, respectively. Of these, in practice the stochastic injury is of dominant interest for external radiation.

EFFECTIVE DOSE EQUIVALENT. To enable one concept to be used, the differing radiosensitivities of organs amenable to stochastic injury have to be accounted for. They may vary over a factor of 40 (figure 2). This has been taken care of in the construction of the effective dose equivalent, which is a sum of weighted dose equivalents, where the weights account for the stochastic radiosensitivity of the particular organ.

DOSE EQUIVALENT INDEX. The effective dose equivalent removes the necessity of specifying many organ doses. It is, however, not very durable since it is likely that the weighting factors might change as knowledge of radiation risks improves. Figure 3 gives one example of the volatility of ICRP risk estimates as expressed in the eye lens dose limit. Also the physical size and composition of the phantom used to represent man may change. The description of the radiation field could be made more durable if a standardised quantity could be used to represent the effective dose equivalent. This has been catered for through the dose equivalent index, which is defined as the maximum dose equivalent in a 30 cm diameter tissue sphere.

ALIGNMENT AND CEILING PROCEDURES. Unfortunately, quantities based on the maximum dose within an object are not additive. This is illustrated in Figure 4 by the simple example of weakly penetrating radiation incident from two different directions. Then the same maximum dose equivalent, 1 mSv, occurs in two different points. If the recording is done on a day-to-day basis, then the total dose equivalent index is 1 mSv if the two irradiations are carried out during the same day. This is because the maximum is still 1 mSv even if it occurs at two points. If the irradiations take place in two different days, the total recorded dose equivalent index will be 1 mSv + 1 mSv, that is 2 mSv. It is possible to remove this inconsistency by maximising procedures using alignment, which I will return to, or the "ceiling" concept suggested by Harvey.

INDIVIDUAL AND ENVIRONMENTAL MONITORING. Environmental (or area) and individual monitoring are serving the same purpose of estimating the exposure of individuals. The quantities used for both should therefore be derived on a common basis in order to simplify comparisons.

ONE POINT OF MEASUREMENT. For environmental monitoring, it is important to have a well defined point of measurement. The dose equivalent index is impractical in that the relevant point was the centre of the sphere, different from the point where the maximum dose equivalent is obtained. For individual monitoring, a sufficient number of points on the body must be examined. In most routine situations, one point is sufficient.

ONE NUMBER TO CHARACTERISE THE FIELD. For environmental monitoring, we want the simplest possible description of the field, that is, using one number. This can be done by ignoring field variations over the studied body - expansion of the field -, and by treating radiations from all directions identically - alignment -. For individual monitoring, the response depends strongly on field variations over the body and on the direction of incidence. In this case, it would be going too far to neglect these variables.

USE OF OLD INSTRUMENTS. It would be desirable to design new quantities that would permit the use of old instruments by a simple change of scales, since large sums of money are invested in existing instruments.

RECOMMENDATIONS UNDER WAY FROM ICRU AND ICRP

ICRU REPORT 39. This year ICRU published its Report 39 : Dose equivalents resulting from external radiation sources. It gives two new quantities for individual monitoring and two for environmental monitoring. Figure 5 gives the terminology and the important characteristics of the individual monitoring quantities.

In order to explain the quantities defined in Report 39 for environmental monitoring, the terms "expanded" and "aligned" must be explained. When we want to simplify the action of a field at a point P on a body, we can limit ourselves to looking at a uniform field which has the same fluence as the actual field in P. The field at P is then said to be "expanded" (Figure 6). If we want to simplify the situation with several expanded fields coming from different directions, we may treat them as if they all came from one direction. The field is then said to be "aligned and expanded (Figure 7). We may now define the "ambient dose equivalent". This is what would be produced in the ICRU sphere by the aligned and expanded field, with the characteristics given in Figure 8. The "directional dose equivalent" is the dose equivalent obtained along any specified radius in the sphere, as detailed in Figure 9. Since an infinite number of radii can be specified, the directional dose equivalent usually takes on an infinite number of values in a given radiation field. Therefore, calibration and application must rely on further simplifications.

OTHER ICRU REPORTS. A second ICRU Report is scheduled to treat the rationale behind the new quantities in Report 39, and their practical application. This report is near completion and may be scheduled for approval by the ICRU in the summer of 1986. A third report on calibration and instrumentation has not yet been drafted and may take longer to emerge.

RECOMMENDED DATA FROM ICRP. The ICRP have in an advanced stage a publication with recommended data for the relationship between the new quantities, other dose equivalent quantities, and field quantities, applicable to the protection of workers. The data include, for instance, the ambient dose equivalent at 10 mm depth per unit particle fluence or per unit effective dose equivalent. The publication is scheduled to be approved by the ICRP Main Commission during 1985. The data in my next section are mainly from the background material provided within the task group drafting that report.

PRACTICAL CONSEQUENCES OF THE NEW QUANTITIES

RELATION TO LIMITING QUANTITIES. Figure 10 shows that the ambient dose equivalent is a perfect match to the deep dose equivalent index for photons in a unidirectional parallel beam. In the case of an isotropic field, the lack of attenuation means that the ambient dose equivalent overestimates the index for low photon energies. For neutrons (Figure 11), the ambient dose equivalent underestimates the index between 10 eV and 1000 eV at unidirectional fields.

The effective dose equivalent is almost always overestimated by the ambient dose equivalent, for both photons (Figure 12) and neutrons (Figure 13). However, the individual dose equivalent, penetrating, at 10 mm depth as measured by the common individual dose meter on the chest, may underestimate the effective dose equivalent by a factor of 3 or 4 for laterally incident neutrons below a few hundred keV, and irradiation from the back with less penetrating radiation may lead to even more pronounced underestimation. Therefore, the number of dosemeters to be used for individual monitoring should be carefully considered for weakly penetrating radiations.

In general, the directional dose equivalent gives a good estimate of the dose equivalent to the sensitive layer of the skin at the point where the directional dose equivalent is specified and when the skin is perpendicular to the specified direction.

RELATION BETWEEN NEW AND OLD QUANTITIES. The goal of not changing the energy response too much in relation to that of old quantities is reasonably well met. For photons, the ambient dose equivalent bears the same relation to exposure for all directions of irradiation, with some overestimation around 100 keV and above all a strong underestimate at lower photon energies (Figure 14). This underestimate, however, it carries in common with many existing instruments due to their attenuating windows, so the energy response of many exposure measuring instruments will already be closer to that of the ambient dose equivalent than that of the exposure quantity. For the directional dose equivalent, the match to exposure is generally closer than that of the ambient dose equivalent.

For neutrons, measurements have traditionally been in terms of the maximum dose equivalent, MaDE, in a slab phantom as specified per unit fluence in ICRP Publication 21. Figure 15 shows that for unidirectional irradiation, the ambient dose equivalent fairly well matches the MaDE for all neutron energies, so that old instruments should continue to be useful for monitoring in terms of the ambient dose equivalent.

SOME PROBLEMS. I believe the goal of simplicity and coherency has been fairly well reached with the new quantities. Often, however, simplicity is obtained at the expense of accuracy, and this is the case also for the dose equivalent monitoring quantities. Some problems related to this have been touched upon already, and the new quantities do not relieve the physicist of his obligation of considering supplementary monitoring when necessary. Here are some situations to be careful about:

* The ambient dose equivalent may overestimate the effective dose equivalent by more than a factor of 4 for photons below 40 keV and neutrons in the range 50-500 keV

* The ambient dose equivalent and the individual dose equivalent, penetrating, for 10 mm depth, may underestimate the effective dose equivalent for photon energies above 10 MeV. In the case where a large portion of the dose equivalent stems from such photons, use of a larger depth through a build-up cap on the monitoring instrument is advisable

* The angular response of the individual dose equivalent, penetrating, may be difficult to realise, and this may impair the accuracy of monitoring

* The directional dose equivalent (0.07 mm) may be very sensitive to the lack of electron equilibrium, which has been assumed in the derivation of its response function. If a lack of electron equilibrium is present at the same time as the directional dose equivalent is important, measurement at a larger depth should be made. Such a situation rarely occurs in practice.

* It may be difficult to realise the directional dose equivalent since the natural way would be to employ a very thin window on a monitoring instrument.

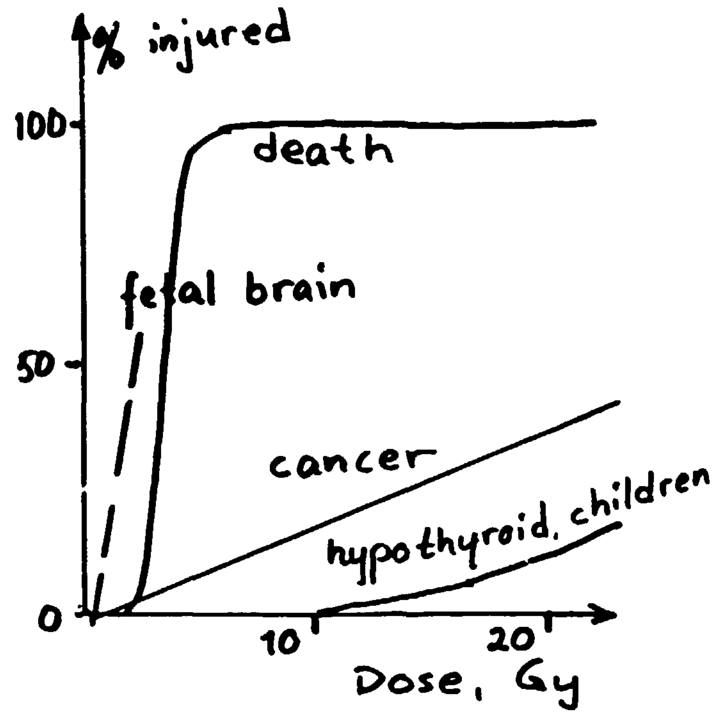
* Sometimes, special monitoring might be required to account for the lens dose equivalent with its 3 mm depth. Normally, however, the lens is sufficiently protected if the skin and effective dose equivalent limits are complied with through monitoring for the 0.07 and 10 mm depths.

* Of course one should monitor other vital organs in the case of significantly non-uniform irradiation, for instance the gonads employing 10 mm depth.

* In particular, the extremities are as interesting as they are today, and normally the 0.07 mm depth would be interesting. For small extremities, the ambient dose equivalent would be particularly inappropriate for intermediate energy neutrons where it would grossly overestimate the extremity dose equivalent.

* Last, but not least, an unforseen problem still awaits international consensus in its practical application. At its meeting in Paris in March this year, the ICRP decided to recommend that as a temporary measure, the quality factor for neutrons should be increased by a factor of 2 to account for fears of an unexpectedly high biological efficiency. Since no other radiations were to be affected, this upsets the whole logic of the dependence of the quality factor on the linear energy transfer. I personally hope that the clarification which is no doubt necessary will have the form that the factor of 2 should be seen as an additional modifying factor for neutrons rather than a change of the quality factor.

How handle different injury?



Different dose limits

- organ function
  (non-stochastic injury)
  500 mSv/a (lens 150)
- other manifestations
  (stochastic injury)
  50 mSv/a
  ("15 mSv/a" in pregnancy)

1

How handle different radiosensivity to stochastic injury?

Risk per sievert for serious ill health or death

Gonads	$20 \cdot 10^{-3}$
Leukemia	$2 \cdot 10^{-3}$
Thyroid cancer	$0.5 \cdot 10^{-3}$

Use effective dose equivalent, H_E:

sum of weighted doses

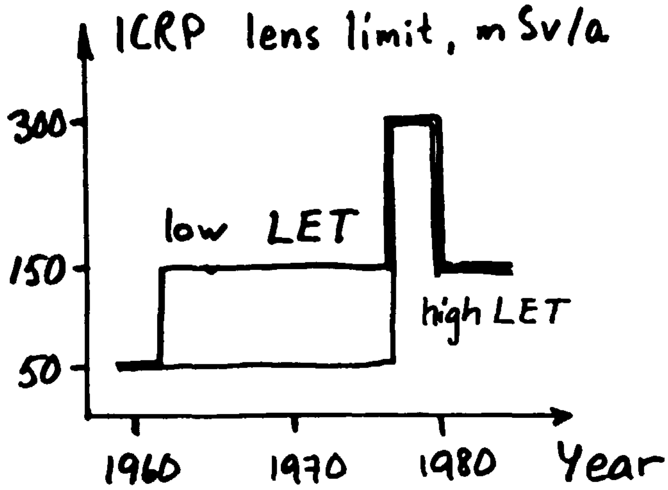
e.g.

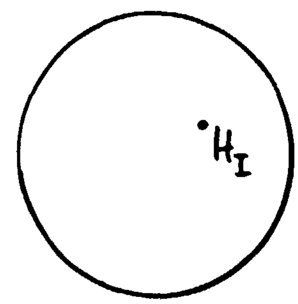
Gonad dose	× 0.25
Bone marrow dose	× 0.12
Thyroid dose	× 0.03

2

How avoid time variations of models for biological risk and body configurations?

Use dose equivalent index H_I



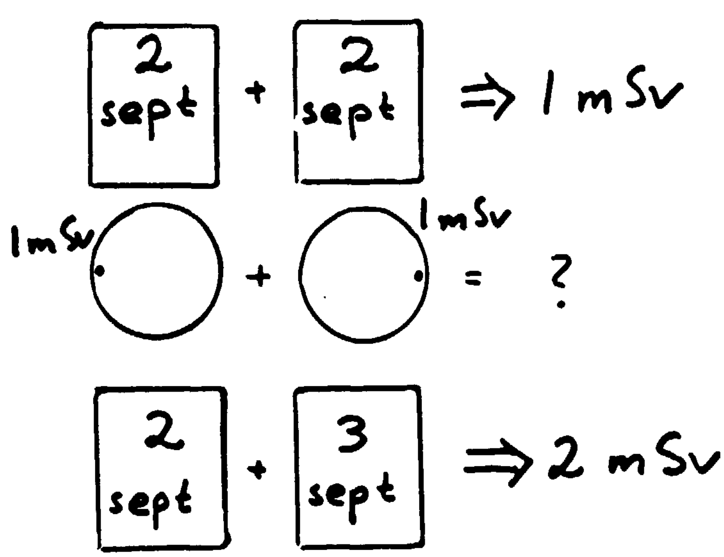


max H in 30 cm sphere

3

How avoid addivity problems with quantities based on maximum dcse?

Apply "alignment" or "ceiling" procedures or use additive quantities



4

Individual dose equivalent,

penetrating $H_p(10)$

soft tissue, 10 mm depth below a specified point on the body (other depths possible).

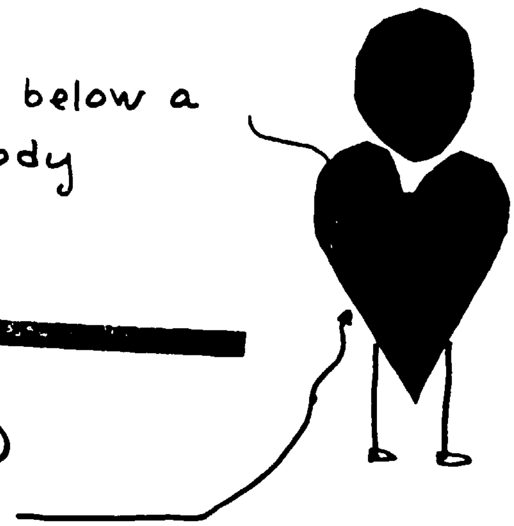
Approximates to H_E

Individual dose equivalent,

superficial $H_s(0.07)$

ditto at 0.07 mm depth

Approximates to H_{skin}



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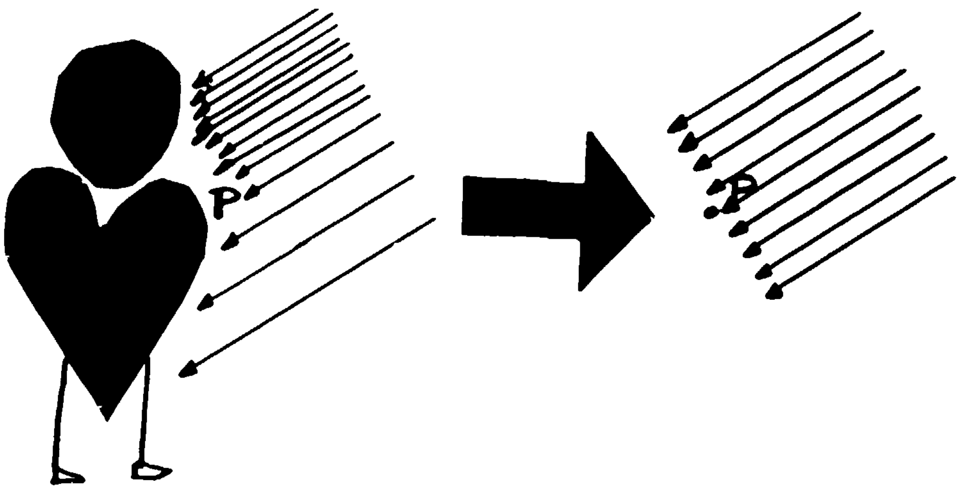
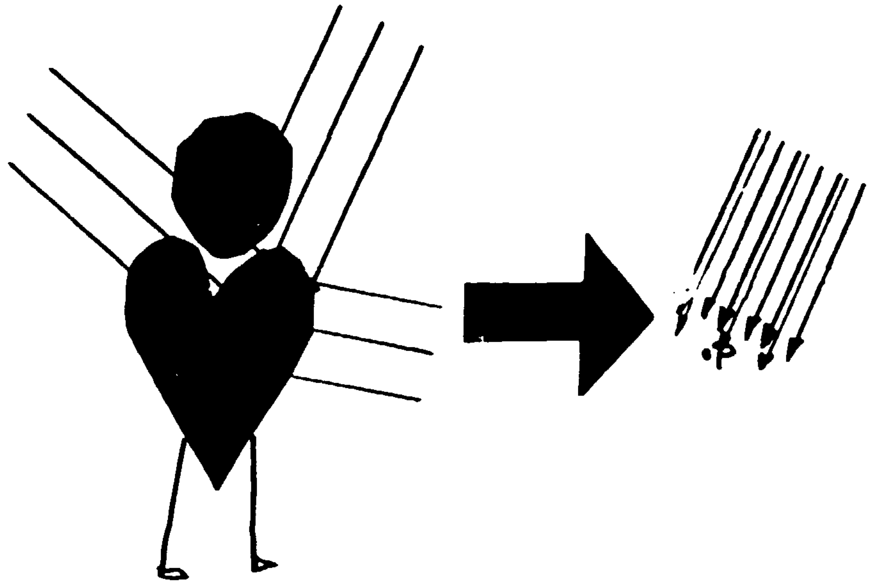


Expanded field at P

6

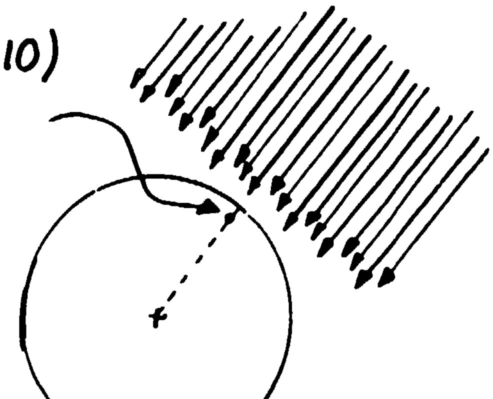


Aligned and expanded field at P

7

Ambient dose equivalent

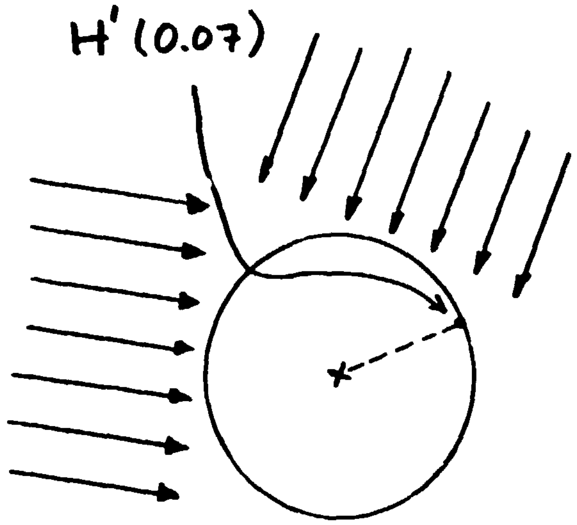
$H^*(10)$



- ICRU 30 cm sphere
- 10 mm depth (others may be used)
- aligned and expanded field
- radius opposing the field
- strongly penetrating radiations ⇒ approximates well to H_E

8

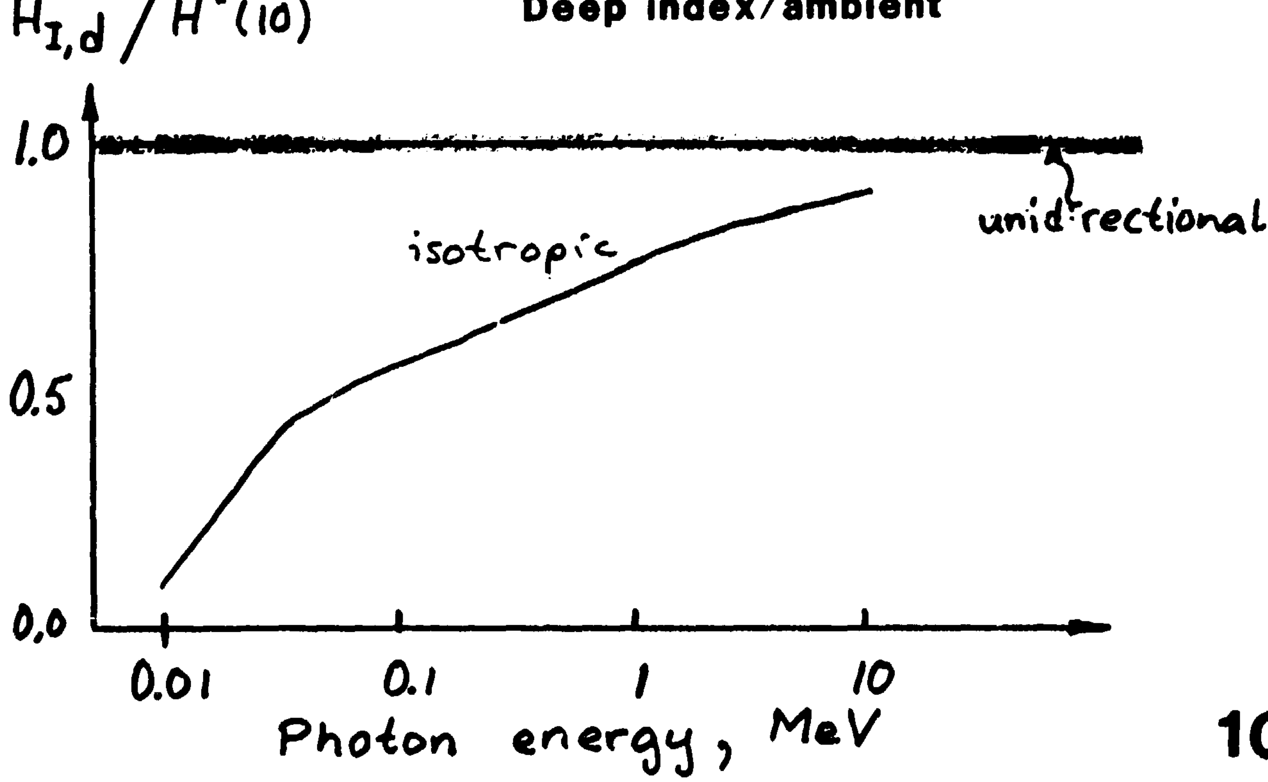
Directional dose equivalent



- ICRU 30 cm sphere
- 0.07 mm depth
- expanded field
- any specified radius
- maximum value over all directions approximates well to H_{sk} for weakly penetrating radiations

9

Deep index/ambient



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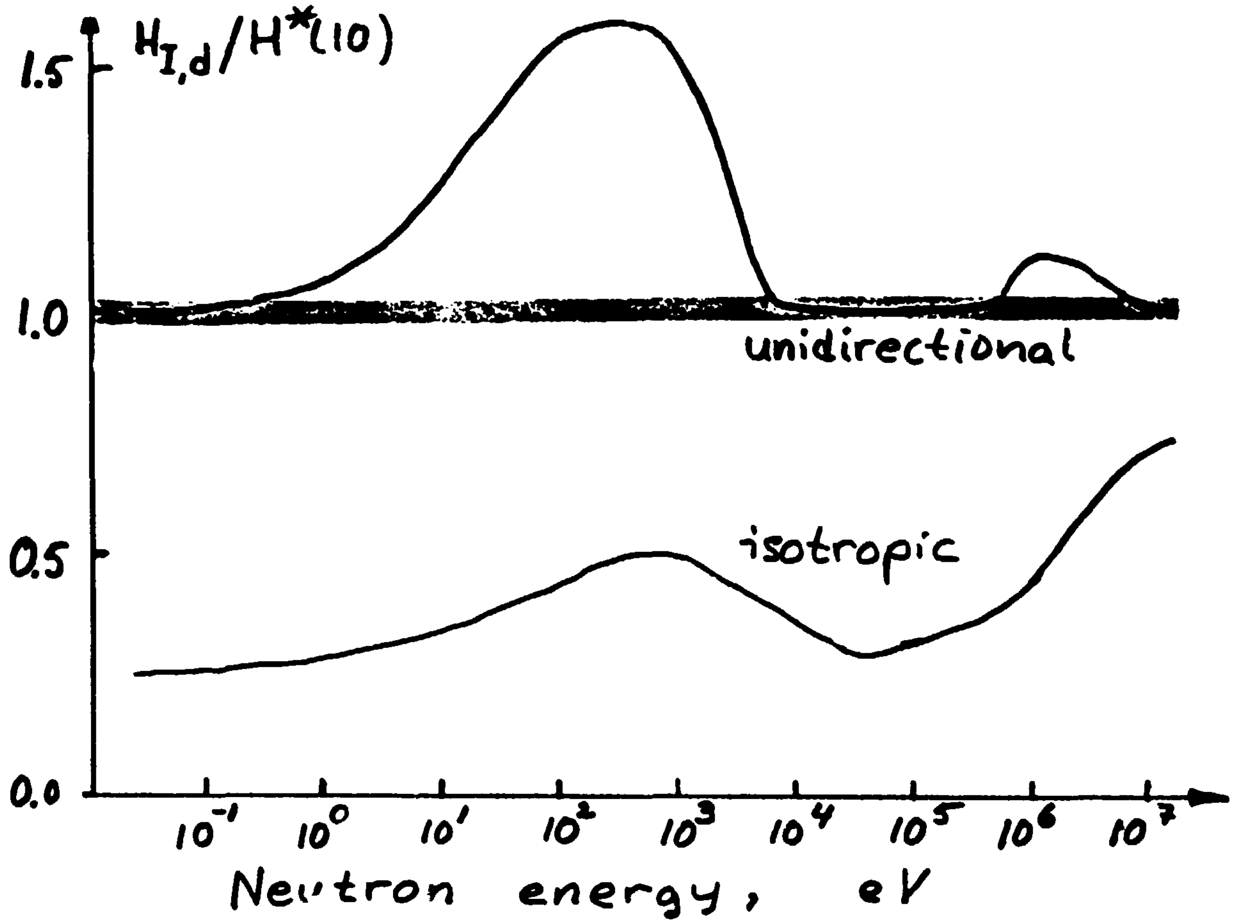
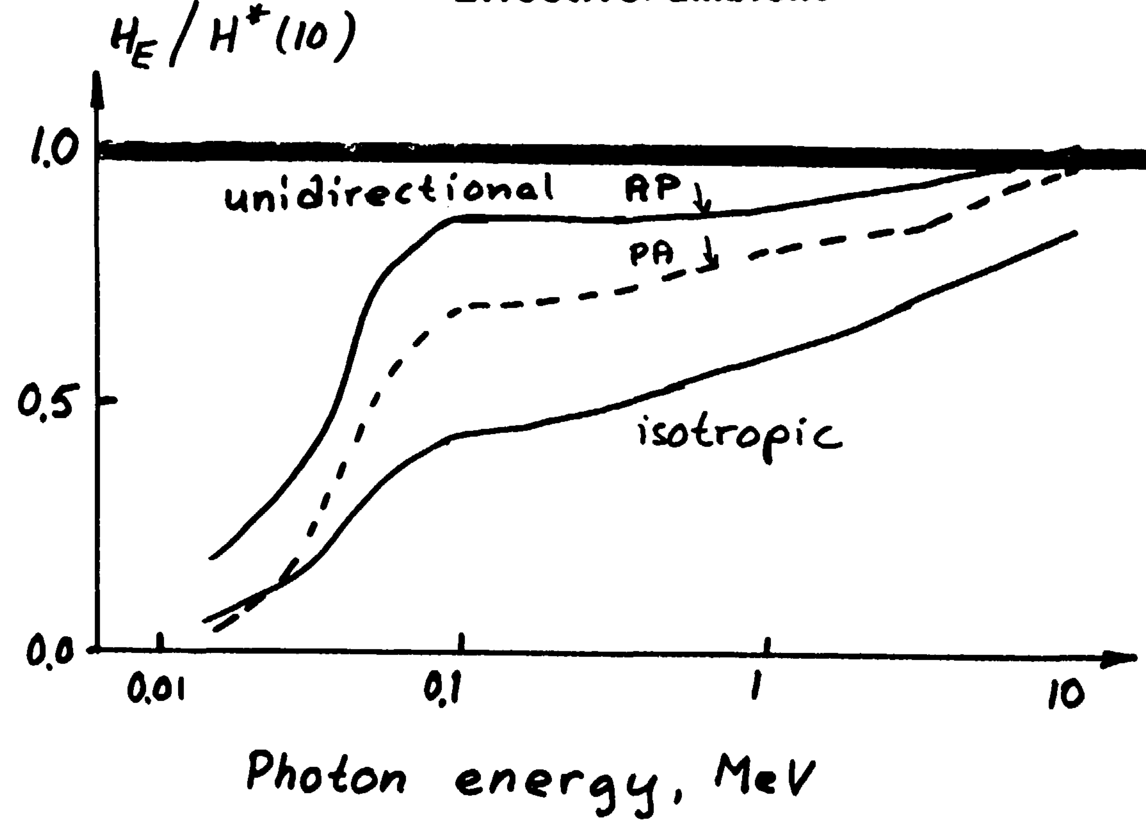


11

Effective/ambient



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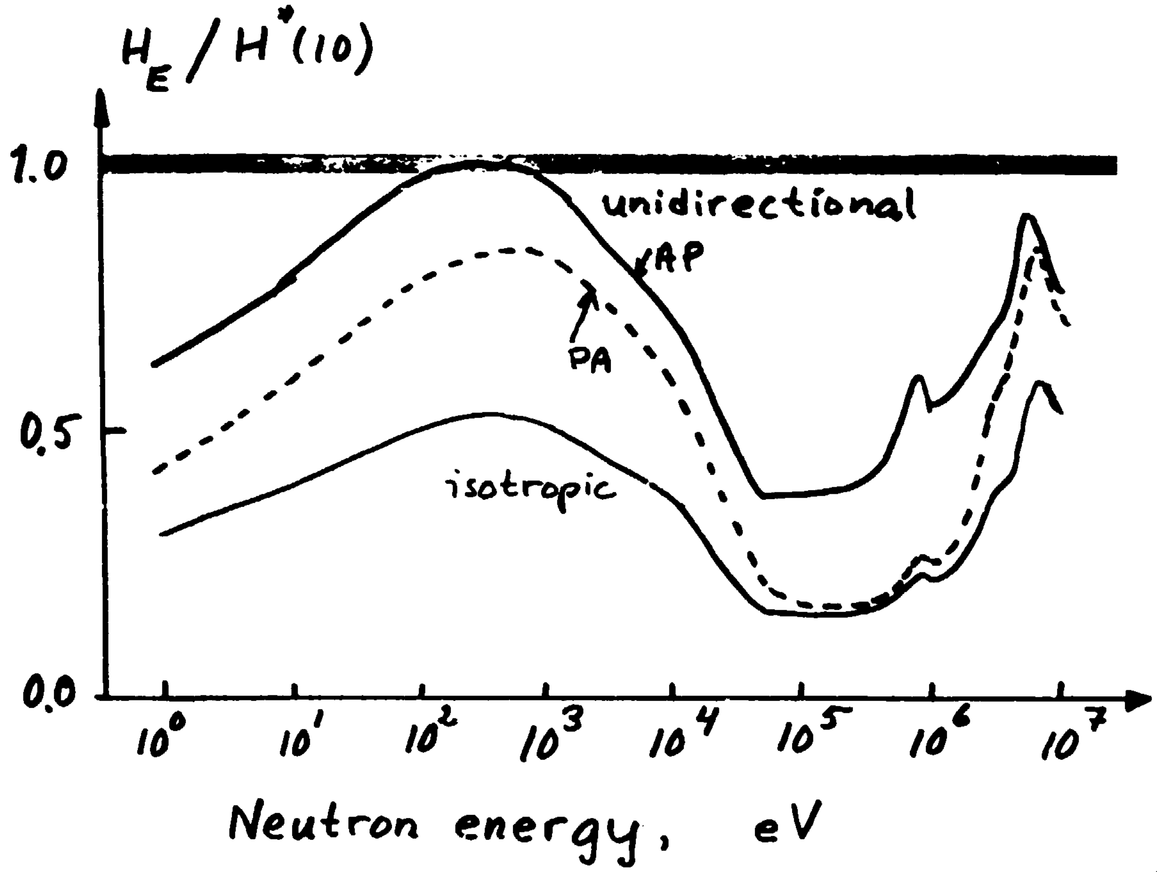
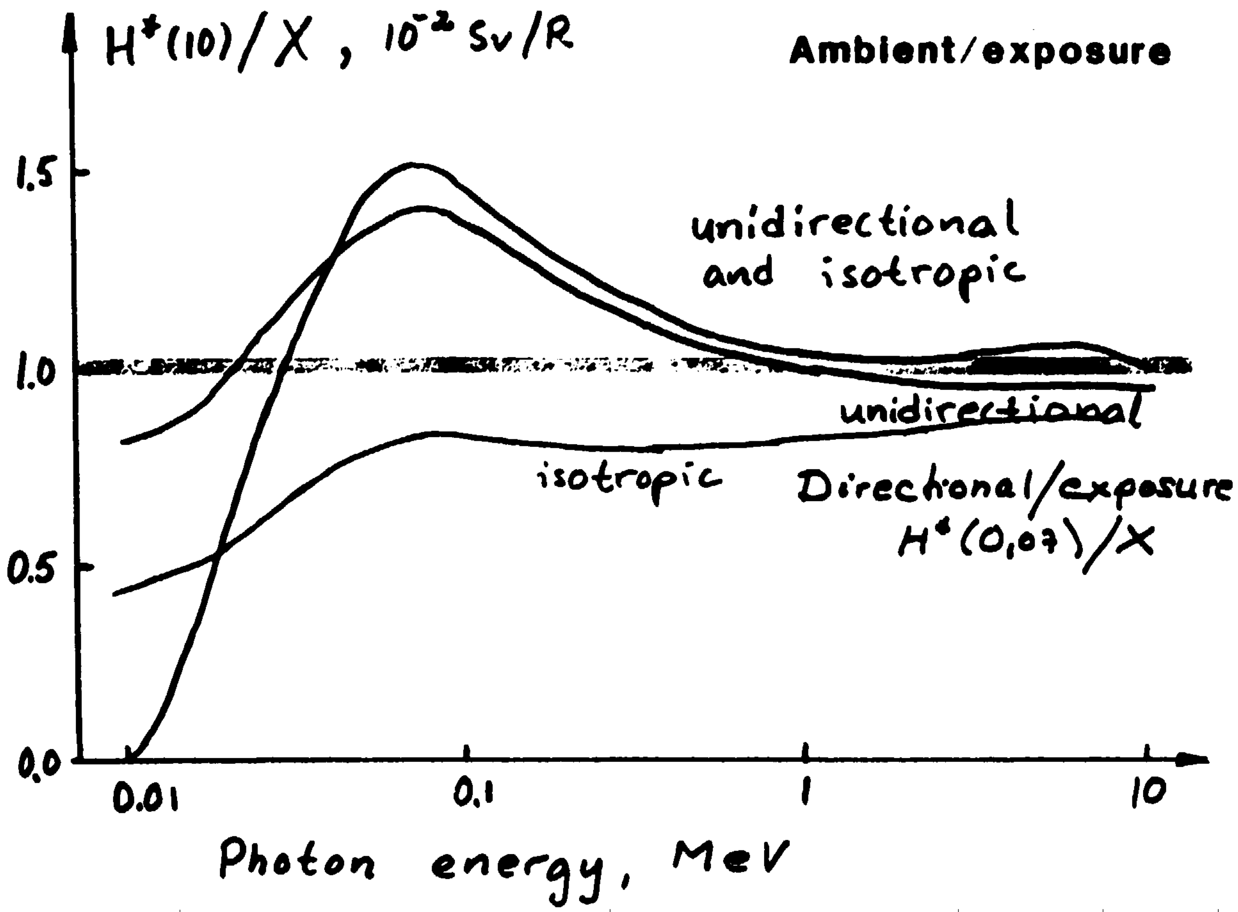


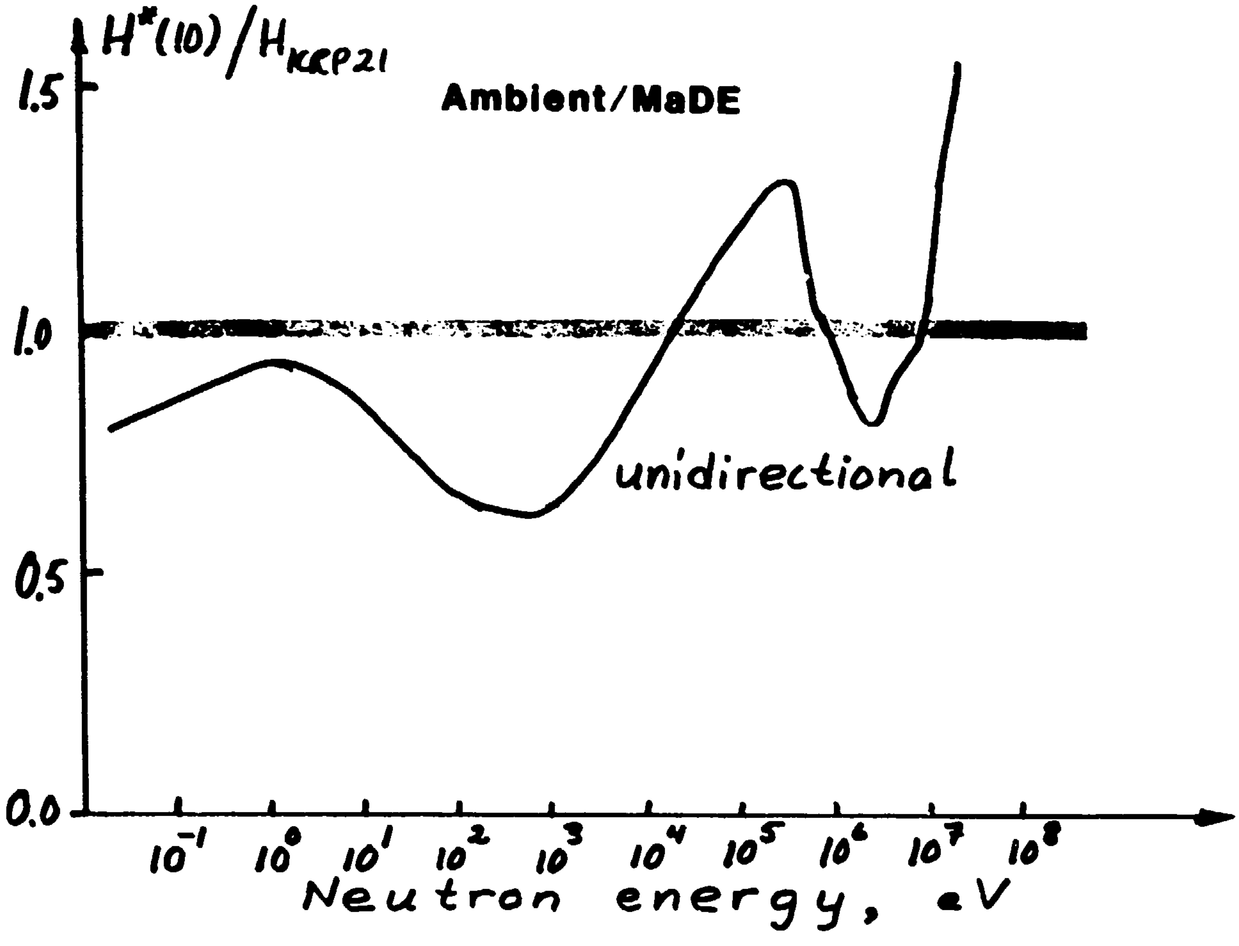
$H_E / H^*(10)$
1.0
0.5
0.0
unidirectional
AP
PA
isotropic
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7
Neutron energy, eV

13



$H^*(10)/X$, 10^{-2} Sv/R
Ambient/exposure
1.5
1.0
0.5
0.0
unidirectional and isotropic
unidirectional
isotropic
Directional/exposure
$H'(0{,}07)/X$
0.01
0.1
1
10
Photon energy, MeV

14



H*(10)/H_ICRP21
Ambient/MaDE
1.5
1.0
0.5
0.0
unidirectional
10^-1 10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8
Neutron energy, eV

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