Soz Präventivmed 1991; *36*: 222–224

0303-8408/91/050222-03 $1.50 + 0.20/0

Comments on radiation dosimetry and linear energy transfer

Imogen Cordt-Riehle

Institute of Radiation Biology, University of Zurich

Dosimetry

Dosimetry means quantification of the physical effects of ionizing radiation. A quantification of these effects must precede any discussion of the risks of ionizing radiation. The different types of ionizing radiation are classified as particles and waves (Fig. 1), whereas UV-light is only partially ionizing.

There are two basically different considerations in dosimetry: to describe the radiation beam itself and to describe the amount of energy it deposits in the body. The discussion here will be restricted to the latter aspect.

There is no way to make the tissue of the body a medium of measurement; it can never serve for directly measuring absorbed energy. Before the determination of dose in the body there must always be a preceding step by which the dose is measured in the material of the detector.

So the question is: How does dosimetry work?

One has to distinguish between two different procedures. Firstly, there are procedures for an absolute determination of absorbed dose. In these procedures, the energy which is transferred to a medium by ionizing radiation is determined on the basis of physical knowledge. Such procedures are calorimetry, chemical dosimetry and ionization dosimetry.

Secondly, there are procedures for a relative determination of absorbed dose. Obviously one has to begin relative dosimetry by comparison with the absolute dosimetry. For example, if one decides to make use of thermoluminescent dosimetry one has to start with the calibration of these dosemeters against the results obtained with an absolute measuring device. In this brief explanation, only the absolute dosimetry principles will be considered, and not the subsequent relative dosimetry.

The only direct method of measuring absorbed dose is by calorimetry, in which the rise in temperature of the medium is measured. All other methods for absolute determination of absorbed dose are based partly on measurements and partly on calculations. Unfortunately a calorimeter is too complex an instrument to be suitable for routine measurements. It has not even been fully adopted by standardization laboratories. As a result, most absorbed dose determinations today are based on a measurement of ionization followed by calculations.

This leads to the next question: How is ionization dosimetry done?

In order to understand that, two radiological quantities have to be introduced, the kerma and the absorbed dose.

Kerma stands for *k*inetic *e*nergy *r*eleased in *ma*terial:

$$K = \frac{dE_{tr}}{dm} \quad \text{Unit: } 1\ \text{J kg}^{-1} = 1\ \text{Gy}$$

where dE_{tr} is the sum of the initial kinetic energies of the charged ionizing particles liberated by un-

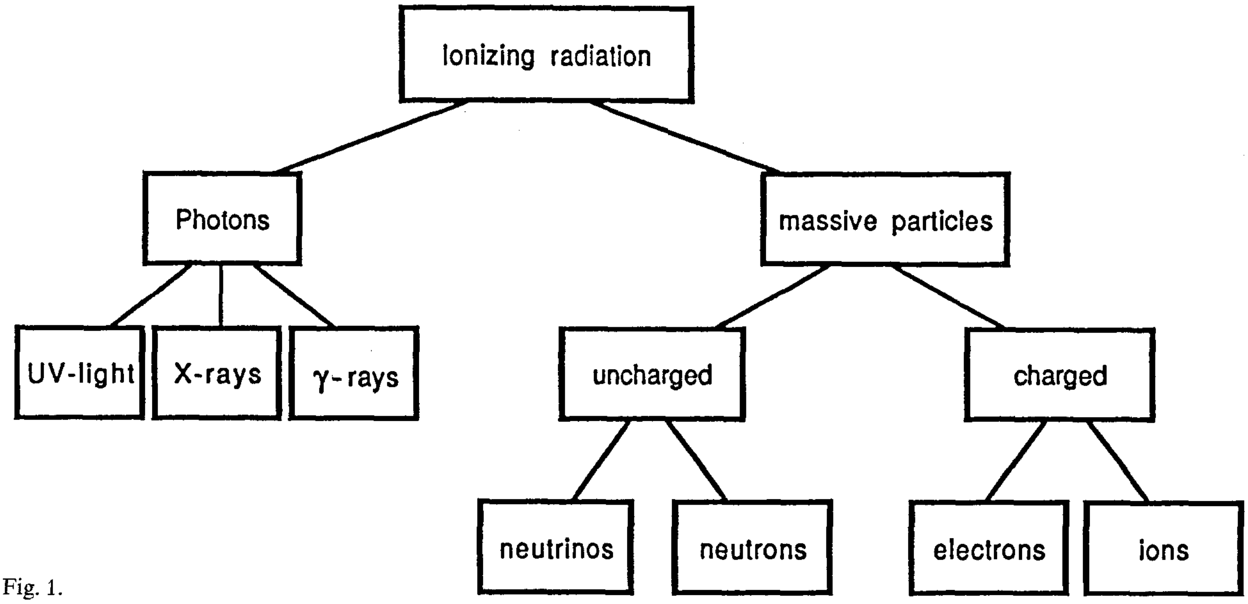

Fig. 1.

charged ionizing particles in a material of mass dm.

From this definition follows that kerma is only defined for uncharged particles, high energy photons and neutrons.

The absorbed dose D is:

$$D = \frac{d\bar{E}}{dm} \quad \text{Unit: } 1\ \text{J kg}^{-1} = 1\ \text{Gy}$$

where $d\bar{E}$ is the mean energy imparted by ionizing radiation to matter of mass dm.

What is the difference between kerma and absorbed dose? This may be explained by looking at a source of high energy photons. The transfer of energy from a photon beam to a medium takes place in two stages. The first stage involves the interaction of a photon with an atom of the medium, causing an electron to be set in motion. Kerma quantifies this first stage.

The second stage involves the transfer of the energy from the high energy electron to the medium through ionizations and excitations. In this second stage, not all the energy which was transferred to an electron by a high energy photon is retained in the medium. Some of it is lost as bremsstrahlung. The absorbed dose is the energy actually retained in the medium, as a result of the ionizations and excitations that take place along the track of the primary liberated electron.

That results in a simple connection between kerma and absorbed dose:

$$D = K(1 - g)$$

where g is the proportion lost as bremsstrahlung. But there is one problem: the energy release (Kerma) does not take place at the same location as the dose absorption. Kerma is easy to calculate if the photon fluence is known, but difficult to measure. Absorbed dose can only be calculated in a simple way from kerma if a state of equilibrium exists between the two quantities.

Therefore the next task is the determination of absorbed dose using an absolute ionization chamber, i.e. an ionization chamber made of known material with a cavity of known volume. Its cavity is filled with a gas, in most cases, air. This kind of chamber can be used for the absolute determination of absorbed dose in a medium.

Therefore it is necessary to collect all charge Q liberated in the cavity by ionizing radiation and to measure this charge accurately. The volume of the cavity must be known as well as the three materials involved: the gas, the wall of the cavity, and the medium in which the ion chamber is placed. Finally the interaction coefficients describing the absorption behaviour of ionizing radiation in these materials must be known. From this information the dose to the medium can be calculated, when Q has been measured for a gasfilled cavity, surrounded by some wall material, placed in the medium. The measurement medium usually chosen is water. The dose in tissue can be derived from the dose in the medium, using similar calculations.

This brief review shows that not only calorimetry but also ionization dosimetry can be used for absolute determination of absorbed dose. Absorbed dose as well as kerma are well-defined physical quantities. If one wants to find a value for one of these quantities, exact physical measurements combined with calculations on the basis of physical knowledge have to be done and can be done. At the end of this process is a very reproducible number.

Linear Energy Transfer

In discussing radiation risk we must not only consider the absorbed dose, but we have also to take into account the density of ionizations effected by one single particle on its way through the tissue.

The density of ionizations caused differs from one type of radiation to the other. For example: to take the case of charged particles, electrons of 20 MeV leave a trail of about 10 ionizations per µm track length, but α-particles, on the contrary, more than 1000.

Each ionization in the tissue produces the same amount of energy transfer to the tissue. The density of ionizations from one charged particle is therefore proportional to the density of energy transfers. This density of energy transfers along the track of one particle is called linear energy transfer, LET. One distinguishes between ionizing radiations with low LET such as electrons or X- and γ-rays, and ionizing radiations with high LET such as α-particles or neutrons.

In short, depending on its specific LET, radiation will have quite different biological effects although the absorbed dose is the same (Michel, Burkart, this volume).

Summary

The quantification of the physical effects of ionizing radiation in human tissue is the basis of risk assessment. This quantification results from determination of kerma or absorbed dose. The procedure for the absolute determination of absorbed dose with an ionization chamber is discussed. The biological effects of ionizing radiation are dependent, not only on the absorbed dose but also on a second physical parameter, the linear energy transfer.

Résumé

Commentaires concernant la dosimétrie des radiations ionisantes et le transfert d'énergie linéique

La description quantitative des effets physiques déclenchés par les rayons ionisants dans les tissus est la base de toute estimation de risque. Pour cela il faut déterminer la dose absorbée ou le kerma. La détermination de la dose absorbée au moyen d'une chambre de ionisations est présentée. Les effets biologiques provoqués par les rayons ionisants dépendent, mise à part la dose absorbée, du transfert d'énergie linéique.

Zusammenfassung

Bemerkungen zur Dosimetrie ionisierender Strahlung und zur linearen Energieübertragung

Die Quantifizierung der physikalischen Effekte ionisierender Strahlung im Gewebe bildet die Grundlage von Risikobetrachtungen. Diese Quantifizierung erfolgt durch die Ermittlung der Dosisgrössen Kerma oder Energiedosis. Ein Verfahren zur absoluten Bestimmung der Energiedosis mit Hilfe einer Ionisationskammer wird dargelegt. Die biologische Wirkung ionisierender Strahlung ist neben der Energiedosis von einem weiteren physikalischen Parameter, der linearen Energieübertragung, abhängig.

Reference

1 *Johns HE, Cunningham JR.* The Physics of Radiology. Fourth Edition. Springfield, Illinois USA: Charles C. Thomas Publisher, 1983.

Address for correspondence:
Imogen Cordt-Riehle
Strahlenbiologisches Institut der
Universität Zürich
August-Forel-Str. 7
CH-8029 Zürich/Switzerland