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# What is "ionizing radiation"?

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**Abstract**

*The scientific background of radiation protection and hence "ionizing radiation" is undergoing substantial progress since a century. Radiations as we are concerned with are from the beginning defined based upon their effects rather than upon the physical origin and their properties. This might be one of the reasons why the definition of the term "ionizing radiation"in radiation protection is still weak from an up to date point of view in texts as well as in international and national standards. The general meaning is unambiguous, but a numerical value depends on a number of conditions and the purpose. Hence, a clear statement on a numerical value of the energy threshold beyond a radiation has to be considered as "ionizing" is still missing. The existing definitions are, therefore, either correct but very general or theoretical and hence not applicable. This paper reviews existing definitions and suggests some issues to be taken into account for possible improvement of the definition of „ionizing radiation".*

## 1. Introduction and background

Ionizing radiation as we are concerned with is from the beginning defined upon the causation of certain effects rather that on their physical properties of the sources. In the very beginning, standards were concerned with either x-rays or radiation- (rather radium) sources /NB 31/, and there was little need to coin a common term for the effects of these sources. Later a more consistent approach was required as the standards were dealing with both x-ray and radioactive radiation sources. Therefore, a common term was needed to describe the radiation the standards are concerned with in a more general form as this was done by "ionizing" as by ICRP 1955. At this time there was no real need for a more precise definition than on the ability of a certain radiation to "ionize". Although other issues undergo an enormous development with time, the definition of ionizing radiation remained unchanged. This might be one of the reasons why the definition of the term "ionizing radiation" is still weak in texts as well as in international and national standards. The general meaning is unambiguous, but all definitions avoid consistently a clear statement on a numerical value of the energy threshold beyond a radiation is to be considered as "ionizing".

Occasionally, other definitions were made in order to fulfil particular requirements, e.g. for measuring quantities. Since the recent European Standards introduce a new definition, it seems due to review the basis of the definitions. This is because in radiation protection standards dealing with "ionizing radiation", a clear statement what radiation in terms of energy they are concerned with is still generally avoided. This might be acceptable in scientific texts or papers, where a scientific dispute and a case oriented interpretation can be expected. However, this does not apply to legal issues as international or national standards, where a legal and pragmatic interpretation is carried out by definition.

## 2. Some more or less recent definitions on ionizing radiation and their properties

The following definitions and statements can be found in some relevant standards and textbooks. Original supplementary paragraphs to the definitions are in italics.

**ICRP 1955:** Ionizing Radiation: electromagnetic radiation (x-ray or γ-ray photons or quanta), or corpuscular radiation (α-particles, β-particles, positrons, neutrons and heavy particles) capable of producing ions.

**BEIR (1980):** Radiation is **directly ionizing** if it carries an electric charge that directly interacts with atoms in the tissue or medium by electrostatic attraction. **Indirect ionizing** radiation is not electrically charged, but results in production of charged particles by which its energy is absorbed. *It takes about 34 eV of energy to produce a ionization. Most human exposures to radiation are of energies of 0.05 - 5 million electron volts (MeV) - energies at which many ionizations occur as the radiation passes through cells.*

**ICRU 33 (1980):** *Ionization* is a process in which one or more electrons are liberated from a parent atom or molecule or other bound state. Ionizing radiation consists of charged particles (for example, positive or negative electrons, protons or other heavy ions) and/or *uncharged* particles (for example, photons or neutrons) capable of causing ionization by primary or secondary processes. *However, the ionization process is not the only process by which energy of the radiation may be transferred to a material. A second important phenomenon is excitation, a process which can also have physical, chemical, or biological consequences. A radiation, such as low energy photons, may be ionizing in one medium but not in another. Hence, the choice of a suitable cutoff, below which a radiation is considered as non-ionizing, will depend on circumstances. The definitions given in this report apply to a specified fixed cutoff value where relevant.*

**DIN 6814 (1980)** Ionisierende Strahlung ist eine Strahlung, die aus Teilchen besteht, die ein permanentes *Gas* unmittelbar (direkt) oder mittelbar (indirekt) durch Stoß zu ioniseren vermögen. Der Begriff „Teilchen" umfaßt in dieser Norm Korpuskeln (Teilchen und Ruhemasse) und Photonen (Teilchen ohne Ruhemasse). *Eine bestimmte Teilchenenergie als Grenze zwischen nichtionisierender Strahlung (zum Beispiel sichtbares Licht) und ionisierender Strahlung läßt sich nicht angeben, da die zur Stoßionisation benötigte Energie auch von der Art des ionisierten Gases abhängt. Die in der Radiologie angewendeten Strahlungen haben im allgemeinen Teilchenenergien oberhalb 1 keV und gehören dehalb eindeutig zu den ionisierenden Strahlungen.*

**ATTIX (1986)** Ionizing radiations are generally characterized by their ability to excite and ionize atoms of matter with which they interact. *Since the energy needed to cause a valence electron to escape an atom is of the order of 4 - 25 eV, radiations must carry kinetic or quantum energies in excess of this magnitude to be called "ionizing". As will be seen, this criterion would seem to include electromagnetic radiation with wavelengths up to about 320 nm, which includes most of the ultraviolet (UV) radiation band (~ 10 - 400 nm). However, for practical purposes these marginally ionizing UV radiations are not usually considered in the context of radiological physics, since they are even less capable of penetrating through matter than is visible light, while other ionizing radiations are generally more penetrating.*

**Austrian Standards ON A6601 (1995):** Ionisierende Strahlung: Photonen- oder Teilchenstrahlung, die in einem *Gas* durch Stoß direkt oder indirekt Ionen erzeugen kann. *In dieser Definition wird Strahlung mit einer Energie über 5 keV als ionisierende Strahlung festgelegt. Eine physikalische Abgrenzung zu nichtionisierender Strahlung ist nicht möglich, weil die Ionisation vom Material abhängig ist.*

**INTERNATIONAL BASIC SAFETY STANDARDS (1996)** For the purpose of radiation protection, radiation capable of producing ion pairs in biological material(s).

**EURATOM Guideline (1996):** Ionizing Radiation: The transfer of energy in the form of particles or electromagnetic waves of a wavelength of 100 nm or less or a frequency of $1.10^{15}$ Hz or more capable of producing ions directly or indirectly.

It can be seen that some definitions are most general, some refer to a certain material or to certain conditions. The definitions referring to a gas are intended mainly for the purpose of measuring external radiation.

Regarding the most recent EURATOM definition, it can be concluded:

a) ionizing radiation is not a transfer
b) since ionization is by mainly by collision processes, an energy corresponding to a wavelength has to be converted to a kinetic energy of particles. This calculation leads to the following numerical figures. A wavelength of 100 nm corresponds to:
   * 6 eV for electrons
   * about $10^{-7}$ eV for neutrons (corresponding to a temperature of <1 K) and protons
   * even less for α-particles
   * 12,4 eV for photons.
c) the wavelength chosen is just the border to radiation which is considered as non-ionizing.

The EU- definition seems not applicable also for some other reasons because the standards covers at the low energy end a much smaller range of energy than the definition of ionizing radiation. It is not advisable to include radiations with certain properties into standards without guidelines applicable for these properties. Since a definition in a formal standard shall keep the possibility of misinterpretation from a formal point of view as low as possible, this definition has to be changed. A definition as in the Intenational BSS is sufficient and reasonable for that purpose and should be adopted as it is.

## 3. Proposal

This paper is not intended yet to suggest a reasonable final definition, but some aspects regarding the low energy end will be addressed.

The most pragmatic approach for defining a lower energy cutoff is to take just the binding energy as the energy required to produce an ion pair. The lowest binding energy is in the order of 4 eV for some elements as Cs, Rb, K, Na, Li, which are not relevant for biological effects. Elements being more important as H, C, O, N have corresponding energies of about 12 eV. However, a particle carrying an energy numerical equal to the binding energy is unable to produce ions, because the incident energy E produces in competing processes ions, excited states, and subexcitation atoms, the yield between the competing processes being energy dependent. For example, it has been shown (ICRU 31 p. 29) for electrons in air that the energy required to produce an ion pair in air is about 33 eV for a particle with an incident energy of 100 eV or more, but more than 1 keV for a particle with an incident energy of less than 15 eV.

However, from a scientific point of view, the present situation as described above is not satisfactory, and an agreement on a numerical value has to be found. However, a single figure will not meet all requirements. This is because a sequence of processes take place until a ion pair which might be relevant for a **possible biological effect** is produced under given circumstances.

a) The energy of the initial radiation must exceed the binding energy of the valence electron $E_0$ of a relevant atom.
b) Only a certain fraction of the initial energy leads to ionization
c) The initial radiation must be capable to penetrate the relevant material (as air and body tissue) to reach the site where the ionization might take place.

d) Ionization takes place only with certain probability (as the cross section for indirect ionizing radiation).
e) The density of the material have to be taken into account (as biological tissue is different than gases)
f) Geometrical and exposure conditions influence the energy required to produce ionization

The requirements of **measurements** of external exposure lead to different constraints than the conditions above. The situation is quite similiar to different approaches of operational and limiting dose quantitites)

**Conclusions**
It was shown that the present definitions of „ionizing radiation" are either general and hence vague or not applicable. It is therefore required to define for certain exposure conditions well founded definitions to satify both radiological as well as measuring requirements

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