CONCEPTS, QUANTITIES AND UNITS FOR NON-IONIZING RADIATION PROTECTION

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Protection against non-ionizing radiation (NIR) is the subject of an increasing interest, but the use of very different concepts, depending on the type of radiation or application, makes it rather difficult to compile studies and the data obtained in an uniform way. Also, the legal application and public appreciation of the concepts of radiation protection are hampered by the lack of uniformity in this field.
The International Non-Ionizing Radiation Committee (INIRC) of the IRPA set up a working group** with the task to prepare a review of concepts, quantities, units and terminology for NIR protection as a service to workers in this discipline. The present paper summarises the results obtained by this working group which are to be published fully in a forthcoming report. The main aim of the report is to provide an inventory of concepts, quantities, units and terminology currently used for purposes of NIR protection. Furthermore a systematic classification and comparison of these quantities is given, and in particular the concepts used to quantify exposure limitation and radiation protection standards are summarised and discussed.

The inventory of quantities and units is following as closely as possible the recommendations of the ISO Standards Handbook. The material is subdivided in four sections:
- periodic and radiation phenomena;
- electromagnetic radiation and fields;
- optical radiation;
- ultrasound.

The classification and comparison of quantities is done according to three criteria:
1. The physical characteristics of the radiation field, taking sources and receptors of radiation into account (radiometric quantities).
2. The interaction of NIR with matter.
3. Quantities adequate for the specification of exposure of biological objects to NIR (dosimetric quantities).

Radiometric quantities can be grouped into seven generic terms: energy; energy per time; energy per area; energy per volume; energy per time and solid angle; and energy per time, area and solid angle. This grouping can be compared for various NIR radiation and the ionizing radiation.
The quantities energy and its time derivative are most frequently applied to characterise a source.
The radiation field at any given point can be characterised by the spatial energy density, and by defining the energy transport through space (energy per area and energy per time and area) at that point. To indicate the existing diversity, consider the term energy per time and area. It can be used in three ways:

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a. radiant power per unit cross section of a small sphere (energy fluence rate, energy flux density, radiant flux density, power surface density, acoustic intensity);
b. radiant power per unit area of the source surface ("radiant exitance" for optical radiation); and
c. radiant power per unit area of a receiving surface (optical "irradiance").

Sources of radiation with an angular dependence can be characterized by the power per solid angle ("radiant intensity") and power per area and solid angle ("radiance").
Great care has been taken to specify the orientation of the surface of a source or receptor in relation to the radiation field. Three approaches are being used and must be carefully distinguished in practical applications:

- Area element perpendicular to the direction of radiation: this approach is used e.g for the definition of optical radiance and for energy radiance in ionizing radiation.
- Cross-sectional area of a sphere: this is the reference surface in the definition of e.g. energy fluence (for ionizing radiation), of power surface density (for the electromagnetic radiation), and of acoustic intensity (for ultrasound).
- Area element not perpendicular to radiation: this reference surface is used e.g. for the definition of irradiation and radiant exposure (da = area element of the receptor surface) since for the optical radiations, the penetration depth in matter is generally very small. Therefore, the degree of biological effect is often determined by the amount of radiant energy incident on a given surface area.

For increasing wavelenghts, energy, power and derived radiometric quantities are concepts which are becoming less satisfactory. In the near field, which becomes more important under such conditions, the inverse square law does not apply, and the ratio of the electric to the magnetic field is not fixed. This problem becomes important for radiofrequencies and extremely low frequencies. Under such conditions, a sufficiently general specification of the electric and magnetic fields, $\underline{E}$, $\underline{H}$, of the electromagnetic wave at each location of interest is required.

Concepts for the characterisation of interaction processes, such as scattering, attenuation, transmission, reflection, refraction and diffraction are well known from the physical theories describing radiation phenomena in media and at boundaries. Analogies between ionizing and non-ionizing radiation are limited, due to the rather different nature of underlying physical interaction processes.

In the broad sense, the term "dosimetry" is used to quantify the parameters necessary for the characterisation of an exposure.
In the field of NIR, different characteristics of physical interaction mechanisms, measurement conditions and techniques, as well as differences in and poorer knowledge of biological response mechanisms have led to a diversity of quantities used for the specification of exposure.

It can be stated in general that, across the NIR spectrum, the temporal characteristics of exposure are of critical importance, and the contribution of ambient factors such as temperature must be taken into account. For example, if the emphasis is on the limitation of thermal effects, in the RF region many data at present seem to support introduction of exposure limits which are based on the instantaneous rate of energy depostion, as opposed to the case of ionizing radiation (see NCRP report no.67). The acoustic and ultrasonic fields represent another example where quantities other than cumulative energy deposition may be useful to specify exposure limits.
A compilation of the quantities used for expressing limits of exposure is given in Table 1. For a detailed discussion of the table, the reader is referred to the forthcoming report of the working group.

In conclusion, a well-developed and internationally accepted terminology exists for the classical fields of electromagnetism, optics and acoustics. It can be utilized for the purposes of NIR protection, under consideration of the practical circumstances and biological constraints.
There exists already a considerable degree of harmonization of radiometric physical concepts, with some remaining differences in the names of quantities.
Interaction coefficients reflect a higher degree of non-uniformity and more work should be done to clarify the picture.
Exposure quantities (Table 1) show a great diversity and non-uniformity. It seems at the moment that the introduction of unified dosimetric concepts is not practicable and desirable for all types of NIR. Coexistence of different quantities for different frequency ranges and purposes appears as a necessity, both for intrinsic and practical reasons, at least at the present time. However existing possibilities of introducing a greater uniformity require further serious examination.

References:

ISO Standard Handbook 2, 1979.
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Table 1.
Selected quantities for the specification of limits of exposure to non-ionizing radiation (dosimetric quantities).

	GENERIC TERMS					
Radiation type	Field parameters	Energy/area	Energy / time/area	Energy / time-area-solid angle	Energy / mass	Energy / mass-time
Ionizing radiation					Absorbed dose (Gy)	Absorbed dose rate (Gy/s)
					Dose equivalent (Sv)	Dose equivalent rate (Sv/s)
Radiofrequencies	Effective electric field strength (V/m) Effective magnetic field strength (A/m)		Power surface density (W/m^2)		Specific absorption (J/kg)	Specific absorption rate (W/kg)
ELF	Electric field strength (V/m) Magnetic field strength (A/m)					
Optical		Radiant exposure (J/m^2)	Irradiance (W/m^2)	Radiance ($W.m^{-2}.sr^{-1}$)		
			Effective irradiance (W/m^2)			
Ultrasound			Acoustic intensity (W/m^2)			
Ultrasound (airborne)			Acoustic pressure level (dB)			