ACCURATE SPECIFIC ABSORPTION RATE (SAR) NUMERICAL EVALUATION

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In recent years, there has been an increasing public concern about the possible risks for human health due to the interaction with electromagnetic (EM) fields. Consequently, the major public organizations in the world have established safety guidelines for radiofrequency (RF) exposure, as for instance the recently revised IEEE RF Safety Standard C.95.1-2006 and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Safety Standard. Such guidelines are based on the specific absorption rate (SAR) averaged over a certain reference tissue mass, usually 1 g, 10 g or the whole body mass; safety limits are accurately fixed distinguishing among occupational and general public exposures and among different body parts, and they are also frequently updated as a consequence of the results produced by the scientific community. Nevertheless, in contraposition to the constant attention dedicated to the refinement of the safety limits, it is quite evident a lack of indications about how the SAR should be evaluated. As well known, in fact, the SAR averaged over a certain reference mass, can be written as:

$$SAR_{rm} = \int_{V(rm)} \sigma |E|^2 / 2 \; dv \Big/ \int_{V(rm)} \rho \; dv \,, \qquad (1)$$

where σ [S/m] is the tissue conductivity, E [V/m] the electric field, ρ [kg/m^3] the tissue density, rm the reference mass (usually 1g, 10g or the whole body mass) and $V(rm)$ is a volume containing rm.

It can be noted that the shape of the volume containing rm does affect the dividend of (1); the distribution of the electric field, in fact, varies greatly from point to point inside the tissues, so that the use of different volumes could generate strong discrepancies.

It is reasonable wondering, hence, how the shape of the volume containing the reference mass could impact the SAR value itself and if, consequently, such a shape must conveniently be standardized. A spherical volume is the most logical choice, because it does naturally select the set of points which are as close as possible to the evaluation point. Moreover, spherical shapes are invariant with respect to the chosen reference system. Nonetheless, IEEE guideline bases its safety limits on cubical volumes, whilst ICNIRP standards lack specific indications on the subject.

Moreover, when numerical techniques are adopted for the EM field evaluation, the simulation domain is discretized in elementary cells, so that the averaged SAR must be computed through the following formula:

$$SAR_{rm} = \sum_{i \in \overline{V}(rm)} (\sigma_i |E_i|^2 / 2) \Delta V_i \Big/ \sum_{i \in \overline{V}(rm)} \rho_i \Delta V_i \,, \qquad (2)$$

where the index i indicates the generic elementary cell and $\overline{V}(rm)$ the discretized volume containing the reference mass rm. The use of a certain volume $\overline{V}(rm)$, the adopted spatial discretization step, the treatment of internal air and other issues, can cause strong discrepancies when estimating (2).

An accurate comparison among many different numerical techniques for the numerical evaluation of the SAR, some of them commonly adopted and some others recently proposed by the authors, shows that even radically different algorithms can comply with the few indications reported in RF safety guidelines. Moreover, discrepancies among results are relevant (up to

90% in some cases), and the necessity of a standardization of the techniques for the SAR calculation emerges as an effective must. This enforces also a more detailed discussion of local SAR values, along with an analysis of the shape of the integration volume, the importance of spherical geometries (instead of cubic ones) and other related issues.