Health Effects

Update of IEEE Radio Frequency Exposure Guidelines

■ **James C. Lin**

The IEEE Standards Association Standards Board had, on 3 October 2005, formally approved IEEE Std C95.1 "Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz." Official publication of the standard by the IEEE was expected to be by the end of 2005 or soon thereafter. It is likely that by the time this column appears in print, the formal publication already may have taken place. In any event, the newly approved standard represents a complete revision of and replaces IEEE Std C95.1-1991. Note that there had been several amendments in the interim.

The 1991 edition was developed by IEEE Standards Coordinating Committee 28 (SCC-28) under the sponsorship of the IEEE Standards Board and was submitted to the American National Standards Institute (ANSI) for recognition as an American standard, in accordance with policies of the IEEE. In 2001, the name International Committee on Electromagnetic Safety (ICES) was approved by the IEEE Standards Association Standards Board in place of SCC-28.

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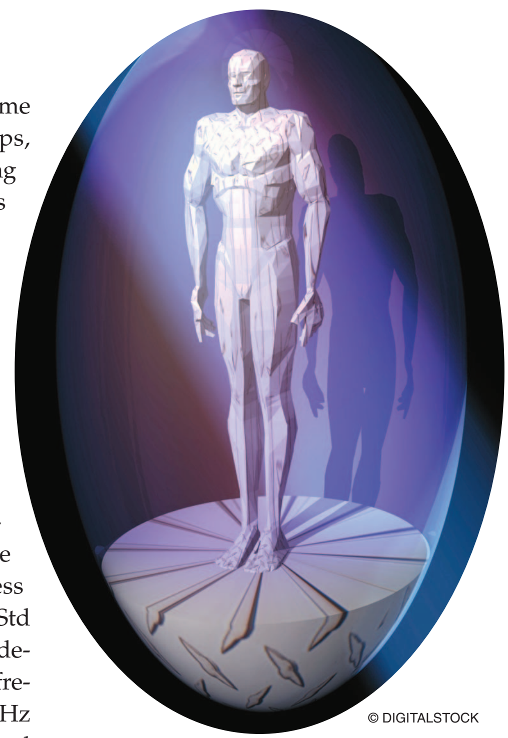
With news of the approval, some observers and interested groups, including the Mobile Manufacturing Forum (MMF), have taken positions with respect to the International Commission on Nonionizing Radiation Protection (ICNIRP) guidelines [1] and their relationship to the new IEEE standard. For example, in a recent *View Point* article titled, "New IEEE C95.1 Revision a Significant Step Towards Global Standards Harmonisation," MMF asserted in two ranges that encompass the frequencies used in mobile telecommunications and wireless devices and systems, the new IEEE Std C95.1 and the ICNIRP exposure guidelines are harmonized [2]. The two frequency ranges mentioned are 100 kHz to 3 GHz with respect to SAR limits and 30 MHz to 100 GHz regarding external field intensity and power density limits for the general public.

Without actually saying it, the *View Point* article seemed to recognize there may be potential differences. To put it simply, the new IEEE standard is not identical to the ICNIRP limits—in contrast to the MMF statement—even for frequencies used in mobile telecommunication systems. Moreover, the newly approved IEEE standard departs in major ways from the 1991 edition. This



column will examine some of the more salient aspects applicable to mobile communication. I plan to cover the other differences at a future date.

In the frequency ranges of 100 kHz to 3 GHz, the new IEEE standard of 0.08 W/kg averaged over the whole body for the general public is based on restricting heating of the body during whole-body exposure. It is to be applied when an RF safety program is not available. The new basic restriction for localized exposure is 2 W/kg for most parts of the body. For the extremities (arms and legs distal from the elbows and knees, respectively, including the fingers, toes, hands, and feet) and for pinnae, the basic restriction expressed in terms of SAR is 4 W/kg. The value of SAR is obtained by averaging over some specified time periods (i.e., 6–30 min) and by averaging over any 10 g of tissue (defined as a tissue volume in the shape of a cube). The basic restrictions for localized exposure are enacted to prevent excessive temperature elevation that might result from localized or nonuniform exposure.

For frequencies between 3–100 GHz, the basic restrictions are the same as the derived limits of maximum permissible exposures (MPEs). The value of MPE is obtained by averaging over some specified time periods that vary 2.5–30 min for different frequencies.

The frequency dependent MPE is a convenient metric for exposure assessment and can be used in determining whether an exposure complies with the basic SAR restrictions. They are referred to as action levels in the new IEEE standard and for incident power densities; they range from 1,000 W/m^2 at 100 kHz, to 10 W/m^2 at 100 GHz, with the lowest value of 2 W/m^2 between 30–400 MHz. Again, these values were established to protect against tissue heating.

The new IEEE standard includes several major differences from the 1991 edition.

First and foremost, for the first time in its history, the new IEEE standard instituted an exclusion for the pinnae or the external ears by relaxation of the above-mentioned basic SAR restriction from 2 W/kg to 4 W/kg. This choice segregates tissues in the pinnae apart from all other tissues of the human head.

Of equal significance is the basic restriction for localized exposure at 2 W/kg in terms of SAR averaged over any 10 g of tissue. The SAR value has been increased from 1.6 W/kg averaged over any 1 g of tissue to 2 W/kg over any 10 g of tissue. Aside from the numerical difference between the SARs, the volume of tissue mass used to define the SARs in the new standard was increased from 1 g to 10 g. The increase in tissue mass can have a profound influence on the actual quantity of RF energy allowed to be deposited in tissue by the new exposure standard. It has been well established that the distribution of absorbed microwave energy is nonuniform, and it varies greatly from point to point inside a body. An averaging volume that is as large as 10 g would tend to artificially flatten out the SAR distribution, whether it is computed or measured. And the smoothing tends to substantially reduce the resulting SAR value. Thus, a 10-g SAR at 2 W/kg could be equivalent to 1-g SARs of 5 W/kg or higher. Simply put, the absorbed energy averaged over a defined tissue mass of 10 g is inherently low compared to a 1-g SAR.

The spherically shaped human eye has a total mass of about 10 g. The use of an averaging volume as large as 10 g does not attribute any distinctions among tissues in the eye and completely ignores the wide variation of SAR distribution throughout the eyeball. The choice of 2 W/kg over 10-g tissue volume in the shape of a cube could permit the deposition of RF or microwave energy in different parts of the eye that exceeds the basic SAR restriction by a large margin, while keeping the SAR for the entire eye below 2 W/kg.

At 2.5 GHz, the penetration depth in muscle tissue for a plane model is about 1.7 cm. A linear dimension of approximately 2.15 cm in the shape of a cube would correspond to 10 g of muscle tissue. Clearly, the exponentially attenuated SAR would be significantly greater close to the superficial layer of muscle tissue, which would be easily revealed by the 1-g SAR but masked by a 10-g SAR.

Moreover, the new IEEE standard stipulates that when averaging SAR over a 10-g volume of tissue in the extremities or pinnae, only SAR values for that tissue may be considered. In any cubic volume containing tissue from both the body and the extremities or pinnae, each must be considered separately. For example, when determining the SAR in a 10-g cube of tissue in the body, any lack of tissue contained in the cube from the extremities or pinnae is treated as air, with zero mass and zero SAR. This procedure appears rather ambiguous and potentially could render a wide variety of SAR values in practice.

The 1-g SAR is scientifically a more precise representation of localized RF or microwave energy absorption and a more biologically significant measure of SAR distribution inside the body or head. It should be noted that the sensitivity and resolution of present day computational algorithms and resources and experimental measurement schemes can provide accurate SAR values with a spatial resolution on the order of 1 mm, in dimensions.

Another difference in the new standard from its 1991 edition pertains to the upper frequency boundary over which whole-body-averaged SAR, serving as the controlling basic restriction, has been reduced from 6 GHz to 3 GHz in the new standard. Likewise, the upward ramp that starts for the relaxation of the power density limits for localized exposure also has been changed from 6 GHz to 3 GHz.

There are other differences in the MPE limits between the new standard and its 1991 edition for the general public in the frequency range between 30 –100 GHz. The new MPE in terms of power density is 2 W/m^2, between 30–400 MHz. It ramps up from 2 to 10 W/m^2 between 400–2,000 MHz. For frequencies greater than 2,000 MHz, the MPE is 10 W/m^2. Also, the designated frequency bands and the associated MPEs are different. Specifically, in the 1991 edition, they were 10 W/m^2 between 30–300 MHz. The ramp up from 10 to 100 W/m^2 took place between 300 and 3,000 MHz. For frequencies greater than 3,000 MHz, the MPE was 100 W/m^2. In comparison, MPEs in the new IEEE standard are, in general, more restrictive between 30 MHz and 100 GHz.

The new IEEE standard contains some of the characteristics of the current ICNIRP guidelines, but it also includes a number of differences. The following section highlights some of these similarities and differences for exposure of the general public.

The principal similarities are basic restrictions in terms of a 2 W/kg SAR averaged over 10 g of tissues in the head and trunk and the reference levels or maximum permissible exposures of 2–10 W/m^2 for certain frequency ranges (i.e., 30 MHz to 100 GHz).

The major differences include the tissue mass and time period over which SAR values are to be averaged and the applicable frequency bands for the MPEs. Also, a most significant difference is the exclusion of pinnae from the head by the IEEE, which made it possible to allow a higher local SAR value for the basic restriction at 4 W/kg. In the ICNIRP guidelines, pinnae are not excluded and are treated, as they should, as integral parts of the human head.

The basic restrictions for whole-body average SAR and local SAR for frequencies between 100 kHz and 10 GHz are 0.08 and 2 W/kg, respectively. Moreover, localized SAR values in the ICNIRP guidelines are to be averaged over any 10-g mass of contiguous tissue. ICNIRP guidelines do not specify a cubic volume of tissue as the averaging mass. In addition, all SAR values are to be averaged over a 6-min period in the ICNIRP guidelines, in contrast to the 2.5–30 min stipulated in the new IEEE standard.

For whole-body exposures, the ICNIRP guidelines specify that the maximum spatial power densities, averaged over 1 cm^2, should not exceed 20 times the allowed spatial averaged values (10 W/m^2) over 20 cm^2 for frequencies between 10–300 GHz. Power densities are to be averaged over any $68/f^{1.05}$-min period (where f is in gigahertz) to compensate for the progressively shorter penetration depth as the frequency increases. Thus, the spatial peak value of the power density should not exceed 200 W/m^2 over any 1 cm^2 for all practical purposes.

As mentioned previously, the new IEEE MPEs are 2 W/m^2 for frequencies between 30–400 MHz. It ramps up from 2 to 10 W/m^2 between 400–2,000 MHz. For frequencies greater than 2,000 MHz, the MPE is 10 W/m^2. Furthermore, it provides that the maximum spatial power density should not exceed 20 times the square of the allowed spatially averaged values at frequencies below 400 MHz and should not exceed the 40 W/m^2 at frequencies between 300 MHz and 3 GHz, $18.56(f)^{0.699}$ W/m^2 at frequencies between 3–30 GHz (f is in gigahertz), and 200 W/m^2 at frequencies above 30 GHz, within the specified averaging time period.

In summary, the new IEEE standard is not identical to the ICNIRP guidelines, in contrast to some claims, even for frequencies used in cellular mobile communications and wireless devices and systems. The new IEEE standard contains some of the characteristics of the current ICNIRP guidelines, but it also includes a number of differences. Moreover, the newly approved IEEE standard departs in major ways from its 1991 edition. While the new IEEE standard and the current ICNIRP exposure guidelines possess some similarities, they are far from harmonized. Global harmonization of RF exposure standards for the general public would be a very desirable goal. However, it should not be approached on the basis of harmonization for harmonization's sake. The process must be aimed toward improvement beyond the current state-of-affairs through better precision in SAR specification, less uncertainty in exposure assessment, more definitive biological results, and greater reliability in health status data and end points. Advances in bioelectromagnetic research and electronic, computer, and wireless technology have and will continue to facilitate this process. After all, a more scientifically based and commonly recognized exposure standard would bring palpable benefits to consumers, manufacturers, operators, and regulators alike.

References

[1] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (UP TO 300 GHz)," *Health Physics*, vol. 74, pp. 494–522, 1998.

[2] [Online]. Available: http://mmfai.info/public/docs/eng/Viewpoint%20C95%2E1%2004Oct05%2Epdf