Abstract

The IEEE Standards Association recently formally approved a new IEEE 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 by late 2005, or soon thereafter. The new IEEE standard contains some features of the current ICNIRP guidelines, but it also includes a number of differences. The new IEEE standard is not identical to the ICNIRP guidelines, even for frequencies used in cellular mobile communications and wireless devices and systems. Moreover, the newly approved IEEE standard departs in major ways from its 1991 edition and subsequent amendments.

Keywords: Biological effects of electromagnetic radiation; electromagnetic radiation; electromagnetic radiation effects; exposure guidelines; public safety; Land mobile radio cellular systems
MMF asserted that in two ranges that encompass the frequen-
cies used in mobile telecommunications and wireless devices and sys-
tems the new IEEE 955.1 and the ICNIRP guidelines are harmonized [2]. The two frequency ranges men-
tioned were 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 that 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 gen-
eral public is based on restricting heating of the body during
whole-body exposure. It is to be applied when an RF safety pro-
gram is not available. The new basic restriction for localized expo-
sure 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 restric-
tion expressed in terms of SAR is 4 W/kg. The value of SAR is
obtained by averaging over some specified time periods (i.e., six to
30 min) and by averaging over any 10 g of tissue (defined as a tis-
ue volume in the shape of a cube). The basic restrictions for
localized exposure were enacted to prevent excessive temperature
elevation that might result from localized or nonuniform exposure.

For frequencies between 3 GHz and 100 GHz, the basic restric-
tions are the same as the derived limits of maximum permis-
sible exposures (MPE). The value of maximum permissible expo-
sure is obtained by averaging over some specified time periods,
which vary from 2.5 to 30 min for different frequencies.

The frequency-dependent maximum permissible exposure is a
convenient metric for exposure assessment, and can be used in
determining whether an exposure complies with the basic SAR
restrictions. The maximum permissible exposures are referred to as
action levels in the new IEEE standard. For incident power densi-
ties they range from 1000 W/m² at 100 GHz, with the lowest value,
of 2 W/m², between 30 and 400 MHz. Again, these values were established to protect against
tissue heating.

The new IEEE standard includes several major differences

First and foremost, for the first time in its history, the new
IEEE standard instituted an exclusion for the pinnae or the external
carapace by relaxation of the above-mentioned basic SAR restriction
from 2 W/kg to 4 W/kg. This change 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 tis-
sue. 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. Furthermore, the smoothing tendency to sub-
stantially 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 eye-
ball. The choice of 2 W/kg over a 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 sig-
ificantly 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 pro-
cedure appears rather ambiguous, and could potentially result in 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 biologi-
cally significant measure of SAR distribution inside the body or
head. It should be noted that the sensitivity and resolution of pre-
sent-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 maximum permissible
exposure (MPE) limits between the new standard and its 1991 edi-
tion for the general public in the frequency range between 30 MHz
and 100 GHz. The new maximum permissible exposure in terms of
power density is 2 W/m² between 30 and 400 MHz. It ramps up
from 2 to 10 W/m² between 400 and 2000 MHz. For frequencies
greater than 2000 MHz, the maximum permissible exposure is
10 W/m². Also, the designated frequency bands and the associated
maximum permissible exposures are different. Specifically, in the 1991 edition, they were 10 W/m² between 30 and 300 MHz. The ramp-up from 10 to 100 W/m² took place between 300 and 3000 MHz. For frequencies greater than 3000 MHz, the maximum permissible exposure was 100 W/m². In comparison, maximum permissible exposures 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 of maximum permissible exposures of 2 to 10 W/m² 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 maximum permissible exposures. 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 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 six minute period in the ICNIRP guidelines, in contrast to the 2.5 to 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 cm², should not exceed 20 times the allowed spatial averaged values (10 W/m²) over 20 cm² for frequencies between 10 and 300 GHz. Power densities are to be averaged over any 68/√π⁰ minute period (where π is in GHz) 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/m² over any 1 cm², for all practical purposes.

As mentioned above, the new IEEE maximum permissible exposures are 2 W/m² for frequencies between 30 and 400 MHz. It ramps up from 2 to 10 W/m² between 400 and 2000 MHz. For frequencies greater than 2000 MHz, the maximum permissible exposure is 10 W/m². 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/m² at frequencies between 300 MHz and 3 GHz, 18.56(√π⁰) W/m² at frequencies between 3 and 30 GHz (π is in GHz), and 200 W/m² 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 features 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 (and its subsequent amendments). While the new IEEE standard and the current ICNIRP exposure guidelines possess some similarities, they are far from harmonized. Global harmonization of radio-frequency 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 accurate 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
