RF Safety Standard Development

RF safety standards review all scientific studies to determine at what exposure levels deleterious effects occur. The earliest work in this field was performed by Herman Schwan in 1953, who proposed an exposure limit of 10 mW/cm^2 at all frequencies. The U.S. Navy, in collaboration with the IEEE, developed an exposure standards committee that published the C95 standard in 1966, which later evolved into the IEEE C95 family of standards and has been updated, as more research became available, in 1974, 1982, 1991, 1999, 2005 and 2019[1]. IEEE RF Safety Standards are developed by the International Committee on Electromagnetic Safety, ICES, and are endorsed by the American National Standards Institute, ANSI.

The 1974 and 1982 editions of the RF safety standards retained the Schwan exposure limit of 10 mW/cm^2 at all frequencies. As the science and understanding of RF absorption in the human body progressed, in 1982 the concept of specific absorption rate (SAR) was introduced to describe the rate of energy absorption in tissue, defined in units of watts per kilogram (W/kg). The concept of averaging exposure over time was also added, with a 6-minute time over which exposure should be averaged. Six minutes was presumed to approximate the thermal time constant of the body. With the safety limits based on SAR, it was realized that a single incident RF energy limit would not be appropriate for all frequencies.

Absorption can occur differently for electric and magnetic fields. Additionally, resonances cause absorption by the body to vary at different frequencies. A table of incident electric fields, magnetic fields and power densities as a function of frequency was introduced as the exposure limits (Radio Frequency Protection Guides) that would produce the SAR limit of 0.40 W/kg in the body that was presumed to be applicable to both those occupationally exposed as well as to the general population. The ANSI C95.1-1986 standard was developed by referring to 177 scientific studies.

Another scientific body, which is chartered by the U.S. Congress, is the National Council on Radiation Protection (NCRP), which developed RF exposure criteria in their NCRP Report #86 in 1986[2]. The NCRP exposure criteria matched the frequency range of the ANSI C95.1-1982 standard, 300 kHz to 100 GHz, but based its conclusions on 973 published scientific studies.

In 1991 the understanding of the interactions between electromagnetic energy and the human body had progressed to the point that an updated RF safety standard was appropriate. IEEE C95.1-1991 was based on science from 498 published studies. This version of the standard introduced the term, Maximum Permissible Exposure (MPE) and the concept of different exposure limits for people who were aware of their exposure and were trained to control it (the occupational population) and those who were either unaware of their exposure or did not have the training to do anything about it (the general public). The recommended exposure limits were set by taking the adverse effect threshold and dividing by a factor of 10 to provide a margin of safety for the occupational limits, and then dividing by another factor of 5 for the general public. Part of the motivation behind the safety factors was that the resulting MPEs would have margins of safety sufficient to account for not only RF-induced heating but, presumably, also any added environmental heat loads caused by ambient heat and humidity.

In 1985 the FCC first adopted rules on protection from excessive RF exposure that were based on the ANSI/IEEE C95.1-1982 standard. At that time, the Amateur service and numerous other services, were excluded from any requirement to comply with the exposure limits. In 1996, the FCC expanded the number of radio services that would have to conform to the commission's RF exposure rules and declared that their rules were based on a combination of NCRP Report #86 and ANSI/IEEE C95.1-1992. The primary difference between the ANSI/IEEE 1982 and 1992 standards was that the earlier standard specified a single Radio Frequency Protection Guide applicable to exposure of both controlled (occupational) and uncontrolled (general population) environments. The 1992 edition of the standard, for the first time, specified additional, more stringent limits for uncontrolled environments accessed by the general population. To date, the FCC MPE values have remained unchanged from the 1996 regulations. The term "uncontrolled environment" was used by IEEE at the time to mean that any RF exposure within that environment did not need to be controlled since it was below the exposure limit.

The IEEE C95.1 standard was updated in 1999 and mostly reaffirmed the conclusions of the 1991 standard. This update was based on 504 published scientific studies.

Criticism of the IEEE C95.1 standards has been voiced by people who believe that electromagnetic energy can affect human tissue without causing an increase in temperature. Up to the present, all of the IEEE standards have been based on preventing thermally initiated adverse effects. While the development of the IEEE standards has attempted to identify any deleterious effect reported in the scientific literature, regardless of whether it was related to excessive heat buildup or not, the most sensitive indicator of potentially adverse health effects has, over the years, always been behavioral disruption of food motivated tasks in laboratory animals.

In 2005 the C95.1 standard was updated with the results of 1287 published scientific studies. It identified the exposure levels at which any deleterious effect occurred and then based its limits on those levels. The same safety margins of 10 and 50 for the occupational population and general public were applied, respectively. Despite all of the additional effort to redefine the safety levels, the MPE levels remained virtually the same from 1991 to 2005.

The latest edition of the IEEE C95.1 standard was published in 2019. By that point, the number of published scientific studies upon which the standard was based had risen to 1550.

In parallel with the electromagnetic exposure standard development by IEEE, a European effort to standardize RF exposure limits resulted in the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines, which have been published in 1998[3], 2010[4] and 2020[5]. Many countries around the world have based their RF exposure rules on the ICNIRP standards. However, the safety levels between IEEE and ICNIRP do not differ by much. Both the IEEE standard and ICNIRP guidelines support the concepts of SAR, MPE, and averaging times. They both cover similar frequency ranges, though ICNIRP has split their standard into two parts: low frequency guidelines that were last updated in 2010 and cover the frequency range of 1 Hz to 100 kHz, and high frequency guidelines that were last updated in 2020 and cover the frequency range of 100 kHz to 300

GHz. The similarities between the IEEE standard and ICNIRP guidelines is not surprising, since they are both derived from the same body of science.

It is relevant to note, however, that with the most recent versions both the IEEE and ICNIRP exposure criteria, a substantive change was made with respect to how time averaging of exposure is applied; exposure of the whole body is based on a 30-minute averaging time while local exposure of just a part of the body is based on a six-minute averaging time. This new aspect of these exposure criteria departs substantially from the previous approach in which the 30-minute averaging time was associated with assessing exposure of the general population and the six-minute time was for assessing occupational exposure. The current FCC MPEs are still based on the older time-averaging approach found in the earlier IEEE standards.

References

1. IEEE C95.1-2019: IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.
2. NCRP Report #86: Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, 1986.
3. ICNIRP 1998: Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz).
4. ICNIRP 2010: Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz to 100 kHz).
5. ICNIRP 2020: Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz).