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Introduction

The federal Telecommunications Act of 1996,[1] enabling Federal Communications Commission (FCC) regulation of wireless communications including cellular telephones, paging systems and personal communications devices, excludes environmental safety and health concerns as reasons to deny local permits for transmitting antennas. Specifically, § 704(a) states:

> No State or local government or instrumentality thereof may regulate the placement, construction, and modification of personal wireless service facilities on the basis or the environmental effects of radio frequency emissions to the extent that such facilities comply with the Commission's regulations concerning such emissions.

The FCC's subsequent Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation state that environmental evaluation is required for non-rooftop cellular antennas only if the "height above ground to radiation center < 10 m and total power of all channels > 1000 W ERP (1640 W EIRP)" and for rooftop antennas only when the power is > 1000 W ERP or 1640 W EIRP.[2] Taken together, the Act and the guidelines define an apparent negligible risk threshold for radio frequency exposures from cellular phone transmitters. This paper reviews the physical and biological properties of

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1 Publ. L. 104-104, 110 Stat. 56 (1996), amending the National Wireless Telecommunications Siting Policy at 47 U.S.C. § 322(c).

2 FCC ET Docket No. 93-62, Aug, 1, 1996, at 86-7. "ERP" is effective radiated power and "EIRP" is equivalent isotropic radiated power.

radio frequency (RF) radiation that form the scientific rationale for a negligible risk threshold in the FCC regulations.

Both hazard and exposure are necessary for increased risk of adverse health effects from any environmental agent. While hazards from high exposures to RF radiation are well-known, the exposures from cellular transmitters are, and will likely remain, very low. In fact, the physical characteristics of cellular and personal communications services (PCS) communications that optimize network efficiency and maximize network capacity coincidently limit public exposures. The nature of biological effects from RF exposures, in this frequency range predominantly related to tissue heating, also obviate concern for adverse health effects from potential low-level exposures below the FCC's cut-off. Table 1 summarizes the physical and biological characteristics that form the rationale for the FCC's regulations.

Table 1

Physical and Biological Characteristics of Cellular RF Radiation that Justify a Negligible Risk Threshold for Environmental Site Evaluations

Physical Characteristics:
- Low power requirement due to small broadcasting areas
- Directional, highly focused antennas
- Duty cycle: antennas are "ON" only during phone calls

Biological/Biophysical Characteristics:
- Principal absorption mechanism is heating
- Energy too weak to break chemical bonds in DNA
- No evidence for effects from cumulative exposure
- No evidence for sensitive subpopulations
- No evidence for effects from exposures under previous Maximum Permissible Exposures (MPEs)

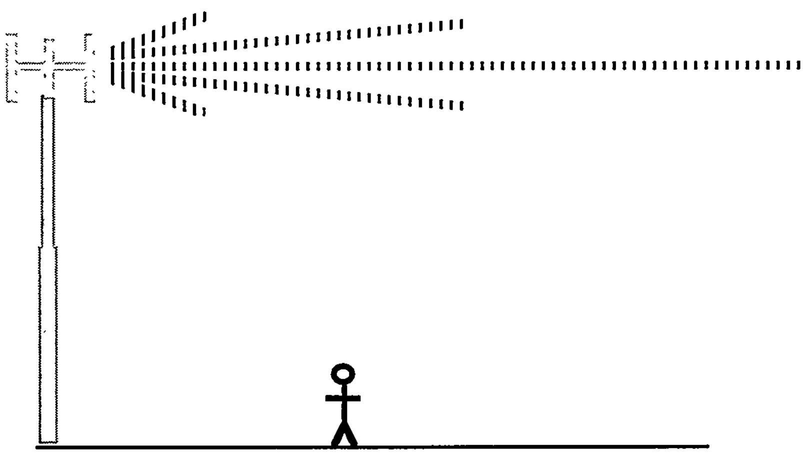
The Physical Characteristics of Antenna Emissions

Cellular telephones operate in the ultrahigh frequency (UHF) range of the electromagnetic spectrum, from about 820 to 960 megahertz (MHz), while PCS operate near 1,200 MHz, or 1.2 gigahertz (GHz). While the technology for generating these radio frequencies has been known for 50 years or more, the microelectronics that enable the use of miniaturized low-power radios and cellular telephones became available only recently. When the microcircuit radio technology is coupled with low-cost computers to encode, decipher and network many phone conversations simultaneously, portable phone networks are a natural result.

The first physical characteristic of cellular phone transmissions limiting potential exposures is that small broadcast areas require low transmission power. The "cell" of cellular telephones generally refers to the region serviced by one antenna. Urban and suburban regions are divided into many cells based on topography and network demand. At any given time, a typical cell manages only one to two dozen phone conversations. Ultimately, the greater the demand for conversations, the smaller the cell area. Thus, many cells are required to service a large urban area making a single, centrally-located antenna impractical.

The transmission power of cellular and PCS antennas is matched to cell size to avoid significant interference in adjacent cells. The smaller the cell, the lower the power necessary to reach to its perimeter. It also follows that smaller cells require less power, and creates lower potential public exposures, per call. This downward trend in the power required per call is likely to continue until a practical limit, ultimately determined by the electronic sensitivity of cellular phones, is achieved for each network configuration.

Figure 1
Relative Power Emitted from a Cellular Frequency Antenna



A second physical characteristic of cellular phone transmissions significantly reducing unnecessary public exposures near transmitting antennas is that they focus the broadcast toward the horizon. Similar to a flashlight, the purpose of focusing the "beam" is to increase the horizontal distance that it can reach for a given input power. The power radiated above, below and behind the antenna is reduced in proportion to the increased power focused toward the horizon. See Figure 1; the dotted lines are proportional to the power emitted in that direction. Most of the RF is directed toward the horizon, not downward. Multiple antennas are used such that the emitted signal pattern is more disk than spherically-shaped around the group of antennas.

The physical concept for the focusing effect is antenna gain (G), which, for the simple case of a half-wave dipole antenna, is given by:

$$G = \frac{\text{Equivalent Isotropic Radiated Power [EIRP]}}{\text{Effective Radiated Power [ERP]}} = 1.64$$

If we envision a spherical surface of equal power around a theoretical antenna emitting electromagnetic fields isotropically, then by comparison the simple dipole antenna "pushes" out the equator by 1.64 times and proportionally decreases power in other directions.[3] A strongly directional antenna, as illustrated, focuses power horizontally to a factor 15 times the isotropic power with proportionally lower emissions above, below and behind the antenna. Since most of an antenna's main power is focused toward the horizon, the emitted power, and therefore exposure in the remaining directions is typically hundreds of times less than that in the main beam. When the strong directionality of the antenna is coupled with the fact that the RF electromagnetic field intensity decreases rapidly with distance, the net effect is that nearby exposures are often tens of thousands of times lower than the Maximum Permissible Exposures (MPEs).

While the exact exposure from a cellular antenna cannot be known until it is measured under operating conditions, conservative over-estimates of exposure can be calculated in advance of installation.[4] The first level of simplified calculation is to treat the maximum potential RF emission as occurring equally in all directions (isotropically). The "worst-case" calculation assumes that the main, most intense beam is directed equally to receptors placed anywhere around the antenna. When such a calculation is made for the FCC's

3 Isotropic as opposed to focused emissions can be visualized by considering the light emitted from a bare flashlight bulb (isotropic) compared with the light emitted with the flashlight reflector installed.

4 E.g., FCC, Office of Engineering and Technology, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields. OET Bulletin 65 Edition 97-01, Aug. 1997.

threshold antenna of ERP = 1000 W (EIRP = 1640 W) and a 10 m elevation, it can be shown that such an antenna is well within the MPE limits for RF radiation. For example, if we assume an average cellular broadcast frequency of 890 MHz, the MPE is approximately 0.6 mW/cm^2 for uncontrolled environments.[5] In the worst-case scenario that a dipole antenna were tilted to focus the maximum power directly to areas immediately below it, exposure at ground level would be 0.13 mW/cm^2, or about 4.6 times lower than the exposure limit. As discussed above, the significant focusing of contemporary antennas reduces exposure levels at ground level directly below and nearby the antennas significantly below the simplified, worst-case estimates.

Other Physical Characteristics

The relentless advance of digital technology is enabling a greater number of voice channels to be carried within a narrow bandwidth and at a given power. As mentioned earlier, cell size and base station power decrease partly as a function of the network demand. The combination of these factors suggests that, as the number of users increases, the antenna-generated exposure per call does not (and has not) necessarily increase(d) in proportion to the number of new users. In fact, it is conceivable that the exposure per call will continue to decrease until physical and engineering limits are achieved.

Finally, the duty cycle for most cellular antennas is significantly less than design capacity when averaged over a day: Antennas operate near rated capacity only during peak phone demand periods. During a 24 hour period, the voice channel power for an antenna is "off," waiting for incoming phone calls. True exposure rates are highly intermittent depending on the current phone conversation activity. In contrast, potential environmental exposures are generally calculated under an assumed, full power and full time operation.[6] While the low duty cycles obviously reduce the true cumulative exposures, this factor is perhaps insignificant in terms of potential biological effect (below).

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5 The definition of an uncontrolled environment is a location "where there is the exposures of individuals who have no knowledge or control of their exposure." ANSI C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, (1992).

6 *Supra* note 3.

Biological and Biophysical Characteristics

Exposure limits are given in specific absorption rates (SARs) in tissue, a measure roughly analogous to dose (Table 2). The use of a thermal absorption rate as an exposure limit reflects the fact that the only mechanism of action that generates reproducible biological effects is thermal absorption of the RF energy.[7] The amount of tissue heating associated with the average SAR limits is similar to the heat generated during light physical activity or normal metabolism. For example, for an average (70 kg) adult male, the limiting rate of 0.08 W/kg is much less than the metabolic energy of 1.24 W/kg generated by a 2400 Calorie/day diet. It is clear that, no matter what the source of the heat (e.g., warm water or air, infrared lamps or metabolic heat from exercise), a normal body can easily remove heat generated from electromagnetic field exposures both at and well above the exposure limits.

Table 2[8]

Specific Absorption Rates Underlying the Maximum Permissible Exposures for Frequencies Between 100 kHz and 6 GHz

Type of Area and Tissue	*Specific Absorption Rate (W/kg)*	*Max. SAR / Averaging Tissue Mass*	*Averaging Time (min)*
Controlled Areas:			
Whole body	0.4	8/1 gram	6
Hands, wrists, ankles, feet	20.0	20/10 grams	6
Uncontrolled Areas:			
Whole body	0.08	1.6/1 gram	30
Hands, wrists, ankles, feet	4.0	4/10 grams	30

The MPEs corresponding to the SAR limits are averaged over six minutes for controlled environments and 30 minutes for uncontrolled environments as long as the maximum SAR limits in Table 2 are not exceeded. For example, a 5 mW/cm^2 exposure for 1 minute is equivalent to a 1 mW/cm^2 exposure for 5 minutes, or a 2.5 mW/cm^2 for 2 minutes. In each case, the product of time and exposure is constant, or 5 (mW/cm^2 * minutes). Although a 500 mW/cm^2 exposure for 0.01 minutes would meet the time-average exposure limit,

7 *Supra* note 3.

8 *Supra* note 5.

the 500 mW/cm^2 power density would likely generate SARs in excess of the limits. Thus, the maximum SARs are intended to obviate scenarios in which a very high SARs might be delivered within very brief moments of time, yet the average SAR over the appropriate averaging time would still meet the exposure limit. It is generally considered that combinations of exposure and time that are within the maximum SAR will always fall within a conservative thermoregulatory capacity of absorbing tissues.

Biological Characteristics

The American National Standards Institute (ANSI) Committee concluded that there was no credible scientific evidence that exposures to RF in the 3 kHz to 300 GHz range was cumulative in any manner. For example, the energy of electromagnetic waves at 900 MHz are too weak to break atomic bonds, a process thought to be necessary in order to initiate cancerous changes in cells. Carcinogens have the apparent property that risk is best expressed as a function of cumulative exposure to the carcinogen.[9] If there is no credible evidence for carcinogenic induction, then it is logical to assume that exposure rates (i.e., over the six-minute averaging period) can be used to manage risk, not necessarily cumulative exposures.

A second issue regarding cancer causation is often raised and that is, even if the energy of 900 MHz radio frequencies is too low to break bonds and initiate cancer, could the radio frequencies promote the development of cancer? While initiation of cancer by most carcinogens involves damage to tissue cell genes, the promotion of cancer is usually associated with the gene expression in initiated cells. Certainly, heat is an agent that can affect gene expression and induce heat shock and stress responses in cells.[10] However, thermal effects in either tumor promotion (or tumor therapy) greatly exceed the normal metabolic range of thermal levels induced at the limiting MPE. Given the abundance of greater heat-producing human activities for which cancer promotion was never considered to be possible, the notion that cancer promotion follows heating from these very low exposures is illogical.

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9 E.g., Henry C. Pitot III & Yvonne P. Dragan, *Chemical Carcinogenesis,* in Curtis D. Klaassen, Casarett and Doull's Toxicology, The Basic Science of Poisons, 201-268 (5th Ed 1996).

10 E.g., George M. Hahn, Hyperthermia and Cancer (1982).

Finally, the ANSI standard risk assessment panel concluded that the "literature revealed once again that the most sensitive measures of potential harmful biological effects were... associated with an increase in body temperature in the presence of electromagnetic fields."[11] The absence of reliably reported non-thermal effects from electromagnetic fields at cellular and PCS frequencies is certainly not in absence of decades worth of attempts to elucidate such mechanisms. While some critics of microwave research suggest that a new physics is yet to be discovered, the remarkable consistency of physical theory across biophysics and biology thus far suggests that discovery of a new science that explains speculative mechanisms of action is unlikely.

Rapidly advancing technology and the sudden, ubiquitous presence of cellular phones and base station antennas has rekindled public concern for exposures from high-frequency and microwave electromagnetic fields. In an apparent attempt to limit both the potential litigation based on "junk science" and the volume of FCC license reviews, Congress reasserted FCC authority to set a "negligible risk" or de minimis threshold for cellular and PCS transmitting sites. Once the very low physical exposures and the attendant low or even zero risk of adverse health effects from exposures at the MPEs are considered as the rationale for the de minimis threshold, it is apparent that public safety and health is protected with an ample margin of safety.

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11 *Supra* note 4 at 27.