Health Issues

Introduction

Let's face it - radio waves are mysterious things. Especially when referred to as "electromagnetic *radiation*" the concept makes many people nervous. In this lesson we want to examine the health issues surrounding RF communication systems. In the U.S. there are three government agencies with a significant involvement in this issue: the Food and Drug Administration (FDA), the Federal Communications Commission (FCC), and the Occupational Health and Safety Administration (OSHA). OSHA is primarily concerned with workplace safety while the FDA and FCC are also involved with the safety of the general public. Before we consider health guidelines for cellular systems, we need to get clear on the issue of ionizing vs. non-ionizing radiation.

Ionizing vs. Non-Ionizing Radiation

All electromagnetic waves, from AM radio to gamma rays, are forms of radiation. The word "radiation" carries scary connotations and upsets most people. But, this is because the popular use of the word is not quite the same as the scientific meaning. Light is a form of radiation, so every time you turn on a light in your house you are filling your environment with radiation. And, of course, the Sun bathes the Earth in radiation for about 12 hours a day.

Electromagnetic energy comes in little packets called *photons*. The energy of a single photon is

$$E = hf \tag{18.1}$$

where h is *Plank's constant*, equal to $6.626\cdot10^{-34}$ Joules/Hz, and f is the frequency in Hz. For a radio wave of frequency 2 GHz, the photon energy is about 10^{-24} Joules or 10^{-5} electron volts. An electron volt is the amount of energy a single electron has when raised to a potential of 1 volt, namely $1.6\cdot10^{-19}$ Joules, e.g., a single electron emerging from an "AA" battery has an energy of about 1.5 electron volts. So one photon at 2 GHz has the same energy as an electron subjected to a potential of 10 μV. On the other hand, for a "hard" X-ray of frequency 10^{18} Hz (a billion GHz) the photon energy is about $7\cdot10^{-16}$ Joules or about 4,000 electron volts.

Example 18.1

Let's say your body absorbs 1 Joule of energy, e.g., 1 Watt of power for a duration of 1 second. A Joule is equal to $6.25\cdot10^{18}$ eV. At the RF frequency of 2 GHz this requires about $6\cdot10^{23}$ photons each having only 10^{-5} electron volts of energy. At the X-ray frequency of 10^{9} GHz we need about $1.5\cdot10^{15}$ photons each having about 4,000 electron volts of energy. The total energy is the same in each case, but in the RF case it is carried via a much greater number of "packets" each having a relatively small amount of energy.

Interactions between radiation and mater at the molecular level generally involve absorption and/or emission of a single photon at a time. It's pretty much an "all or nothing" affair. If a single photon has enough energy to knock an electron loose from a molecule, i.e., *ionize* the structure, then it can seriously damage that molecule. It typically takes somewhat more than 1 eV of energy to do this sort of damage. That corresponds to frequencies of somewhat more than 10^{14} Hz, i.e., about 100,000 GHz. Radiation at these frequencies is called *ionizing radiation.*

On the other hand if the photon energy is far below this *ionization energy* of the molecule's electrons, then it cannot do damage of this sort. A photon can't damage a molecule "just a little" followed by another photon adding a little more damage and so on until the molecule if finally "broken." A trash bag full of cotton balls may has as much mass as a small rock, but if you throw the cotton balls at a window one at a time it's never going to break, whereas a toss of a single rock may indeed break the window.

Biological tissue consists of, generally, very complex molecules such as proteins, DNA, and so on. If a single photon has enough energy to knock an electron loose from a molecule then it can seriously damage these biological structures. For this reason, ionizing radiation, even at relatively low levels, poses a health threat in the forms of genetic mutation, cancer, and so on.

Radiation at lower frequencies, since the photon energies are too low to cause ionization, is called *non-ionizing radiation*. Photons of non-ionizing radiation will not break molecular bonds, and there is no solid evidence that non-ionizing radiation creates a risk of cancer and the like. On the other hand, photons of non-ionizing radiation can stimulate molecular vibrations and rotations that are then manifest as heat.

Thermal Effects of RF Radiation

Although cellular systems use non-ionizing radiation, there are potential health dangers in the form of thermal effects. Indeed, a frequency of 2450 MHz is commonly used for microwave ovens, and this is very close to frequencies used for PCS and wireless LANS. Obviously you wouldn't want to be cooked inside a microwave oven, so, *at some point,* RF exposure is a potential health danger. The danger comes when heat is generated in tissue faster than the body can remove it – primarily through the flow of blood. In this case temperature continues to rise until heat-induced damage can occur to tissue and organs. The eyes and testes are two of the areas of the body most vulnerable to thermal damage.

With respect to RF absorption in the human body due to the use of a cell phone, the most important parameter is *SAR*. SAR stands for Specific Absorption Rate and is given in terms of W/kg, i.e., the amount of power absorbed per kg of tissue. Through extensive computations, simulations, and measurements, a SAR limit of 1.6 W/kg has been set for cell phones.

One calorie, equal to 4.187 Joules, is the amount of energy required to raise the temperature of a gram of water by one degree Celsius. Since 1.6 W/kg is equal to 382 μ cal gm^{-1} sec^{-1}, at this SAR it would take 2616 seconds, roughly 45 minutes, to increase the temperature of water by one degree Celsius. And that assumes no heat is removed in the process.

The U.S. Food and Drug Administration has this to say on the issue of cell phone health effects:

> *"The available scientific evidence does not show that any health problems are associated with using wireless phones. There is no*

> *proof, however, that wireless phones are absolutely safe. Wireless phones emit low levels of radiofrequency energy (RF) in the microwave range while being used. They also emit very low levels of RF when in the stand-by mode. Whereas high levels of RF can produce health effects (by heating tissue), exposure to low level RF that does not produce heating effects causes no known adverse health effects. Many studies of low level RF exposures have not found any biological effects. Some studies have suggested that some biological effects may occur, but such findings have not been confirmed by additional research. In some cases, other researchers have had difficulty in reproducing those studies, or in determining the reasons for inconsistent results."*

Most people seem to take the safety of cell phones for granted. However, cell site base stations look quite a bit more imposing and usually transmit considerably more power than a phone. On the other hand a phone operates adjacent to your head while there is typically a significant distance between the public and a base station. As we have seen, field strength drops off quite rapidly with increasing distance from a transmitter. The issue with base stations is therefore to make sure that they are a safe distance from the general public.

FCC Exposure Guidelines

The FCC publishes RF exposure guidelines based on the latest research results. There are two categories: "controlled" and "uncontrolled" exposure. Controlled exposure refers to an occupational environment where people realize they are being exposed and can follow specific safety procedures. Uncontrolled exposure refers to a situation where the general public is exposed. For obvious reasons, the standards for uncontrolled exposure are more restrictive. The FCC has this to say about their Maximum Permissible Exposure (MPE) limits:

> *"The MPE limits adopted by the FCC for occupational/controlled and general population/uncontrolled exposure incorporate a substantial margin of safety and have been established to be well below levels generally accepted as having the potential to cause adverse health effects."*

Here are the FCC guidelines for controlled exposure. Notice that the maximum power densities are a function of frequency. This is because the body more readily absorbs certain frequencies. Note that these are *average* exposures over a 6-minute interval.

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-3.0	614	1.63	(100)*	6
3.0-30	1842/f	4.89/f	($900/f^2$)*	6
30-300	61.4	0.163	1.0	6
300-1500	--	--	f/300	6
1500-100,000	--	--	5	6

Here are the guidelines for the general population. Notice that the maximum power density is generally about a factor of 1/5 of the controlled limit. Also, the averaging time is 30 minutes.

(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	($180/f^2$)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

Example 18.2

Suppose you transmit 100 W isotropically at a frequency of 900 MHz. What is the closest you can allow people to get to your transmitter and still maintain the uncontrolled exposure limit?

At 900 MHz the power density limit is 900/1500 or 3/5 mW/cm^2 or 6 W/m^2. At a distance r the 100 W of transmitted power creates a power density of $100/(4\pi r^2)$ W/m^2. So $6 = 100/(4\pi r^2)$ and r is 1.2 m.

You can see that it doesn't take much distance to meet the exposure guidelines. For this reason many structures are "categorically excluded" from requiring detailed field strength calculations and measurements.

Categorically Excluded Facilities

The following quotes are from the FCC publication, "A Local Government Official's Guide to Transmitting Antenna RF Emission Safety: Rules, Procedures, and Practical Guidance."

> *"The Commission has determined through calculations and technical analysis that due to their low power or height above ground level, many facilities by their very nature are highly unlikely to cause human exposures in excess of the guideline limits, and operators of those facilities are exempt from routinely having to determine compliance. Facilities with these characteristics are considered "categorically excluded" from the requirement for routine environmental processing for RF exposure …*
>
> *"a cellular facility is categorically excluded if the total effective radiated power (ERP) of all channels operated by the licensee at a site is 1000 watts or less. If the facility uses sectorized antennas, only the total effective radiated power in each direction is considered …*
>
> *"In addition, a cellular facility is categorically excluded, regardless of its power, if it is not mounted on a building and the lowest point of the antenna is at least 10 meters (about 33 feet) above ground level. A broadband PCS antenna array is categorically excluded if the total effective radiated power of all channels operated by the licensee at a site (or all channels in any one direction, in the case of sectorized antennas) is 2000 watts or less. Like cellular, another way for a broadband PCS facility to be categorically excluded is if it is not mounted on a building and the lowest point of the antenna is at least 10 meters (about 33 feet) above ground level. The power threshold for categorical exclusion is higher for broadband PCS than for cellular because broadband PCS operates at a higher frequency where exposure limits are less restrictive."*

In practice, therefore, most cellular base stations are categorically excluded from having to monitor compliance with the FCC exposure guidelines.

References

1. http://www.fcc.gov/oet/rfsafety/ (2002-Aug-01)
2. http://www.fda.gov/cellphones/ (2002-Aug-01)
3. http://www.osha.gov/SLTC/radiofrequencyradiation/rfpresentation/intro.html (2002-Aug-21)
4. Osepchuk, J. M. (ed.), *Biological Effects of Electromagnetic Radiation,* IEEE Press, 1983, ISBN 087942-165-7.