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Biological Effects of EM Radiations from Mobile Phones

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الآثار الصحية للإشعاعات الناجمة عن الهواتف المتنقلة

عادل أحمد علي و أحمد محمد النعماني

خلاصة : بدأ الاهتمام يتزايد حول الآثار الصحية الناجمة عن استخدام الهاتف السيار، كما ان المعلومات المؤكدة عن تلك الآثار الصحية بدأت في الانتشار أيضا، ويبقى العديد من التساؤلات في انتظار نتائج الأبحاث العلمية حتى يمكن التأكد بصورة قاطعة وحاسمة من مدى خطورة أو عدم خطورة تلك الآثار على الصحة العامة. وتتجه الكثير من المناقشات حول الآثار الصحية للإشعاع الناجم عن الهاتف السيار إلى النواحي العاطفية والغير علمية، مما يزيد من حدة القلق لدى المواطنين. لذا ينبغي على العلماء والمتخصصين القيام بدورهم بالمساهمة بتوعية المواطنين بصورة علمية مبسطة حتى يمكن تفهم تلك الآثار بصورة غير مشوهة.
وبصورة عامة يمكن القول بعدم وجود ما يدعو إلى القلق من الآثار الناجمة عن الإشعاع وذلك على المدى القصير ، حيث لم يثبت أي آثار سلبية على الصحة الجسمية أو النفسية.

ABSTRACT: Direct health effects could result following exposure to RF by thermal (heating effects). Recent Studies have shown that there are public fears on effects that can be caused mainly by holding mobile phones close to the body, or as a result of possible non-thermal effects from both phones and base stations. This paper offers an overview on the biological effects of electromagnetic radiation caused by mobile phones. Exposures of individuals to RF radiation from these sources will depend upon their proximity and may be above those from mobile phone base stations, although still well below guidelines. From a review of the scientific literature, it is concluded that there were no established health effects from exposure to the RF fields from mobile phones. However, there are gaps in knowledge requiring further research, but current knowledge suggests that RF exposure to levels below the guidelines were not a risk to health.

KEYWORDS: Electromagnetic Radiation, Mobile Phones, Exposure, Biological Effects.

1. Introduction

Mobile phones and base stations both emit radio frequency (RF) radiation. In both cases levels of exposure generally reduce with increasing distance from the source. For mobile phones, exposures will be principally to the side of the head for hand-held use, or to the parts of the body closest to the phone during hands-free use. Lin (2000) and Moulder (2000) point out that, base station emissions, exposures of the general population will be to the whole body but normally at levels of intensity many times less than those from handsets.

A biological effect occurs when a change can be measured in a biological system after the introduction of some type of stimuli. However, the observation of a biological effect, in and of itself, does not necessarily suggest the existence of a biological hazard. ICNIRP (1998) stipulate that biological effect only becomes a safety hazard when it "causes detectable impairment of the health of the individual or of his or her offspring".

There are many published reports in the scientific literature concerning possible biological effects resulting from animal or human exposure to RF energy. Biological effects that result from heating of tissue by RF energy are often referred to as "thermal" effects. It has been known for many years that exposure to high levels of RF radiation can be harmful due to the ability of RF energy to heat biological tissue rapidly. This is the principle by which microwave ovens cook food, via exposure to very high RF power densities, i.e., on the order of 100 mW/cm^2 or more can clearly result in heating of biological tissue and an increase in body temperature. Tissue damage in humans could occur during exposure to high RF levels because of the body's inability to cope with or dissipate the excessive heat that could be generated. Under certain conditions, exposure to RF energy at power density levels of 1-10 mW/cm^2 and above can result in measurable heating of biological tissue (but not necessarily tissue damage). The extent of this heating would depend on several factors including radiation frequency; size, shape, and orientation of the exposed object; duration of exposure; environmental conditions; and efficiency of heat dissipation.

The following discussion only provides highlights of current knowledge, and it is not meant to be a complete review of the scientific literature in this complex field. A number of references are listed at the end of this document that provide further information and details concerning this topic and some recent research reports that have been published

2. The Radio Frequency Spectrum

X-rays, ultraviolet light, visible light, infrared light, microwaves, radio-frequency radiation (RF or RFR), and electromagnetic fields from electric power systems are all parts of the electromagnetic spectrum. The parts of the electromagnetic spectrum are characterized by their frequency (or wavelength), and different electromagnetic frequencies produce fundamentally different types of biological effects. Cellular and personal communication systems (PCS) reside in the ultra high frequency (UHF) region from 300 to 3000 MHz. Here classical mathematical analysis with Maxwell's equations is usually appropriate, and there are few, if any, biological effects that cannot be attributed directly or indirectly to the heating of tissue (Bernhardt *et al,* 1997; Verschave *et al*, 1998; Lai and Singh, 1995; and Brusick *et al*., 1998).

Like any wave-related phenomenon, electromagnetic energy can be characterized by a wavelength and a frequency. The wavelength (λ) is the distance covered by one complete electromagnetic wave cycle. The frequency is the number of electromagnetic waves passing a given point in one second. The wavelength λ of an electromagnetic wave is related to the frequency (f) and velocity (v) by the expression

$$V = f\,\lambda \tag{1}$$

In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately 3x 10^8 m/s.

We usually talk about electromagnetic sources as though they produced waves of energy. However, electromagnetic energy can also act like particles, particularly at high frequencies; and the energy of these particles (photons) increases as the frequency increases. The energy carried by an EM photon ξ in Joules is

$$\xi = h\,f \tag{2}$$

Where h (6.625x10^{-34} Js^{-1}) is the Planck constant and f is the frequency of the wave in Hz (cycles/s). IEEE standard (1992) for safety levels with respect to Human Exposure to radio Frequency Electromagnetic Fields emphasize the importance of the particle nature of electromagnetic energy because the energy per particle (photon energy) is a major determinant of what biological effects a particular frequency of electromagnetic energy will have.

3. Terminology and units for measuring radio-frequency radiation

For radio-frequency radiation, the energy flux, in watts per square meter (W/m^2 or mW/cm^2), across a surface is called the "power density". Power density measures the strength of the incident radio-frequency radiation and is the favored metric of external exposure to radio-frequency radiation; in part because it is relatively easy to measure.

Table 1: CNIRP reference levels for public exposure at mobile telecommunications frequencies

Freq (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (W/m^2)
400–2000	$1.375\ f^{1/2}$	$0.0037\ f^{1/2}$	f /200
2000 –3000	61	0.16	10

f is the frequency in MHz.

However, power density is an imperfect indicator of the relevant conditions inside an irradiated organism. Instead, scientists specify a metric of internal exposure, the specific absorption rate, SAR (in W/kg). The SAR is generally used as the dose metric in laboratory experiments, and SAR serves as the scientific basis of modern radio-frequency radiation safety standards. For typical biological tissue, the SAR is given by

$$SAR = \frac{\sigma E^2}{\rho} \tag{3}$$

E is the electric field strength in the tissue, σ is the conductivity of the tissue, ρ is the mass density of the tissue. The SI unit of SAR is W/kg.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998) has recently recommended power-density guidelines for limiting exposure of the general public to RF radiation. These limits keep humans from being overheated by restricting exposures to levels that are relatively weak, compared, for example, to summer sunshine, which peaks at roughly 1000 W/m^2. Table1 presents the ICNIRP reference levels for public exposure at mobile telecommunications frequencies (ICNIRP, 1998). The maximum allowed level is 10 W/m^2 ($1mW/cm^2$).

Table 2: Standards for base station antennas

Power Density mW/cm^2	Types of Installation
0.0002	Typical Near a Modern Phone Tower
0.01	Maximum Near a Cell Phone Tower
0.4 -1.2	**FCC/ICNIRP/IEEE/NRPB Public Exposure Standards**
4	Unconfirmed Reports of Effects
40	Reproducible Effects
100	Clear Hazards

Table 2 shows Moulder's (2000) comparison of the ICNIRP $1mW/cm^2$ standard with expected radiation levels near base stations. Also depicted are the power density levels associated with possible effects.

4. Effects of Radiation

In terms of potential biological effects, the electromagnetic spectrum can be divided into four portions with three of these portions being of Non–Ionizing part of spectrum as follows:

1. The non-ionizing portion of the spectrum, which can be subdivided into:
    a. The optical radiation portion, where electron excitation can occur (e.g., visible light, infrared light).
    b. The portion where the wavelength is smaller than the body, and heating can occur (e.g., microwave ovens, mobile phones, broadcast TV, FM radio). See Figure 1 and 2.
    c. The portion where the wavelength is much larger than the body, and heating seldom occurs (e.g., AM radio, power frequency fields, static fields).
2. The ionizing radiation portion, where direct chemical damage can occur (e.g., X-rays).

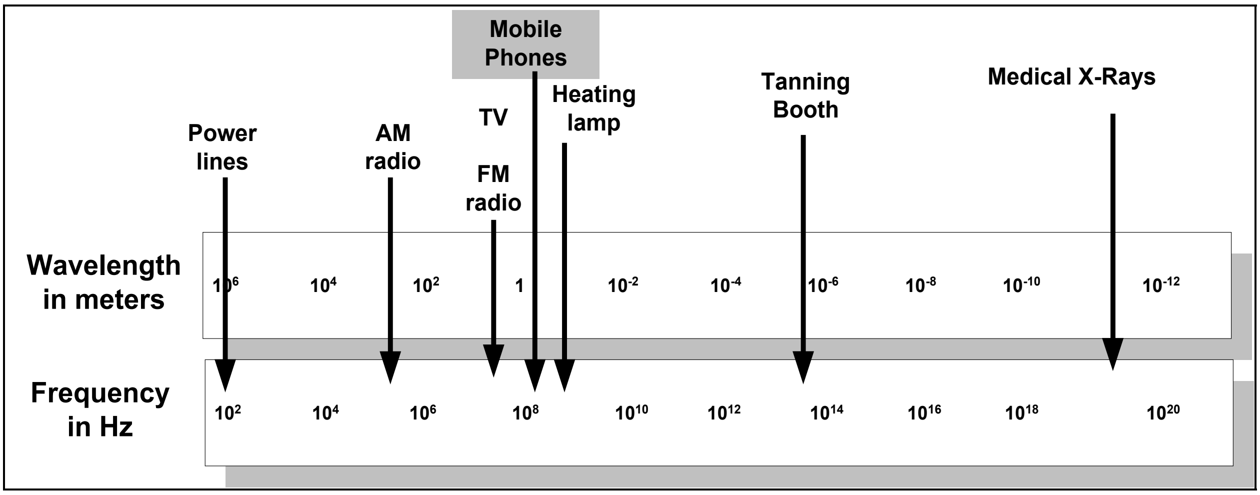

Figure 1. Mobile phone position in electromagnetic spectrum.

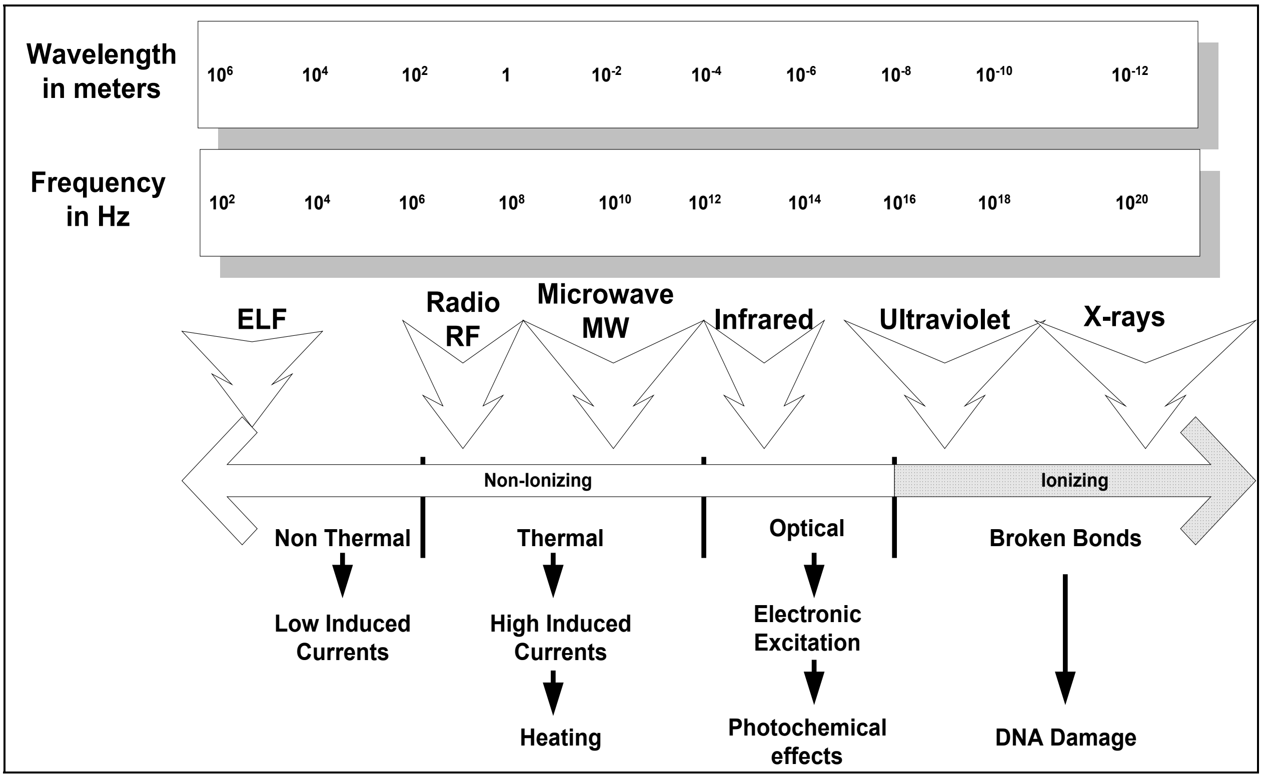

Figure 2. Electromagnetic spectrum.

To effect a change in biological material through which it is passing, an EM wave must deposit enough energy to alter some structure significantly. But every material particle within the body already possesses an average thermal kinetic energy (in joules, J) of the order of kT; where k ($1.38\text{x}10^{-23}$ J/K) is the Boltzmann constant and T is the absolute temperature (in Kelvin, K), and these particles continually collide with other particles of similar energy. For a change to occur in biological material the EM wave seemingly should transfer energy considerably above kT to selected particles, and at 310 K (37^{o}C, body temperature), kT is 4.3 x10^{-21} J. Another standard of comparison is the chemical bond, because to be effective in promoting change the field should be able to deposit packets of energy larger than the bond energy, and bonds are typically within an order of magnitude of an electron volt ($1.6\text{x}10^{-19}$J).

Table 3 shows comparisons between the bond energy of the human cells and the Heat energy as well as the photon energy. In the UHF realm (300 to 3000 MHz) the energy ξ of one photon can be estimated using (2). It can be shown that $\xi<2\text{x}10^{-24}$ J is less than 0.1% of either kT ($4\text{x}10^{-21}$ J) or the bond energy ($1.6\text{x}10^{-19}$J).

Table 3: Energy comparisons.

Heat energy: k T	~ 4.3 x10^{-21} Joules
Bond energy: e V	~ 1.6x10^{-19} Joules
Photon energy: h f at UHF	~ (0.2-2.0) x10^{-24} Joules

5. Near Field and Far Field Standards

Intensity is expressed either as an electric (magnetic) field strength in V/m (Tesla), or as a power density, in units of Watts/cm^2, according to whether we deal with a near or far field conditions, the former being relevant to handset use, and the latter to public exposure in the vicinity of a base-station. Cited values are usually average ones, which in the case of the GSM duty cycle are 1/8 of the peak values.

It should be noted that the current preoccupation with attempting to assess the relative merits of different makes of handset in terms solely of the maximum recorded (rms) *SAR* values is open to the objection that a low value does not necessarily mean a correspondingly low overall electromagnetic absorption. There are two reasons for this: *i*) the cited maximum value for a given model refers to a single location (relative to the head), which does not necessarily correspond either to the location of the phone when in use, or to the conditions that obtain during a call, *ii*) there is a vast variation in the spatial radiation patterns of different antennae. Accordingly, the energy deposited in the head by a low *SAR* model with an antenna that radiates diffusely can exceed that from a high *SAR* model with more localised emission characteristics.

6. Antenna location criteria

Sites should be designed so that people cannot access areas that exceed public exposure standards. In general, public exposure standards will not be exceeded at distances more than 2 meters above or below an antenna, and more than 6 meters away from the antenna in the direction of the main lobe, and behind a high-gain antenna (Moulder, 2000). If there are areas accessible to workers that exceed the *public exposure* standard, workers must know where these areas are. Workers must know what precautions to take. If there are areas accessible to workers that exceed the *occupational exposure* standard, workers must know where these areas are. Workers must power-down and lock out the antennas before entering these areas. People who live or work at the top of buildings that have roof top antennas have concern regarding radiation hazards. Base station antennas on towers are highly unlikely to cause any health hazards, however, antennas on roof tops my cause health hazards.

7. Human Exposure

The meaning of the 1.6 W/kg local SAR limit in the IEEE/ANSI standard as per Lai and Singh (1995) and the similar 2–4 W/kg local SAR restrictions in the ICNIRP guidelines as stipulated by Brusick *et al* (1998) can be judged by noting that this closely matches the human whole-body resting metabolic rate, and is of the order of one-eighth of the brain's resting metabolic rate. A typical cellular telephone has a time-averaged power output of 600 mW or less and yields numerically modeled brain SARs which may sometimes have exceed the 1.6- W/kg limit, but which generally lie within the ANSI/IEEE ''controlled environment'' limit of 8 W/kg averaged over 6 min (ICNIRP, 1998; Foster and Moulder, 2000). This 600 mW is less than 1% of the body's normal resting metabolic output and under 4% of the brain's normal resting metabolic output.

In ''uncontrolled environments'' ANSI/IEEE as mentioned in IEEE standard for safety levels with respect to Human Exposure to radio Frequency Electromagnetic Fields (1992) limits the spatial-average SAR to 0.08 W/kg whole-body, and to 1.6 W/kg as averaged over any 1g of tissue; under ANSI/IEEE it is permissible to average both power density and SAR over 30-min intervals. The ICNIRP (1998) ''basic restrictions'' on SAR are similar to the ANSI/IEEE limits see Table 4

SAR or Specific Absorption Rate is the *rate at which RF energy is imparted to a unit of mass* of a biological body.

Table 4: Permissible SARs by different international organizations.

SAR $W\ kg^{-1}$	NRPB **All People**	ICNIRP **Workers**	**Public**	ANSI/IEEE **Controlled**	**Uncontrolled**
Whole Body	0.4	0.4	0.08	0.4	0.08
Head	10 (10 g)	10 (10 g)	2 (10 g)	8 (1 g)	1.6 (1 g)
Averaging Time	6 min	6 min	6 min	6 min	6 min

8. Ongoing Research and The Precautionary Measures

Having reviewed all relevant epidemiological studies, National Radiological Protection Board (NRPB) concluded that the results were inconclusive and did not provide an adequate starting point from which to derive exposure guidelines (Moulder *et al*, 1999; Kustler *et al*, 1997; USEPA, 1996, Repacholi, *et al*, 1997; Foster *et al*., 1997). Instead, therefore, the guidelines were based on the potential of RF radiation to cause illness or injury through heating of body tissues. While some research had suggested that adverse health effects might occur from exposures lower than those needed to produce significant heating, the evidence for this was not considered sufficiently robust to form a basis for the derivation of exposure guidelines. There is an extensive amount of research on the biological effects of RF energy. Thermal hazards were well understood. Well-accepted standards existed to prevent thermal injuries, however, little of the research dealt with cancer, little dealt with the kind of pulse modulated RFR produced by modern phones and little dealt with small-volume near-field RFR exposure. There are many un-replicated reports of "effects" at "low exposure" levels.

The Independent Expert Group on Mobile Phones (2000) terms of reference is:

"To consider present concerns about the possible health effects from the use of mobile phones, base stations and transmitters, to conduct a rigorous assessment of existing research and to give advice based on the present state of knowledge. To make recommendations on further work that should be carried out to improve the basis for sound advice."

The Expert Group Report on *Mobile Phones and Health* was published in May 2000. The 160-page report is a based on a comprehensive summary of scientific literature and gathering of stakeholder opinions. The report concludes that the balance of existing scientific evidence does not suggest adverse health effects, there is scientific evidence suggesting there might be biological effects, the extent of uncertainty about the true position justifies a precautionary approach. In line with a precautionary approach, the report recommends a range of measures designed to be prudent and other recommendations designed to empower members of the public in their choices relating to mobile phone technology. For hands free kits, the report recommends that the government sets up an independent, testing system for hands free kits and shielding devices so that consumers have access to clear and impartial advice.

The Expert Group believes that, on the basis of the evidence currently available, there is no need for the general population to be worried about the use of mobile phones. In line with the precautionary approach highlighted in the report, the Expert Group notes that individuals may choose to

- Use phones for as short a time as possible
- Use phones with low specific energy absorption rate (SAR) values
- Use hands-free kits and other devices provided they have been proved to reduce SAR.

Exposure to members of the public from macro-cell base stations is very much less than current guidelines. In giving special attention to schools, the Expert Group was responding very largely to public concern rather than any proven health hazard. In defining the “beam of greatest intensity”, the aim of the recommendation by the Expert Group was to ensure that the accessible location where the greatest exposure to the radio frequency radiation signal occurs is not within school grounds. It would be up to the operator to demonstrate this by measurement or other means.

Since there are no scientific grounds for setting guidelines below the levels set by the International Commission for Non-ionizing Radiation Protection (ICNIRP) for the public, the Expert Group avoided setting exposure limits for school buildings and grounds below these limits. For the same reason it did not wish to recommend that there should be a particular minimum distance between the base station and the school.

9. Conclusions

Understanding of cellular phone health effect is evolving. Many questions must be answered before consistent, dependable and scientific conclusions can be drawn. However, there is no immediate cause for concern from short-term exposure. No physiologic or pathologic consequence. Exposure criteria must be evaluated periodically.

Some people’s well being may be adversely affected by the environmental impact of mobile phone base stations sited near their homes, schools or other buildings, as well as by their fear of perceived direct effects. This may only happen if the required exposures guidelines/limits are neglected by the telecommunication organizations and the mobile vendors/manufacturer.

Measurements that have been made indicate that exposures of the general population from base stations are typically many hundreds, or thousands of times lower than existing exposure guidelines. There are concerns, nevertheless, about whether the emissions from all base stations are uniformly low, about whether the emissions could cause unknown health effects, and whether, with the increased use of mobile telecommunications, their output will have to rise.

Discussions about biological impacts of electromagnetic fields are highly emotional. The concern on health effects is expected to increase as newer generations of mobile communications are set to appear in the market with even more applications. The Third Generation mobile is expected to incorporate both voice and data with much wider coverage. As a result, anxiety and feelings are expected to dominate the discussions. It is necessary to establish confidence in science and research. Such confidence can only be created in the general public if detailed information is supplied. Scientists and engineers are called upon to provide sound contributions in order to help making discussions more objective. It seems advisable to draw general conclusions from the present discussions for the introduction of future-oriented technologies. Careful consideration must be given in time to the consequences of (new) technologies for people and the environment including psychological effects on the general public in respect of introduction. It may be assumed that the subject of implications of electromagnetic fields for the environment will continue to be in the focus of discussions for quite some time in the future - until new findings are available.

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Appendix A: Internet Web Sites for Further Information

Note: All Internet addresses below should be preceded by "http://". Also, some URL's may be case sensitive

1. American Radio Relay League: www.arrl.org
2. American National Standards Institute: www.ansi.org
3. Bioelectromagnetics Society: www.bioelectromagnetics.org
4. COST 244 (Europe): www.radio.fer.hr/cost244
5. DOD: www.brooks.af.mil/AFRL (select radiofrequency radiation)
6. European Bioelectromagnetics Association: www.ebea.org
7. Electromagnetic Energy Association: www.elecenergy.com
8. Federal Communications Commission: www.fcc.gov/oet/rfsafety
9. ICNIRP (Europe): www.icnirp.de
10. IEEE: www.ieee.org
11. IEEE Committee on Man & Radiation: www.seas.upenn.edu/~kfoster/comar.htm
12. International Microwave Power Institute: www.impi.org
13. Microwave News: www.microwavenews.com
14. J Moulder, Med. Coll. of Wisconsin.: www.mcw.edu/gcrc/cop/cell-phone-health-FAQ/toc.html
15. National Council on Radiation Protection & Measurements: www.ncrp.com
16. NJ Dept Radiation Protection: www.state.nj.us/dep/rpp (select non-ionizing radiation)
17. Richard Tell Associates: www.radhaz.com
18. US OSHA: www.osha-slc.gov/SLTC (select subject: radio frequency radiation)
19. Wireless Industry (CTIA): www.wow-com.com
20. Wireless Industry (PCIA): www.pcia.comWorld Health Organization EMF Project: www.who.ch/peh-emf

Appendix B: Glossary

AGNIR	Advisory Group on Non-ionizing Radiation
ANSI	American National Standards Institute
Base station	Facility providing transmission and reception for radio systems. For macro cells, the infrastructure comprises either roof- or mast-mounted antennas and an equipment cabinet or container. For smaller micro cells and Pico cells, the antennas and other equipment may be housed in a single unit.
DNA	Deoxyribonucleic acid. The compound that controls the structure and function of cells and is the material of inheritance
GSM	Global System for Mobile Communications or *Groupe Spéciale Mobil*e. The international, pan-European operating standard for the new generation of digital cellular mobile communications. Enables mobile phones to be used across national boundaries. PCN operators work to the same standard but at different frequency allocations.
ICNIRP	International Commission on Non-Ionizing Radiation Protection
NRPB	National Radiological Protection Board
SAR	Specific energy absorption rate.
Third Generation	The next evolution of mobile phone technology based on **UMTS** and expected to result in widespread use of videophones and access to multimedia information.