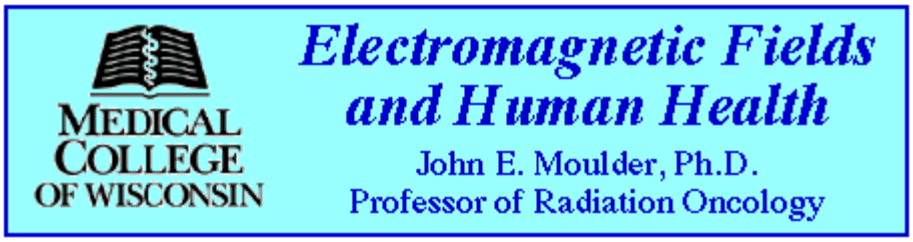

Cellular Phone Antennas (Mobile Phone Base Stations) and Human Health

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Version: 5.2.3
Last-modified: 2-November-2003
Author: John Moulder, Professor of Radiation Oncology, Medical College of Wisconsin, Milwaukee, Wisc, U.S.A.
Address: jmoulder at mcw dot edu

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- **This FAQ addresses the issue of whether base station transmitter/antennas for cellular phones, PCS phones, mobile phones, and other types of portable transceivers are a risk to human health.**
- Issues surrounding the phones (transceivers) themselves, including the regulation of radiation-frequency radiation from the phones, are discussed only indirectly. For detailed discussions of the evidence that RF radiation from mobile phones is associated with cancer or other health risks see:
  - JE Moulder et al: Cell Phones and Cancer: What Is the Evidence for a Connection? Radiation Research 151(5):513-531, May 1999.
    (http://www.radres.org/rare_151_05_0513.pdf)
  - KR Foster and JE Moulder: Are mobile phones safe? IEEE Spectrum, August 2000, pp 23-28.
    (http://www.spectrum.ieee.org/publicfeature/aug00/prad.html)
  - Human Exposure to Radio Frequency and Microwave Radiation from Portable and Mobile Telephones and Other Wireless Communication Devices. IEEE Eng Med Biol, Jan/Feb 2001, pp 128-131.
    (http://ewh.ieee.org/soc/embs/comar/phone.htm)
  - H Frumkin, A Jacobson et al: Cellular phones and risk of brain tumors. CA Cancer J Clin 51:137-141, 2001.
    (http://www.cancer.org/eprise/main/docroot/PUB/content/PUB_3_8X_Environmental_Carcinogens-Cellular_Phones_and_Risk_of_Brain_Tumors)
  - Research and regulatory efforts on mobile phone health issues (GAO-01-545). US General Accounting Office, Washington, D.C., 2001.
    (http://www.gao.gov/new.items/d01545.pdf).
  - Mobile telephones: an evaluation of health effects. Health Council of the Netherlands, The Hague, 2002.
    (http://www.gr.nl/pdf.php?ID=377)
  - Cell Phone Facts: Consumer Information on Wireless Phones, Food and Drug Administration and the Federal Communications Commission..
    (http://www.fda.gov/cellphones/)
  - JD Boice and JK McLaughlin: Epidemiological studies of cellular telephones and cancer risk -- A review. Stockholm, Swedish Radiation Protection Authority, 2002.
    (http://www.ssi.se/ssi_rapporter/pdf/ssi_rapp_2002_16.pdf)
- Many aspects of the FAQ are also relevant to other types of broadcast antennas.
- Specific technical and regulatory sections have a US bias, but the basic engineering and biology are relevant to any country. Where possible notes have been added to help readers outside the US relate this information to their national systems. Such notes are color coded.

- El documento "Preguntas y respuestas sobre antenas de telefonía móvil y salud humana" está disponible en español: http://www.mcw.edu/gcrc/cop/telefonos-moviles-salud/toc.html
- Queste FAQ riguardanti "le antenne per telefonia mobile e i loro effetti sulla salute" sono disponibili in italiano all'indirizzo: http://space.tin.it/clubnet/albpales/Telefonia_mobile/toc-it.htm
- An older version of this document is available in Chinese at: http://www.ym.edu.tw/rad/cbase/
- This document is available in Japanese at: http://www.iftech.or.jp/cellular/health.html

- There are two related FAQs:
  - Power Lines and Cancer FAQs (http://www.mcw.edu/gcrc/cop/powerlines-cancer-faq/toc.html)
  - Static Electromagnetic Fields and Cancer FAQs (http://www.mcw.edu/gcrc/cop/static-fields-cancer-faq/toc.html)
- This FAQ was designed with Netscape v6.2 and for conformation with HTML 4.0 transitional.

Table of Contents

NEW What's New?

v5.2, Oct/Nov 2003:

- RF radiation alone was not genotoxic to human blood cells, but it enhanced the genotoxic effects of a chemical carcinogen [241].
- Exposure of human volunteers to base station RF radiation caused decreased feelings of "well-being" and improvement on some reaction time and memory tests. The effect on "well-being" was found only for the type of signal used by G3 systems; the effect on cognitive function was found for both G3 and GSM signals [240]. Discussed in 19C.
- A US federal judge ruled in September 2002 that the plaintiffs in one of the major mobile phone - brain cancer law suits had presented "no sufficiently reliable and relevant scientific evidence to support either general or specific causation." [206, 210]. In October 2003, this ruling was upheld by the Court of Appeals [206].

Additions and changes earlier in 2003:

- Governmental reports and academic reviews:
  - A review of the thermal effects of RF radiation on tissues and organs [235].
  - A review of the carcinogenic potential of thermal exposure to RF radiation [234].
  - In June 2003, the U.S. FCC proposed changes in the rules about which base stations would need formal RF radiation safety evaluations. This is discussed in Note 19. *There are clearly some editing/typographical errors in the part of the proposal that affects RF radiation standards for base stations.*

    - A review of thermal stress and its relationship to RF radiation safety guidelines [232].
    - A new Australian RF radiation standard [230] and a companion Q and A document are discussed in International Note 12.
    - A review of the reports of effects of mobile phones on brain function and behavior [214] concluded that: "Most of the reported effects are small as long as the radiation intensity remains in the nonthermal range."
- Epidemiology and experimental human studies:
    - Exposure of human volunteers to mobile phone RF radiation was reported to result in better performance in a test of attention [238].
    - Further studies on the claim that low level exposure to mobile phone RF radiation caused physiological effects in humans [228].
    - The Koivisto group reported [226] that they could not replicate their own earlier finding [117] of RF radiation effects on human reaction time.
    - A Swedish study on mobile phone use and brain cancer is published for a third [221] and fourth [222] time.
- Cellular and animal studies:
    - Two years of exposure of rats to mobile phone RF radiation produced no effects on cancer incidence or life span [237].
    - Exposure of human white blood cells to mobile phone RF radiation did not cause chromosome damage oraffect cell growth [236].
    - Exposure of rats to a 900-MHz GSM mobile phone signal did not promote chemically-induced breast cancer [239].
    - Exposure of mice to mobile phone RF radiation does not promote skin cancer induced by ultraviolet (UV) radiation and did not affect melatonin excretion [233].
    - Rats exposed to mobile phone RF radiation showed behavioral changes, but only if the exposure was intense enough to raise body temperature [229].
    - Exposure of human white blood cells to 1900 MHz RF radiation did not produce genotoxic injury [227].
    - Rats exposed to 1600 MHz RF radiation for lifetime showed no evidence of genotoxic injury [223].
    - Exposure of rats to RF radiation was reported to cause blood-brain barrier leakage and nerve damage [219].
    - Exposure of human white blood cells to thermal levels of RF radiation was reported to cause genotoxic injury [217].
    - Four letters to the editor, and authors' responses [216A], concerning the 2002 Utteridge et al report [197] that the 1997 mouse lymphoma study of Repacholi could not be replicated.
- Dosimetry and biophysical studies:
    - A review of biophysical limits for nonthermal effects of RF radiation [215].

Questions and Answers

1) What are mobile phone base stations; and are there health hazards associated with living, working, playing, or going to school near one?

Mobile phone base stations are low-power multi-channel two-way radios. A mobile phone (cell phone) is a low-power, single-channel, two-way radio. When you talk on such a mobile phone, you (and perhaps dozens of other people around you) are talking to a nearby base station. From that base station your phone call goes into the regular land-line phone system.

Because mobile phones and their base stations are two-way radios, they produce radio-frequency radiation (that's how they communicate), and they expose people near them to radio-frequency (RF) radiation. However, because both the phones and the base stations are low power (short range), the RF radiation exposure levels from them are generally very low.

The consensus of the scientific community, both in the US and internationally, is that the power from these mobile

phone base station antennas is far too low to produce health hazards as long as people are kept away from direct access to the antennas (see Q13 and Q14).

It is critical to be aware of the difference between **antennas**, the objects that produce RF radiation; and **towers or masts**, the structures that the antennas are placed on. It is the **antennas** that people need to keep their distance from, not the **towers** that hold the antennas.

It is also important to be aware that there are many different designs of mobile phone base stations that vary widely in their power, their characteristics, and their potential for exposing people to RF radiation.

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2) Are scientists seriously concerned about possible health risks from mobile phone base station antennas?

Not really. There are some reasons to be concerned about human health effects from the hand-held mobile (cellular) phones themselves (although it is not certain that any risks to human health actually exist). These concerns exist because the antennas of these phones deliver much of their radiofrequency energy to very small volumes of the user's body [83]. Base station antennas do not create such "hot spots" (unless you are standing directly in front of one), so the potential safety issues concerning the phones have no real applicability to the base station antennas.

For further discussion of health issues related to hand-held phones see:

- the 1996 ICNIRP report [1]
- the 1999 and 2000 reviews by Moulder and colleagues [95, 131]
- the 2000-2001 review by the Royal Society of Canada [99]
- the 2000 report of the UK Independent Expert Group on Mobile Phones (the "Stewart Commission") [128]
- the 2001 IEEE position paper [26]
- the 2001 review from the World Health Organization [165]
- the 2001 the review from American Cancer Society [163]
- the 2001 report from the US GAO [168]
- the constantly updated US FCC/FDA website [189]
- the 2002 report from the Health Council of the Netherlands [185]

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3) Do the differences between cell phones, PCS phones, and other types of portable (mobile) phones matter when evaluating the potential impacts of base station antennas on human health?

No. There are many technical differences between cell phones, PCS phones, and the types of "mobile" phones used in other counties [2, also see international note 2]; but for evaluation of possible health hazards, the only distinction that matters is that they operate at slightly different frequencies. The RF radiation from some base stations (e.g., those for the older 800 MHz mobile phones used in the U.S.) may be absorbed by humans somewhat more than the RF radiation from other types of base stations (e.g., those for the 1800-2000 MHz "PCS" phones used in the U.S.) [23]. However, once the energy is absorbed the effects are the same.

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4) Do the differences between base station antennas and other types of radio and TV broadcast antennas matter when evaluating their potential impacts on human health?

Yes and no. The RF radiation from some antennas (particularly FM and VHF-TV broadcast antennas) are absorbed more by humans than the RF radiation from other sources (such as mobile phone base station antennas); but once the energy is absorbed the effects are basically the same.

FM and TV antennas send out 100 to 5000 times more power than base station antennas, but are usually mounted on much higher towers (typically 800 to 1200 ft).

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5) Do mobile phone base station antennas produce radiation?

Yes. Mobile (cellular) phones and their base station antennas are two-way radios, and produce radiofrequency (**RF**) radiation [3]; that's how they work. This radiofrequency radiation is "non-ionizing", and its biological effects are fundamentally different from the "ionizing" radiation produced by x-ray machines [see Q6].

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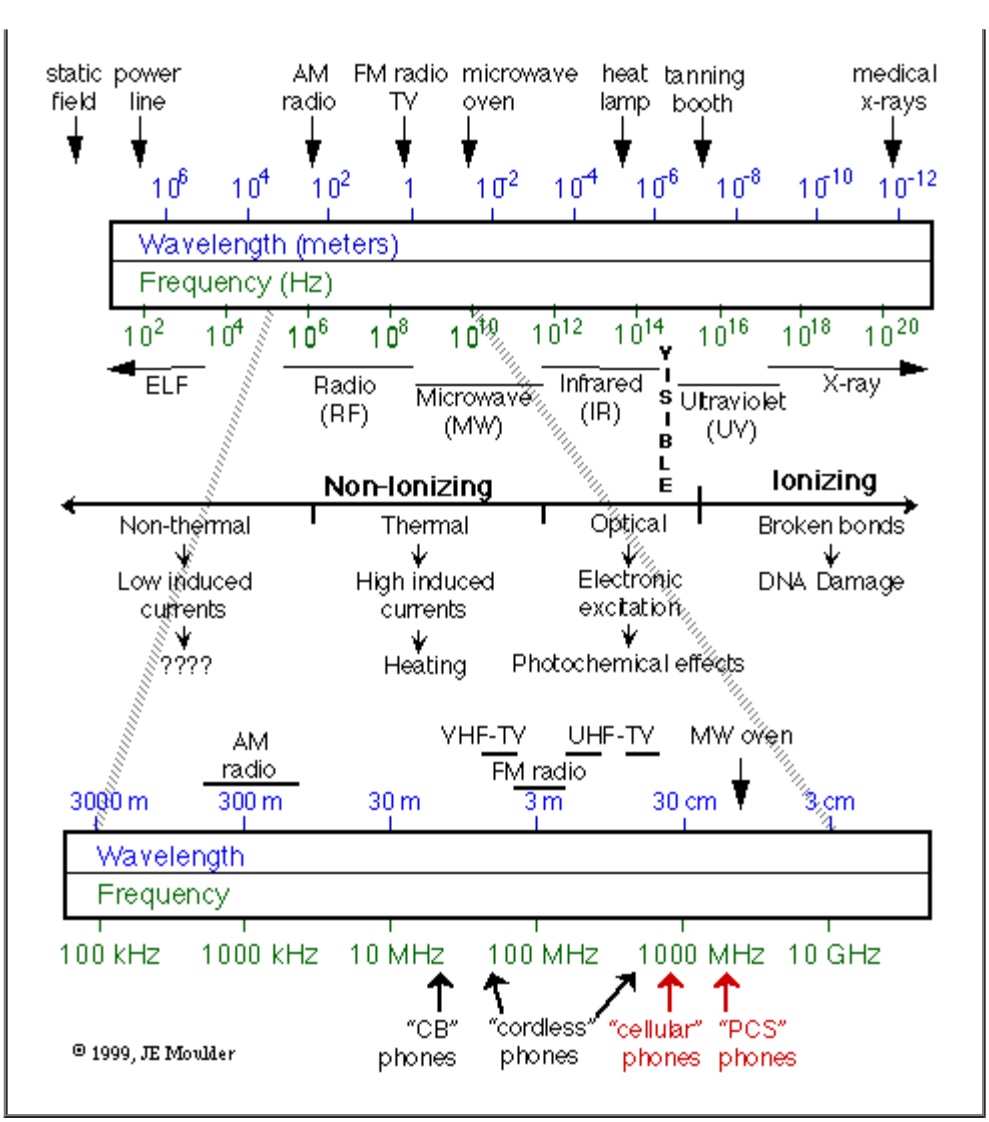
6) Is the non-ionizing radiation (RF radiation) from mobile phone base station antennas similar to ionizing radiations such as X-rays?

No. The interaction of biological material with an electromagnetic source depends on the frequency of the source [4]. X-rays, RF radiation and "EMF" from power lines are all part of the electromagnetic spectrum, and the parts of the spectrum are characterized by their frequency. The frequency is the rate at which the electromagnetic field changes direction and is given in Hertz (Hz), where one Hz is one cycle (wave) per second, and 1 megahertz (MHz) is one million cycles (waves) per second.

Electric power in the US is at 60 Hz. AM radio has a frequency of around 1 MHz, FM radio has a frequency of around 100 MHz, microwave ovens have a frequency of 2450 MHz, and X-rays have frequencies above one million MHz. Cellular (mobile) phones operate at a variety of frequencies between about 800 and 2200 MHz [also see international note 2].

At the extremely high frequencies characteristic of X-rays, electromagnetic particles have sufficient energy to break chemical bonds (ionization). This is how X-rays damage the genetic material of cells, potentially leading to cancer or birth defects. At lower frequencies, such as RF radiation, the energy of the particles is much too low to break chemical bonds. Thus RF radiation is "non-ionizing". Because non-ionizing radiation cannot break chemical bonds, there is no similarity between the biological effects of ionizing radiation (x-rays) and nonionizing radiation (RF radiation) [4].

The Electromagnetic Spectrum



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7) Is the RF radiation from mobile phone base station antennas similar to the "EMF" produced by power lines?

No. Power lines produce no significant non-ionizing radiation, they produce electric and magnetic fields. In contrast to non-ionizing radiation, these fields do not radiate energy into space, and they cease to exist when power is turned off. It is not clear how, or even whether, power line fields produce biological effects; but if they do, it is not in the same way that high power RF radiation produces biological effects [4, 53]. There appears to be no similarity between the biological effects of power line "EMF" and the biological effects of RF radiation.

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8) Are there safety guidelines for mobile phone base station antennas?

Yes. There are national and international safety guidelines for exposure of the public to the RF radiation produced by mobile phone base station antennas. The most widely accepted standards are those developed by the Institute of Electrical and Electronics Engineers and American National Standards Institute (**ANSI/IEEE**) [5, 169], the International Commission on Non-Ionizing Radiation Protection (**ICNIRP**) [6], and the National Council on Radiation Protection and Measurements (**NCRP**) [7].

These radiofrequency standards are expressed in "plane wave power density", which is measured in mW/cm-sq (milliwatts per square centimeter) [8, 169]. For base stations that operate in the 1800-2000 MHz range (for example, PCS base stations in the USA), the 1992 ANSI/IEEE exposure standard for the general public is 1.2 mW/cm-sq. For antennas that operate around 900 MHz (for example, base stations for analog phones in the USA), the ANSI/IEEE exposure standard for the general public is 0.57 mW/cm-sq [9]. The ICNIRP standards are slightly lower and the NCRP standards are essentially identical [10].

In 1996 the U.S. Federal Communications Commission (FCC) released radiofrequency guidelines for the frequencies and devices they regulate, including mobile phone base station antennas [11]. The FCC standards for mobile phone base station antennas are essentially identical to the ANSI/IEEE standard [5].

The public exposure standards apply to power densities averaged over relatively short periods to time, 30 minutes in the case of the ANSI/IEEE, NCRP, and FCC standards (at mobile phone frequencies). Where there are multiple antennas, these standards apply to the total power produced by all antennas [13].

See international note 12 and Erdreich and Klauenberg [164].

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9) Is there a scientific basis for these radiofrequency radiation safety guidelines?

Yes. When scientists examined all the published literature on the biological effects of RF radiation they found that the literature agreed on a number of key points [see 1, 5, 6, 7, 14, 53, 83, 90, 95, 96, 99, 164, 169, 212, 230, 232 for details]:

1. The research on RF radiation is extensive [15], and is adequate for establishing safety guidelines.
2. Exposure to RF radiation can be hazardous if the exposure is sufficiently intense. Possible injuries include cataracts, skin burns, deep burns, heat exhaustion and heat stroke. See Reeves [126] for a discussion of the known effects of overexposure to RF radiation in humans.
3. Biological effects of RF radiation depend on the rate of energy absorption [8]; and within a broad range of frequencies (1 to 10,000 MHz), the frequency matters very little.
4. Biological effects of RF radiation are proportional to the rate of energy absorption; and the duration of exposure matters very little [96].
5. No biological effects have been consistently shown below a certain rate of whole body energy absorption (this rate is called the specific absorption rate or SAR) [16].

Based on this scientific consensus, different agencies and countries took different approaches to setting safety guidelines. A typical approach was that used by ANSI/IEEE [5] and the FCC [11]:

- To establish occupational exposure guidelines, ANSI/IEEE and FCC applied a 10-fold safety margin to the lowest energy absorption rate shown to have biological effects.
- They then applied an additional 5-fold safety margin for continuous exposure of the general public.
- Finally, detailed studies were done to establish the relationship of power density, which can be routinely measured, to the energy absorption rate (SAR), which really matters [8].
- The result was a highly conservative public exposure guideline that was set at a level that is only 2% of the level where replicated biological effects have actually been observed.

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10) Are all the safety guidelines the same?

No. There are differences between the standards. ANSI/IEEE, ICNIRP, NCRP and FCC all use the same biomedical data, and the same general approach to setting safety guidelines. However, there are differences in the models used by the different groups, and hence there are slight differences in the final numbers [17, 164, 169]. No biological significance should be associated with these slight differences.

A number of countries have their own regulations for public exposure to RF radiation from mobile phone base station antennas. While most of these regulation follow the same patterns and rationales used by ANSI/IEEE [5] and ICNIRP [6], they do differ. See note 12 and Erdreich and Klauenberg [164] for details.

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11) Does the U. S. have safety guidelines for mobile phone base stations?

Yes. Until 1996 the U. S. Federal Communications Commission (FCC) used an out-dated (1982) ANSI standard. In 1996 the FCC adopted a new standard [11] that was based on a combination of the 1992 ANSI standard [5, 169] and

the 1986 NCRP guidelines [7].

The new FCC standard for mobile phone base stations is 0.57 mW/cm-sq at 900 MHz and 1.0 mW/cm-sq at 1800-2000 MHz. This 1996 FCC standard applied to all new transmitters licensed after 15-Oct-97, but pre-existing facilities had until 1-Sep-2000 to demonstrate compliance.

The FCC power-density standards described above apply to whole-body public exposure to radio-frequency radiation from mobile phone base stations; they do not apply to exposure from the phones themselves or to occupational exposure. For a discussion of exposure from the phones or a discussion of occupational RF radiation exposure see FCC OET Bulletin 56 [135], the FCC guideline itself [11], and Foster and Moulder [131].

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12) Can mobile phone base station antennas meet the safety guidelines?

Yes. With proper design, mobile phone base station antennas can meet all safety guidelines by a wide margin.

A mobile phone base station antenna, mounted 10 meters (33 ft) above publicly-accessible areas and operated at the maximum intensity, might produce a power density as high as 0.01 mW/cm-sq in publicly-accessible areas near the antenna site; but power densities in publicly-accessible areas will more often be in the 0.00001 to 0.0005 mW/cm-sq range [57, 77, 123, 130]. These power densities are far below all the safety guidelines, and the standards themselves are set far below the level where potentially hazardous effects have been seen.

Within about 200 meters (650 ft) of the base of the antenna site, the power density may be greater at elevations above the base of the antenna site (for example, at the second floor of a building or on a hill). Even with multiple antennas on the same tower, power densities should be less than 5% of the FCC guidelines at all heights and at all distances of more than 40 meters (130 ft) from an antenna site.

Further than about 200 meters (650 ft) from the antenna site power density does not rise with increased elevation.

Power density inside a building will be lower by a factor of 3 to 20 than outside [54, 130].

Petersen et al [77] measured power densities around mobile phone base stations. The measurements were for antennas radiating 1600 W ERP (see Q14C for a discussion of antenna power) on towers that ranged from 40 to 83 meters (130 to 275 ft) in height. The maximum power density on the ground was 0.002 mW/cm-sq, and the maximum was at 20 to 80 meters (65-265 feet) from the base of the towers. Within 100 meters (330) feet of the base of the towers, the average power density was less than 0.001 mW/cm-sq. These maximum RF power densities are all less than 1% of the FCC, ANSI/IEEE, NRPB and ICNIRP standards for public exposure.

In 1999 in Vancouver Canada, Thansandote et al [123] measured RF levels in five schools, three of which had base stations on them or near them. All schools met Canadian, US and international RF standards by a wide margin. The maximum readings are shown in the following table.

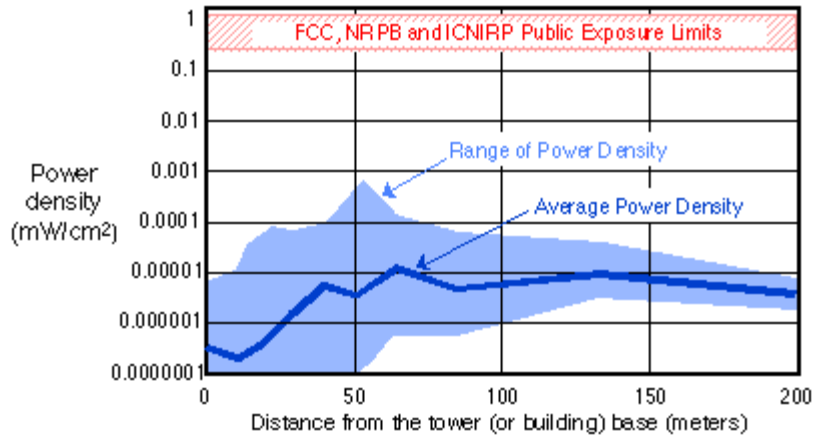
RF Levels in Canadian Schools Near mobile phone Base Stations

School	Base Station Location	Maximum RF Level
1	PCS base station across street	0.00016 mW/cm-sq
2	analog base station on roof	0.0026 mW/cm-sq
3	analog base station across street	0.00022 mW/cm-sq
4 and 5	no antennas nearby	less than 0.00001 mW/cm-sq
	Canadian Standard	less than 0.57 mW/cm-sq

In 2000, the U.K. National Radiation Protection Board [130] measured radiofrequency radiation levels at 118 publicly-accessible sites around 17 mobile phone base stations. The maximum exposure at any location was 0.00083 mW/cm-sq (on a playing field 60 meters from a school building with an antenna on its roof). Typical power densities were less

than 0.0001 mW/cm-sq (less than 0.01% of the ICNIRP public exposure guidelines). Power densities indoors were substantially less than power densities outdoors. When radiofrequency radiation from all sources (mobile phone, FM radio, TV, etc.) was taken into account the maximum power density at any site was less than 0.2% of the ICNIRP public exposure guidelines. Details are shown in the following figure.

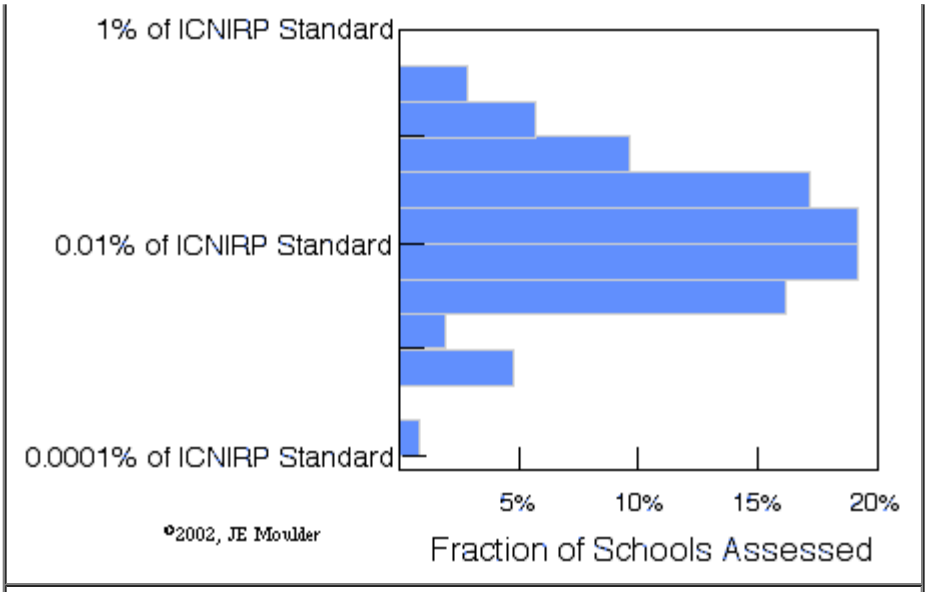
Radiofrequency Radiation Levels Near Mobile Phone Base Stations in the UK



The relationship between the RF power density and distance from the base of the tower or building on which the mobile phone base antenna was located. Adapted from Mann et al. [130].

In 2001, the Radiocommunications Agency of the UK Department of Trade and Industry measured RF radiation levels at 100 schools that had mobile phone base stations near them. The maximum RF level measured at any school was less than 1% of the ICNIRP standard [6] for public areas; the maximum in most schools was less than 0.1% of that standard. The results of this audit are summarized in the figure below and the details are on the web at: http://www.radio.gov.uk/topics/mpsafety/school-audit/audit.htm.

Radiofrequency Radiation Levels in Schools Near Mobile Phone Base Stations in the UK (in comparison to the ICNIRP guidelines for public areas)

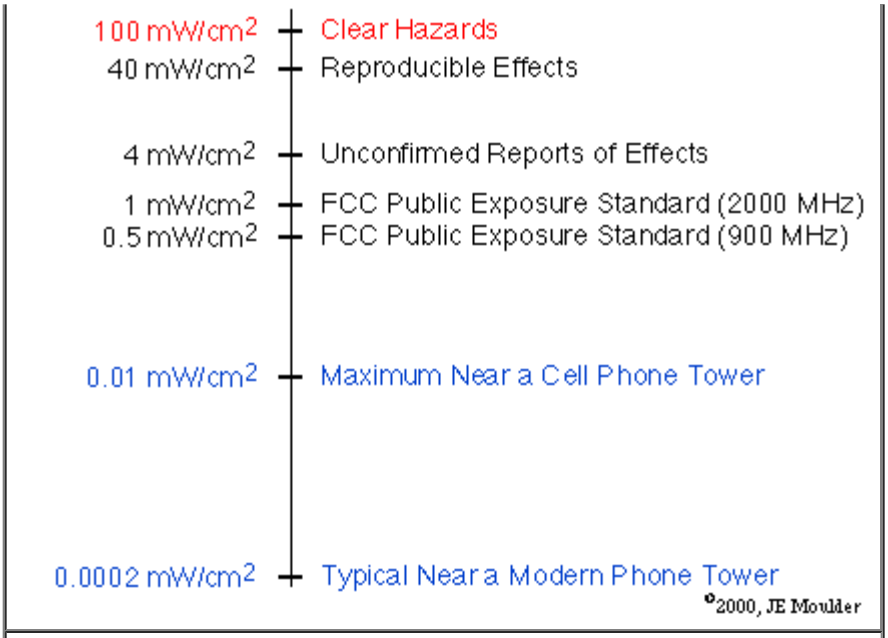


Maximum RF radiation levels (in comparison to the ICNIRP standard for public areas) in UK schools that have mobile phone base stations near them. Adapted from . http://www.radio.gov.uk/topics/mpsafety/school-audit/audit.htm/.

A 2000 survey of GSM base stations by the Australian Radiation Protection and Nuclear Safety Agency found that public exposures to RF radiation were less than 0.1% of their standard [231]. The highest exposure level they found was less than 0.0002 mW/cm-sq (less than 0.01% of the ICNIRP public exposure guidelines), and the average exposure level was less than 0.0001 mW/cm-sq. At most of the 13 sites they measured, there were other types of RF radiation signals that were more powerful than the base station signal (AM radio was more powerful in 12 cases, FM radio in 6 cases, and TV in 3 cases). At all sites measured the total RF radiation from all sources combined (mobile phone base stations, AM radio, FM radio, VHF TV, UHF TV, paging) was less than 0.1% of the Australian (or the ICNIRP or FCC) RF safety guidelines.
The Australian report is on line at: http://www.arpansa.gov.au/pubs/eme_comitee/rfrep129.pdf

The relationship between the RF levels required to produce known biological effects, the RF levels specified in the FCC safety guidelines, and the RF levels found around mobile phone base stations is shown in the following figure.

Standards for Mobile Phone Base Stations



The relationship between the RF power density level required to produce known biological effects, the RF power density levels specified in the FCC safety guidelines, and the RF power density levels found around mobile phone base stations. Because the RF power density required to produce biological effects is dependent on frequency, this figure only applies to frequencies between 800 and 2200 MHz (that is, those currently used by analog and digital mobile phones).

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13) Are there circumstances where mobile phone base station antennas could fail to meet the safety guidelines?

Yes. There are some circumstances under which an improperly designed (or inadequately secured) mobile phone base station site could fail to meet safety guidelines.

Safety guidelines for uncontrolled (public) exposure **could be** exceeded if antennas were mounted in such a way that the public could gain access to areas within 10 meters/33 feet (horizontal) of the antennas themselves [18]. This could arise for antennas mounted on or near the roofs of buildings. For example, Petersen et al [77] found that 2-3 feet (1 meter) from a roof-top antenna radiating 1600 W ERP, the power density was as high as 2 mW/cm-sq (compared to the ANSI [9] public exposure standard of 1.2 to 0.57 mW/cm-sq).

For antennas mounted on towers, it is somewhat difficult to imagine a situation that would not meet the safety guidelines. However, there are reports (principally from outside North America and Europe) of base antennas facing directly at nearby buildings. Whether these antennas would meet FCC, ANSI/IEEE or ICNIRP safety guidelines would depend on the ERP, the exact geometry and the degree of shielding provided by the building.

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14) What siting criteria are required to ensure that a mobile phone base station antenna will meet safety guidelines?

While specific recommendations require a detailed knowledge of the site, the antenna, and the mounting structure, some general criteria can be described.

14A) What are some general siting criteria?

1. Antenna sites should be designed so that the public **cannot access** areas that exceed the 1992 ANSI [5] or FCC [Q11] guidelines for public exposure. As a general rule, the uncontrolled (public) exposure guideline cannot be

exceeded more than 10 meters (33 feet) from an **antenna** [18].
2. If there are areas accessible to workers that exceed the 1992 ANSI [5] or FCC [Q11] guidelines for uncontrolled (public) exposure, make sure workers know where the areas are, and what precautions need to be taken when entering these areas. In general, this would be areas less than 10 meters (33 feet) from the antennas [18].
3. If there are areas that exceed the 1992 ANSI [5] or FCC [Q11] guidelines for controlled (occupational) exposure, make sure that workers know where these areas are, and that they can (and do) power-down (or shut down) the transmitters when entering these areas. Such areas may not exist; but if they do, they will probably be limited to areas within 3 meters (10 feet) of the antennas [18].

If there are questions about whether these guidelines are met, compliance should be verified by measurements done after the antennas are activated.

The FCC guidelines [11] require detailed calculations and/or measurement of radiofrequency radiation for some types of base stations [19]. In June 2003, the FCC proposed some significant changes in these rules (see note 19).

In general, the above guidelines will usually be met when antennas are placed on their own towers. Problems, when they exist, are generally confined to:

- Antennas placed on the roofs of buildings; particularly where multiple base station antennas for different carriers are mounted on the same building;
- Antennas placed on structures that require access by workers (both for regular maintenance, and for uncommon events such as painting or roofing).
- Towers that are placed very close to buildings.

See international note 19.

14B) What are the differences between a high-gain antenna and a low-gain antenna?

There are many different types of base station antennas, and the RF radiation patterns from them can be quite different. The most basic difference is between high-gain antennas and a low-gain antennas. Because siting and safety issues for high- and low-gain antennas are different, it is important to be able to tell them apart (see Q14B for a discussion of antenna gain). In the early days of mobile phones, you could usually tell by looking. Unfortunately, the development of newer antenna designs and the variety of different ways to stealth (hide) antennas now often makes it impossible to determine what kind of antenna has been installed just by looking,

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14C) What do the phrases "antenna gain", "transmitter power" and "effective radiated power (ERP)" mean?

The power of a mobile phone base station is usually described by its **effective radiated power (ERP)** which is given in watts (W). Alternatively, the power can be given as **transmitter power** (in watts) and the **antenna gain**.

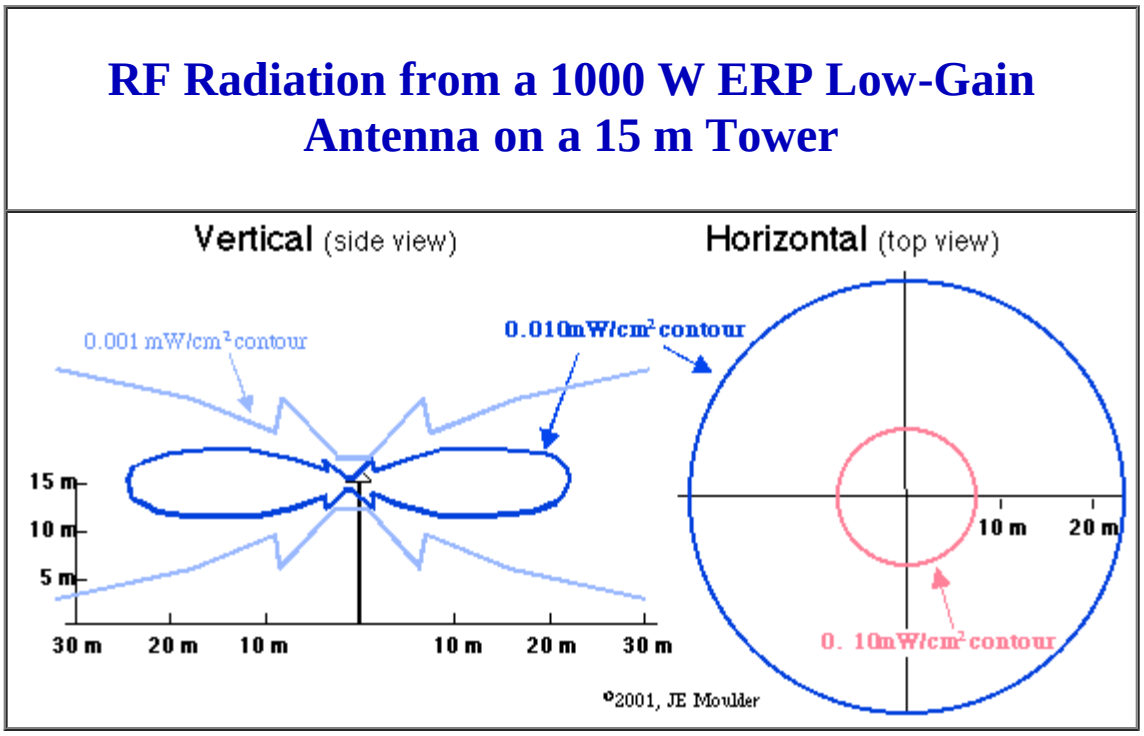
Transmitter power is a measure of total power, while ERP is a measure of the power in the main beam. If an antenna were omni-directional and 100% efficient, then transmitter power and ERP would be the same. But mobile phone base station antennas (like all antennas) are not omni-directional; they are moderately (low-gain antennas) to highly (high-gain antennas) directional. The fact that they are directional means that they concentrate their power in some directions, and give out much less power in other directions. Antenna gain is a measure of how directional an antenna is, and it is measured in decibels. As a result, a 20-50 W base station transmitter with a high-gain antenna could produce an ERP of anywhere from several hundred watts to over 1000 watts.

The concept of "gain" and "ERP" are best explained by analogy to light bulbs. Compare a regular 100 W light bulb to a 25 W spot light. The spot light has less total power than the regular light, but is much brighter when you are in its beam and much weaker when you are outside its beam. A mobile phone base antenna (particularly a high-gain sector antenna) is like the spot light, and ERP is equivalent to the effective power in the spot light's main beam.

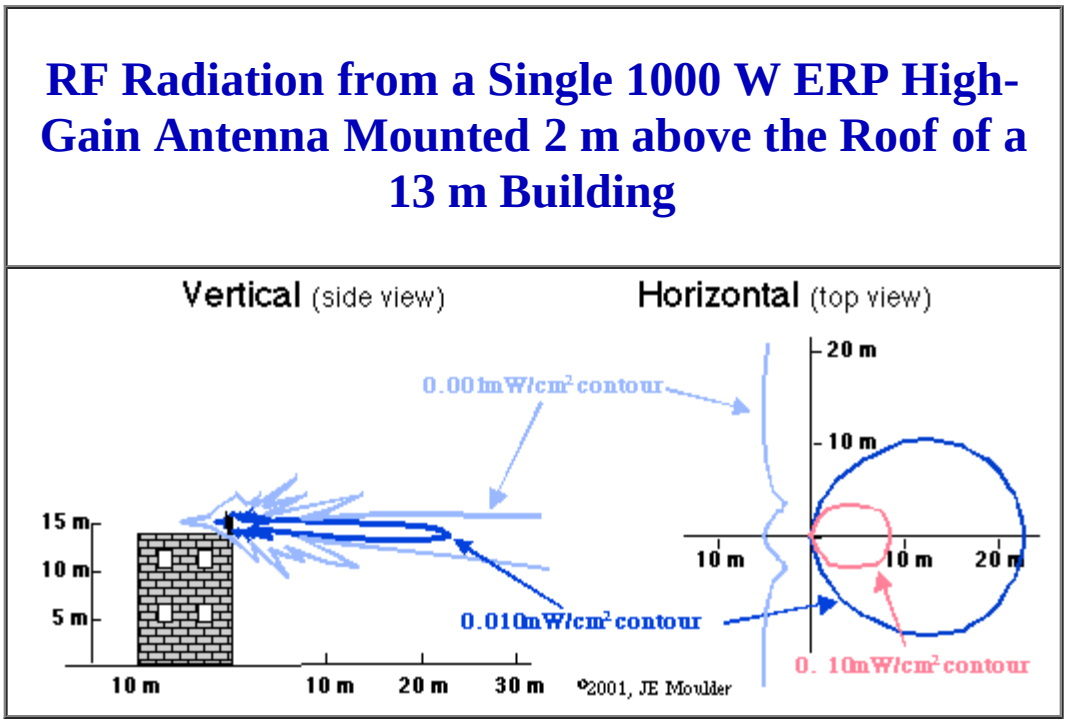
For a more complete technical discussion of these issues see Section 2.2.11 of NCRP Report No. 119 [134].

14D) What is the difference between the RF patterns for high-gain and low-gain antennas?

The RF patterns for different types of antennas are very different. For a low-gain antenna with a 1000 W ERP (see Q14C for a discussion of antenna power and gain) of the type formerly used by many mobile phone base stations, the pattern can look like this:



For a high-gain (sector) antenna of the type used in many of the newer base stations, the pattern can look like this:



Keep in mind that mobile phone base station that use high-high-gain sectored antennas will usually use 3 (or occasionally 4) of these transmission antennas, all pointing in different directions.

The data for the above figure were adapted (with permission) from drawings provided by UniSite Inc. of Tampa, Florida.

14E) Is it safe to live on the top floor of a building that has a mobile phone base station antenna on it?

In general this will not be a problem.

1. As can be seen from the antenna patterns shown in Q14D, neither high- or low-gain antennas radiate much energy straight down.
2. The roof of the building will absorb large amounts of the RF energy. Typically a roof would be expected to decrease signal strength by a factor of 5 to 10 (or more for a reinforced concrete or metal roof).
3. FCC requires RF radiation evaluations of high-power roof-top transmitters (see note 19).
4. Even a worst-case calculation predicts that power density on the floor below an antenna will meet all current RF safety guidelines [55].
5. Actual measurements in top floor apartments and corridors confirm the power density is far below all current RF safety guidelines [55].

14F) Are use restrictions or "set-backs" required around mobile phone base station antenna sites and what is the "minimum safe distance"?

Radiofrequency safety guidelines do not require either **setbacks or use restrictions** around mobile phone base station antenna sites, since power levels on the ground are never high enough to exceed the guidelines for continuous public exposure (see Q8 and Q12).

As discussed in Q13 and Q14, there may be circumstances where use restrictions will have to be placed around the antennas themselves.

The "Minimum Safe Distance" from a mobile phone base antenna is described by the FDA/FCC [189] as follows:

> "To be exposed to levels at or near the FCC limits for cellular or PCS frequencies an individual would essentially have to remain in the main transmitted radio signal (at the height of the antenna) and within a few feet from the antenna... In addition, for sector-type antennas RF levels to the side and in back are insignificant."

Note that the above quote about **safe distances** applies to the actual radiating antenna, not to the tower (or building) the antenna is on. For a mobile phone base station antenna mounted on tower that is 5+ meters high, there should be no areas that will come anywhere close to the RF radiation safety guidelines, so the concept of a "minimum safe distance" really doesn't mean anything.

Some people have argued that base stations should be kept some distance away from **"sensitive" areas.**
There is little logic to this argument:

1. As discussed in Q12 and documented in the 2000 NRPB report [130], the ground level power density does not drop with distance in any regular manner until you get at least several hundred meters away from a base station.
2. People living, working or studying in a building usually get less exposure from a base station that is on their building than they would from a base station several hundred meters away (Q12 and Note 130).
3. Horizontal distance from a base station is less of a factor in ground level power density than antenna height, the antenna power and antenna pattern.

In addition, moving base antennas away from an area where there are mobile phone users may:

1. Increase the exposure of the users from their handsets.
2. Require the base antenna power to be increased.
3. Require the base antennas to placed further above the ground.

4. Increase the cell size and thus limit the number of users allowed in an area.

14G) What precautions need to be taken when working around mobile phone base station antennas?

A detailed discussion of radio-frequency radiation occupational safety guidelines is beyond the scope of this FAQ.

In a detailed discussion of guidelines for telecommunications antenna installation, Tell [116] makes the following recommendations:

Specific Antenna Installation Guidelines (from Tell [116])

1. For roof-mounted antennas, elevate the transmitting antennas above the height of people who may have to be on the roof.
2. For roof-mounted antennas, keep the transmitting antennas away from the areas where people are most likely to be (e.g., roof access points, telephone service points, HVAC equipment).
3. For roof-mounted directional antennas, place the antennas near the periphery and point them away from the building.
4. Consider the trade off between large aperture antennas (lower maximum RF) and small aperture antennas (lower visual impact).
5. Remember that RF standards are stricter for lower-frequency antennas (e.g., 900 Mhz) than for higher-frequency antennas (e.g., 1800 MHz).
6. Take special precautions to keep higher-power antennas away from accessible areas.
7. Keep antennas at a site as far apart as possible; although this may run contrary to local zoning requirements.
8. Take special precautions when designing "co-location" sites, where multiple antennas owned by different companies are on the same structure. This applies particularly to sites that include high-power broadcast (FM/TV) antennas. Local zoning often favors co-location, but co-location can provide "challenging" RF safety problems.

Work Practices for Reducing Radio-frequency Radiation Exposure (from Tell [116])

1. Individuals working at antenna sites should be informed about the presence of RF radiation, the potential for exposure and the steps they can take to reduce their exposure.
2. "If radiofrequency radiation at a site can exceed the FCC standard for general public/uncontrolled exposures, then the site should be posted with appropriate signs." [Per Richard Tell, personal communication, Feb 2000]
3. Radio-frequency radiation levels at a site should be modeled before the site is built.
4. Radio-frequency radiation levels at a site should be measured.
5. Assume that all antennas are active at all times.
6. Disable (lock out) all attached transmitters before working on an antenna.
7. Use personal monitors to ensure that all transmitters have actually been shut down.
8. Keep a safe distance from antennas. "As a practical guide for keeping [radio-frequency radiation] exposures low, maintain a 3-4 ft [1-1.2 m] distance from any [telecommunications] antenna." [116]
9. "Keep on moving" and "avoid unnecessary and prolonged exposure in close proximity to antennas".
10. At some site (e.g., multiple antennas in a restricted space where some antennas cannot be shut down) it may be necessary to use protective clothing.
11. Remember that there are many non-RF hazards at most sites (e.g., dangerous machinery, electric shock hazard, falling hazard), so allow only authorized, trained personnel at a site.

Also see Bernardi et al [147] for an analysis of actual exposure levels to a person on a roof near a base station antenna.

14H) How do you assess compliance with radio-frequency radiation guidelines for mobile phone base stations?

Compliance can be assessed through measurements or calculations. Both methods require a solid understanding of the physics of RF radiation. Measurements require access to sophisticated and expensive equipment. Calculations require detailed knowledge about the power, antenna pattern and geometry of a specific antenna.

Nothing as simple as distance from an antenna site is adequate for assessing compliance or estimating exposure levels [130, 171]. As discussed and illustrated in Q12, RF radiation exposure may not even increase as you get closer to an mobile phone base station site.

Calculation: If the effective radiated power (ERP), the antenna pattern and the height of the base station antenna are known (see Q14C for a discussion of ERP and gain), then "worst case" calculations of ground level power density can be made. However, the calculation method is not simple and the ERP and antenna pattern are often unknown. See Barbiroli et al [224] for an example of how exact calculations can be made if all relevant technical specifications are known.

Measurement: Actual measurement of power density from mobile phone base stations requires sophisticated and expensive equipment and considerable technical knowledge. The instruments designed to measure power line fields and the instruments designed to test microwave ovens are not suitable for measuring base stations. Determining that base stations meet ANSI/IEEE, FCC, or ICNIRP guidelines is "relatively easy", but the instruments required cost well over US$ 2000. Actual measurement of the power-density from a base station antenna is much more difficult, as there are many other sources of RF radiation at a typical site (see Mann et al [130] and Line et al [231]).

Calculations (and sometimes even measurements) must take into account possible sources of RF radiation other than the mobile antenna site being assessed [130, 171]. It is not unusual for there to be other RF radiation signals that are stronger than those from the base station being assessed [231].

For a technical discussion of measurement techniques and instrumentation see Mann et al [130], NCRP Report No. 119 [134] and Line et al [231].

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15) What are other scientists, scientific organizations and governmental review groups saying about RF radiation safety and mobile phones base stations?

This section will deal with what other scientists, scientific organizations and governmental review groups are saying about RF radiation safety and mobile phone base stations. Occasionally this section will also deal with reports on RF radiation safety and mobile phones base stations that appear in the mass media.

15A) What does the U. S. Environmental Protection Agency think about the current RF radiation safety guidelines?

The EPA asked the FCC to adopt parts of the 1986 NCRP guidelines [7] rather than the entire 1992 ANSI guidelines [5]. This the FCC did [11], and EPA has formally endorsed the FCC safety guidelines.

In a 30-April-1999 letter to the FCC, Robert Brenner (EPA Acting Deputy Assistant Administrator for Air and Radiation) stated:

> "The FCC guidelines expressly take into account thermal effects of RF energy, but do not directly address postulated non-thermal effects, such as those due to chronic exposure. That is the case largely because of the paucity of scientific research on chronic, non-thermal health effects. The information base on non-thermal health effects has not changed significantly since the EPA's original comments in 1993 and 1996. A few studies report that at non-thermal levels, long term exposure to RF energy may have biological consequences. The majority of currently available studies suggests, however, that there are no significant non-thermal human health hazards. It therefore continues to be EPA's view that the FCC exposure guidelines adequately protect the public from all scientifically established harms that may result from RF energy fields generated by FCC licensees."

15B) Claims on British, American and French TV that there is new data suggesting that mobile phones might cause cancer.

In the summer and fall of 1999 (and repeated in 2000 and possibly in 2001), programs on British, American and French TV claimed that there was new data suggesting that RF radiation from mobile phones could cause injury to humans. Four sources of "new" information were generally cited:

1. An epidemiology study of mobile phone use and brain cancer by Hardell et al [100]. See Q16E for a detailed discussion of this study.
2. A report by Preece et al [97] that exposure of human volunteers to mobile phone RF radiation might decrease reaction times.
3. A new and then unpublished genotoxicity study.
4. A new and then unpublished epidemiology study.

The last two of these "new" studies were only vaguely described in the TV reports, but they appear to be references to studies sponsored by the mobile phone industry in the US (under the program called WTR).

The WTR epidemiology study was presented at a meeting in June of 1999, and has now been published in the peer-reviewed literature [138,188]. The published version reports no significant association between malignant [138] or benign [188] brain cancer and the use of hand-held mobile phones. See further discussion of the study in Q16E.

The WTR genotoxicity study was presented at a meeting in March of 1999 [102, 103]. Parts of this WTR study were published in early 2002 [182]. The published version [182] reports that RF radiation at 5 or 10 W/kg was capable of causing a one specific type of genotoxic injury (increased micronucleus formation); but did not enhance DNA strand breaks. Vijayalaxmi et al [150], Bisht et al [191] and McNamee et al [207, 208] have reported that they cannot replicate the micronucleus findings. The authors of the WTR genotoxicity study speculate that their reported effect on micronucleus formation may be due to heating.

15C) What have expert scientific panels in the United Kingdom said about the safety of mobile phone base stations?

In 2000, a special committee in the U.K., the "Independent Expert Group on Mobile Phones" (also known as the "Stewart Commission") issued a report on mobile phone safety issues [128]. The full text is available at: http://www.iegmp.org.uk/report/text.htm.

On the general issue of radio-frequency radiation safety, the U.K. Independent Expert Group concluded that:

> "The balance of evidence to date suggests that exposures to RF radiation below NRPB [14] and ICNIRP [6] guidelines do not cause adverse health effects to the general population... There is now scientific evidence, however, which suggests that there may be biological effects occurring at exposures below these guidelines. This does not necessarily mean that these effects lead to disease or injury, but it is potentially important information..." [Sections 1.17 and 1.18]

The "new scientific information" the Stewart Commission refers to were largely the reports by Preece et al [97] and Koivisto et al [117] that mobile phone RF radiation might decrease reaction times, and studies by dePomerai et al [127, 148] which suggest that nonthermal exposures of nematode worms can lead to expression of heat shock proteins.

With respect to mobile phone base stations, the U.K. Independent Expert Group concluded that:

> "The balance of evidence indicates that there is no general risk to the health of people living near to base stations on the basis that exposures are expected to be small fractions of guidelines." [Section 1.33]

However, the U.K. Independent Expert Group was quite critical of the planning process used for siting base stations in the U.K., and recommended that:

- "...the siting of all new base stations should be subject to the normal planning process." [Section 1.36]
- "...protocols be developed, in concert with industry and consumers, which can be used to inform the planning

process and which must be assiduously and openly followed before permission is given for the siting of a new base station." [Section 1.37]
- " [the protocols should include] a requirement for public involvement, an input by health authorities/health boards and a clear and open system of documentation which can be readily inspected by the general public." [Section 1.38]
- "...an independent random, ongoing, audit of all base stations be carried out to ensure that exposure guidelines are not exceeded outside the marked exclusion zone... and that particular attention should be paid initially to the auditing of base stations near to schools..." [Sections 1.40 and 1.41].
- Specifically with respect to schools, the U.K. Independent Expert Group also recommended that: "... [for] base stations sited within school grounds, that the beam of greatest intensity should not fall on any part of the school grounds or buildings without agreement from the school and parents. Similar considerations should apply to base stations sited near to school grounds." [Section 1.42].

Probably the most controversial recommendations made by the U.K. Independent Expert Group referred to the phones themselves rather than base stations, when they recommended that:

- "...drivers be dissuaded from using either hand-held or hands-free phones while on the move." [Section 1.22]
- "...the widespread use of mobile phones by children for non-essential calls should be discouraged and... that the mobile phone industry should refrain from promoting the use of mobile phones by children." [Section 1.53].

The recommendation that children be discouraged from using phones is based largely on the cognitive effect studies of Preece et al [97] and Koivisto et al [117] and on the European Union "Precautionary Principle" [129]. This rationale for this recommendation has been criticized on multiple grounds:

- The notion that there may be neurological effects at the SAR levels produced by hand-held mobile phones is based on reports of effects that are both weak and contradictory. Note that in 2003, the Koivisto group reported [226] that they could not replicate their earlier report [117] of cognitive effects that was partially the basis for this recommendation.
- There is no evidence that the reported cognitive effects would cause an adverse health effect, and the reported effects appear to be too small to have any real functional significance.
- The Committee provided no evidence to justify the premise that children are more susceptible to the reported effects, other than to speculate about the susceptibility of the "developing nervous system". Since most nervous system development is done by the end of infancy, the relevance of this to phone use by teenagers is unclear.
- The suggestion that phones will produce higher SARs in the head of a child compared to an adult was provided without any supporting argument.
- The Committee's application of the precautionary principle to children's exposure to hand-held mobile phones appears to violate the guidelines established by the European Union [129].

15D) What have expert scientific panels in Canada said about the safety of mobile phone base stations?

An Expert Panel assembled by the Royal Society of Canada issued a report on mobile phone safety in 1999 [99]. The report is online at: http://www.rsc.ca/english/RFreport.pdf.

Regarding mobile phone base stations, the Expert Panel concluded:

> "Surveys conducted in proximity to base stations operating in Canada indicate that the public is exposed to extremely low intensity RF fields in the environment. These exposures are typically thousands of times lower than the recommended maximum exposure in Safety Code 6."

15E) What have expert scientific panels in the United States said about the safety of mobile phone base stations?

In 2001 the Institute of Electrical and Electronics Engineers (IEEE) published a statement on mobile phone base stations [27]. The report is on-line at: http://ewh.ieee.org/soc/embs/comar/base.htm.

The statement concluded that:

> "In nearly all circumstances, public exposure to RF fields near wireless base stations is far below recommended safety limits... Consequently, wireless base stations are not considered to present a risk to the general population including aged people, pregnant women, and children"

In a website (http://www.fda.gov/cellphones/) that went on-line in May 2002, the US Food and Drug Administration and the Federal Communications Commission states that:

> "The electromagnetic RF signals transmitted from base station antennas stations travel toward the horizon in relatively narrow paths... Therefore, RF exposure on the ground is much less than exposure very close to the antenna and in the path of the transmitted radio signal. In fact, ground-level exposure from such antennas is typically thousands of times less than the exposure levels recommended as safe by expert organizations. So exposure to nearby residents would be well within safety margins."
>
> "Measurements made near cellular and PCS base station antennas mounted on towers have confirmed that ground-level exposures are typically thousands of times less than the exposure limits adopted by the FCC. In fact, in order to be exposed to levels at or near the FCC limits for cellular or PCS frequencies an individual would essentially have to remain in the main transmitted radio signal (at the height of the antenna) and within a few feet from the antenna..."
>
> "When cellular and PCS antennas are mounted on rooftops, RF levels on that roof or on others near by would probably be greater than those typically encountered on the ground. However, exposure levels approaching or exceeding safety guidelines should be encountered only very close to or directly in front of the antennas..."

15F) What have expert scientific panels in the Netherlands said about the safety of mobile phone base stations?

In 2002, the Health Council of the Netherlands issued a report on the safety of mobile phones [185]. The report is on-line at: http://www.gr.nl/pdf.php?ID=377. On the general issue of mobile phone safety, the Health Council concluded that:

> "The electromagnetic field of a mobile telephone does not constitute a health hazard, according to the present state of scientific knowledge."

With respect to mobile phone base stations, the Health Council reaffirmed their earlier (2000) conclusion [186] that:

> "The chance of health problems occurring among persons living and working below bases stations as a result of exposure to electromagnetic fields originating from the antennas is, in the Committee's opinion, negligible. The field levels are always considerably below the exposure limits."

15G) What have expert scientific panels in France said about the safety of mobile phone base stations?

In 2001, the Directeur Général de la Santé issued a report on the safety of mobile phones and their base stations (Les Téléphones Mobiles, leurs Stations de Base et la Santé) [179]. An English-language summary is on-line at: http://www.sante.gouv.fr/htm/dossiers/telephon_mobil/conclus_uk.htm. On the general issue of mobile phone safety, the French report concluded that:

> "The risk of accident and fatality associated with the use of mobile telephones when driving has definitely been established. In the current state of knowledge, this is the only known health risk, albeit a very serious one."

With respect to mobile phone base stations, the report concluded that:

> "There is considerably less personal exposure in the vicinity of base stations with the exception of exclusion areas than there is when making a call with a mobile phone...In view of the exposure levels observed, the group of experts does not back the hypothesis that there is a health risk for populations living in the vicinity of base stations."

15H) What have expert scientific panels in Australia said about the safety of mobile phone base stations?

In a supplement to their 2002 RF radiation protection standard [231] the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) wrote:

> "Radiofrequency radiation (RFR) from mobile phone towers makes only a minor contribution to the total environmental RFR that arises primarily from other communications sources. Depending on location the RFR from mobile phone towers is generally less than 3% of all RFR from other contributing sources including AM and FM radio, television, paging systems and emergency services.
> Further, the exposure levels from all combined radiofrequency sources as measured adjacent to the mobile phone towers are generally much less than 2 microwatts per square centimeter [0.002 mW/cm-sq]. Such RFR levels are below 1% of the maximum allowable public exposure levels."

Elsewhere in that document ARPANSA wrote:

> "Significant safety factors are incorporated into the exposure limits -- that is, the limits are set well below the level at which adverse health effects are known to occur. Current data does not establish the existence of adverse heath effects for exposure levels below the limits of the ARPANSA."

Note that with respect to public exposure to RF radiation from mobile phone base stations the Australian standard is largely (if not completely) in agreement with the ICNIRP Guidelines.

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16) Are there epidemiological studies showing that RF exposure from base stations is safe?

Yes and no. While there have been no epidemiology studies of cancer and mobile phone base stations, there have been epidemiology studies of cancer and other types of exposure to radiofrequency radiation. For summaries see the 1999 review by Elwood [94], the 2000 review by Rothman [139], and the 2002 review by Boice and McLaughlin [204].

Epidemiology studies of RF radiation from base stations have generally been concluded to be "infeasible, as there is no possibility to estimate individual exposure accurately enough" [199].

In general, epidemiology studies of radiofrequency radiation and cancer have not found significant correlations between exposure and cancer. The studies include:

- geographic correlation studies that compare cancer rates among areas with different potential exposures to radiofrequency radiation
- "cancer cluster" studies
- studies of cancer in people with military or occupational exposure to radiofrequency radiation
- users of hand-held mobile phones

16A) Geographic correlation studies

Geographic correlation studies estimate the strength of RF radiation in geographic areas and correlate these estimates with disease rates in these areas. Even when the design of geographic correlation studies is optimal, they are considered exploratory and are not generally used for determining causality.

The geographical correlation studies done to date show no consistent relationship between exposure to RF radiation and either adult of childhood cancer. See Elwood [94] for a detailed discussion of these studies.

The best known geographical correlation studies are those of cancer in people living near TV or FM radio broadcast towers.

- In 1996, Hocking and colleagues [28] compared municipalities "near TV towers" to those further away. No RF radiation exposures were actually measured, but the authors calculate that exposures in the municipalities "near TV towers" were 0.0002 to 0.008 mW/cm-sq. No other sources of exposure to RF are taken into account, and the study is based on only a single metropolitan area. The authors report an elevated incidence of total leukemia and childhood leukemia, but no increase in total brain tumor incidence or childhood brain tumor incidence.
- In 1998, McKenzie and colleagues [62] repeated the Hocking study [28]. They looked at the same area, and at the same time period; but they made more precise estimates of the exposure to RF radiation that people got in various areas. They found increased childhood leukemia in one area near the TV antennas, but not in other similar areas near the same TV antennas, and they found no significant correlation between RF exposure and the rate of childhood leukemia. They also found that much of the "excess childhood leukemia" reported by Hocking et al [28] occurred before high-power 24-hour TV broadcasting had started. This replication study, plus the failure to find any effect in the larger UK studies (see below [34,35]), suggests that correlation reported by Hocking et al [28] was an artifact.
- In 1997, Dolk and colleagues [34] investigated a reported leukemia and lymphoma cluster near a high-power FM/TV broadcast antenna at Sutton Coldfield in the UK. They found that the incidence of adult leukemia and skin cancer was elevated within 2 km of the antenna, and that the incidence of these cancers decreased with distance. No associations at all were seen for brain cancer, male or female breast cancer, lymphoma or any other type of cancer.
- Because of the above finding, Dolk and colleagues [35] extended their study to 20 other high-power FM/TV broadcast antennas in the UK. Cancers examined were adult leukemia, skin melanoma and bladder cancer, and childhood leukemia and brain cancer. No elevations of cancer incidence were found near the antennas, and no declines in cancer incidence with distance were seen. This large study does not support the results found in the much smaller studies by the same authors at Sutton Coldfield [34] or by Hocking et al [28] in Australia.
- In 2002, Michelozzi et al [196] reported that the incidence of childhood leukemia was elevated within 6 km of Vatican Radio (31 transmitters at 4-44 kHz and 0.5-1.6 MHz, with power of up to 600,000 W). The authors also report elevated leukemia in adult men residing near the transmitters, but not in adult women.
- In 2002, Hallberg and Johansson [195] speculated that the increase in melanoma seen in Sweden (and industrialized countries) since 1960 is due to exposure to FM radio broadcasting.

16B) Cancer cluster studies

The major steps in evaluating reports of "cancer clusters" are:

1. Define a logical (as opposed to arbitrary) boundary in space and time;
2. Determine whether an excess of a specific type of cancer has actually occurred;
3. Identify common exposures and characteristics.

The above steps have not generally been followed in studies of RF radiation, and the reports of "cancer clusters" are of essentially no value in determining whether exposure to RF radiation is a cause of cancer (see Elwood [94] for details of these studies).

16C) Occupational exposure studies

The majority of the occupational studies of RF radiation exposure have deficiencies in exposure assessments because occupation or job title was used as an estimate of exposure; that is, actual RF radiation exposure levels are not known.

There are five epidemiological studies of occupational exposure to RF radiation that are generally considered to have acceptable design and analysis, adequate sample size, and sufficient follow-up time: Robinette et al [67], Hill [68], Milham [69], Morgan et al [118] and Groves et al [187]. These five studies do not show consistent associations between exposure to radio-frequency radiation and either cancer in general or any specific kind of cancer.

In a study published in early 2000, Morgan and colleagues [118] studied all major causes of mortality (with emphasis on brain cancer, lymphoma and leukemia) in employees of Motorola, a manufacturer of wireless communication products. Based on job titles, workers were classified into high, moderate, low, and background RF exposure groups. For workers with moderate or high RF radiation exposure no elevation in rates of brain cancer, leukemia and lymphoma were found. Actual peak and/or average RF radiation exposure levels are not known.

In a study published in 2002, Groves et al [187] reported that exposure to RF radiation from US Navy radar during the Korean War is not associated with a subsequent increase in cancer rates. In comparison with navy men who served at the same time, but who had "low radar exposure potential", the sailors with "high radar exposure potential" showed less overall cancer and brain cancer than expected. The rate of nonlymphocytic leukemia was elevated, but the authors note that this increase was statistically significant in only one of the three high exposure occupations. This is a follow-up study to Robinette et al [67].

The other studies of acceptable design (Lilienfeld et al [70 and Q16D], Lagorio et al [71], Muhm [72], Tynes et al [73], Grayson et al [33], and Thomas et al [105]) have more limitations in exposure assessment, case ascertainment, or follow-up time; but they also do not suggest that RF radiation exposure increases the risk of either cancer in general or any specific kind of cancer.

Szmigielski [79] studied Polish military personnel who may have had RF radiation exposure. The incidence of cancer of all types, brain cancer, leukemia and lymphoma are reported to be elevated in exposed personnel. Because the methods of data collection and analysis are inadequately described or unsuitable, and because assessment of RF radiation exposure is very deficient, the report does not meet basic epidemiological criteria for acceptability. Elwood [94] concludes that the methods used in the Szmigielski study may have created a systematic bias "that would be expected to produce an increased relative risk for all types of cancer".

16D) Microwave irradiation of the US Embassy in Moscow

There have been claims (by Goldsmith [29], for example) that microwave irradiation of the US Embassy in Moscow caused cancer and other injuries to people working there. This exposure to RF radiation occurred, but there is no real evidence that it caused any health effects.

From 1953 to 1976, low-intensity microwaves were aimed at the American Embassy building in Moscow. Lilienfeld et al [70] performed a comprehensive survey of the health experience of 1827 foreign service employees who had been assigned to work at the embassy (and their dependents). Their health experience was compared to 2561 foreign service workers assigned to other East European embassies (and their dependents). Measurements of several different exposed areas of the Moscow embassy in three time periods indicated the maximum exposure was at 0.015 mW/cm-sq (at 0.5 to 9 GHz) for 18 hours/day. For most of the exposure period, the maximum level was lower. The embassies of the comparison population were said to be at background levels.

Lilienfeld et al [70] found no evidence that individuals in the Moscow group experienced higher mortality for any cause, or higher mortality from cancer in general or from any cancer subtype. Although this study was well-designed, the relatively small cohort size and short follow-up time limited its power. The power of this study is also limited by the extremely low RF radiation levels, although it should be noted that the RF levels are larger than those found near most mobile phone base station antennas. The study concluded that:

> "Personnel working in the American Embassy in Moscow suffered no ill effects from the microwaves beamed at the Chancery"

16E) Studies of exposure to mobile phone RF radiation

In 1996, Rothman et al. [121] published a study that reviewed health records of more than 250,000 mobile phone users. They found no difference in mortality between the users of hand-held portable phones (where the antenna is placed close to the head) and car-mounted mobile phones (where the antenna is mounted on the vehicle). In a 1999 follow-up study [122], the same group examined specific causes of death among nearly 300,000 mobile phone users in

several U.S. cities. The investigators found no difference in overall cancer rates, leukemia rates, or brain cancer rates between the users of hand-held portable phones and the users of car-mounted mobile phones. The only specific cause of death that correlated with use of hand-held mobile phones was death from motor vehicle collisions.

In 1999-2001, four studies evaluated brain cancer in users of hand-held mobile phones: the first by Hardell et al [100], the second by Muscat et al [138], the third by Inskip et al [143], and the fourth by Johansen et al [155]. These studies found no consistent associations between mobile phone use and brain cancer (see figure below), and none found exposure-response trends. In general, the temporal lobe of the brain gets the highest RF radiation exposure in users of hand-held mobile phones; Hardell et al [100] reported a non-significant excess of temporal lobe tumors, but Muscat et al [138], Inskip et al [143] and Johansen et al [155] reported a non-significant decrease of these tumors. Hardell et al [100] reported a non-significant excess of tumors on the side of the head where the patients reported using their phones, but Muscat et al [138] and Inskip et al [143] reported non-significant trends in the opposite direction (see details below).

In the first of these studies, Hardell et al [100] analyzed mobile phone use in 233 Swedish brain tumor patients, some of whom has used hand-held mobile phones for as long as 10 years. This was done as part of a larger study of possible causes of brain cancer (other possible causes evaluated included occupation, radiation therapy for cancer, exposure to diagnostic radiation, and exposure to a wide variety of chemicals). Exposure was assessed by questionnaires, and analyses were based on use of hand-held mobile telephones (use of "hands-free" devices and use in a car with a fixed antenna were not considered to be "exposure"). No elevation of brain tumor incidence was found in users of either digital or analog phones, and no exposure-response trend was observed (see figure below). When analysis was restricted to temporal lobe (or temporal, occipital plus temporoparietal lobe) tumors on the same side of the brain where the mobile phone was reported to have been used, a non-significant excess incidence of brain cancer was found. This "handedness" was seen for use of analog phones, but not for the use of digital phones.

In 2002-2003 Hardell and colleagues published four separate analyses of a followup study of 1617 brain tumor patients [198, 209, 221, 222]. It is not clear whether patients from the earlier report [100] are included in this new study, or why this study has been published in four different formats. This study included both benign and malignant brain tumors, and both mobile phones and cordless phones. Benign (non-cancerous) brain tumors made up 55% of the total, and 35% on the phones used were cordless rather than "cellular".
It is very difficult as assess the significance of this follow-up study:

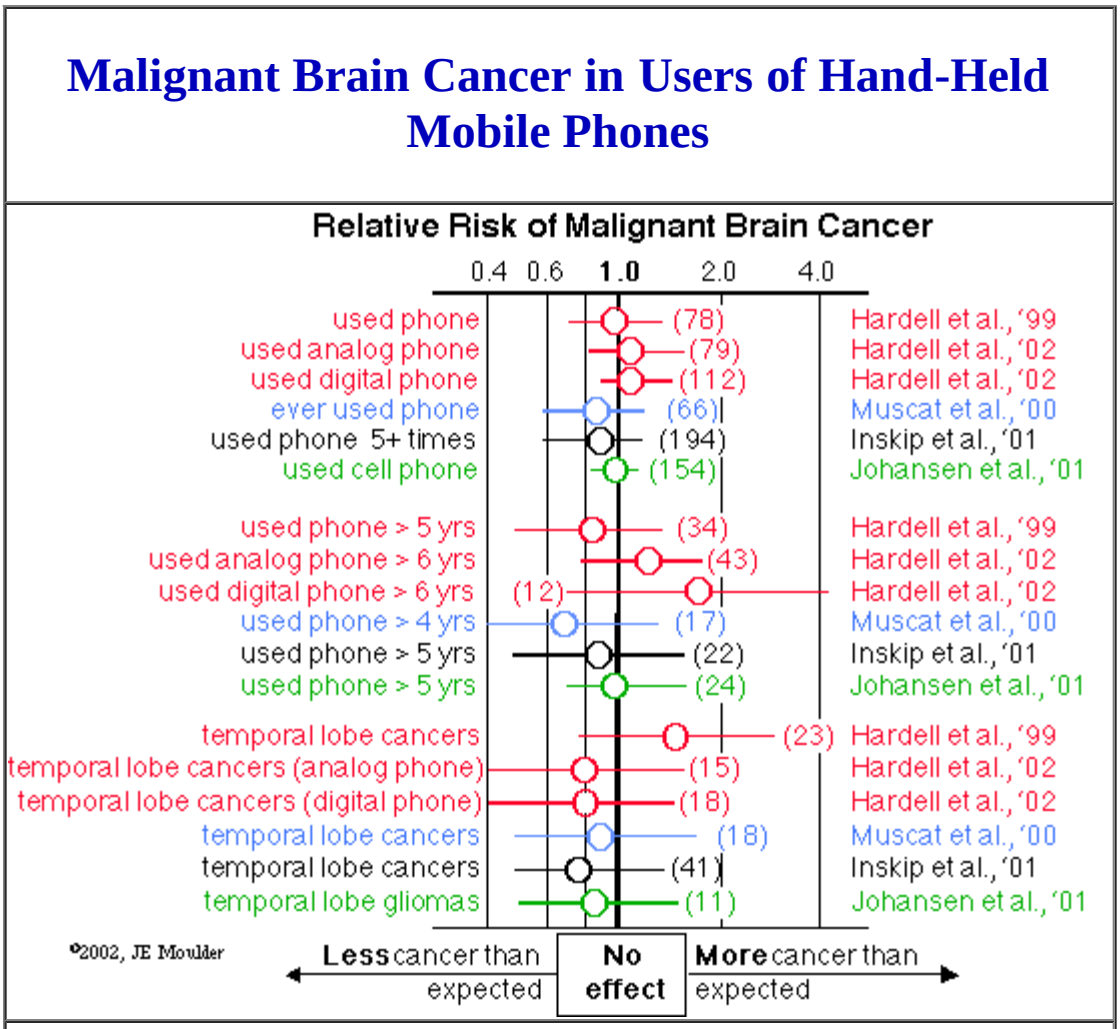
- First, there are problems with the experimental design (see the 2002 review commissioned by the Swedish Radiation Protection Authority [204]).
- Second, the data has been analyzed in many different ways. For example, the data has been subdivided by type of phone (analog vs digital vs cordless), operating frequency, hours of use, years of use, type of tumor, location of tumor and tumor latency. If fact, the four papers together contain over 500 separate subgroup analyses, and with this many looks at the data is impossible to tell whether any observed associations are real or a matter of chance.
- Third, the different analyses show different numbers of cases and controls (and calculate different relative risks) for what appear to be the same subgroups. Compare, for example, Table 2 of the first analysis [198] with Table II of the third version [221]. There is no obvious explanation why the four analyses of the same data yield different answers.
- Fourth, in many subanalyses (particularly in the first and third versions), malignant brain cancers and non-malignant lesions are merged, so it is impossible to determine whether the incidence of malignant tumors is affected or not.

None of the three versions of the study by Hardell and colleagues that looked at malignant brain tumors [198, 209, 221] appear to show significant elevations in the incidence of malignant brain tumors in users of analog mobile phones, digital mobile phones and cordless phones (see Fig below). In fact, the incidence of malignant temporal lobe tumors were slightly decreased in users of both analog and digital mobile phones in some analyses (see Fig below). In the second analysis [209], Hardell et al report that the incidence of brain tumors was increased on the side of the head where the phone was used and *decreased on the other side*, with no statistically-significant overall increase in the incidence of brain cancer.

The three versions of the study by Hardell and colleagues that looked at benign brain tumors [198, 221, 222] appear to show that the incidence of acoustic neuromas was elevated in users of analog phones, but whether the increase is statistically significant after correction for multiple comparisons is unclear. The only other study of acoustic neuromas (Muscat et al, 2002 [188]) reported that use of mobile phones was not associated with an increased risk (see below). Note that "acoustic neuroma" [188], "acoustic neurinoma" [221] and "vestibular schwannoma" [222] are different names for the same type of benign brain tumor.

The studies done by Hardell and colleagues [100, 198] were rather harshly criticized in a 2002 review commissioned by the Swedish Radiation Protection Authority [204]. That review concluded:

> "Because only living cases were interviewed and well over 500 cases were excluded and because there is evidence for selection and information bias, this study of cancer survivors cannot provide the basis for causal inferences. The health risks for cordless telephones which operate at power levels up to 100 times lower than analogue [mobile] telephones in Sweden indicate a reporting bias. The increase for ipsilateral (same side) phone use is balanced by a decrease for contralateral (opposite side) phone use, suggesting a reporting bias... There was no evidence of a dose-response... Because of the above listed shortcomings and the large number of comparisons made, over 200, bias and chance are the most likely explanations of the associations reported."



Relative risk of malignant brain cancer (with 95% confidence interval) in users of hand-held mobile phones from the epidemiological studies of Hardell et al [100,198,209], Muscat et al [138], Inskip et al [143], and Johansen et al [155]. The number of exposed cases in the overall analysis, and the sub-analyses are shown in parentheses. The top set of relative risks looks at the least restrictive definition of "mobile phone use" reported by each group, the middle set of relative risks looks at

the group with the longest use analyzed by each group, and the bottom group looks at tumors in the lobe of the brain expected to get the highest exposure to RF radiation.

In December 2000, Muscat et al [138] published a case-control study of 469 brain tumor patients in the US, some of whom has used hand-held mobile phones for as long as 4 years. Exposure was assessed on the basis of in-hospital interviews. No elevation of brain tumor incidence was found in users of hand-held phones, and no exposure-response trend was observed (see figure above). The incidence of temporal lobe tumors (where RF radiation exposure should be the greatest in users of hand-held phones) was not elevated. There was a non-significant trend for tumors to be on the side of the head where the patients reported using their phones; but when analysis was confined to the temporal lobe tumors, there were fewer tumors than expected on the side of the head where the phones were used.

When Muscat et al [138] analyzed tumors by histopathological type, there was no excess of gliomas (the most common and deadly form of brain tumors); but there was an excess of neuroepitheliomas. This increase was not statistically significant. Hardell et al. [100, 198] did not explicitly analyze this histopathological subtype of tumor, but Inskip et al [143] found a decreased incidence of neuroepitheliomas.

As soon as Muscat et al [138] was published, NEJM rushed a similar study onto their website that had been scheduled for publication in January of 2001. Inskip et al [143] studied 782 brain tumor patients in a different part of the US, some of whom had used hand-held mobile phones for as long as 5 years. They found no elevation of brain tumor incidence in users of hand-held phones, and observed no exposure-response trend (see figure above). The incidence of temporal lobe tumors (where RF radiation exposure should be the greatest in users of hand-held phones) was not elevated. There was a non-significant trend for tumors to be on the side of the head **opposite** to where the patients had reported using their phones. When Inskip et al [143] analyzed tumors by histopathological type, there was no significant excess of any types of malignant or benign brain tumors.

In early 2001, Johansen et al [155] published a retrospective cohort study of all types of cancer in Danish mobile phone users, some of whom has used mobile phones as long as 5 years. This included 154 brain cancer patients. Mobile phone use was associated with a significantly decreased overall risk of cancer that was attributable largely to less smoking-related cancer. No increased risk of brain cancer, leukemia, lymphoma, ocular cancer or melanoma was found in mobile phone users. No significant increase in any types of cancer were found in mobile phone users. No exposure response trends in leukemia or brain cancer incidence were seen in mobile phone users. There was no increase in temporal or occipital lobe tumors in mobile phone users (see figure above).

In the accompanying editorial [155B] Park wrote:

> "Regardless of how convincing the evidence exonerating mobile phones may be, there will continue to be those who will argue that the issue has not been completely settled. In science, few things ever are. The scientific community has a responsibility to put all the evidence into perspective for the public."

In January 2001, Stang et al [152] reported that the use of "radio sets, mobile phones, or similar devices at [the] workplace for at least several hours per day" was associated with uveal (intraocular) melanoma. Of 118 individuals with intraocular melanoma, 6 (5.1%) reported that they were "probable or certain" to have "ever been exposed" to mobile phones at work. According to the authors, this occupational mobile phone use is 4 times higher than expected. Mobile phone use outside of work was not assessed, and other risk factors (for example, UV exposure and light skin color) were not assessed. In the only other comparable study, Johansen et al [155] found less melanoma and ocular cancer than expected in mobile phone users. According to the accompanying editorial [153]:

> Stang and colleagues raise the possibility that we should add a new type of cancer to those already under leading consideration as possible hazards of RF radiation, and it may well be that future studies will support their hypothesis. At this point , however, given the small size of the study, the relatively crude exposure assessment, the absence of attention to UVR exposure or other possible confounding variables, and limited support from the literature, a cautious interpretation of their results is indicated.

In 2002 Muscat et al [188] reported that use of mobile phones was not associated with an increased risk of acoustic neuromas (a benign brain tumor). This study parallels Muscat's earlier report [138] on malignant brain tumors and the use of hand-held mobile phones. The tumors that were found in mobile phone users were more likely to be on the side opposite where the phone was used, than on the side where the phone was reported to have been used. Note that the 2002 Hardell et al study [198] does report an excess of acoustic neuromas in users of analog phones.

In 2002, Auvinen et al [193] reported that there was no statistically-significant association of mobile phone use with the overall incidence of brain cancer or the incidence of salivary gland cancer. When brain cancers were subdivided by type, a weak association was seen for gliomas and use of analog phones -- for digital phones, there was no association.

16F) Reviews of the epidemiology

The lack of associations between exposure to RF radiation and total cancer, and the lack of consistent associations between exposure to RF radiation and any specific type of cancer, suggests that RF radiation is unlikely to have a strong causal influence on cancer.

In a 1999 review of the RF radiation epidemiology literature, Elwood [94] concluded that:

> "Several positive associations suggesting an increased risk of some types of cancer in those who may have had greater exposure to RF emissions have been reported. However, the results are inconsistent: there is no type of cancer that has been consistently associated with RF exposures. The epidemiologic evidence falls short of the strength and consistency of evidence that is required to come to a reasonable conclusion that RF emissions are a likely cause of one or more types of human cancer. The evidence is weak in regard to its inconsistency, the design of the studies, the lack of detail on actual exposures, and the limitations of the studies in their ability to deal with other likely relevant factors. In some studies there may be biases in the data used."

In a 2000 review of the RF radiation epidemiology literature, Rothman [139] concluded that:

> "Based on the epidemiological evidence available now, the main public health concern is clearly motor vehicle collisions, a behavioral effect rather than an effect of RF exposure as such. Neither the several studies of occupational exposure to RF nor the few of cellular telephone users offer any clear evidence of an association with brain tumors of other malignancies. Even if the studies in progress were to find large relative effects for brain cancer, the absolute increase in risk would probably be smaller than the risk stemming from motor vehicle collisions."

In a 2002 review of the mobile phone epidemiology, Boice and McLaughlin [204] concluded that:

> "In our view, a consistent picture has emerged from these studies that appear to rule out, with a reasonable degree of certainty, a causal association between cellular [mobile] telephones and cancer to date. No consistent evidence was observed for increased risk of brain cancer, meningioma, acoustic neuroma, ocular melanoma or salivary gland cancer, examined over a wide range of exposure measures... Complementing the human data are the emerging results of experimental studies which have failed to confirm earlier reports of possible adverse outcomes from RF [radiation] exposure. Moreover, there is no biologically plausible mechanism to support a carcinogenic effect of non-ionizing RF waves."

On a related issue [206, 210], a US federal judge ruled in September 2002 that the plaintiffs in one of the major mobile phone - brain cancer law suits had presented "no sufficiently reliable and relevant scientific evidence to support either general or specific causation." The ruling may result in the dismissal of most of (or all of) the US law suits claiming that mobile phones cause brain cancer. The plaintiffs relied heavily on the epidemiological studies of Hardell et al [100,198,209] and the laboratory studies of Lai and Singh [31]. The actual ruling is on-line at: http://www.mdd.uscourts.gov/Opinions152/Opinions/newman0902.pdf

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17) Could pulse modulated RF radiation produce different effects than the continuous-wave (CW) RF radiation

used in many laboratory studies?

Possibly, but there is no replicated evidence for such effects. It has been suggested that amplitude-modulated (AM) and pulse-modulated RF radiation might have different effects than continuous-wave (CW, unmodulated) RF radiation (see for example Hyland [140]). This could be important, since mobile phones and their base stations produce a modulated signal, and much of the research has been done with unmodulated RF sources.

The issue of amplitude modulation was reviewed in 1998 by Juutilainen and de Seze [90] who concluded that:

> The literature relevant to the possible biological effects of AM radiofrequency radiation consists of scattered observations using a wide variety of experimental models and exposure parameters... Several studies have reported findings consistent with effects on the nervous system and cancer-related biological processes. However, the methods and exposure parameters vary widely, and no independent replications of the positive finds have been reported. The results available today fail to support the existence of well-defined modulation-specific bioeffects from exposure to radiofrequency radiation.

For recent reports of attempts to find differences between the biological effects of continuous-wave and modulated RF radiation, see Pakhomov et al [178] (who reported no difference) and d'Ambrosio et al [180] (who reported a difference).

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18) Are there groups (such as children or the elderly) that are more sensitive to the effects of RF radiation?

Possibly. Some groups in the general population might be more sensitive to the effects of RF radiation than others, but no such groups have actually been found. The possible existence of such sensitive individuals is one of the main reasons that an additional 5-fold safety margin is added to the public exposure guidelines (see Q9).

See the discussion of whether children should use hand-held mobile phones in Q15C

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19) Will mobile phone base station antennas affect heart pacemakers, cause headaches, etc?

Although the public's principal health concern about mobile phone base station antennas appears to be the possibility of a cancer connection (see Q21 and Q23A-Q23C), other health-related issues come up periodically. Particularly common are questions about interference with heart pacemakers (covered in Q19A). This section will also cover less common issues. The possibility of a connection with miscarriages and birth defects is covered in Q22.

19A) Will mobile phone base station antennas affect medical devices such as cardiac pacemakers?

No. There is no evidence that mobile phone base station antennas will interfere with cardiac pacemakers or other implanted medical devices as long as exposure levels are kept within the ANSI guideline for uncontrolled exposure (see Q8 and Q12).

It is possible that digital mobile phones themselves might interfere with pacemakers if the antenna is placed directly over the pacemaker. This problem is reported to occur with only some types of digital phones and some types of pacemakers [46, 137].

19B) Do mobile phones or mobile phone base stations cause headaches?

It is possible that use of mobile phones causes headaches.

In 1998, Frey [48] reported anecdotal evidence that mobile phones cause headaches.

In 2000, Oftedal et al [154] found that users of mobile phones commonly report having headaches, but since the study contains no data on non-users it is not known whether the rate of headaches reported by these mobile phone users is

unusual. An extension of the study by Sandström et al [162] reported that headaches and other symptoms were higher in users of analog (NMT 900) phones than users of digital (GSM) phones.

In 2000, Chia et al [142] reported that headaches were significantly more common among users of hand-held mobile phones than among non-users (65% vs 54%). Headache prevalence increase significantly with duration of use, and the use of hand-free equipment eliminated the increase.

No one has claimed that there is scientific evidence that base stations cause headaches, and there are no biophysical or physiological bases for expecting such an effect.

19C) Does radio-frequency radiation from mobile phones or mobile phone base stations cause physiological or behavioral changes?

There are unreplicated reports of such effects. There are some studies that suggest that RF radiation from hand-held mobile phones or mobile phone base stations might cause subtle biochemical, physiological or behavioral changes. However, none of the studies provides substantial evidence that mobile phone base stations might pose a health hazard.

- Most of the reports are of "effects" that do not imply the existence of hazards.
- Most of the studies use RF radiation of an intensity far above those associated with mobile phone base stations.
- Many of these reports have not been independently confirmed, and there are grounds for being skeptical about most of them.
- Some of the reports could not be confirmed by the groups that reported them in the first place.

Recent (post-1998) reports about such effects include:

- Borbély, Huber and colleagues [110, 141, 228] reported that exposure to a mobile phone signal could cause slight changes in sleep patterns and sleeping EEG.
- Preece et al [97] reported that exposure of human volunteers to mobile phone RF radiation might decrease reaction times. The press coverage was extensive; but the actual study has no obvious implications for human health since the effect was seen for just one of many tests and it appears to be far too small to have any real functional significance.
- D'Andrea [96] reviewed reports of the behavioral effects of RF radiation and concluded that: "Recent studies have suggested that microwave effects on specific cognitive aspects of behavior such as attention, learning, memory, discrimination, and time perception may occur at SAR levels far below the SARs needed to cause work stoppage."
- Freude et al [111] exposed human volunteers to RF radiation from a GSM phone and found small changes in EEG that "did not indicate any influence on human performance, well-being and health".
- Wagner et al [159] reported that exposure to a mobile phone signal at 5 mW/cm-sq had no effect on sleep patterns. This contradicted an earlier report by the same group which had found effects on sleep at 0.05 mW/cm-sq.
- Wang and Lai [109] reported that rats exposed to 2450 MHz pulsed RF radiation were slower than normal animals to learn a maze. Animals received whole-body RF exposure for 1 hr/day; the average SAR was 1.2 W/kg with peaks of 3-4 W/kg. The signal is quite different from that associated with a mobile phone base station and the peak SAR may have been high enough to cause thermal stress. The exposure intensity (SAR) was 15 times higher than the FCC standard for whole-body exposure of the general public. Somewhat later, Sienkiewicz et al [120] performed a similar experiment in mice (but using a signal and a power-density simulating a European digital mobile phone base station signal) and found no effects on maze performance.
- Koivisto et al [117, 132] studied human volunteers who were exposed to 902 MHz RF from a GSM phone and given a battery of reaction time tests. For some tests, exposure reduced (improved) the time required, other tests showed less significant time improvements. Some tests showed no significant effects. For the test in which Preece et al [97] found an effect for the analog signal, Koivisto et al [117] found no effect for a digital signal. In further studies, Koivisto et al [160] found that a 30-60 minute exposure to RF radiation from GSM phones had no detectable subjective effects on human volunteers.

In 2003, the Koivisto group reported [226] that they could not replicate their own finding of RF radiation effects on human reaction time. They concluded that: "Our results indicate that our [mobile phone signal] had no immediate effect on human cognitive functioning or that such effects are so small that they are observed on behavior only occasionally".

- Krause et al [146] reported a study of human volunteers who were exposed to 902 MHz RF from a GSM phone and given memory and reaction time tests. Effects on error rate and reaction time were not significant. Some effects on EEG were observed under some test conditions. According to the authors: "The present results do not allow any conclusions concerning the possible effects of cellular phone use on cognition".
- Tsurita et al [133] reported that RF radiation had no effect on the blood-brain barrier in rats. These rats were exposed to a 1339 MHz digital (TDMA) signal for one hour per day for 2-4 weeks. The average whole body SAR was 0.25 W/kg and the brain SAR was 2 W/kg. No effects were observed on body weight, brain morphology or blood-brain barrier permeability. The Tsurita et al [133] paper includes a detailed discussion of previous studies of RF effects on the blood-brain barrier. In a similar studies, Finnie et al [170, 205] reported that RF radiation at up to 4 W/kg had no effect on the blood-brain barrier of mice.
- Bornhausen and Scheingraber [145] reported that exposure of pregnant rats to RF radiation had no effect on the behavior of their off-spring. Free-roaming pregnant rats were continuously exposed to GSM signal at 0.1 mW/cm-sq (SARs ranged from 17.7-75 mW/kg). No cognitive deficits were found in their offspring.
- Braune et al [201] reported that an earlier study where they had found that mobile phone use caused a small rise in blood pressure was actually due to an artifact in the design of the original study; and that RF radiation from mobile phones had no real effect on blood pressure.
- Edelstyn and Oldershaw [183] reported that exposure of human volunteers to 900 MHz RF radiation from mobile phones improved their performance on tests for "attention".
- Dubreuil et al [184] reported that head-only exposure of rats to 900 MHz pulsed RF radiation (SAR of 1 or 3.5 W/kg) for 45 minutes had no effect on learning.
- In June-July 2002, there were wide-spread press reports that a Finnish group had shown that mobile phone RF radiation affected the blood-brain barrier. The actual published study [192] does not support the press claims. The actual study was of cells exposed in cell culture to RF radiation; the authors report activation of "heat shock protein 27". The authors then **speculate** that if this occurred in users of mobile phones it "may cause an increase in blood-brain barrier permeability". The authors do not actually study the blood-brain barrier in this report.
- Ozturan et al [194] reported that mobile phone RF radiation had no effect on hearing.
- Heitanen et al [200] reported on studies of a group of people who claimed to be sensitive to RF radiation from mobile phones. They found that these self-identified hypersensitive individuals could not distinguish real RF radiation exposures from sham exposures.
- Hamblin and Wood [202] reviewed 14 published studies of the effects of mobile phone RF radiation on human brain activity (EEG) and sleep. They concluded that while the studies are inconsistent, there is some evidence for effects on EEG. The further write that "current international safety standards do appear to be adequate to minimize the possibility of harm, if the currently reported effects become substantiated"; and that "in reality no adverse health effect has been found in any published human study on the effects of mobile phones".
- In a 2002 review of "electromagnetic hypersensitivity", Ziskin [211] concluded that: "Taken as a whole, the provocation studies strongly suggest that electromagnetic hypersensitivity symptoms are not related to actual exposures to electric or magnetic fields, and that electromagnetically hypersensitive individuals are no better than non-hypersensitive individuals in detecting the presence of fields."
- In 2002, Burch et al [213] reported that mobile phone use of greater than 25 min per day was associated with a drop in melatonin excretion in electrical workers. Earlier studies by De Seze et al [108] and Radon et al [166] had found that mobile phone RF radiation had no effect melatonin levels in humans; and Heikkinen et al [233] reported in 2003 that mobile phone RF radiation had no effect on melatonin excretion in mice.
- In a 2002 review of the reports of effects of mobile phones on brain function and behavior, Hossmann and Hermann [214] concluded that: "Most of the reported effects are small as long as the radiation intensity remains in the nonthermal range... However, health risks may evolve from indirect consequences of mobile telephony, such as the sharply increased incidence rate of traffic accidents caused by telephony during driving, and possibly also by stress reactions which annoyed bystanders may experience when cellular phones are used in public places."
- In 2003 Salford et al [219] reported that 2 hours of exposure of rats to GSM-type RF radiation (SARs of 0.02 and 0.2 W/kg) caused leakage of the blood-brain barrier that resulted in nerve damage. The authors do not

address the fact that other studies using longer and more intense exposures (see for example: Tsurita et al [133], Finnie et al [170,205]) have found no evidence for such effects, or that fact that studies of long-term exposure of rats and mice to RF radiation have not found any evidence of CNS injury (see for example: Adey et al [24, 50], Zook and Simmens [104]).

- In 2003, Yamaguchi et al [229] exposed rats to pulsed mobile phone RF radiation at low intensity (brain SAR of 7.5 W/kg, whole body SAR of 1.7 W/kg) and high intensity (brain SAR of 25 W/kg, whole body SAR of 5.7 W/kg) for 45 min daily for 4 days. Behavioral effects were seen only at the higher intensity which also caused at a 3°C rise in body temperature.
- In 2003, Lee et al [238] reported that exposure of human volunteers to mobile phone RF radiation resulted in better performance in one of two measures of attention.
- NEW In 2003, Zwamborn et al [240] reported that laboratory exposure of human volunteers to base station RF radiation caused decreased feelings of "well-being" and improvement on some cognitive function tests (e.g., reaction time and memory tests). The effect on "well-being" was found only for the UMTS (Universal Mobile Telecommunications Service) type of signal used by G3 (third generation) mobile phone systems; it was not found for GSM mobile phone signals (the system that now dominates Europe). The effects on cognitive function were found for both UMTS-like and GSM signals; the effects occurred in 8 of 30 tests, with no obvious pattern.
    - Two groups of volunteers were tested, one made up of people who had complained about health effects of exposure to GSM base stations, and one made up of people without complaints. The effect of the UMTS-like signal on "well-being" was worse in the group that had previously reported health effects from GSM base stations, but the effects on cognitive function were about the same.
    - "Well-being" analysis is based on a set of tests that measure symptoms of anxiety, inadequacy and depression.
    - Exposures were in the main beam at a distance of 3 meters (10 feet), the peak (10 gram) SARs were calculated to be between 0.05 and 0.08 **milli**W/kg.
    - Some media reports claimed that the study had found that the UMTS-like base station caused "headaches and nausea", but the actual report contains no support for that claim.
    - The actual report is on-line at: http://www.ez.nl/beleid/home_ond/gsm/docs/TNO-FEL_REPORT_03148_Definitief.pdf.

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20) Can RF radiation produce biological effects?

Yes. If exposure is sufficiently intense, RF radiation can cause biological effects (for a review, see Dewhirst et al. [235]). Possible injuries include cataracts, skin burns, deep burns, heat exhaustion and heat stroke. Most, if not all, of the known biological effects from exposure to high-power radiofrequency sources are due to heating [20]. The effects of this heating range from behavioral changes to eye damage (cataracts) [for details, see 1, 5, 6, 7 14, 53, 83, 90, 99, 232, 235]. Except possibly within a few feet of the antennas themselves [128], the power produced by mobile phone base station antennas is too low to cause heating.

There have been scattered reports of effects [21] that do not appear to be due to heating, the so called non-thermal effects [20, 25, 158]. None of these effects have been independently replicated, and most have no obvious connections to human health risks.

The lack of biological effects from exposures to radio-frequency radiation that do not produce biologically significant temperature changes is not surprising, as there are no known biophysical mechanisms that would suggest that such effects were likely [25, 124, 158, 165, 215].

In a 2001 review, Pickard and Moros [158] conclude that:

> "The prospects of UHF (300-3000 MHz) irradiation producing a nonthermal bioeffect are considered theoretically and found to be small... This supports previous arguments for the improbability of biological effects at UHF frequencies unless a mechanism can be found for accumulating energy over time and space and focusing it. Three possible mechanisms are then considered and shown to be unlikely... Finally, it is concluded that the rate of energy deposition from a typical fields and within a typical tissue is so small as to make unlikely any significant nonthermal biological effect."

in a 2003 review, Adair [215] concluded that:

> "Continuous radiofrequency (RF) and microwave radiation with intensity less than 10 mW/cm-sq are unlikely to affect physiology significantly through athermal mechanisms. Biological systems are fundamentally noisy on the molecular scale as a consequence of thermal agitation and are noisy macroscopically as a consequence of physiological functions and animal behavior. If electromagnetic fields are to significantly affect physiology, their direct physical effect must be greater than that from the ubiquitous endogenous noise. Using that criterion, I show that none of a set of interactions of weak fields... can affect biology on the molecular scale. Moreover, I conclude that such weak fields are quite unlikely to generate significant effects in their interactions with larger biological elements such as cells."

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21) Is there any replicated evidence that RF radiation can cause cancer?

No. Even at high levels of exposure, there is no substantial evidence that RF radiation can either cause or contribute to cancer (for a review, see Dewhirst et al. [234]). Although research in this area has been extensive, there is no replicated laboratory or epidemiological evidence that RF radiation at the power levels associated with public exposure to RF radiation from mobile phone base station antennas are associated with cancer [for details, see 1, 5, 6, 7, 14, 74, 83, 95, 99, 128, 234].

There are two laboratory reports that exposure to RF radiation might produce cancer, or cancer-related injuries in animals. These studies are discussed in Q23A and Q23C. Both studies use RF levels far above those found in publicly-accessible area near base station antennas, and both studies have failed replication attempts.

The epidemiological studies of RF show no consistent association with total cancer, or with any specific type of cancer (see Q16).

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22) Is there any evidence that RF radiation can cause miscarriages or birth defects?

Indirectly, yes. Exposure to levels of RF radiation sufficient to cause whole body heating can cause miscarriages or birth defects. The power produced by mobile phone base station antennas is far too low to cause such heating. There is no laboratory or epidemiological evidence at all that RF radiation at the power levels associated with public exposure to RF radiation from mobile phone base station antennas are associated with miscarriages or birth defects [see refs in 1, 5, 6, 7 and 14 for details].

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23) What do the most recent scientific laboratory studies of RF radiation and cancer show?

There is a constant flow of new information. Studies which attract major attention will often get their own sections, such as the mouse and rat cancer studies discussed in Q23A and Q23B, and the DNA strand break studies discussed in Q23C.

23A) The report that exposure of mice to mobile phone RF radiation causes lymphoma.

A 1997 Australian study by Repacholi et al [37] reported that lymphoma-prone mice exposed for 18 months to strong, but intermittent, RF radiation of the type used by digital mobile phones have an increased incidence of lymphomas. No increases in the incidence of other types of tumors were found. The field intensities used are above the guidelines for public exposure recommended in the ANSI/IEEE guideline (Q8), and are far above those that exist in publicly-accessible areas near mobile phone base station antennas [16].

In 2002, Utteridge et al [197] reported that they could not replicate this increase in lymphoma in either normal mice or in the same lymphoma prone mice.

The original Repacholi et al [37] study was criticized on a number of grounds:

1. The RF radiation dose in the study was poorly defined, so that the possibility of thermal stress could not dismissed.
2. No normal animals were used, so there was no way to determine whether the effect was unique to the animals that had been genetically-engineered to make them lymphoma prone.
3. Only one RF radiation dose was used, so that the nature of the dose-response was unknown.
4. The animals that were still alive at the planned end of the study were assumed to be lymphoma-free, but were not proven to be.

The Utteridge et al [197,216] replication study was designed to address the above criticisms:

1. A different type of exposure system was used so that RF radiation doses could be more tightly defined and shown to be non-thermal.
2. Normal animals, as well as lymphoma-prone animals were used.
3. Four different dose groups were used (SARs of 0.25, 1.0, 2.0 and 4.0 W/kg).
4. Surviving animals were examined for tumors at the end of the study.

In the 1997 Repacholi et al [37] study, 100 lymphoma-prone mice were exposed to pulsed 900 MHz RF radiation for 1 hour per day for 18 months at an SAR that varied between 0.01 and 4.2 W/kg. Lymphoma incidence was raised by a factor of 2.4 compared to a similar group of mice that had been sham-exposed.

In the 2002 Utteridge et al [197,216] study, 120 normal and 120 lymphoma-prone mice were exposed to 898 MHz GSM-modulated RF radiation for 1 hour per day for 24 months at SARs of 0.25, 1.0, 2.0 and 4.0 W/kg (120 mice of each type at each SAR). No statistically-significant increase in lymphoma incidence were found and no statistically-significant dose-response trend was observed.

Four letters to the editor concerning the Utteridge et al report and the authors' response appeared in early 2003 [216A, 216B].

Note that there are at least 15 other studies of long-term exposure of rodents to radiofrequency radiation. None of these studies used lymphoma-prone mice and none have reported excess lymphoma. See Q23B for details.

23B) Other studies in which rodents were exposed to mobile phone RF radiation to see if they got cancer.

There are more than 20 other studies of long-term exposure of rodents to radio-frequency radiation. These studies find that long-term exposure of rodents to RF radiation does not appear to induce or promote lymphoma (see Q23A), or brain cancer (see Q23C) or tumors in general. Life time exposure of rodents also does not appear to cause any decrease in life span. The studies are summarized below.

1971: Spalding el al [64] published a study of mice that had been exposed to 800-MHz RF radiation for 2 hr/day, 5 days/wk, for 35 wks at a SAR of 13 W/kg. The average life span of the RF-exposed group was slightly, but not significantly, longer than that of the sham-exposed group.

1982: Szmigielski et al [65] published a study of mice that were exposed to 2450-MHz RF for 2 hr/day, 6 days/wk, for up to 6 months. Exposures were at 2-3 and 6-8 W/kg. Controls included both sham-irradiated animals and animals subject to "confinement stress" (see Stagg et al [161]). Both RF exposure and confinement stress significantly accelerated the appearance of both chemically-induced skin and breast tumors. The dosimetry in this study is questionable, and seems likely that the mice exposed at the higher dose were subjected to physiologically-significant heating.

1988: Saunders et al [98] published a study of male mice that were exposed to 2450-MHz RF radiation (power density of 10 mW /cm-sq and SAR of 4 W/kg) for 6 hrs/day for a total of 120 hr over an 8-week period. At the end of the treatment the mice were mated with unexposed females. There was no significant reduction in pregnancy rate, so that there had been no increase in dominant lethal mutations. Examination of spermatogonia showed no increase in chromosome aberrations. The authors conclude that "there is no evidence in this experiment to show that chronic

exposure of male mice to 2450-MHz microwave radiation induces a mutagenic response".

1994: Liddle et al [66] published a study that examined the effects of life-time 2450-MHz RF exposure in mice. Mice were exposed for 1 hr/day, 5 days/week throughout their life at either 2 or 6.8 W/kg. Life span was significantly shortened in mice exposed at 6.8 W/kg (median of 572 days vs 706 days in the sham-exposed group). However, at 2 W/kg, the RF-exposed animals lived slightly, but not significantly longer (median of 738 days) than the sham-exposed group. The authors suggested that the heating from exposure at 6.8 W/kg was stressful enough to decrease life span.

1992: Chou et al [43] published a study of 100 normal rats that were exposed to pulsed 2450 MHz RF at 0.15-0.40 W/kg [8] for 21.5 hrs/day and 25 months. No effects were observed on life-span or cause of death. An increase in total cancer was seen in exposed group, with no effect on survival. The malignancy rates in the controls was unusually low for this strain, and no increase in benign tumors were observed. Two primary lymphomas were seen in the exposed animals, and two in the controls. No benign or malignant brain tumors were seen in either exposed or control rats. The authors concluded:

> Microwave exposure... showed no biologically significant effects on general health... The findings of an excess of primary malignancies in exposed animals is provocative. However, when this single finding is considered in light of other parameters, it is conjectural whether the statistical difference reflects a true biological influence. The overall results indicate that there are no definitive, biologically significant effects...

1994: Wu et al [56] published a report on 26 mice that were exposed to a chemical carcinogen plus 2450 MHz RF at 10 mW/cm-sq (10-12 W/kg). Exposure continued for 3 hrs/day, 6 days/week for 5 months. The chemical carcinogen is one that causes colon cancer. No difference in colon cancer rates were seen between animals treated with the carcinogen alone and the animals treated with the carcinogen plus RF.

1997: Toler el [45] published a report on 200 mammary-tumor-prone mice exposed to pulsed 435 MHz RF at 1.0 mW/cm-sq (0.32 W/kg). Exposure continued for 22 hrs/day, 7 days/week for 21 months. The authors reported no differences in survival or mammary tumor incidence. The authors reported that there was no difference in the rates of any types of tumors between the exposed and the control group. Of particular note, there was no difference in the lymphoma, leukemia or brain tumor rate between the exposed and the control group.

1998: Frie et al [44] published a report on 100 mammary-tumor prone mice that were exposed to 2450 MHz RF at a SAR of 0.3 W/kg. Exposure was for 20 hrs/day, 7 days/week for 18 months. The study found no difference in tumor incidence or survival between the exposed and the control group.

1998: Frie et al [47] published a second study using the same mouse model and the same exposure regimen, but a higher SAR of 1.0 W/kg. Again, the study found no difference in tumor incidence or survival between the exposed and the control group. There were no differences in lymphoma, leukemia or brain tumor incidence between the exposed and the control group in either study.

1998: Imaida et al [63a] published a report on 48 rats that were given a chemical carcinogen that cause liver cancer, and were then exposed to 929 MHz RF an a SAR of 0.6-0.9 W/kg. Exposure was for 90 min/day, 5 days/week for 6 weeks. No difference in liver cancer rates were seen between RF-exposed rats and rats given only the chemical carcinogen.

1998: In a second paper, Imaida et al [63b] reported a similar lack of liver cancer promotion in rats exposed to 1500 MHz RF at a SAR of 2.0 W/kg. Again, exposure was for 90 min/day, 5 days/week for 6 weeks.

1999: Adey et al [24] reported that exposure to pulse-modulated 837 MHz RF did not induce or promote brain tumors in rats. RF exposure started with continuous whole-body far-field exposure of pregnant rats and continued through weaning. At 7 weeks of age, localized near-field exposure of the head was begun, and this exposure continued for 22 months (2 hrs/day, 7.5 min on - 7.5 min off, 4 days/wk). Some rats were also treated with a chemical brain tumor carcinogen (ethylnitrosourea, ENU). Brain SARs ranged from 0.7 to 1.6 W/kg, and whole-body SAR ranged from 0.2 to 0.7 W/kg; the range of SARs was due to changes in weight and variability in animal positioning. The number of

brain tumors was less in the RF-exposed groups than in the sham-exposed groups, but the difference was not statistically significant. This non-significant decrease was seen in both rats treated with RF alone, and in rats treated with RF plus the chemical brain tumor carcinogen.

1999: Chagnaud et al [106] reported that exposure of rats to a pulsed mobile phone RF radiation (GSM) did not promote chemically-induced breast cancer. At various times after exposure to a chemical carcinogen, rats were exposed for 2 weeks at 2 hours per days to a 900-MHz GSM signal at 0.075 or 0.27 W/kg. No effects on tumor incidence, tumor growth or animal survival were observed.

1999: Higashikubo et al [107] reported that exposure of rats that had brain tumors to radio-frequency radiation had no effect on the growth of these brain tumors. Rats were exposed to either 835 MHz continuous wave RF radiation or 848 MHz pulsed RF radiation at SARs of 0.75 W/kg. Exposure was for 4 hrs/day, 5 days per week, starting 28 days prior to tumor implantation and continuing for 150 days after tumor implantation.

2000: Adey et al [50] reported that exposure to continuous wave 837 MHz RF did not induce or promote brain tumors in rats. Other than the difference in modulation, the 2000 study used the same design and exposure protocol as the 1999 study [24].

2001: Zook and Simmens [104] reported the absence of an effect on brain tumor incidence in rats exposed to continuous-wave or pulsed 860-MHz radio-frequency radiation at 1.0 W/kg. Exposure was for 6 hrs/day, 5 days/week for 22 months, starting when the rats were 2 months old. Zook and Simmens also reported that the same RF protocols did not promote chemically induced brain cancer. No statistically-significant RF-related increases in overall cancer or any specific types of cancer (including lymphoma) were found.

2001: Jauchem et al [156] reported that there were no significant effects on mammary tumor development or animal survival in mammary tumor-prone mice exposed to pulses composed of an ultra-wideband (UWB) of frequencies, including those in the RF range. Histopathological evaluations revealed no significant effect on the numbers of neoplasms in any tissue studied (including lymphomas).

2001: Heikkinen et al [172] reported that exposure of mice to RF radiation of the type used by analog or digital mobile phones did not increase the incidence of cancer (particularly lymphoma) induced by ionizing radiation. Mice were exposed to ionizing radiation and then to pulsed (GSM-type) or continuous wave (NMT-type) RF radiation. RF radiation exposure was at 1.5 W/kg (analog signal) or 0.35 W/kg (digital signal) for 1.5 hrs/days for 78 weeks. No increase in any types of cancer were observed in the animals exposed to RF radiation.

2001: Imaida et al [177] reported that pulsed RF radiation of the type used by Japanese digital mobile phones did not increase the incidence of chemically-induced skin cancer in mice. Imaida et al [177] tested both promotion and co-promotion (with TPA) protocols, and found no promotion in either.

2001: Mason et al [175] reported the absence of promotion or co-promotion of chemically-induced skin cancer in mice exposed to 94 GHz RF radiation.

2002: Bartsch et al [181] reported that exposure of rats to mobile phone RF radiation does not promote chemically-induced breast cancer. The rats were exposed to a chemical breast cancer carcinogen and for life-time to pulsed 900 MHz RF radiation at 0.1 mW/cm-sq (SAR of 0.018-0.070 W/kg). No effect on latency or incidence of benign or malignant breast cancer were found. Interesting, prior to publication it had been widely claimed (although not by the authors) that this study would show significant effects on breast cancer development.

2003: Heikkinen et al [233] reported that exposure of mice to mobile phone RF radiation did not promote skin cancer induced by ultraviolet (UV) radiation. Mice were exposed for 52 weeks to UV radiation or to UV radiation plus pulsed RF radiation. RF exposure was to 849 MHz (DAMPS-type) or 902 MHz (GSM-type) RF radiation at 0.5 W/kg for 1.5 hrs/day. UV radiation alone caused an increase in skin tumors, but the addition of RF radiation did not significantly increase the skin tumor incidence.

2003: LaRegina et al [237] reported that exposure of rats to mobile phone RF radiation had no effect on cancer

incidence (including brain cancer and lymphoma) or on life span. Rats were exposed to 836 MHz continuous wave (FDMA) or 848 MHz pulsed (CDMA) RF radiation for 4 hrs/day, 5 days/wk for two years. Exposure began when the rats were 6 weeks old and continued for two years. The brain SAR was 1.3 W/kg.

2003: Anane et al [239] exposed rats to a breast cancer carcinogen (DMBA) and/or to a 900-MHz GSM mobile phone signal. Exposure was 2 hr/dy, 5 dy/wk for 9 wks at 6 SARs ranging from 0.1-3.5 W/kg. Statistically significant promotion of chemically-induced breast cancer was observed at 1.4 W/kg in one experiment, but no such increase was found in a second experiment or at higher or lower SARS. There was no dose-response relationship.

23C) Studies of whether exposure of animals or cells to mobile phone RF radiation causes DNA damage.

Agents that can damage the DNA of cells are presumed to have carcinogenic potential [4]. Agents that can damage DNA are called genotoxins, or are referred to as having genotoxic activity. In general, studies of cells exposed to RF have not found evidence for genotoxicity unless the SAR was high enough to cause thermal (heat) injury [5, 6, 7, 14].

In 1995 and 1996, Lai and Singh [31] reported that RF caused DNA damage (genotoxic injury) in rats. In these experiments, rats were exposed to 2450 MHz RF at 0.6 and 1.2 W/kg. After exposure, the animals were killed, and their brain cells were analyzed for DNA injury. The authors reported an increase in DNA stand breaks 4 hours after exposure.

The work of Lai and Singh [31] has failed independent attempts at replication. In 1997, Malyapa et al [49a, 49b] reported that they could not detect the effect seen by Lai and Singh, but there were some differences between the studies. In 1998, Malyapa et al [49c] reported that they could not detect the effect in an exact replicate of the Lai and Singh [31] study. In 2002, Tice et al [182] and McNamee et al [207, 208] also reported that RF radiation did not cause DNA strand breaks. In a related 2002 study, Takahashi et al [190] reported that head-only exposure of mice to 1500 MHz RF radiation at 0.7 and 2.0 W/kg (90 min/day, 5 days/week, for 4 weeks) did not produce mutations in their brain cells.

Other recent (post-1998) studies on the genotoxic potential of RF have reported no evidence for genotoxicity (damage to DNA):

- Vijayalaxmi et al [119] found no evidence for genotoxic injury in human lymphocytes exposed in cell culture to 2450 MHz RF at 2.1 or 12.5 W/kg.
- Gos et al [136] reported that RF radiation of the type produced by GSM phones (at 0.13 or 1.3 W/kg) was not mutagenic and did not enhance the activity of a chemical carcinogen.
- Maes et al [149] reported that RF radiation exposure of human blood cells at 6.5 W/kg did not damage chromosomes, did not enhance the activity of a chemical carcinogen, and did not enhance chromosome damage induced by X-rays.
- Roti Roti et al [151] reported that RF radiation (analog or digital) exposure of mammalian cells at 0.6 W/kg did not cause cell transformation.
- Vijayalaxmi et al [150, 167] reported that RF radiation exposure of human blood cells at 4.4-5.5 W/kg did not cause chromosome damage.
- Maes and Collier [157] found no increase in chromosome aberrations or SCE in human lymphocytes exposed to 600 MHz GSM at 0.4-10 W/kg for 4 hrs. RF exposure also did not enhance the genotoxic effects of X-rays or of a chemical carcinogen (tests for epigenetic activity).
- Teichman et al [176] reported that RF radiation of type used in MRI did not cause mutations in a bacterial test system (the Ames assay).
- Vijayalaxmi et al [174] reported that exposure of mice to RF radiation for 24 hours at 12 W/kg did not cause chromosome injury in their blood or bone marrow cells.
- NEW Li et al [242] reported the absence of DNA damage in cells exposed to mobile phone RF radiation at SARs up to 5 W/kg.
- Bisht et al [191] reported that mobile phone RF radiation did not cause increased micronucleus formation in mammalian cells.
- Vijayalaxmi et al [223] reported that rats exposed to 1600 MHz RF radiation for 2 years (2 hrs/day) at 0.16 or

1.6 W/kg showed no evidence of genotoxic injury (as assessed by micronucleus frequency in red blood cells).
- McNamee et al [227] reported that a 24-hour exposure of human white blood cells to 1900 MHz RF radiation (pulsed or continuous wave) at SARs of up to 10 W/kg did not produce genotoxic injury.
- Zeni et al [236] reported that exposure of human white blood cells to continuous wave or pulsed 900 MHz mobile phone RF radiation at 1.6 W/kg did not cause chromosome damage.

In contrast, a few recent (post-1998) studies have reported some evidence for RF exposure might be genotoxic:

- d'Ambrosio et al [180] reported that phase-modulated 1748 MHz RF radiation was genotoxic to human cells at 5 W/kg (micronucleus assay), but that a continuous wave signal was not.
- Tice et al [182] reported that while RF radiation did not cause DNA strand breaks, it might enhance micronucleus formation.
- Mashevich et al [217] reported that exposure of human white blood cells to thermal levels of RF radiation caused genomic instability, but that similar genomic instability was not caused by another method of heating.
- Trosic et al [218] exposed rats to 2450 MHz RF radiation at 5-10 mW/cm-sq for 2 hr/day for up to 30 days (SARs were estimated to be 1-2 W/kg). An increase in micronucleus incidence was seen after 8 days of exposure, but not after longer or shorter intervals.
- NEW Zhang et al [241] exposed human blood cells to 2450 MHz RF radiation for 2 hrs at 5 mW/cm-sq and/or a chemical carcinogen. The RF radiation alone was not genotoxic (DNA strand breaks and micronucleus assay), but the RF radiation was reported to enhance the genotoxic effects of the chemical carcinogen.

Two reviews of the genotoxic potential of RF were published in 1998.
Verschaeve and Maes [80] concluded that:

> "According to a great majority of papers, RF fields, and mobile telephone frequencies in particular, are not genotoxic: they do not induce genetic effects in vitro [in cell culture] and in vivo [in animals], at least under non-thermal conditions [conditions that do not cause heating], and do not seem to be teratogenic [cause birth defects] or to induce cancer."

Brusick et al [81] concluded that:

> "The data from over 100 studies suggest that RF radiation is not directly mutagenic and that adverse effects from exposure of organisms to high power intensities of RF radiation are predominantly the result of hyperthermia [heating]; however, there may be some subtle indirect effects on the replication and/or transcription of genes under relatively restricted exposure conditions."

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24) Where can I get more information?

The documentation of the various radiofrequency standards [5, 6, 7 and 14] contain extensive references. Reasonably up-to-date reviews of this area include:

- The 1999 Q and A sheet from the US FCC [135].
  On line at: http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet56/oet56e4.pdf
- The 2000 report from the Health Council of the Netherlands [186].
  On line at: http://www.gr.nl/pdf.php?ID=34F.
- The 2000 report from the U.K. Independent Expert Group on Mobile Phones [128].
  On line at: http://www.iegmp.org.uk/report/text.htm.
- The 2000 report from the Royal Society of Canada [99].
  On line at: http://www.rsc.ca/english/RFreport.pdf.
- The 2000 report from the New Zealand Ministry for the Environment [212].
  On line at: http://www.mfe.govt.nz/publications/rma/radio-freq-guidelines-dec00.html
- Safety Issues Associated With Base Stations Used for Personal Wireless Communications. IEEE Eng Med Biol, Mar/Apr 2001, pp 110-114.
  Online at: http://ewh.ieee.org/soc/embs/comar/base.htm

- The 2001 review from the World Health Organization [165].
- The 2001 review from the American Cancer Society [163].
  On line at: http://www.cancer.org/docroot/pub/content/pub_3_8x_environmental_carcinogens-cellular_phones_and_risk_of_brain_tumors.asp
- The US FCC/FDA website (up-dated 17-Jul-03) [189].
  On line at: http://www.fda.gov/cellphones/
- The 2002 review by Lin [203].
- The Dec 2002 report on mobile phone base station RF radiation safety from the U.S. NCRP [225].
- The 2002 Q and A document from the Australian Radiation Protection and Nuclear Safety Agency.
  Online at: http://www.arpansa.gov.au/pubs/rps/rfqa.pdf

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25) Who wrote these Questions and Answers?

This FAQ sheet was written by Dr. John Moulder, Professor of Radiation Oncology, Radiology and Pharmacology/Toxicology at the Medical College of Wisconsin. Dr. Moulder has taught, lectured and written on the biological effects of non-ionizing radiation and electromagnetic fields since the late 1970's.

The original version of this FAQ was written in 1995 under a contract with the City of Brookfield, Wisconsin. The FAQ has been maintained and expanded since 1995 as a teaching aid at the Medical College of Wisconsin. The web server and web management is provided by the General Clinical Research Center at the Medical College of Wisconsin. The development and maintenance of this document is not supported by any person, agency, group or corporation outside the Medical College of Wisconsin.

Parts of this FAQ are derived from the following peer-reviewed publications:

- KR Foster, LS Erdreich, JE Moulder: Weak electromagnetic fields and cancer in the context of risk assessment. Proc. IEEE, 85:733-746, 1997.
- JE Moulder: Power-frequency fields and cancer. Crit. Rev. Biomed. Eng. 26:1-116, 1998.
- JE Moulder, LS Erdreich, RS Malyapa, J Merritt, WF Pickard, Vijayalaxmi: Cell phones and cancer: What is the evidence for a connection? Radiat. Res., 151:513-531, 1999.
- KR Foster and JE Moulder: Are mobile phones safe? IEEE Spectrum, August 2000, pp 23-28.
- KR Foster and JE Moulder: Mobiles et cancer, un vrai casse-tête. La Recherche 337:39-47, 2000.
- KR Foster, P Vecchia et al: Effetti sulla salute dei telefoni mobili. AEI 87:36-41, 2000.
- JE Moulder: Radiaciones de Radiofrecuencias y Cancer: Efectos Biologicos y Posibles Mecanismos. In: P. Gil-Loyzaga and A. Ubeda Eds. , Ondas Electromagneticas y Salud, Informes Sanitarios, Siglo XXI, No. 1, Madrid, Spain, pp: 287-336, 2002.
- JE Moulder: Mobile phones and cancer. Radiat. Prot. Austral. 19:87-95, 2003.

Dr. Moulder maintains similar "FAQ" documents on "Powerlines and Cancer" and "Static EM Fields and Cancer".

Technical Notes:

1. International Commission on Non-Ionizing Radiation Protection: Health issues related to the use of hand-held radiotelephones and base transmitters. Health Physics 70:587-593, 1996.

2. PCS (Personal Communication Systems) phones are hand-held two-way radios that use a digital, rather than the analog transmission system used by older "cell phones". In the U.S., most of the older mobile phones operate at 860-900 MHz, while PCS phones operate at 1800-2200 MHz. In appearance, cellular and PCS phones and their base station antennas are similar. In the U.S., "cordless" phones operate at frequencies ranging from 45 to 2500? MHz, and "citizens band (CB)" two-way radios operate at about 27 MHz. Some cordless phones operate at power levels that equal or exceed some mobile phones.

International note: Around the world a variety of other frequencies are used for both analog and digital hand-held

transceivers and mobile radios, and other names are given to the systems (see Table 1 in Stuchly [83] for details). The most common frequencies for "cellular" systems are 800-900 MHz (analog and digital) and 1800-2200 MHz (digital); but hand-held transceivers exist that use frequencies from as low as 45 MHz to as high as 2500 MHz. Power output from hand-held units seldom exceeds 2 W, but power output from vehicle-mounted units such as those used by law enforcement personnel can be as high as 100 W.
Canada: Analog and digital phones operate around 800-900 MHz, and there is a new 2000 MHz digital system (similar or identical to PCS service in the US).
Australia: The analog AMPS phones operate around 800-900 MHz and the digital GSM phones operate around 900-1000 MHz.
Europe: Analog systems at about 900 MHz; digital (GSM) systems at around both 900 and 1800 MHz.

3. The specific frequencies used by mobile (cellular) phones can be called either microwaves (**MW**) or radiofrequencies (**RF**) or radiofrequency radiation (**RFR**) or radiowaves. For the discussion of health effects the distinction between radiowaves and microwaves is semantic, and the term radiowaves (or radiofrequency or RF or RFR) is used in this document for all frequencies between 3 kHz and 300 GHz.

4. For a detailed discussion of the biological effects of power-frequency fields, see:
- JE Moulder and KR Foster: Biological effects of power-frequency fields as they relate to carcinogenesis. Proc Soc Exper Biol Med 209:309-324, 1995;
- JE Moulder: Power-frequency fields and cancer. Crit Rev Biomed Engineering 26:1-116, 1998.

5. IEEE Standards Coordinating Committee 28 on Non-Ionizing Radiation Hazards: Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz (ANSI/IEEE C95.1-1991), The Institute of Electrical and Electronics Engineers, New York, 1992.

6. International Commission on Non-Ionizing Radiation Protection: Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields. Health Physics 74:494-522, 1998.

7. National Council on Radiation Protection and Measurements: Biological effects and exposure criteria for radiofrequency electromagnetic fields. NCRP Report No. 86, 1986.

8. The biological effects of RF radiation depend on the rate at which power is absorbed. This rate of energy absorption is called the Specific Absorption Rate (SAR) and is measured in watts/kilogram (W/kg). SARs are difficult to measure on a routine basis, so what is usually measured is the plane wave power density. Average whole body SARs can then be calculated from the power density exposure (see Stuchly [83] for details).

Note that some documents express power density as µW/cm-sq (microwatts/cm-sq), where 1000 µW/cm-sq (1000 microwatts/cm-sq) equals 1 mW/cm-sq.

9. The power density guidelines are stricter for some frequencies than for others because humans absorb RF radiation more at 860 MHz than at 1800 MHz, and it is the amount of power absorbed that really matters [8].

10. Specifically, the ICNIRP standard is 0.40 mW/cm-sq at 800 MHz and 0.90 mW/cm-sq at 2000 MHz, while the NCRP guidelines are 0.57 mW/cm-sq and 1.00 mW/cm-sq for these same frequencies.

11. Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation (FCC 96-326), Federal Communications Commission, Washington, D.C., 1996. Available from the FCC web page.

12. **International note -- Standards for public exposure to RF radiation from mobile phone base station antennas in countries other than the U.S.** This list is not comprehensive or necessarily up-to-date; the information should be checked with the appropriate regulatory authorities in each country. Also see Erdreich and Klauenberg [164].

- **Australian standard:** The 2003 Australian standard is:
  Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz. Australian Radiation Protection and Nuclear Safety Agency, 2003. It is online at: http://www.arpansa.gov.au/pubs/rps/rps3.pdf
  A companion Q and A document is on-line at: http://www.arpansa.gov.au/pubs/rps/rfqa.pdf
  With respect to public exposure to RF radiation from mobile phone base stations the Australian standard appears to be largely (if not completely) in agreement with the ICNIRP Guidelines [6].
- **New Zealand standard:** The 1999 New Zealand standard is:
  NZS 2772.1:1999 Radiofrequency fields - Part 1: Maximum exposure levels - 3 kHz to 300 GHz.
  With respect to public exposure to RF radiation from mobile phone base stations the New Zealand standard appears to be largely (if not completely) in agreement with the ICNIRP Guidelines [6]. The 1999 New Zealand standard does not contain the reduced exposure levels at higher frequencies that were part of the earlier New Zealand standards.
  Also relevant is the "National guidelines for managing the effects of radiofrequency transmitters" from the New Zealand Ministry for the Environment. It is on-line at: http://www.mfe.govt.nz/publications/rma/radio-freq-guidelines-dec00.html
- **Canadian standard:** [Health Canada: Limits of exposure to radiofrequency fields at frequencies from 10 kHz - 300 GHz Safety Code 6, Canada Communication Group, Ottawa, Canada, (1993)] At the frequencies of relevance to base stations the Canadian standard appears to be identical to the FCC standard.
- **UK standard:** In mid-2000 the UK stopped using its own standard for mobile phones and mobile phone base stations [14] and adopted the ICNIRP standard [10].
- **Greek standard** [Measures for protection of the public from operation of land-installed antennas. Athens, Hellenic Republic, 2000]: The standard is essentially identical to ICNIRP [6] standard.
- **Swiss standard** [Regulation about Protection against Nonionizing Radiation. Swiss Federal Council, 1999]: For wireless communication transmitters above 6 W (ERP) the standard is 4.0 V/m (0.0042 mW/cm-sq) at 900 MHz and 6.0 V/m (0.0095 mW/cm-sq) at 1800 MHz. For broadcast radio (and TV?) the standard is 3.0-8.5 V/m (0.0024-0.019 mW/cm-sq).
- **Italian standard:** Ministero Dell'Ambientem, Decreto 10 Settembre 1998, n. 381, Regolamento recante norme per la determinazione dei tetti di radiofrequenza compatibili con la salute umana.
  At mobile phone frequencies the standard appears to be 0.10 mW/cm-sq. For situations where exposure is expected to exceed 4 hours/day, the limit appears are further reduced to 0.010 mW/cm-sq. Local regional administrations appear to have the authority to further reduce these limits, and several regions appear to have limits 4 times lower (0.0025 mW/cm-sq).

13. Where there are multiple transmitting antennas at different frequencies, the method for assuring adherence to the ANSI [5] or FCC [11] standards is complex. However, there is also an easy way to check adherence under these conditions: add the power densities of all the antennas and apply the strictest power density standard. Anything which passes this easy check will pass the more stringent and complex test. Something that fails this easy check must be analyzed by the more stringent and complex method described in the ANSI standard.

14. National Radiation Protection Board: Restrictions on human exposure to static and time varying electromagnetic fields and radiation. Doc NRPB 4:1-69, 1993.

15. The 1992 ANSI standard [5], for example, is based on the review of 321 papers from the peer-reviewed literature; and the NCRP guidelines [7] are based on a review of nearly 1000 reports.

16. Specifically, no potentially-hazardous effects have been consistently shown below a SAR of 4 W/kg.
- At mobile phone frequencies it would require a power density of 20-100 mW/cm-sq to achieve a SAR as high as 4 W/kg.
- Under worst-case assumptions (multiple low-gain, high-ERP antennas), the SAR of a human in publicly-accessible locations near a FCC-compliant base station would be less than 0.01 W/kg.
- Under realistic conditions the SAR to a human near such a base station would be less than 0.0005 W/kg.

17. ANSI, ICNIRP and NCRP all agree that whole body exposure of the general public should be kept below a whole body SAR of 0.08 W/kg. Where the standards disagree is about the specific relationship of SAR to power-density, a

relationship that is determined from a combination of dosimetry and biophysical modeling.

International note: As a result of differences between approaches and frequencies used, world-wide standards for the continuous exposure of the public to RF from base station antennas ranges from 0.20 to 1.20 mW/cm-sq.

18. For the high-gain sector antennas used by most newer base stations, the area of concern is only at the front of the antennas. For the low-gain antennas used in many older base stations, the area of concern would be in all directions. This differences becomes clearer after an examination of the RF patterns from each type of antenna (see Q14D). Unfortunately, the RF radiation pattern from an antenna cannot always be determined from looking at it.

These general statements about minimum safe distances assume that total ERPs per sector for base station antennas will not exceed 2000 W. In the U.S., this is generally the case; and under the U.S. FCC guidelines, sites with total ERPs above 2000 W will require specific site evaluations [see note 19].

International note: More powerful antennas may be used elsewhere, in which case the minimum safe distances would be larger. Minimum safe distances will also be larger when there are multiple antennas broadcasting in the same sector.

19. Specifically, the 1996 FCC regulations require evaluations for:

- non-rooftop 1800-2000 MHz base station antennas less than 10 meters (30 feet) off the ground and with a total ERP of greater than 2000 W (3280W EIRP);
- rooftop 1800-2000 MHz base station antennas with a total ERP of greater than 2000 W (3280W EIRP).
- non-rooftop 800-900 MHz base station antennas less than 10 meters (30 feet) off the ground and with a total ERP of greater than 1000 W (1640W EIRP);
- rooftop 800-900 MHz base station antennas with a total ERP of greater than 1000 W (1640W EIRP)
- see Q14C for a discussion of ERP

"rooftop" is defined as: "the roof or otherwise outside, topmost level or levels of a building structure that is occupied as a work place or residence and where either workers or the general public may have access." I would assume that a mount on a water tower would be considered "non-rooftop"
"total power" is defined as: "the sum of the ERP or EIRP of all co-located simultaneously operating transmitters of the facility. When applying the [exclusion] criteria, radiation in all directions should be considered. For the case of transmitting facilities using sectorized transmitting antennas, applicants and licensees should apply the criteria to all transmitting channels in a given sector, noting that for a highly directional antenna there is relatively little contribution to ERP or EIRP summation for other directions."

In June 2003, the FCC proposed changes in the rules for which types of bases stations would require RF exposure evaluations. *There are clearly some editing/typographical errors in the part of the proposal that affects RF radiation standards for base stations.* A preliminary reading of the proposed rules indicates that evaluations would be required in the following situations:

- **At frequencies below 1500 MHz:**
  - Base stations with a "separation distance" of less than 3 meters (10 ft) regardless of "total power", except for the exclusion of certain "micro" transmitters (see below).
  - Base stations with a "separation distance" of less than 10 meters (33 ft) if the "total power" is greater than or equal to 100 W.
- **At frequencies of 1500 MHz and above:**
  - Base stations with a "separation distance of less than 3 meters (10 ft) regardless of "total power", except for the exclusion of certain "micro" transmitters (see below).
  - Base stations with a "separation distance" of less than 10 meters (33 ft) if the "total power" is greater than or equal to 200 W.
- **"Micro" base transmitters** would be exempt if their "total power" was below 3 W, and they were designed to keep people more than 20 cm from the radiating structure.

"Separation distance" is defined as: "the minimum distance from any part of the radiating structure of a transmitting

antenna in any direction to any area that may be entered by a member of the general public".
"Total power" *was probably meant to be defined as (there are clearly some editing errors in this part of the FCC proposal):* "total power of the transmit operation in terms of effective radiated power... of all co-located simultaneously operating transmitters owned and operated by a single licensee."
Note: This definition of **total power** seems to be different than that of the current regulations in that it applies only to a single operator, rather than the sum of all co-located antennas at a site. *This may also be editing error.*

International note: Strictly speaking, these criteria only apply in the U.S. Nevertheless, they are useful criteria for determining what types of antenna sites are most likely to violate RF standards.

20. One distinction that is often made in discussions of the biological effects of RF radiation is between "nonthermal" and "thermal" effects. This refers to the mechanism for the effect: non-thermal effects are a result of a direct interaction between the RF radiation and the organism, and thermal effects are a result of heating. There are some reported biological effects of RF radiation whose mechanisms are unknown, and it is difficult (and not very useful) to try to draw a distinction between "thermal" and "nonthermal" mechanisms for such effects. Also see Valberg [25], Foster [124], Pickard and Moros [158] and Adair [215].

21. These effects have included changes in the electrical activity of the brain, changes in enzyme activity, and changes in calcium ion transport across membranes [for details see 1, 5, 6, 7 and 14]. Also see Hyland [140].

23. The increased human absorption at 900 MHz (U.S. cell phone frequency) versus 2000 MHz (U.S. PCS phone frequency) applies to whole body exposure at a distance from the antenna (the case for public exposure near a base station antenna site). This difference may not apply to partial body exposures in very close proximity to an antenna.

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Actual measurements in the top floor apartments of a building with high-gain sector base stations antennas mounted to

the outside of the parapet just above the apartments found a maximum power density of 0.0004 mW/cm-sq [101]. Measurements in a corridor in the floor directly below a roof-top base station (antennas 3 meters above the main roof) found a maximum power density of 0.008 mW/cm-sq. Both maximums assume that the base stations are operating at their maximum capacity [101].

In 2000, NRPB (UK) [130] made measurements in multiple apartment buildings and schools that had a wide variety of mobile phone base station antennas on their roofs. On the top floor of these buildings the maximum RF power density from all sources combined was 0.0001 mW/cm-sq.

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