Are mobile phones safe?

Research intensifies as the public grows wary of one of its favorite communications tools

By Kenneth R. Foster, University of Pennsylvania & John E. Moulder, Medical College of Wisconsin

A MOTORIST USING A WIRELESS TELEPHONE might be worried about having an accident, even while being reassured that if one were to happen, he or she could call for help. Recently some scientists and lay people have expressed alarm at another possible danger—that the use of mobile phones itself may harm the user's health, perhaps even causing cancer.

There is good reason to be concerned. The widespread use of hand-held mobile phones means that many people routinely place radio frequency (RF) transmitters against their heads—in some European and Asian countries, a majority of the adult population does so. That fact alone would warrant examination of the safety of this form of radiant energy.

Concern about the possibility of mobile phone's ill effects on health took shape in mid-1992 in a U.S. court. A lawsuit filed in Florida by David Reynard alleged that the use of a cell phone had caused his wife's fatal brain cancer. The suit was dismissed by a Federal court in 1995 for lack of valid scientific evidence, and similar suits since have been no more successful. But they have raised questions for which no entirely satisfactory answers existed at the time they were filed. Driven in part by these disturbing allegations, a new wave of research in the United States and elsewhere is exploring possible links between cell phone radiation and cancer. Brain cancer, the topic of this article, is not the only health concern, but it dominates public discussion. Now, nearly eight years after the Reynard suit, a substantial body exists of pertinent scientific evidence.

Fields and frequency

Wireless communication systems operate at several frequencies in the electromagnetic spectrum. In the United States, cell phones operate in two main frequency ranges—the older systems near 850 MHz, and the newer personal communications services, or PCS, near 1900 MHz. European mobile phones use the Global System for Mobile Communications (GSM), a different technology than most U.S. phones, and operate at slightly different frequencies, near 900 MHz and 1800 MHz. Many other applications transmit energy in nearby frequency bands. [Fig. 1]

Energy in this frequency range is called non-ionizing because the photon energy is insufficient to knock electrons from atoms in living tissue, a source of serious biological damage from radiation such as X-rays. The most apparent biological effects of RF energy at cell phone frequencies are due to heating. Many mechanisms not due to heating have been demonstrated, too; but those well enough understood to be analyzed quantitatively are found to produce observable effects only at very high exposure levels.
Exposure standards in the United States and most Western countries are designed to give protection against all identified hazards of RF energy. At present, these are associated only with excessive tissue heating, which is hardly a likely problem with low-powered mobile phones. Analog hand-held phones radiate 600 mW or less of time averaged power, and many digital models produce 125 mW. However, most modern phones' output is adaptively controlled by the base station: the handset constantly adjusts its power to provide the minimum signal needed to communicate reliably with the base station.

Research, Old and New
Since World War II, there has been a massive amount of research on the biological effects of RF energy, nearly all of it funded by governments. Most of this research has involved fields at 915 and 2450 MHz, close to the frequencies used by mobile phones.

But, despite early claims by cell phone makers, little of this research proves that mobile phones are safe. Few of the studies on whether RF exposure is dangerous to animal tissue have involved standard toxicology work—the sort that a chemical or a pharmaceutical company would do to gain regulatory approval for a new product. In addition, little of the research deals specifically with the kinds of pulse-modulated energy transmitted by newer generations of digital phones or with the exposure conditions typical of those produced by cell phones.

The body of research is controversial in several respects. It includes many reports of biological effects of RF fields on cells and animals, sometimes at low exposure levels, which are poorly understood and often not reproducible. It also includes a scattering of reports of human health effects from low-level exposure to RF fields. Standards-setting committees, while acknowledging this research, have concluded that it provides insufficient basis for exposure guidelines [see “Setting limits for exposure to mobile phone energy”].

Spurred by the Reynard lawsuit and its attendant publicity, a new round of studies began in the mid-'90s, largely funded by mobile phone makers and mainly focused on carcinogenesis and mobile phones. One notable effort was the US $27 million Wireless Technology Research (WTR) program based in Washington, D.C. It was funded mostly by U.S. phone manufacturers but operated at arm's length from industry. That effort came to an end in December 1999 with no official pronouncement and only a handful of published studies, some of which are discussed below.

Many other research programs in other countries are underway, sponsored by either industry or government. One review of the issue, presented at a meeting in Erice, Sicily in November 1999, identified more than 200 ongoing and recently completed studies related to possible health hazards of RF energy.

Looking for a Link
Identifying links between cancer and environmental exposure of any kind is surprisingly difficult because of the absence of a single cause of cancer and for a variety of other reasons. Even if mobile phones had no connection to cancer, thousands of users would develop brain cancer every year, given the hundreds of millions of mobile phone users around the world and given so-called background rates of brain cancer (in the United States, it strikes about six in 100 000 people per year). Identifying an effect of cell phones against this background of the disease requires carefully designed studies.

When investigating suspected carcinogens, health agencies rely mostly on two sorts of studies: epidemiology studies, which involve statistical analyses of health records, and standardized tests, made on animals. On neither front does recent evidence support links between mobile phones and brain cancer.

In 1996, in the first follow-up study to Reynard's brain cancer allegations, the health records of more than 250 000 mobile phone users were reviewed by Kenneth Rothman, a senior epidemiologist at Epidemiology Research Institute, in Newton Lower Falls, Mass. This industry-sponsored WTR study reported no difference in mortality between the users of hand-held portable phones, where the antenna is placed close to the head, and mobile cellular phones, where the antenna is mounted on the vehicle, resulting in lower RF exposure. In a later, follow-up study, the same investigators examined the causes of death among nearly 300,000 mobile phone users (including some from the previous study) in several U.S. cities. "The only category of cause of death for which there was an indication of increasing risk with increasing minutes of use," the investigators reported in a November 1999 letter in the Journal of the American Medical Association, "was motor vehicle collisions."

Other epidemiology studies have been mostly or entirely negative. In a study that received extensive press coverage even before it was published, Lennart Hardell and his colleagues at the Örebro Medical Centre in Örebro, Sweden, assessed mobile phone use by 209 Swedish brain tumor patients in comparison to 425 healthy controls. The study, funded by the Swedish Medical Research Council, was negative in virtually all respects.

In reporting the study, the lay media focused on one finding: users of mobile phones who had developed certain types of brain tumors were more likely to report having used the phone on the side of the head with the tumor than on the other side. But the association was weak. It was not statistically significant and might easily have been a result of recall bias—a well-established tendency of subjects to remember exposures to something more readily if they developed a disease. The brain cancer patients in Hardell's study knew their
diagnosis before they were asked about their use of mobile phones.

Brain cancer takes years or decades to develop, and these studies say nothing about future risks. Detecting small or long-term cancer risks is not an easy task. Detecting small increases in risk would require large studies that are hard to control and usually are controversial in their interpretation. Any valid study would also have to assess an individual's use of mobile phones over a decade or more, an assessment complicated by the rapid technological developments in this industry.

Answers from animal studies

Animal studies, the other main source of information used in cancer risk assessment, also have not supported a link between mobile phones and cancer [Table 1].

Exposing rats to pulse-modulated 837 MHz RF energy, similar to that emitted by some digital cell phones, does not cause or promote brain cancer. That was the finding of a Motorola-funded study designed specifically to look for brain cancer and reported in a 1999 paper by W. R. "Ross" Adey, now at the University of California at Riverside. More recently, in April 2000, Adey reported the same finding for continuous wave RF, such as that emitted by analog cell phones. And in a 1999 meeting report, Bernard Zook of George Washington University in Washington, D.C., confirmed all of Adey's findings. The other studies in the table were not focused on brain cancer, but they evaluated the animals for the disease and would have noted a pronounced increase in this disease had it occurred.

Animal studies, while easier to control than epidemiology studies, have uncertain relevance to human health. For example, former WTR chief George Carlo pointed out to IEEE Spectrum that none of the animal studies done to date has adequately mimicked the head-only exposure of a user of a mobile telephone; rather, the animals are exposed to whole-body radiation. A countervailing argument is that whole-body exposures are more likely to produce toxic effects than partial body exposures. Issues of this nature involve professional judgment about which experts routinely disagree.

Exceeding the limits

The focus on mobile phones' health effects has intensified the scrutiny of exposure to RF energy in the United States. The FCC limits peak exposure to 1.6 W/kg of tissue averaged over any single gram of tissue (or 1.6 mW/g). European limits are less restrictive, specifying 1.6 W/kg averaged over 10 grams.

Mobile telephone handsets operate at low power levels, but the antenna, which radiates about 600 mW for an analog mobile phone and 125 mW for a digital unit, is placed very close to the head, which can push exposure levels close to the regulatory limits. A complicating factor is that the exposure depends greatly on the exact position of the handset with respect to the head and on the exact shape and electrical characteristics of the head—all variable quantities. Moreover, the exposure cannot be measured directly in the head of the user, but has to be estimated by computer models or measurements in tanks of liquids in the shape of the head [Fig. 2].

Manufacturers can reduce exposure by tweaking handset design, up to a point. Significant reductions in power create the need for more closely spaced base stations, which are unpopular with residents in many areas. Moving antennas and other circuit elements farther from the user's head might enlarge the handset, which would work against consumer demands for small phones.

Industry and academic investigators have reported data showing that mobile phones on the market meet regulatory limits, by and large. There have been some exceptions, though. In 1998, the FCC announced that Sony Electronics Inc. would recall 60 000 cell phones that exceeded FCC exposure limits.

Controversy continues

Many areas of contention remain. For instance, in a 1995 study that received wide media attention, Henry Lai and colleagues at the University of Washington in Seattle reported exposing rats to RF radiation at an average whole-body exposure of 1 W/kg of body weight. The result: breaks in their brain cells' DNA—an indicator of potential cancer causing effects.

But more recent studies have cast doubts on this finding. Attempts to confirm Lai's results, by a Motorola-funded group led by Joseph Roti Roti at Washington University in St. Louis, were unsuccessful. A Belgian government-funded group led by Luc Vershaeve has reported that similar RF exposure to rats does not cause DNA strand breaks in other types of cells. Moreover, the Washington University group has identified an experimental artifact that might have accounted for Lai's positive results. Lai continues to defend his original studies.

Scientific data can spark public controversies even before they are published, let alone digested by health agencies. Take the recent epidemiological study by Joshua Muscat, a research scientist at the American Health Foundation in New York City. Results of this WTR funded study were presented at a scientific meeting in June 1999 but so far they have not been published in any detail.

In a Canadian TV interview four months later, former WTR chief Carlo, referring to the Muscat study, said...
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The epidemiological results, so far, are certainly inconsistent with any large increase in risk (a doubling or more) of brain cancer from use of cell phones—the implication of the original Reynard lawsuit. Nor do the animal studies show clear-cut carcinogenic effects. However, the epidemiological studies lack the sensitivity to detect small increases in risk, and the relevance of animal studies to human health is uncertain—both familiar problems with carcinogen risk assessment.

In a document posted on the Web in February 2000, the U.S. Food and Drug Administration noted that "[T]here is currently insufficient scientific basis for concluding either that wireless communication technologies are safe or that they pose a [health] risk to millions of users."

The term "safe" brims with legal, regulatory, and ethical implications. Health agencies on the whole shy away from pronouncing technologies safe, but instead evaluate evidence for possible hazards. For example, the International Agency for Research on Cancer (IARC), in Lyon, France, has received about 8 million euros from the European Commission for a large epidemiological study of cell phone use in relation to head and neck cancers. Ten countries will participate in the study, which is foreseen as including 1500 cases and 1500 healthy controls. The research is in its pilot phase and is expected to be completed within three years. But even with extensive data, IARC virtually never pronounces an agent to be a "noncarcinogen," and therefore is unlikely to do so with RF energy.

In contrast, mobile phone manufacturers must prove, not that their products are safe, but that they meet exposure limits—a different matter entirely. The standards that set limits on exposure to energy from phones were developed largely on the basis of whole-body exposure data and engineering considerations.

More research is clearly needed on the biological and biophysical effects of near-field exposure. A better-defined threshold for hazard might even lead to relaxed exposure limits for handsets. Most current research is going on outside the United States. Michael Repacholi, director of a project on health effects of electromagnetic fields at the World Health Organization in Geneva, estimates that there is about $100 million in ongoing research on possible health effects of mobile telephones, very little of which is being done within the United States.

But U.S. industry and government have not given up. In June 2000, the Cellular Telephone Industry Association (CTIA) and the U. S. Food and Drug Administration announced an agreement, under which the CTIA would fund a $1 million research program, with FDA input, on mobile phones and health. This funding is dwarfed by the huge costs of toxicology and epidemiology studies; it will pay for limited follow-up studies to address issues raised by the WTR program.

Whatever the outcome of the latest generation of studies, debate over the health effects of mobile phones will continue. Mobile phones will join other forms of electrical technology, such as police radar sets, computer display terminals, and power lines, that have triggered public fears because of their electromagnetic fields. Such issues are very difficult and time-consuming to resolve. How to respond appropriately to public fears, identifying any real hazard while avoiding unproductive controversy, is not a purely scientific matter but a question with deep social aspects [see "Will people believe mobile phones are safe?"]

In a bid to stay ahead of the public debate CTIA recently revealed that by the end of 2000 its members would begin including SAR information with new models of phones. The data and some explanatory language will appear as a pamphlet inside boxes of new phones, a CTIA spokesperson told IEEE Spectrum. SAR data is already available at an FCC website [www.fcc.gov/oet/rfsafety], but that site is very difficult to navigate. Even if the CTIA initiative makes SAR data more easily accessible, it is is unclear how consumers can make use of the data [see "A precautionary RF report"].

Meanwhile, a mobile phone user with health concerns has simple remedies: use an external earpiece that keeps the phone away from the head, decrease phone use, or avoid using the phones in areas where the signal is poor—a weak signal from the base station causes modern handsets to increase their broadcast power. Neither of us would recommend such measures on health grounds, but people can decide for themselves whether to take such precautions.

To Probe Further


Abstracts of the reports cited in this article are available at http://infoventures.com/emf/top/spectrum.html.


The Federal Communications Commission (FCC) posts information on RF exposure compliance at www.fcc.gov/oet/rfsafety.

The World Health Organization (WHO) has a Web site with educational and other material about RF fields and health. See www.who.int/peh-emf.

One of the authors (John E. Moulder) appeared on Larry King Live to discuss cell phones use and cancer. The transcript of that program can be found at http://www.cnn.com/TRANSCRIPTS/0008/09/lkl.00.html.

**About the authors**

Kenneth R. Foster is professor of bioengineering at the University of Pennsylvania in Philadelphia, immediate past president of the IEEE Society on Social Implications of Technology, and immediate past chair of the IEEE's Engineering in Medicine and Biology Committee on Man and Radiation.

John E. Moulder is professor of radiation biology at Medical College of Wisconsin, Milwaukee. He is a specialist in cancer biology and author of a highly respected Internet site on health and safety issues related to electromagnetic fields.
In terms of the electromagnetic spectrum, cell phones fall between microwave ovens and TV transmitters. Such radiation, though non-ionizing, can induce biologically significant heating.

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### Table 1: Brain cancer in rats after RF radiation exposure

<table>
<thead>
<tr>
<th>Researchers, dates*</th>
<th>Frequency, MHz</th>
<th>SAR, W/kg</th>
<th>Duration, months</th>
<th>RF exposed</th>
<th>Unexposed</th>
<th>Tumor generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.K. Chou et al., 1992</td>
<td>2450 PM</td>
<td>0.15–0.4</td>
<td>25</td>
<td>100</td>
<td>100</td>
<td>None</td>
</tr>
<tr>
<td>J.C. Toler et al., 1997</td>
<td>435 PM</td>
<td>0.32</td>
<td>21</td>
<td>200</td>
<td>200</td>
<td>No significant difference between groups</td>
</tr>
<tr>
<td>M.R. Frei et al., 1998</td>
<td>2450 FM</td>
<td>0.3</td>
<td>18</td>
<td>100</td>
<td>100</td>
<td>None</td>
</tr>
<tr>
<td>M.R. Frei et al., 1998</td>
<td>2450 FM</td>
<td>1.0</td>
<td></td>
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</tbody>
</table>

**Brain tumor generation PLUS promotion of chemically induced tumors**

<table>
<thead>
<tr>
<th>Researchers, dates*</th>
<th>Frequency</th>
<th>SAR</th>
<th>Duration</th>
<th>RF exposed*</th>
<th>Unexposed*</th>
<th>Tumor generation</th>
<th>Tumor promotion</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.R. Adey et al., 1999</td>
<td>837 PM</td>
<td>0.3–2.3</td>
<td>25</td>
<td>60*</td>
<td>60</td>
<td>Insignificant decrease in RF-exposed rats</td>
<td>None</td>
</tr>
<tr>
<td>W.R. Adey et al., 2000</td>
<td>837 FM</td>
<td>0.3–2.3</td>
<td>26</td>
<td>90</td>
<td>90</td>
<td>No sig diff.</td>
<td></td>
</tr>
<tr>
<td>B.C. Zook et al., 1999</td>
<td>860 FM</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>B.C. Zook et al., 1999</td>
<td>860 PM</td>
<td>1</td>
<td>22</td>
<td>60</td>
<td>60</td>
<td>No sig diff.</td>
<td></td>
</tr>
</tbody>
</table>

*a Abstracts of these researchers’ papers are to be found on the Web at [http://infoventures.com/emf/spectrum.htm](http://infoventures.com/emf/spectrum.htm).

*b Different sets of rats were used in the tumor generation and tumor promotion experiments. The same number of rats were used in both parts of the study, except in the case of W.R. Adey et al., 1999. In that study, only 56 rats were RF exposed in the tumor promotion experiment.

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A precautionary RF report