RADHAZ:
The unmentionable hazard?

Every few weeks the popular press features a new article relating to potential health dangers of mobile phones or base stations. Large sums of money are being spent on research in laboratories all over the world. In this article Brian Collins reviews the sources of non-ionizing radiation to which we are exposed, and our present state of knowledge on their effects

Multi-user transmitting site

It is widely understood that some kinds of radiation are harmful to human health, although we all live in a world full of natural radiation of every frequency – from noise at the low-frequency end of the radio spectrum to hard ultra-violet (UV) radiation. Without it we would not be here.

Fortunately the earth is surrounded by ionized particles that absorb most of the more harmful radiation at frequencies from UV upwards. Almost all the radiation that reaches the ground is non-ionizing radiation: the energy carried is not sufficient to ionise atoms by knocking out charged particles. At UV and visible light frequencies there is still enough energy to break the bonds that hold molecules together. We are all familiar with plastics which discolour in the sunshine and dyes that fade in the light. Infra-red (IR) radiation is mainly associated with the transfer of heat. When food is placed in a grill it cooks because the IR radiation is absorbed in the surface of the food, imparting its energy to the molecules from which the food is made.

As the frequency falls further we enter the radio frequency (RF) spectrum. Electromagnetic waves at radio frequency ('radio waves') carry energy which is transferred into any object which absorbs them. We all know that if we irradiate food with a few hundred watts of microwave energy it will get hot and cook. Today's world is full of sources of RF energy with powers from a small fraction of a watt up to a million watts (1MW) and more; we need to understand the effects they can have on our bodies. Clearly we must avoid cooking ourselves, but are there other effects we need to guard against? This apparently simple question is at the heart of the current debate.

Proving negatives

It's clear that there are no major short-term risks in normal levels of exposure to RF fields. If there were we would have seen an epidemic of disease or early death among exposed populations or groups of workers. What is less certain is that continuing exposure to fields at lower intensities causes no long-term ill effects.

The methods of science are not well suited to proving that a suggested cause has no long term effect. There are two reasons for this. Firstly, we don't know for certain what effect we are looking for, and secondly we can only assign some degree of probability to our conclusions. The result of thorough and well-conducted investigations costing millions of pounds/euro/dollars can only be expressed in terms that sound to many laymen like prevarication. Any experimental campaign will conclude at best that in the conditions of the experiment (at the frequency, exposure intensity, duration, modulation scheme &c) the effects searched for (mortality, soft tissue cancers of a particular type, nightmares &c) in the population (or animal or cell type) studied are (within a stated confidence limit) less than (a stated incidence). This inevitable state of affairs means that while investigators can use their best imagination and experience, they can never say that something is absolutely 'safe', and those who assert that an effect has been missed (or worse that something is being hidden) can always make any statement relating to safety look insecure by challenging the conditions and subject of the experiment, whether the right effects were looked for, and the sensitivity of the outcome. Worse, different groups are seen as having different interests in 'proving' that some situation is 'safe', so the credentials of the investigators and the source of their funds is seen to colour the result.

A well known technique is that of epidemiology. Take a sample population (say a million mobile phone users) and compare them for the incidence of some possible effect (say increased hair growth) with a control population (say a million people without mobile phones). It sounds easy, yet there are many problems. Is phone use the only difference between the populations? Obviously not; in particular we may find that the mean income of the non phone-users is lower than that of the phone users. Anyhow, what do we mean by a phone user? Is my wife, who only turns her phone on when she needs to make a call a 'phone user'? These confounding factors, working like noise in a communications system, reduce the sensitivity of the experiment and make the results fuzzy and imprecise.

Figure 1: IndexSar measurement equipment

Even the existence of a study often creates concern in the popular press. The headline will always read *'Scientists seek (or fear) connection between mobile phones and x'*, and as we have seen, negative results will always look less than categorical.

As far as mobile phone usage is concerned, I believe that my probability of death from the effects of RF radiation from my phone are less than the probability that my phone will at some point save my life (and/or someone else's life).

Individual sensitivity

There's a huge difference between individuals' ability to sense exposure to RF fields. Some individuals are reported to be able to detect when a laboratory signal generator is turned on and off at power levels of only a few milliwatts, even when connected only to a coaxial cable with an open connector placed in front of the test subject. I was recently within 10m of an antenna radiating 600kW at about 1MHz and could sense it was on only because my feet became hot where I stood on a ground conductor. It's natural that people with enhanced sensitivity will be more concerned about any effects of RF fields, and their enhanced sensitivity to RF is often paralleled by enhanced sensitivity to other environmental stimuli. (Try Googling for 'Electromagnetic hypersensitivity' if you are interested.)

Specifying and measuring limits of exposure

There are various ways of measuring the level of exposure of individuals to RF fields. For waves propagating in free space the field is characterised by the power density (W/m^2). Close to an antenna, consideration must be given to separate criteria for the E-field (V/m) and H-field (A/m). If we wish to investigate the absorption of fields into the body we describe the level of absorption in watts per kilogram (W/kg) of body tissue; this quantity is referred to as the specific absorption rate (SAR). We may be interested in whole-body exposure, or more often the power density in each separate 10g or even 1g of tissue.

The body responsible for internationally specified limits is ICNIRP (International Committee on Non-Ionising Radiation Protection). National guidelines are laid down in many countries, often by health and safety administrations; these often coincide with ICNIRP, but sometimes differ – often in the direction of being less stringent. The competent authority in the UK is the National Radiological Protection Board (NRPB), while in the US the FCC, OSHA and IEEE are responsible for various aspects of regulation. The ICNIRP limits have been set with a large factor of safety below any known ill effects.

Calibrated hazard meters are now readily available and are routinely worn by riggers and engineering staff required to climb antenna structures. They usually operate over a wide frequency range and have an audible alarm that sounds if the safety limit is exceeded.

Measuring the absorption of energy in human tissue is difficult, especially as high spatial resolution is needed to make sure there are no small hot-spots which might suffer damage. Measurements are usually made by placing a phone close to a bath of liquid electrolyte with similar

Typical streetworks base station site

electrical properties to a human head and probing inside the electrolyte with a remotely-controlled probe. A typical measurement system with probe scanning inside a liquid-filled 'phantom head' is shown in **Figure 1**. It is now routine practice to measure the SAR distribution in this type of apparatus for every new model of mobile handset.

Effective radiated power

Most antennas concentrate the power they radiate into a beam which may be directional in the azimuth or elevation plane, or both. The *effective isotropic radiated power*, (EIRP), is the input power to the antenna multiplied by the gain of the antenna in the direction we are interested in, relative to an isotropic radiator [or in decibels, eirp (dBW) = Pin(dBW) + G(dBi)]. The larger an antenna, measured in wavelengths, the more directional it can be made. The concept of eirp is not valid when the distance from the antenna to the point of interest is small (certainly when it is less than the longest dimension of the antenna). Fields and power flows close to an antenna are best calculated using an electromagnetic simulation program or by measurement with a small probe.

The power density at a distance from an antenna is easily calculated. If an isotropic antenna radiates p watts, then at a distance r the power density is $p/(4\pi r^2)$ w/m^2, so for an eirp of P watts the power density is $P/(4\pi r^2)$ w/m^2 and the associated field strength $E(V/m) = \sqrt{(120\pi P)}$. These simple relationships apply to the far field of the antenna, which starts about 10m away from a typical base station antenna.

The effects of exposure to high fields

These are well documented. At very high levels of continuous exposure the body is heated and death will be caused by heat stroke when the body's cooling system is no longer able to cope. Pulsed fields can give rise to sensations such as pinging in the ears. Some tissues, notably the retina and the testes can be damaged at sub-lethal exposures, resulting in blindness or sterility. Eyes are particularly at risk from radiation in the upper microwave bands where most energy is deposited in surface tissues (such as the cornea) which have relatively low blood flow, and consequently are not efficiently cooled.

Exposure limits are set with the object of limiting the rise in body temperature to a small value within the normal limits of variation during light exercise. To give some sense of scale, the total power radiated by a GSM mobile phone typically has a peak power of around 1 watt, transmitted in short bursts for only 1/8 of the time for which the transmitter is active – a mean power less than 1/8 watt. Summer sunshine in the UK has a typical power flux of around 1000W/m^2, so when sitting on a beach on a sunny day we may be irradiated by 500W of electromagnetic energy, much of it deposited in the surface tissues in the form of heat.

Most standards recognise acceptable occupational exposure limits and set lower limits for the general public, a population which may include potentially more vulnerable individuals – for example children, old people with poor health, pregnant women – and whose exposure may be for much longer time periods than those of a typical worker.

RF exposure in the 21st century

Mobile phones

The currently most publicised source of exposure is the mobile phone and its associated base stations. The mobile phone is the first portable transmitter to be carried and used by a huge number of individuals, so it is natural that its safety should be of great concern. Unlike occupational exposure – generally experienced by healthy adults, mobile phones are used by every section of the community including groups who may be more sensitive to low levels of energy absorption, children, pregnant women, old people, and by people with circulatory problems, cancer and other pre-existing medical conditions. The peak SAR associated with a typical mobile phone is often between 50% and 90% of the ICNIRP limit when operating at maximum power. The actual power radiated by a mobile phone is automatically reduced to the minimum necessary to establish communication; the largest powers are required when the user is close to the limit of coverage of a base station.

Microwave ovens

The leakage of energy from a microwave oven is required to be less than 5mW/cm^2 at a distance of 5cm from any surface of the oven (BS 5175:1976). Even so the total power escaping may exceed 0.5 watt – say 1/1000th of the total RF power generated – representing a screening effectiveness of only -30dB. It's not surprising that there are stories of people putting mobile phones inside a microwave oven and successfully making calls to them! (You should only be able to do this if you live fairly close to a base station – and if you want to try, first make sure the oven is OFF.) The door seal will wear and become dirty through use, so the screening effectiveness is likely to fall as the oven ages. Even so the HSE circular to local authorities states 'The incidence rate … for injuries arising at microwave ovens … appears minimal and derives almost entirely from reports published in the USA.'

Mobile phone base stations

A base station is equipped with

several transceivers, each generating up to about 40W. Allowing for the loss of signal through filters and cables the total power reaching the antennas is typically up to about 200W for each of the three sectors served by the base station. Some stations use two antennas for each sector and each will transmit up to 100W; where dual polar antennas are used a single antenna is used for each sector and transmits up to 200W. The associated power densities are the same. In order to provide the best possible coverage, the base antennas are built as a vertical array of radiating elements. This focuses the radiated energy into a narrow beam directed just below the horizontal; typically the beam is 6° wide and is directed 2° below the horizontal. On a typical low structure (10m high) the beam centre reaches head level 285m from the mast base.

If we do the calculation, we find that the power density in the example will be 0.013W/m^2, compared with an ICNIRP limit of 10W/m^2. Even allowing for sidelobes that lie below the main beam but are of lower gain, there is a substantial margin below the recommended limit. This is a pessimistic example as we have used the shortest structure combined with a power near the high limit of what would be encountered. When four networks are co-sited on a 20m structure we can see that the power densities at head height will still be well below recommended limits. Sites on building roofs can only create a hazard for people walking in front of them and close to their beam centre line – typically window cleaners and service personnel; to alert people to this hazard suitable fences and warning notices are usually provided.

So-called 'streetworks' base stations are mounted on structures like lamp posts, often only 8 – 10m high. These typically transmit 4 x 2W carriers, with an eirp of 16dBW. The gain of a typical base station antenna in the direction of the ground below the antenna is typically 30dB less than that in the maximum direction so there is no brightly lit area below the structure.

To put the potential hazard provided by a base station into perspective, I conducted the following experiment. A standard RF hazard meter with an alarm level set at one half of the ICNIRP limit was moved towards a standard GSM handset while a call was in progress. The hazard meter beeped when it was about 1cm from the antenna of the handset (the user's ear would normally be closer than this). The same hazard meter was then moved towards the front of a typical 12-element 1800MHz base station antenna fed with 2 x 20W signals; the meter beeped when it was 30cm (1ft) from the front of the antenna. The simple distribution of the total power over the physical area occupied by the antenna reduces the power density, even at the antenna itself, and as the power leaves the antenna it is progressively distributed over a larger area, typically the frontal area of a beam 60º wide in azimuth and 5º wide in the elevation plane.

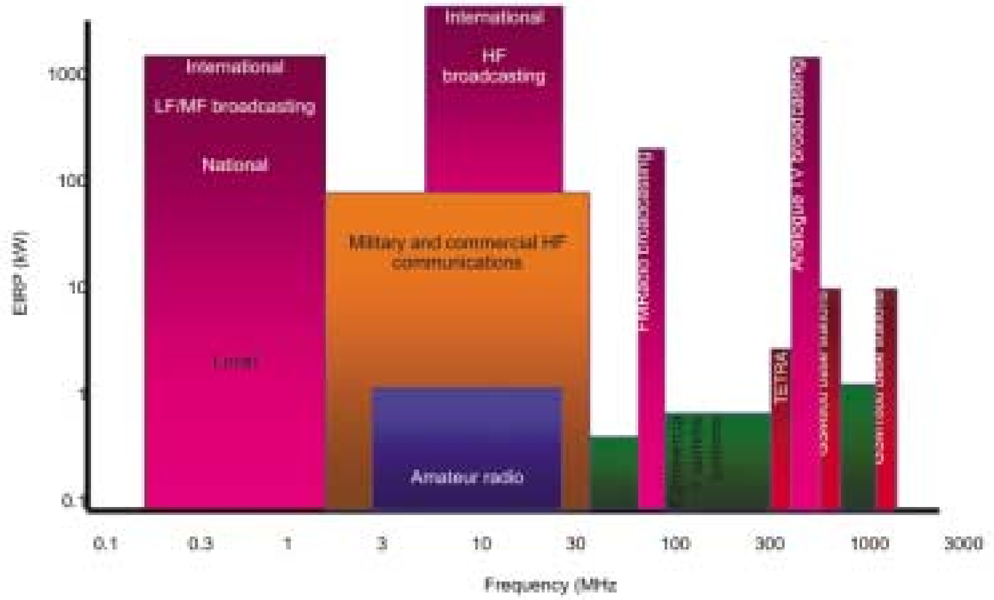

Figure 2: Simplified diagram showing typical range of EIRP radiated by major spectrum users

TETRA

Much publicity has been given to health concerns related to TETRA, the TErrestrial TRunked RAdio system being introduced for use by the police and other public services. The main source of concern relate to the relatively high power in use at the handsets, and the low frequency of the bursts they transmit. A report published in the 1980s suggested that the diffusion of sodium from brain cells was accelerated by exposure to RF signals with a pulse frequency around 16Hz. A large amount of more recent work has failed to confirm this effect and no health-related effects have been identified for exposures at or below the ICNIRP limits. Future developments in which handsets transmit in more than one burst in each frame (TETRA uses a frame with four bursts) might lead to users experiencing SARs at or above the ICNIRP limit, and this development may require additional precautions to meet the limit. TETRA base stations transmit a continuous signal and the associated eirps are generally lower than those used for GSM, so there are no special reasons for concern.

Radio and TV transmitters

The highest power densities are radiated by the main UHF television transmitters. A total eirp of 6MW is radiated by several TV stations in the UK, but the antennas are even more directional than those used for mobile radio, and the structures are typically 300m high, so the beam maximum is directed at the ground more than 8km from the structure (if the structure is on flat ground) and the ground level power density is very small. A classic epidemiological study was conducted a few years ago around the UHF TV station at Sutton Coldfield (UK).

VHF radio transmitters operate at rather lower eirps at frequencies around 100MHz. Although the ground level power densities are modest, this frequency band corresponds to a wavelength of 3m, so body resonances may increase the effect of exposure; this possibility is included in the ICNIRP limit which is correspondingly reduced.

Terrestrial digital radio and TV transmitters operate at much lower mean eirps, although their peak/mean ratio is relatively high.

High power radio systems at HF and lower frequencies create very high local field strengths at ground level and antenna systems are usually fenced to prevent access to hazardous zones.

All high power broadcast systems present hazards to those working within the radio stations. These personnel are well instructed in these matters and will normally carry personal alarms when they need to work near active antennas. At lower frequencies the heating effect of the fields is relatively low, so permitted power densities are higher. Typical effects are that any large conducting object carries induced currents/voltages and contact with a hand can create a painful burn; even when working in areas within safe limits personnel will usually wear insulating gloves while handling wire ropes and steelwork.

Relative powers of the all the above are illustrated in **Figure 2**.

The present state of knowledge

The Stuart Report (UK) is one of the most comprehensive and objective reviews of the possible effects of mobile radio systems. Some comprehensive epidemiological studies are beginning to report results and there are many on-going studies that will report over the next few years. Work on non-thermal effects is examining matters like the change in action potential in cells exposed to RF fields, and looking for effects on memory and perception. While various effects are reported it is not clear whether any has negative health significance.

The UK Independent Expert Group on Mobile Phones (IEGMP), chaired by Sir Richard Doll has reported even more recently. If you are seriously interested in the subject it is well worth reading. The research work reported spans investigations into the incidence of cancers (whether induced by RF fields operating alone or in combination with a number of other factors). The overwhelming impression on reading the document is of the wide scope and diligence of the work reported.

Are the published results biased?

Some people see much of the available information as being the result of a conspiracy not to tell 'the truth' about the perceived dangers of sources of electromagnetic fields. They see bias in the experts' dismissal of positive associations as being unrepeatable, of little statistical significance, or the result of badly designed experiments. When the language of the conclusions of an experimental campaign is careful, guarded and precise the sceptic sees this as lacking in confidence and hiding 'the truth'.

There are several reasons why the actual bias in results is likely to be in the conservative direction. Results reporting positive associations between exposure and health effects are newsworthy and bring publicity to the investigators responsible; grant allocating bodies are more likely to back further investigation of positive results rather than negative ('no effect') results. A newspaper will headline a positive result, but there are no headlines for solid research producing a conclusion of no adverse effects. This view is confirmed if you dip into the research literature: you may well recognise many of the positive findings, while the bulk of the negative reports are unfamiliar.

Reading the reports of many investigations suggests that there has been too little involvement by engineers with detailed knowledge of radio systems. There is little sign that the medics are being led by the nose by technical experts from the mobile radio industry. The strong impression is that many experiments would have been better designed – and more reliable results would have been obtained – if more advice had been taken from engineers before the investigations had begun.

The good news is that the more of the published literature you study, the more you realise just how much investigative work has been done and is in progress. While everyone is properly guarded about the possible emergence of long-term effects, the strong consensus is that no effects on health occur within the ICNIRP exposure limits. The 2003 report of the Independent Advisory Group on Non-Ionizing Radiation (Documents of NRBP Vol 14 No 2) concludes: "The weight of evidence now available does not suggest that there are adverse health effects from exposures to RF fields below guideline levels, but the published research on RF exposures and health has limitations, and mobile phones have only been in widespread use for a relatively short time. The possibility therefore remains open that there could be health effects from exposure to RF fields below guideline levels: hence continued research is needed."

The perception paradox

The 2002 report on the possible health effects of mobile phone systems to the French Senate comments on the fact that although most public protest relates to the siting of base stations, most people who oppose their construction use mobile phones and allow their children to use mobile phones, failing to admit that if a risk does exist it is in respect of handsets, which create far higher levels of personal exposure. As we have observed, mobiles used at the coverage limit of a cell radiate much more power than one near a base station, so the successful protesters enjoy a much higher level of RF exposure than those who live across the road from a typical base station.

Further information

There is a vast and fast-growing literature on the limits of RF exposure and the study of possible health effects. The author's website at www/bscassociates.co.uk/links.html carries links to all the documents mentioned in this article as well as to a number of other authoritative websites and sources of further references. The reports of the Independent Experts Group are written in language accessible to anyone with an interested lay person's knowledge of both radio and physiology and anyone interested in the subject will find they are well worth reading.

Anyone working with radio transmitters needs to be aware of the current regulations and to make sure staff working with live antennas are aware of potential hazards and carry hazard warning devices.

The author

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He currently runs his own consultancy business while retaining part time employment as Technical Director at CSA Ltd (base station antennas) and Chief Applications Engineer at Antenova Ltd (handset and other consumer antennas).