Base stations and wireless networks: exposures and health consequences

Proceedings
International Workshop on Base Stations and Wireless Networks:
Exposures and Health Consequences
Switzerland, Geneva,
June 15-16, 2005

Editors
Mike Repacholi
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World Health Organization

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FOREWORD

The WHO Workshop on Base Stations and Wireless Networks: Exposure and Health was held in Geneva on June 15-16, 2005. This meeting was jointly sponsored with the European Cooperation in the Field of Scientific and Technical Research (COST 281), the European Commission Coordination Action EMF-NET, the Research Association for Radio Applications (FGF) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

This workshop covered issues such as the exposure from mobile phone base stations and other wireless networks, future wireless technologies, review of possible health consequences from the above, risk communication to the public related to radio base stations exposure, and response from governments and other stakeholders. The aim of the conference was to review the current state of knowledge and opinions of the conference participants and propose ways forward on this issue.

The meeting was convened by the WHO International EMF Project as part of the scientific review process to determine biological and health effects from exposure to EMF. The purpose of these workshops is to bring together expert scientists so that established health effects and gaps in knowledge requiring further research can be identified.

Exposure to radiofrequencies from radio base stations is a topic much debated by the scientific community, policy and health authorities, other stakeholders and the general public. In the course of the workshop, over 25 contributions were discussed. The editors thank all speakers to the Workshop for their contribution to this Proceedings.

The Editors

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RAPPORTEUR'S REPORT

Rapporteur's Report

Colin Roy
Australian Radiation Protection and Nuclear Safety Agency ARPANSA, Australia

The opening talk of the Workshop was given by Mike Repacholi, WHO, Switzerland, who set out its 'Scope and Objectives'

In his talk he emphasised that the workshop was designed to answer the following questions:
- What are the current and future wireless technologies?
- What RF exposures do people receive from these technologies?
- Is there evidence of health effects from long-term, low-level RF exposures?
- What further research is needed, if any?
- What international standards exist or are being developed?
- What have national authorities done in response to this issue?
- How can we provide effective communication to all stakeholders on this issue?
- What policy options can be recommended for national authorities?

He summarised the expected outputs from the workshop as:
- Compilation of presentations on the WHO EMF Webpage
- A Rapporteur's report summarising the conclusions and recommendations
- Proceedings of key papers
- A peer-reviewed journal publication
- A fact or information sheet for the general public
- A brochure for local authorities with practical advice related to mobile phone base stations and wireless networks.

After this introduction, the workshop began with a tutorial by four eminent speakers, setting the scene from a technological and scientific point of view.

Mike Walker, Vodafone, UK, 'The mobile revolution'
This provided the interesting statistic that more than 1.4 billion people, or 20% of the global population, have a mobile phone, and 2 billion people in the world have yet to make a phone call. When that call takes place it will most likely be on a mobile phone not a fixed line.

The history of the mobile phone was covered from the 1970's when Bell Labs developed the Advanced Mobile Phone Standard (AMPS) that initiated the Cellular revolution. Then to the 1980's when the Nordic Mobile Telephone standard was deployed in the Scandinavian countries to today's model which includes video games and playback, email access, internet browsing, video telephony, high speed data access and music downloads. These together with infrared, Bluetooth, memory cards and USB interconnecting devices. To the future with further near-field communications, such as WLAN, UWB and wireless USB.

For base stations the concern for design and deployment is with the "3 Cs": Coverage - Capacity - Capability and in particular how far - how fast.

Kevin Hughes, ITU, Switzerland 'International Standardization of wireless technologies and EMF'.

This talk set out the activities of the ITU (International Telecommunication Union) and in particular the activities of the ITU-R, which has responsibilities for radiocommunication standards and spectrum management. Wireless access systems with the vision of anywhere/anytime connection were described. The workshop heard about the chronology of the developments of 2G, 3G and to systems beyond IMT-2000 (4G), (high data rates) and WLAN connection to laptops through local area networks. Other areas for wireless connectivity were described including:

- PAN (personal)– LAN – MAN – WAN
- Short-range devices - with personal devices
- WiFi – now commonly deployed, e.g. private houses, hot-spots
- Wider area networks – broadband within a metropolitan area
- Even wider possibilities through cellular networks – looking to 3G & further.

With regard to health effects from EM radiation, the ITU has no direct role to play. Being conscious of the basic restrictions and reference levels promulgated by regulatory agencies and standards bodies, ITU *Recommendations* make reference to them where appropriate. This is the case with respect to *Recommendations* addressing the measurement and calculation of EM fields. The talk described three such *Recommendations* which help the user assess whether precautionary measures are required to protect the public and occupational personal from hazardous fields, based on the EMF reference levels for the particular case of interest.

Niels Kuster, Swiss Federal Institute of Technology, Switzerland, 'Assessment of human exposure by electromagnetic radiation from wireless devices in home and office environments'.

This talk set out the background to and results of exposure assessments, related to the growing use of wireless connectivity technologies. These include DECT (digital enhanced cordless telecommunication) Bluetooth, Wireless LANs (IEEE 802.11) and a variety wireless PC peripherals (wireless mice, 27and 40 MHz, wireless keyboard, 27 MHz) and baby surveillance devices (40, 446 and 863 MHz). Exposure assessment (SAR determination) and the development of a compliance procedure were described. For the devices tested it was found that:

- Worst-case peak spatial SAR values were close to public exposure limits e.g., IEEE802.11b and Bluetooth class I devices
- Maximum incident field exposures at 1 m can significantly exceed those of base stations (typically 0.1 - 1 V m^{-1}) and at very close distances the derived reference levels are exceeded

The recommended procedure for evaluation of exposure and demonstration of compliance is dosimetric evaluation under worst-case conditions.

Peter Valberg, Gradient Corporation, USA, 'Modulated RF energy'

Transmission of information by mobile telephony is via modulation of the central or carrier wave. As the technology has advanced it has been necessary to change the modulation and it has been speculated that this could have an adverse effect on biological systems. An interaction mechanism capable of detecting the difference between a modulated and a non-modulated signal must be either fast enough to respond to the carrier frequency or sensitive to the power changes occurring at the modulation frequency.

The applicability of the principle of physics in all systems was elegantly explained and it was emphasised that the simple conservation laws (energy, motion, charge) were applicable and that biology was no exception. A discussion of 'photon energy' showed the unlikelihood of significant changes occurring. However, reports still appear showing biological effects apparently occurring at very low levels (and often related to modulation effects). A 'repeatable, explicit, and predictive mechanism capable of producing biologically significant responses (modulation dependent or not) from low-level RF fields has not been found'. This provides the encouragement to continue to examine experimental protocols and underlying biophysics, and seek evidence of replication.

The afternoon session on the first day began with three presentations concerning health effects, summarizing the state of knowledge on non-thermal effects from RF fields, and overviews of provocation and epidemiological studies.

Bernard Veyret, University of Bordeaux, France, 'A review of non-thermal health effects from RF fields'

This presentation reviewed the literature in relation to base station exposure. The sources considered were far-field low-level sources that contribute to whole body exposure of people in contrast to the local (head) exposure from mobile phones. The exposure categories can be thought of as high (1 W kg^{-1}), medium (0.1) and low associated with (0.01) with most studies in the 0.1-1 range. However, exposure associated with base stations is more likely to be 0.0001 W kg^{-1}. Various mechanisms (established and proposed) were discussed, including thermal/non-thermal, threshold/stochastic and single/multiple window. Problems associated with much of the earlier research have been eliminated with a more multi-discipline approach resulting in better and more characterized exposure systems. It was concluded that laboratory studies at very low levels (related to base station exposure) were:

- Difficult to perform
- Difficult to extrapolate to humans
- Not necessary

Elaine Fox, University of Essex, UK 'Base stations and electromagnetic hypersensitivity symptoms: A review of scientific studies'

This presentation addressed the issue of "EHS" in the context of health reviews, the precautionary approach and residual public concern. A recent review of all published double-blind studies concluded that there was no link between EHS symptoms and EMF exposure they also point out that we are not yet in a position to draw a firm conclusion.. It was emphasized that most of the previous research is very underpowered (usually only testing 15-20 participants) so larger scale double-blind studies are needed. There are currently at least 3 such studies being undertaken (a) a replication of the TNO study being conducted in Switzerland; (b) University of Essex study in which it is hoped to test 132 EHS and 132 matched controls with GSM, UMTS and sham exposures; and (c) a study looking at GSM in Denmark. Discussion emphasized that there was a need to show compassion to sufferers but to accept that the cause of the problem lay elsewhere. There was also some discussion with regard to the recent WHO workshop on EHS (Prague, October 2004).

Anders Ahlbom, Karolinska Institute, Sweden, 'Studies on base stations and other telecommunication towers'

In this presentation it was emphasized that most studies published to date were based on proximity to transmitters but the exposure patterns were complex and not necessarily related to distance. None of the studies provided evidence that RF exposure from the transmitters increased the risk of cancer or any other health effect. The ensuing discussion centred on the possibility of conducting an ideal study. Key requirements included:

- Personal exposure assessment
- Well-defined study group
- Mechanism to define cases
- Being large enough to have acceptable statistical power

The second set of presentations in the afternoon was concerned with dosimetry for both the general public and occupational workers.

Georg Neubauer, Austrian Research Centers Gmbh – ARC 'Study on the feasibility of future epidemiological studies on health effects of mobile telephone base stations: Dosimetric criteria for an epidemiological base station study'

Here, a recently completed feasibility study that had two elements was discussed; the first to identify strengths and weaknesses of existing epidemiological studies and the second to evaluate existing exposure assessment methodologies and to assess their suitability for epidemiological studies. It was concluded that the important steps were to gain knowledge on the exposure of people from all sources of RF in the environment with a second aim to identify characteristics that would allow a valid prediction of individual exposure levels. A variety of exposure metrics would need to be considered including cumulative, time-weighted and exposure above a predetermined threshold.

Joe Wiart, France Telecom, France, 'Personal RF exposure assessment' and
Simon Mann, Health Protection Agency, UK, 'Laboratory and volunteer trials of an RF personal dosimeter'

The need for a good personal RF dosimeter or PEM (personal exposure meter) has been discussed in many fora. These two papers discussed the development of the PEM, ongoing modifications and a trial involving 10 volunteers. The requirements for a good PEM include:

- Being small, light and wearable
- Capable of measuring exposure over the entire spectrum
- Good precision as environmental levels will be very close if not lower than the detection limit.

Although the instrument had many positive attributes, discussion centred on the need for further development, for example battery life, (all data are lost when the battery flattens) and cumulative exposure of multiple sources with similar and different frequencies. Another problem was the frequency channels; for example, although FM\TV\GSM\UMTS were covered, there were no channels for TETRA\DECT\WIFI.

Elisabeth Cardis, IARC, France, 'Evaluation of general population radiofrequency exposure in a pilot study in France'
This presentation, which was unscheduled, looked at characterising the RF exposure levels of the general population with an aim of identifying factors which can assist in the prediction of personal exposure. The study will use 10 PEMs in 2 regions of France (Besaçon and Lyon) with a focus on children older than 12 years. The outcome will assist in planning for better targeted exposure studies.

Kjell Hansson Mild, National Institute for Working Life, Sweden, 'Occupational RF exposure from base station antennas on roof-tops and buildings'
This talk addressed the problem of accessibility to RF sources by people who could never be classed as 'occupationally exposed' in the sense of being a radiofrequency radiation worker. It is also important to note that different countries have different rules on who is occupationally exposed. A typical example is the exposure of painters and maintenance personnel to roof-top RF sources which could exceed the general public limits. It was concluded that in order to protect the health and safety of workers clear identification of the control person and procedures as well as audited measurements and appropriate signage were required.

The first day was brought to a close with an open discussion moderated by Roger Matthes. The discussion addressed many of the points that had been raised in the earlier presentations. These included:

- The need for controlled areas for rooftop antennas,
- How useful the PEM would be when, generally, it is not in the detection range and given that the appropriate exposure metric is not known, and
- Considerable discussion about EHS including some of the outcomes of the WHO Prague workshop.

The second day of the workshop began with several presentations outlining current policy options in several countries, both at the national and local levels.

Olivier Borraz (CNRS, France) and Danielle Salomon (Risques and Intelligence, France), 'Regulating the risks of mobile phone base stations: a comparative study in 5 countries'
This addressed the problem of regulating uncertain risks in the scientific context ('known unknowns' and 'unknown unknowns') and social (including economic and political) context. A comparative study of mobile phone base station deployment was conducted in 5 European countries- France, UK, Belgium, Switzerland and Spain. The countries have not taken similar decisions in regard RF exposure and their regulatory measures have not eliminated controversy. It was found that:

- The countries did not share a similar assessment of base station risks
- In most countries an intermediate level of government exerted pressure on the central government
- Mobile phone operators exerted pressure on the central government.

These elements explained the differences in regulatory measures but two other issues had an effect (inflaming or calming) – local charters to apply stricter rules and the ability to take matters to court. In the end it is action and interaction between five stakeholders that hold the key, namely central government, scientific experts, operators, local authorities and the courts.

In countries where controversy is greatest there is also the greatest instability and inconsistency between the five agents.

Four short presentations that address policy options based on the concept of precaution were outlined, showing the diversity of measures that are being taken around the world.

Yury Grigoriev, Russian National Committee on Non-Ionizing Radiation protection, Russia, 'Mobile phone base stations and safety of the population: general situation in Russia'.

Jürg Baumann, Swiss Agency for the Environment, Forests and Landscape, Switzerland, 'The Swiss regulation and its application'.

David Black, University of Auckland, New Zealand, 'Current government responses in New Zealand and Australia'.

Paolo Vecchia, National Institute of Health, Italy, 'Current national government responses – Italy'.

These four presentations compared and contrasted the approach taken by 5 governments. As could be expected there were differences in exposure guidelines, regulation, compliance audit and the adoption of a precautionary approach.

Of particular interest was the Italian approach where arbitrary low exposure limits were adopted and in Australia where the RF standard spelt out the following precautionary approach "Minimising, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided this can be readily achieved at reasonable expense. Any such precautionary measures should follow good engineering practice and relevant codes of practice. The incorporation of arbitrary additional safety factors beyond the exposure limits of this Standard is not supported." With regard to base stations the two approaches gave very similar results but the Australian approach avoids the need for a 'numbers' debate. Switzerland on the other hand considered it necessary to frame the precautionary limitation of emissions in an unambiguous way in order to provide legal security for operators and the planning authorities and to avoid the need for an evaluation of possible precautionary measures in every single case. Therefore so called installation limit values were defined on the basis of best available technology. These technically based limit values have to be respected by all base stations.

Paolo Vecchia, National Institute of Health, Italy, 'Local decision making for the installation of mobile telephony base station: possible options'.

Here the options available to local authorities were discussed and they can include:

- Ordinance on a minimum distance from identified sites
- Ordinance on maximum exposure levels
- Agreement between the involved parties

Also discussed were, specific examples including Salzburg (the milliwatt limit), Paris (charter between municipality and operators) and Italy where a charter between the municipality, university, operators and concerned public was developed. It was concluded that none of the approaches have completely achieved their goal but they do provide input into future approaches.

The following four presentations provided an account of stakeholders approach to the base station issue, including European Commission sponsored activities (EMF-NET and COST

281), a mobile phone operator association (GSMA) and a grass-root movement association (Plattform Mobilfunk-Initiativen).

Paolo Ravazzani, Istituto di Ingegneria Biomedica CNR, Italy, 'The EC coordination Action EMF-NET and the radio base stations and health issue'.
This described the primary aim of EMF-NET as being the provision of good scientific information to appropriate authorities to enable make to take appropriate actions and decisions. To achieve this, the plan is to review current research, investigate the right approach to risk perception and communication and to monitor emerging technologies.

Norbert Leitgeb, COST Action 281, Austria, 'Epidemiologic studies on mobile phone base station exposures'.
COST acknowledged the public call for studies on base station exposures and the COST Action 281 was to make a judgement on the issue. It was emphasised that epidemiological studies are useful for hypothesis testing but they cannot prove a causal relationship where other evidence is lacking (established interaction mechanism, animal and cellular studies). The following points were made:

- Contribution of base stations to a person's RF exposure is minimal
- No rationale for studying this agent
- Extremely difficult exposure situation (including a changing technology)
- To be successful the biological endpoints would need to have very short latency times

It was not expected that such studies, because of the difficulties, could contribute to the reduction of public concern.

Jack Rowley, GSM Association, Ireland, 'Wireless networks – regulatory good practice'
Here the following points were made:

- Standards should be developed internationally and adopted nationally
- Local governments should not be imposing their own standards
- Imposed requirements for measurements are of limited value
- Consultation mechanisms at the local level should be consistent with other types of infrastructure
- Appeal processes should be transparent.

In conclusion it was emphasised that there is a need for an independent national authority, a separation between the health and planning agencies, an approach to dealing with the issue of low scientific uncertainty and the perception of greater uncertainty and the need for ongoing consultation between stakeholders.

Eva Maršálek, Plattform Mobilfunk-Initiativen, Austria, 'Necessities for public acceptance of mobile phone and wireless-infrastructure'.
The presenter indicated that it was necessary for the public to accept mobile phones and wireless infrastructure but identified many problems including:

- Lack of public involvement in the process
- Insurance problems
- Lack of protection against long-term exposure from the ICNIRP guidelines
- Community requirement for low exposure levels

She emphasised that low exposure levels are technically and financially possible and recommended the use of intelligent siting, evaluation software and the application of the precautionary principle.

The morning session ended with a panel discussion on policy options moderated by Agnette Peralta.

Agnette Peralta, Chair, Panel discussion on policy options
Short presentations were made by representatives of various agencies in Argentina (Jorge Skvarca), Israel (Stelian Ghelberg), USA (Edwin Mantiply), Japan (Naohisa Maeda), Korea (Jeong-Ki Pack) and Germany (Axel Böttger) . Some of the points made included:

- Need to adopt international guidelines (ICNIRP)
- Requirement for a good research programme
- Separation of health, regulatory and planning agencies a necessity
- Need for operators to site-share where possible
- Good public information required
- Consultation between all stakeholders needed from the outset

The topic of the afternoon session revolved around risk perception and risk communication regarding base stations and wireless networks with two presentations by well-known experts in the field.

Julie Barnett, University of Surrey, UK, 'Understanding public responses to precautionary action and advice'.
Here the speaker set out to answer the question 'what is the effect of precautionary action and advice upon public concerns?' It has been claimed that precautionary approaches may have an effect opposite to that anticipated. Her group studied the question through focus groups and a national survey and found:

- The precautionary approach may work in the opposite sense
- The precautionary approach may raise other concerns
- Some people were reassured
- Some people expressed cynicism with the government approach.

It was concluded that if the precautionary approach is to be widely used then a much greater understanding of its impact and interpretation by the public is required.

Ortwin Renn, University of Stuttgart, Germany, 'Strategies for communication on base stations'.
This presentation addressed the questions the requirements and implementation of effective risk communication, the role of trust and credibility and how to balance public concerns with mobile service requirements. The following points were made:

- Introducing precautionary measures may not have the desired effect
- Public is always happier with certainty usually problems with any uncertainty
- All messages to the public need to be simple, clear but factually correct
- Need to show the public how to protect themselves but recognise that this approach has limited value for base station
- Important to be aware that terms can have quite different meanings in different countries

- Stakeholder meetings are important and care should be taken in deciding who speaks, who can be trusted (will be different in different countries) and whether a facilitator is required

Michael Repacholi then opened a discussion on the key issues identified by participants during the workshop, summarized the outcomes of the meeting and drew it to a close. Some of the points made included:

- Unless precaution is used carefully a situation could be inflamed,
- Many participants were concerned about the issue of 'sensitive sites' and again the best of intentions may result in an undesirable outcome for stakeholders,
- WHO should provide some specific case studies on siting, and
- A WHO booklet for local authorities on wireless communication would play an important role if it was able to reflect the contributions to this workshop.

Michael Repacholi thanked all the participants for their presentations and discussions at the Workshop and indicated that it would prove to be an important contribution to the EMF Project. He also thanked his staff for excellent organization of the Workshop.

TUTORIALS

The Mobile Revolution

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Abstract

Mobile phones continue to develop with more user features being implemented as new technology is released commercially. The boundaries will blur between internet, broadcast and mobile telecommunications. Significantly more radio base stations will be needed as communications technology nears the physical limits in spectrum efficiency and to support increasing data-rates. The impact of transmitter power control, DTX, and capacity design on base station transmit power is discussed showing why GSM base stations transmit well below their maximum power even at their busiest time. Typical public exposures to radio frequency fields from base stations are several orders of magnitude below ICNIRP guidelines. It is shown how the 30 dB GSM terminal power control window in coverage areas with a 70 dB range in pathloss can explain the observed increased population of maximum and minimum power control settings.

Keywords: GSM, base station, technology development, RF exposure

Mobile communications – the last 20 years

Mobile technology has developed enormously from the 1970's analogue systems through to present day family of mobile technologies. In the 1970's a mobile telephone was a large unit installed in an expensive car. The systems could only support a few thousand subscribers and if the car was not a Rolls Royce or top of the range Mercedes, you probably couldn't afford the phone. In the late 1970's Bell labs developed the Advanced Mobile Phone standard (AMPS) operating at previously unimaginably high frequencies of over 800MHz and the Nordic Mobile Telephone standard was deployed in Scandinavia using frequencies around 450MHz. These early cellular systems began the revolution which has led to today's mass market in mobile phones.

Let us briefly review the steps from those early days to where we stand in 2005. Vodafone opened service in the UK on 1st January 1985 using the "TACS" standard – a derivative of the US AMPS system. The first two phones were a mobile for car-installation with an output power of over 5W and the first "portable" phone, the Nokia Talkman (Figure 1) which weighed in at 4.8kg and cost around £3000. Within a couple of years the first truly portable phones appeared, but they still weighed 700-800g, cost £3000 and radiated several hundred milliwatts. By 1990 over a million people in UK had a mobile phone.

Figure 1: *1986 Terminal*

When the first GSM digital phones were introduced in 1992 they were slightly larger and more power hungry than their analogue counterparts, but the rapid development of digital electronics soon led to the first mobile phone weighing under 200g in 1995. Prices were falling fast too, so at last we had a phone which did not damage your pocket in either sense of the expression. Again the average transmitted power was reduced compared to the previous generation, with a nominal output of 250mW, though the peak power was greater at 2W due to the 1/8 duty cycle of transmission of the digital system.

By the end of the nineties the phone had become more than just a voice device, with phones incorporating sophisticated personal organiser functionality, the popularity of text messaging and the introduction of colour displays and WAP access to information services. The new millennium brought phones weighing well under 100g and phones with Mp3 music players, polyphonic ring tones, Bluetooth headsets and even a built-in FM radio.

2002 brought the first camera phone, followed closely the following year by a phone able to record video. In 2004 Vodafone launched 3G networks in 13 countries with both phones and data cards. Again the new technology reduced the transmitted power, with most terminals in 3G mode radiating under half the power of a GSM terminal. In 2004, on some commercial tariffs, terminals were free to the user, (Figure 2). As well as reducing the maximum power of terminals over the last 20 years, the systems for dynamically adjusting the transmitted power have become more sophisticated. In early systems the transmitted power might be adjusted every few seconds. Today's WCDMA systems fundamentally rely for their successful operation on adjusting the transmitted power 1500 times per second to keep it at the absolute minimum for communication.

Figure 2: *2004 Terminal*

In 2005 we have two-way video calling, internet browsing, music and video downloads, location-based services and ability to link a laptop computer to a corporate LAN from half-way round the world.

At the end of 2004, more than 1.7 billion people, or 20% of the global population, had a mobile phone and 1.3 billion (over 75%) are GSM customers [1]. Yet 2 billion people in the world have yet to make a phone call – when it happens it will be on a mobile phone not on a fixed line.

Mobile communications – where to from here?

The mobile phone has already become an essential part of every day life for a large proportion of the world's population, but how can we expect it to develop over the next few years? Technically, we can expect continued development of displays towards VGA (640 x 480) resolution, capable of DVD quality. This will be about as much as the eye can resolve at a typical viewing distance, but display size limits the user experience. Innovations such as organic LEDs, 3D displays, head-up displays and micro-projectors will be the next step.

We can expect the phone of the future to incorporate new wireless local connectivity to enable high speed communication with other nearby devices. This may extend today's Bluetooth links to include wireless local area networks or personal area networking based on ultra-wide-band or other physical layers. Near-Field Communication (NFC) (technologies deliberately constrained to operate over only a few centimetres at most) will open up new and simpler ways of establishing secure links with other equipment. Setting up a Bluetooth link today requires a time consuming entry and exchange of passwords. NFC will allow a user to touch two devices together and then perhaps just press one key on each to acknowledge their connection. It may also allow users to pick up information based on posters and signposts. For example, a poster advertising a concert may have “touch here to buy tickets” printed in one corner. A phone user could touch the poster with a phone and instantly be connected to a web site where tickets could be selected and purchased. The phone is likely to incorporate the sort of storage capacity which would have been large for a PC hard disk only a few years ago. Solid state memory cards of 1GB are already readily available and miniature disk drives of several GB are being incorporated in the latest terminals.

There will be a diversification of products building upon internet and/or broadcast technology. An example is Mobile TV; available anywhere with interactivity allowing the user to vote, purchase and download. Mobile technology is increasingly used in medical and emergency support applications enabling immediate expert advice at the scene of an accident and long-term remote health-monitoring while people live their lives normally. Examples already in trial include monitoring of diabetes patients in Oxford, people with heart and lung problems in Spain, and AIDS patients in South Africa. The technology can also provide personal security for the vulnerable, controlled freedom for the young and rapid access to emergency services.

The need for base stations

Naturally, support of the vast growth in mobile phone use over the last 20 years has required the deployment of an increasing number of base stations, but what determines how many base stations are required, and how will the need for base stations develop in the future?

Base stations are deployed for two reasons – coverage and capacity. Without coverage, terminals will not have any service. If there is insufficient capacity, then at busy times due to congestion, users may need to make several call attempts before being able to make a call or their incoming calls may not be delivered. Initially it is coverage that drives site planning. If radio spectrum were an unlimited resource which was freely available, there would never be a need to add sites for capacity. However, spectrum is limited, and high densities of users have driven demand to a point where the network deployed for coverage has insufficient capacity. However, these two factors are intimately related to each other. Increasing demand for mobile services has developed together with increasing expectations of their capabilities. Early networks served high-power mobile terminals installed in cars, requiring a moderate number of cell sites to achieve coverage. As user demand increased to the point that these cells were overloaded, handheld terminals also increased the number of cell sites needed for coverage. As these cells became overloaded, expectations of indoor coverage increased, again balancing the need for new base stations for coverage and capacity.

What are the factors determining how many sites are needed to support a given service? The most significant factor is the nature of the coverage required – i.e. where is the terminal located? Table 1 illustrates this by comparing the number of sites needed to support different kinds of service. In the first case we consider a fixed wireless access system (i.e. not mobile at all) using a rooftop antenna. Such a system has a substantial cost of fixed installation, but benefits from the use of a high gain antenna at a height clear of most surrounding buildings. Taking this as a reference, let us compare it with some different options. If we wish to offer a fixed service but want to allow the subscriber to go to his local computer store and buy a terminal, we may consider the case where a small box with a slightly directional antenna is positioned in a first floor window. Even this small drop of antenna from the rooftop will increase the number of sites by a factor of 12. If we wish to provide service to a small handheld terminal, PDA or laptop PC at ground level but outdoors, then we need to increase the site density by a factor of 60 from the original rooftop case. If the user wants to move indoors in suburban areas we would need 230 times the number of base stations, and if we want to provide good indoor coverage in large commercial buildings in urban areas then we would need 800 times the sites compared to the rooftop fixed service.

The second factor affecting site numbers is data rate. For a given radio path, a fixed amount of energy is required to deliver each data bit, so the power required is directly proportional to the data rate. Conversely, for a fixed transmitter power, the range achievable decreases with data rate. Figure 3 illustrates this effect, again using a hypothetical system based on a conventional cell site design and an outdoor terminal using a PC card modem.

	Gain	Height	Building loss	Range	Relative site count
Rooftop non-line-of-sight	**10 dBi**	**8 m**	**0 dB**	**6.2 km**	**1**
Terminal / Gateway in upstairs window	**3 dBi**	**5 m**	**0 dB**	**1.8 km**	**12**
Outdoor PCcard	**0 dBi**	**1.5 m**	**0 dB**	**780 m**	**60**
Indoor PCcard - Suburban	**0 dBi**	**1.5 m**	**10 dB**	**410 m**	**230**
Indoor PCcard - Urban	**0 dBi**	**1.5 m**	**20 dB**	**210 m**	**800**

Source: COST231-Hata model for a hypothetical 1Mb/s system at 2GHz [2]

Table 1: *Effect of terminal location on site numbers*

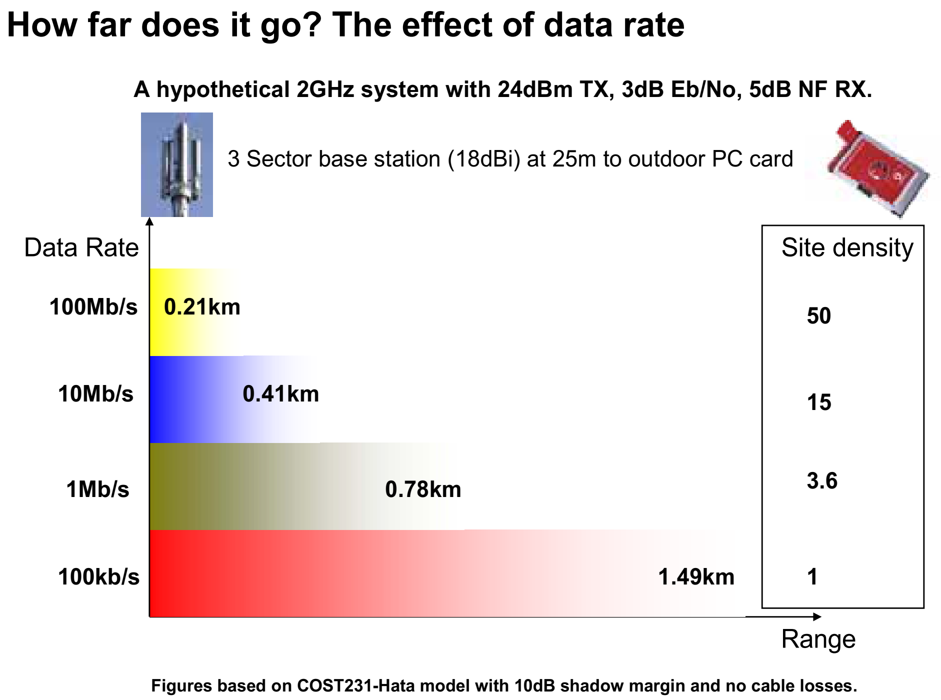

Figure 3: *The effect of data rate on range*

Finally, the fourth factor affecting the number of base stations is the transmit power allowed at base station and terminal. Higher power would provide greater coverage, but the design of terminals to have long battery life; low operating temperature and the requirements to limit user exposure to RF are key limiting factors challenging terminal design.

Exposure guidelines and measurement standards

International guidelines recommend limits to the human exposure to RF fields based on a large body of biological science and are designed to avoid health effects for all people. For the frequencies used in public telecommunications, these guidelines define the maximum Specific Absorption Rate (SAR), the measure of the rate of energy deposition in a material. Since SAR is not directly measurable, the guidelines also include limits in the form of RF field parameters that if met assure the compliance with the SAR limits.

The most internationally applied guidance is provided by the International Commission for Non-Ionizing Radiation Protection [3]. Another set of guidelines is provided by the IEEE [4] and these are used in the USA and in some other national territories. While there are a number of National guidelines [5], they are often based on ICNIRP and for the rest of this paper only ICNIRP levels are considered for simplicity.

ICNIRP recommends that the general public exposure should be limited to 2 W/kg in any 10g for the head and body, 4 W/kg in any 10g for limbs and in addition 0.08 W/kg for the whole body and all of these subject to an averaging period of 6 minutes.

Test standards have been developed for terminals used against the ear [6,7,8]. For evaluating exposure against the body, the IEC is developing a standard. In the European Union, work is well advanced in defining base station standards [9] and IEC/ITU are developing global base station standards.

Before being put on the market, a new terminal design is tested to confirm that when used according to the manufacturers' operating instructions; the user will not be exposed to RF fields above the relevant guidelines for the country of sale.

Each base station is evaluated and measures defined so as to ensure that people cannot be over exposed.

Factors affecting base station transmitted power

GSM base stations are designed on a case by case basis to provide the coverage and capacity required. For in-building systems, each pico-cell transmitter may operate at a maximum transmit power of 100 mW or even less - sometimes providing service through a number of distributed low-gain antennas each fed with few mW. For large macro-cells, providing wide area coverage, each transmitter may operate at up to 10W to high gain antennas with narrow vertical beamwidth and wide or omni-directional horizontal beamwidth. It should be noted that the base station transmits on one frequency and receives on another with terminals operating on the reverse frequencies.

Each network's GSM base station site may support one or more cells depending if the coverage for each cell is provided from its centre (omni-directional) or from its edge (sectored). In the case of a sectored site, in any given location one of the sectors will be dominant over the others and will provide the coverage. As you move around the site, which sector is dominant will change.

One transmitter per cell transmits continuously at its maximum power. This supports the Broadcast Control Channel (BCCH) which informs the terminals which frequency they may access the network and defines terminals' maximum transmit power when such access is made. The GSM standard uses time division which means that information is transmitted in bursts or timeslots. One timeslot supports one full-rate or two half-rate voice calls. Each transmitter supports 8 timeslots and can therefore support up to 8 simultaneous full-rate calls. The transmitter supporting the BCCH has capacity to support up to 6 full-rate voice calls.

The base station commands the terminal to transmit the optimum RF power to give an adequate received signal at the base station. Indoor and micro base stations enable lower terminal powers in areas of high use. Base stations commonly also use downlink power control to limit their transmit power in order to minimise interference to terminals operating on nearby cells on the same or adjacent frequencies. In order to guarantee a good quality of service, operators ensure that base stations are designed to operate well within their maximum theoretical capacity. For GSM, this means that although the base station may have capability to transmit on a number of frequencies each with 6-8 timeslots, in practice, not all of these frequencies/timeslots will be active at the same time. The number of transmitters installed depends on the capacity required to limit congestion to an acceptable figure e.g. to ensure that less than 2% of calls fail due to not having an available radio resource.

The GSM standard also supports some other features that reduce the transmit power of both the terminal and the base station. One is discontinuous transmission (DTX) which means that when two people are in conversation, only the timeslots supporting the person actually speaking are transmitted. Another feature is half-rate, where the network instructs the terminal to transmit on only one in 16 timeslots – effectively halving the average transmitter power. This reduces speech quality and so is not universally used. However, if a cell starts to become congested, the operator may configure the network to provide a slightly reduced voice quality to ensure that there is enough capacity to support the call.

The instantaneous total transmitted power from the base station is therefore defined by the number of timeslots transmitting and their transmit power. Network capacity design, power control, discontinuous transmission and the occasional use of half-rate ensures that even at the busiest time of day not all timeslots are used and those timeslots that are in use are not all transmitting at maximum power.

Figure 5 shows how, for a given number of installed transmitters, the equivalent number of active transmitters will be reduced in practice through over dimensioning to limit congestion to less than 2% and implementing power control and DTX. The transmitted power is derived by multiplying the equivalent number of active transmitters by the individual transmitter maximum power. Reference [2] suggests that power control reduces the power of timeslots supporting voice to between 50% and 70% of the maximum power. If people are in conversation, it is reasonable to suggest that DTX introduces a further similar reduction factor when people talk for only 50% to 70% of the time. Figure 5 suggests that for a base station with 6 installed 10 watt transmitters operating at full design capacity of 2% blocking the output power will be between 20 and 30 watts or only 33% to 50% of the theoretical maximum output power.

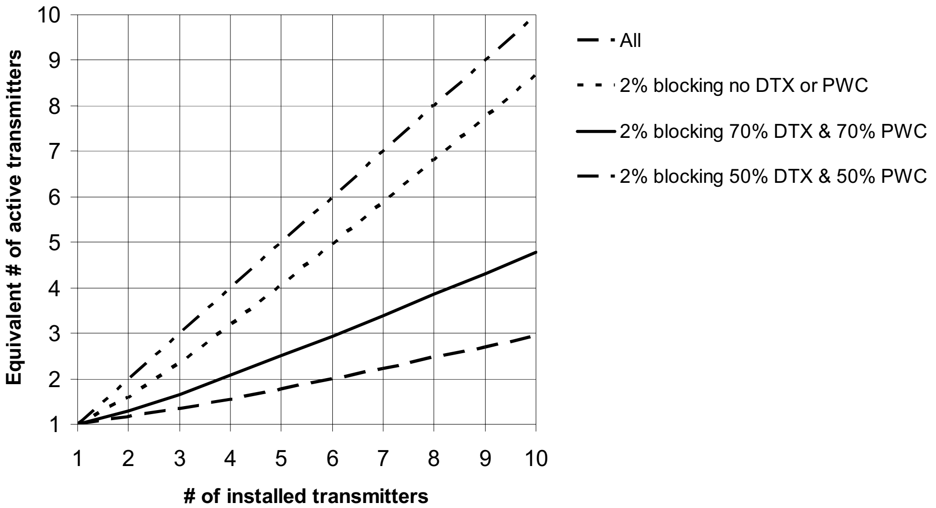

Figure 5: *Equivalent No. of active transmitters against No. of installed transmitters for 2% blocking and DTX / PWC*

Figure 6 shows the results from monitoring traffic over a 24 hour period on a typical 6 transmitter base station in the UK. At all times of the day, the maximum % of active transmitters is below that which would result in 2% blocking. Applying the Figure 5 criteria for power reduction due to discontinuous transmission and power control, the peak output power will be between 30% and 44% of the theoretical maximum power for the base station. In the evening and over the night, this falls to under 20%

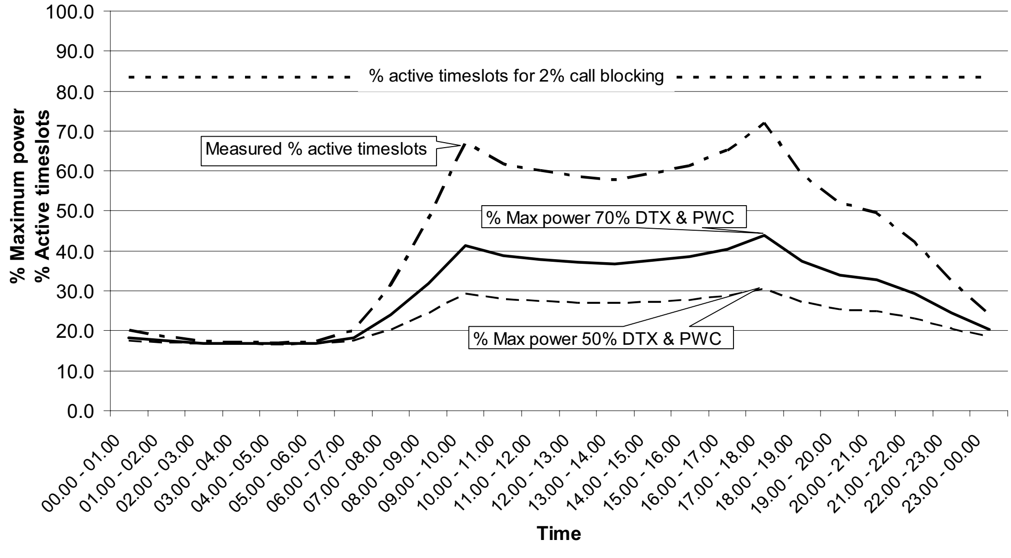

Figure 6: *% of Maximum Power Output v Time for a 6 transmitter base station*

In order to translate the above information to field levels from the base station, it is necessary to consider the antenna parameters and the propagation path between the antenna and the measurement point. From large cellular antennas (1 to 2m length), the power flux falls initially approximately in proportion with distance for the first ~5-8m and then falls in proportion to the distance squared and then the power flux will be increasingly dependent on the physical environment due to reflections and obstructions [9].

Over the period 2001 to 2004, the UK Radiocommunications Agency (now part of OFCOM) conducted radio surveys [10] at 289 schools with base stations on or near them. At each school, measurements were made at several locations around the school looking at the GSM 900 and GSM 1800 frequency bands. The field values were then compared to the ICNIRP [3] guidelines for limiting the exposure of the general public to radiofrequency fields and a compliance factor derived.

Figure 7 shows that the spread of the highest compliance factors from each school. A compliance factor of 1 would imply that the measured field just complied with the ICNIRP guidelines. In fact, the highest compliance factor measured anywhere was 3.5 x 10-3, with the 90% of the schools having a highest compliance factor below 2.9 x 10-4 – very low values indeed.

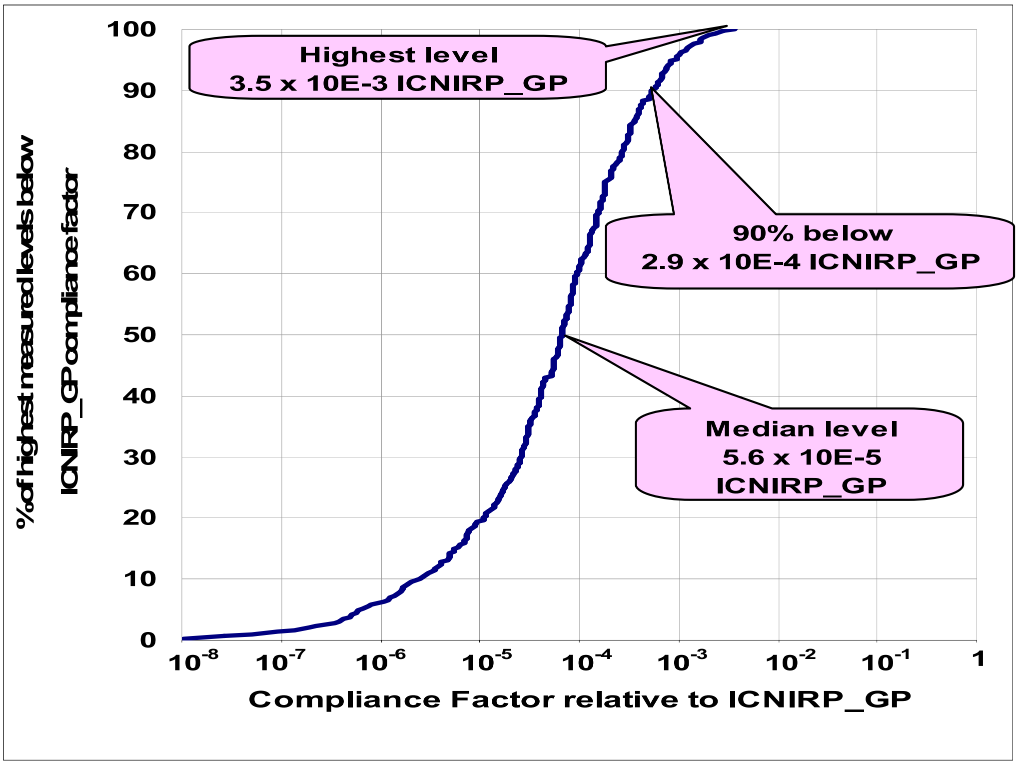

Figure 7: *Typical field levels in public areas near base stations; UK RA cellular RF survey 2001 to 2004 related to ICNIRP General Public guidelines*

Base stations control terminal transmit power

In GSM, the base station monitors the received signal strength from the terminals in its coverage and provides instructions to the terminal on which power level it should transmit. During handover between base stations, the terminal communicates at the maximum power control level permitted by the target base station, often at full terminal power. Where there is a high density of small cells or for indoor installations it is quite likely that the terminal power will be limited to be below maximum even for handover.

Studies examining the relative probabilities of a GSM terminal being on each of its power control levels observe that the terminals are often set to maximum power [11]. It has been postulated that this is due to the effect of handovers which are often initiated at maximum power. However, the GSM standard shows that after the terminal is given an instruction to go to a power level, the power will start to reduce in less than 1/10 second and normally be completed in less than 2 seconds [12]. It is not clear how this would completely explain the observed time at maximum power. However repeated handovers may have a minimal effect in some areas where the network is not best optimised.

An alternative explanation is presented in Figure 8. As a terminal is moved further away from the base station antenna, the fraction of its transmit power received by the base station falls quickly. Within the coverage area of the base station, terminals will often be used in locations that are not visible from the base station antenna such as indoors or on the other side of buildings to the base station. Between nearest public approach to the base station and limit of its coverage, communication loss varies by about 70dB (a factor of ten million times) [13].

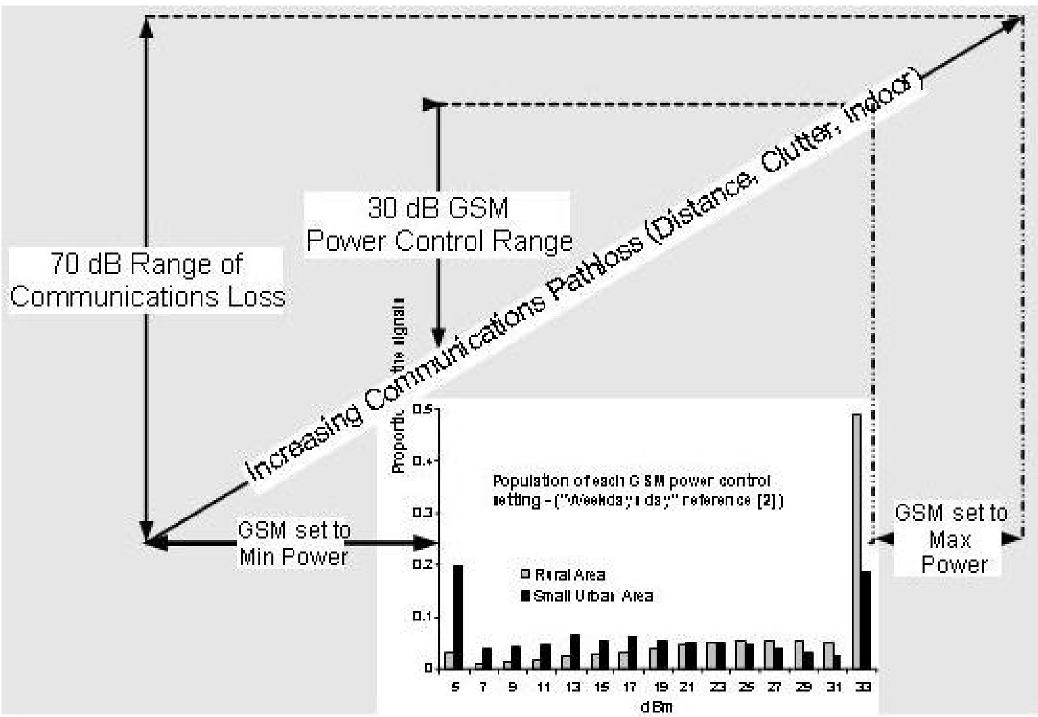

Figure 8: *Communications pathloss and population of GSM 900 terminal power level settings*

The GSM terminal power control range is of the order of 30 dB [14], a factor of one thousand times. Therefore, when the terminal is in areas outside its control range it will naturally be set to either its maximum or its minimum power level.

In Figure 8, the data from [11] shows that for the sample of rural cells, there is a large population spike for full power +33dBm and no population spike for minimum power +5dBm. This suggests that the majority of calls making up the data set were in locations where the communications loss was higher than the optimum control range of the GSM terminal. In the case of the small urban areas, population spikes are observed at both the maximum and minimum power control levels. This suggests that the calls making up the data set fell across the optimum control range and included about the same number of calls very close to the base station (low communications loss – minimum power control level) as locations towards the edge of coverage (high communications loss – maximum power control level). In the case of the rural data, the average terminal power adjusted by power control was about 0.6 of the maximum and the corresponding figure for small urban area 0.25 of the maximum.

3G technology offers improved optimisation of the transmit power of both terminal and base station. According to the specific communication demands, transmitter powers are dynamically adjusted 1500 times a second [15] to address both the specific coverage and data-rate needed for the call at that time. The 3G terminal power control range is at least 70 dB [13] matching the communications pathloss range thereby optimising spectrum use. For a 3G system the instantaneous transmitter power will also depend on the data rate.

Discussion

Mobile technology has come a long way over the last 20 years from analogue through second generation digital to the introduction of third generation technology in 2004. Size, cost and user experience has continually improved to the point that as of the end of 2004 more than 1.7 billion people or 20% of the global population have a mobile phone.

Display technology has advanced to the point where the physical size is the main limitation. 3D displays, head-up displays and micro-projectors will provide the next step. Near-field communications and other wireless technologies will enable users to link to nearby equipment, high-speed data networks and may even enable users to make purchases at the point of advertisement. In future, terminals will include data storage of several GB. There will be a diversification of products based on internet, broadcast or point to point communications including mobile TV with interactivity.

Base stations are needed to provide coverage and capacity. As we make the terminals smaller, with lower transmit power, operating on higher frequencies band with higher data rate – the number of base stations will need to increase significantly perhaps by 2 to 3 orders of magnitude. The size of many of such base stations will be more like the present WI-FI boxes rather than the current large-area coverage sites.

Transmitter power control, capacity dimensioning, discontinuous transmission and use of half-rate all mean that GSM base stations transmit well under their theoretical maximum power capability even for the part of the day when usage is highest. At a given time, the transmit power from a base station largely depends on the traffic it is carrying. New technologies use spectrum more efficiently but are getting closer to the physically achievable limits. The public's RF exposure from base stations is extremely low and much less than experienced by a terminal user. Typical values are hundreds to hundreds of thousands of times lower than the ICNIRP guideline limits.

GSM terminal transmit power is monitored and adjusted via commands sent from the base station. The GSM terminal power control range is 30dB (70dB for 3G). Between nearest public approach to the base station and limit of its coverage, communication loss varies by about 70dB. A consequence of this 30dB control window is a higher probability of the GSM terminal operating at either its maximum or its minimum power control levels rather than at any of the other individual intermediate power control levels.

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Assessment of Human Exposure to Electromagnetic Radiation from Wireless Devices in Home and Office Environments

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Abstract

Short-range wireless RF devices are rapidly pervading home and office environments. Nevertheless, their contribution to the electromagnetic field exposure of humans has not yet been systematically assessed nor have procedures for testing compliance been developed. In this study we have assessed the range of exposure in terms of the dosimetric and incident field quantities for devices of the most common technologies, i.e., DECT, WLAN and Bluetooth, as well as wireless communication devices based on proprietary standards in the frequency range of 30 MHz to 6 GHz. Since operation in the near-field of these devices cannot be excluded, dosimetric evaluation is the most straightforward technique for testing compliance when low-power exclusions are not applicable. The suitability of the suggested methods is demonstrated through the examination of five classes of short-range transmitters.

Keywords: radio frequency, dosimetry, exposure assessment setups

Introduction

Short-range wireless radio frequency (RF) devices are pervasively being used in home and office environments, although their contribution to the electromagnetic field exposure of humans has not yet been systematically assessed. Here we report exposure measurements from several classes of wireless RF devices under worst-case and normal operating conditions.

Current standards are focused on exposures occurring in the closest near-field of transmitters, i.e., <200 mm between the body and transmitter, or in the very far-field, i.e., at distances of several wavelengths. Thus, none of the currently developed standards and exposure assessment techniques are directly applicable to short-range transmitters operating within buildings. The standards for testing the compliance of mobile phones operated at the ear are issued and consistently applied, e.g., [FCC 01-012001, ARIB STD-T56 Ver.22002, IEC62209 Part 12005, IEEE P1528 D1.22003, CENELEC EN503612001]. The standard for the compliance testing of body-worn and hand-held devices is close to completion [IEC62209 Part 22004]. Standards for testing the compliance of fixed transmitters are also available, e.g., [IEC619832000,CENELEC EN503922004]. We assessed general mobile transmitters with current experimental exposure assessment methods and evaluated these methods regarding applicability for the exposure assessment of wireless devices in home and office environments. The methods for testing the compliance of the considered device classes are presented in [Kühn et al. 2005].

Objective

The aim of this study was to provide classifications for RF exposures from wireless devices other than mobile phones used in home and office environments. The results were evaluated with respect to current safety guidelines and other sources of RF exposure, such as mobile phones and cellular telephony base stations. The results were also evaluated with respect to the applicability of the different assessment methods for compliance tests.

Methods

The evaluation of the devices under test (DUT) with respect to electromagnetic field (EMF) exposure was conducted according to the following steps:

1. A market survey to determine the most frequently used wireless communication technologies applied in home and office environments. Additional attention was placed on devices operated in sensitive environments, such as baby surveillance.
2. Determination of the exposure relevant parameters of the considered device classes (DUT output power, RF range, extreme low frequency (ELF) components). This was based on evaluation of the underlying standards or data sheets. Where this was not possible, an experimental determination based on a spectral analysis of the DUT RF and ELF components was conducted.
3. Selection of individual devices for experimental exposure assessment.
4. Determination of the worst-case operational modes with respect to the highest time averaged antenna input power. Design of appropriate measurement setups and extrapolation formulas in order to ascertain worst-case conditions during the EMF exposure assessment.
5. Evaluation of the incident E-fields from the DUT in free-space.
6. Dosimetric evaluation of the DUT attached to a body-emulating phantom.

The methods and worst-case operational modes applied in evaluation steps 4-6 are described in [Kühn et al. 2005].

Results

In home and office environments wireless technologies are applied in manifold cases. Standardized technologies are applied for wireless networking, wireless telephony and peripheral device interconnections. Digital Enhanced Cordless Telecommunications (DECT) [ETSI EN3001751004] is the most frequently used standard for wireless telephony. The wireless local area network technologies (IEEE 802.11 a/b/g/h [IEEE 802.11a1999, IEEE 802.11b1999, IEEE 802.11g2003, IEEE 802.11h2003]) also exhibit increasing pervasion with respect to wireless telephony. However, their main application is still the high-speed internet protocol based interconnection of personal computers. Bluetooth [Bluetooth Special Interest Group 2003] is increasingly entering the field of wireless peripheral interconnection. In addition to standardized devices, there are numerous devices applying proprietary standards. Most of these devices operate in ISM (Industrial, Scientific, and Medical Band) and are available without additional licensing. Only DECT devices do not operate in ISM. The output powers of the devices vary considerably. Nevertheless, the maximum permissible limits are reached in the considered frequency bands. Some devices apply adaptive output power control (IEEE802.11h, Bluetooth, DECT mobile part) or static power control (DECT fixed part, baby surveillance devices). The frequency range and maximum output power levels of the considered device classes for Europe are summarized in Tab.1.

Technology	**RF range (MHz)**	**Peak output power (mW)**
DECT	1880 ... 1900	250
Bluetooth	2402 ... 2480	100
802.11b/g	2400 ... 2483.5	100
802.11a/h	5250 ... 5350, 5470 ... 5725	200
Wireless PC peripherals	27 ... 2400	10
Baby surveillance	27 ... 2400	500

Table 1: *Frequency ranges and maximum output powers from typical device classes in home and office environments. The peak output power represents the maximum peak output of the investigated device classes.*

Due to time division channel access mechanisms, some communication systems can cause significant extremely low frequency components. We investigated the possible ELF components for IEEE802.11b, Bluetooth and DECT devices. In Table the ELF components together with the reason for these components are summarized. For further experimental assessment we selected:

- 3 WLAN (802.11b) access points;
- 4 Bluetooth devices (power classes 1, 2 and 3);
- 4 DECT telephones;
- 3 Baby surveillance devices;
- 3 Wireless peripheral devices.

Technology	**LF spectral components (Hz)**	**Generated by**
DECT	0.25, 6.25, 100, 100 ... 2400	hyper-, multi- and basic frames, time division multiple access
Bluetooth	0.78, 267 ... 800, 1600	standby, multi-slot transmission, single-slot transmission
IEEE802.11b	−10, −10 ... 1500	beacon bearer, time division duplex

Table 2: *ELF spectral components of standardized communication devices used in home and office environments.*

Incident E-field exposure assessment

The incident E-field exposure from the considered devices was measured in a semi-anechoic chamber. The fields were mapped over distance in the direction of the antenna main beam. The results are displayed in Fig. 1. Also displayed are typical values of field exposure in residential sites in the proximity (up to 200 m) of wireless telephony base stations [Coray et al.2002].

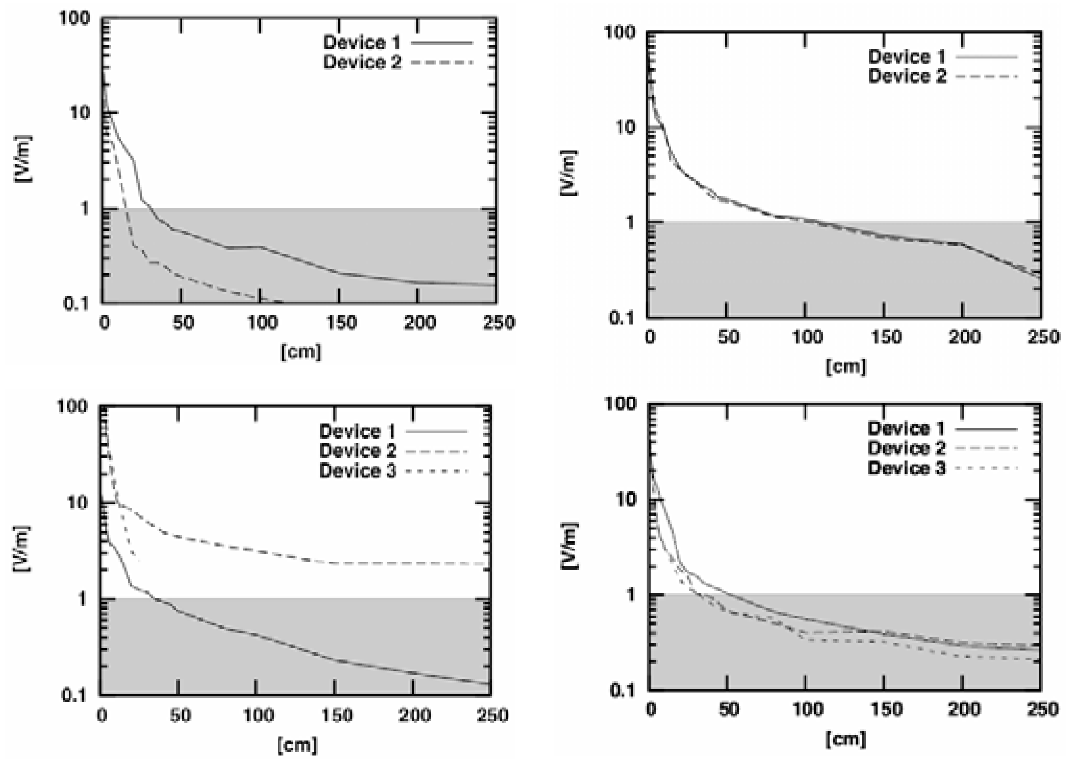

Figure 1: (a) *Incident E-fields over distance from two Bluetooth USB dongle devices (Device 1: power class 1, Device 2: power class 2);* (b) *Incident E-fields over distance from three baby surveillance devices (Device 3 measured only up to 25 cm distance due to limited sensitivity of appropriate field probe);* c) *Incident E-field over distance from two WLAN access points (Both devices IEEE802.11b);* (d) *Incident E-fields over distance from three DECT base stations.*

Dosimetric Exposure Assessment

The results for the SAR measurements of the considered devices are summarized in Tab. 3 The devices were operated with the realistic maximum antenna input power during testing [Kühn et al. 2005]. The devices were tested either in typical operational positions with respect to the body emulating phantom or where such a position could not be defined at different positions with respect to the phantom surface. The values shown represent the maximum values from the different evaluations.

To compare these results with typical exposure values from mobile phones, we performed a statistical analysis of mobile phone SAR measurements according to the United States standards, i.e., 1g SAR and IEEE-1528 [IEEE P1528 D1.22003], as well as according to the European standards, i.e., 10g SAR and EN50361 [CENELEC EN503612001] (Figs. 2.3)The determined mean SAR values are 0.74 W/kg for Europe (10g SAR) and 1.13 W/kg for the United States (1g SAR).

Bluetooth devices		
Device	**1g [mW/g]**	**10g [mW/g]**
1 (Power Class 1)	1.31	0.466
2 (Power Class 2)	0.02	0.0092
3 (Power Class 3)	<0.005	<0.005
4 (Power Class 3)	0.009	<0.005
WLAN access points		
Device	**1g [mW/g]**	**10g [mW/g]**
1	1,93	0,81
2	0,11	0,06
3	0,52	0,19
DECT handsets		
Device	**1g [mW/g]**	**10g [mW/g]**
1	0.023	0.019
2	0.019	0.013
3	0.087	0.052
4	0.047	0.027
Baby surveillance devices		
Device	**1g [mW/g]**	**10g [mW/g]**
1	0.115	0.077
2	0.012	0.01

Table 3: *Maximum results of the 1g/10g SAR measurements. (<0.005 W/kg indicates SAR values below measurement sensitivity)*

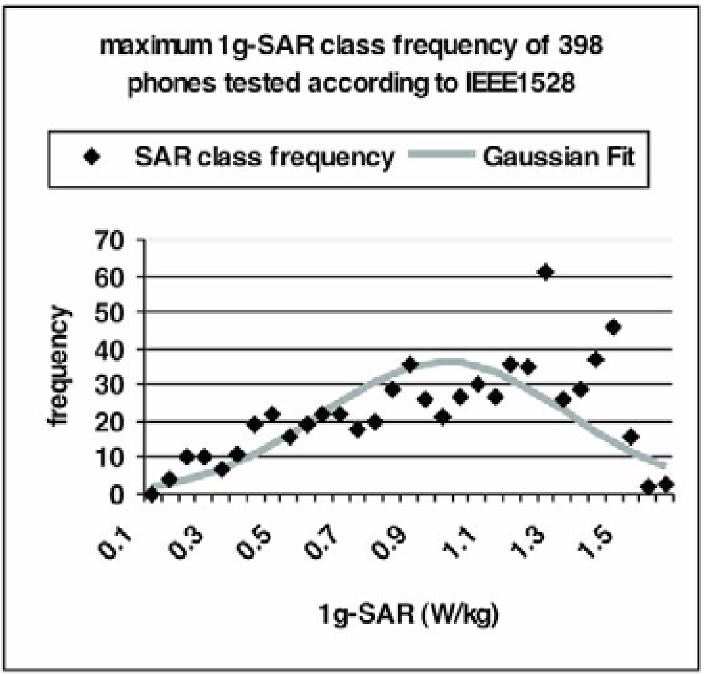

Figure 2: *Statistical distribution of maximum 1g SAR measured for 687 mobile phones according to IEEE-1528 [IEEE P1528 D1.22003] (Years: 1999 - 2005).*

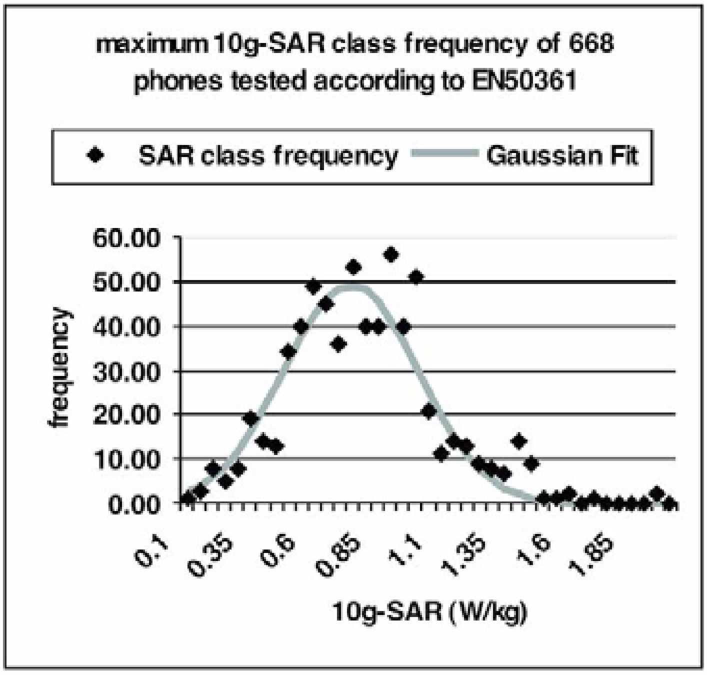

Figure 3: *Statistical distribution of maximum 10g SAR measured for 668 mobile phones according to EN50361 [CENELEC EN503612001] (Years: 2000 - 2005).*

Discussion

Table 4 gives an overview of the tested device classes and the results of the dosimetric and far-field exposure assessments. Only the maximum values of each device class are shown. The E-field values are indicated for a distance of 20 cm and 1 m.

All tested devices are compliant with European exposure limits regarding SAR (2 W/kg 10g SAR). One WLAN access point exceeded the United States exposure limit with respect to SAR (1.6 W/kg 1g SAR). The incident field exposure levels at 1 m are in the same range as exposures from base stations operated in the closer vicinity of an apartment/office. Typical values inside of buildings at distances up to 200 m from GSM base station sites are in the range of 0.1 - 1 V/m. High incident fields were measured close to baby phones. At very close distances the incident E-fields of several devices exceeded the ICNIRP [International Commission on Non-Ionizing Radiation Protection (ICNIRP)1998] limits for incident E-field exposure. Since very small device to body distances cannot be excluded for the considered devices, we propose the conduct of dosimetric compliance tests by adapting the procedures defined in [IEC62209 Part 22004].

In conclusion, in the very near future the background exposure in everyday life situations will exceed exposures from base stations and broadcast stations. This will considerably increase the complexity of epidemiological studies. The dominant source with respect to local and cumulative exposure will, however, remain the cellular phone.

Device class	test frequency range [MHz]	max. 1g SAR W/kg]	max. 10g SAR [W/kg]	max. E-field [V/m] (20 cm)	max. E-field [V/m] (100 cm)	ICNIRP limit [V/m]	ONIR* limit [V/m]
Baby surveillance	40 - 863	0.115	0.077	8.5	3.2	29	4
DECT**	1880 - 1900	0.087	0.055	11.5	2.9	60	6
WLAN	2400 - 2484	1.93	0.81	3.9	1.1	61	6
Bluetooth	2402 - 2480	1.31	0.49	3.1	1	61	6
PC peripherals	27 - 40	<0.005	<0.005	<1.5	<1.5	28	4

*Swiss ordinance for non-ionizing radiation (ONIR) limits for fixed transmitters with ERP of >6W

** Extrapolated maximum for asymmetric transmission mode (fixed part only)

Table 4: *Worst-case results of the incident E-fields and 1g/10g SAR of the different device classes.*

Acknowledgments

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Modulated RF Energy: Mechanistic Viewpoint on the Health Implications

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Abstract

Cellular telephone radio waves transmit information that is encoded into electromagnetic waves by means of "modulation," which refers to the patterns of change in the frequency and/or amplitude of the radiofrequency (RF) carrier wave. As cellular telephone technology has advanced, the modulation patterns have become increasingly complex, and the question has been raised as to whether a high-frequency modulated RF wave might have greater health effects than a pure sinusoidal RF wave. One means by which to examine this question is via what is known about the physics of the interaction of electromagnetic waves with matter. The applicability of fundamental physics to all systems, and to biology in particular, permits conclusions to be drawn about the interaction of modulated RF with ions, molecules, cells, and organisms. The basic interactions of electromagnetic fields with matter involve force on fixed and moving charges, with the possibility of classical energy transfer (thermal energy) and quantum interactions with molecules (photon effects). These basic interactions are not affected by modulation of the RF carrier wave, unless the responding system has components capable of either demodulating the RF, or responding over a timescale that corresponds to the period of oscillation of the RF wave. Biological systems would seem to have neither of these capabilities. Moreover, by examining the magnitude of the possible biophysical interactions (thermal, photon, force) it is possible to conclude that under modulated RF exposure conditions allowed by the current safety limits, there does not appear to be an overlooked hazard specific to RF modulation, with the possible exception of very short, intense RF pulses, which are not encountered in cellular telephone technology.

Keywords: radio frequency, cellular telephone technology, modulation, biophysical models, RF energy, RF interaction mechanisms, photon, cellular force, sensory force, metabolic energy, thermal energy

Introduction

Cellular telephones utilize high-frequency radio waves to transmit information that is encoded in the electromagnetic waves by means of "modulation." Non-modulated radiofrequency (RF) energy consists of a pure sinusoidal RF "carrier wave" having a single frequency and a constant amplitude. Because of its spectral purity and unchanging nature, a carrier wave does not convey any information other than its mere presence or absence. Information is added via changes, called "modulation," in the frequency, amplitude, or phase of the carrier wave. Modulating a pure sinusoidal RF wave of necessity results in the appearance of new frequency components above and below the central carrier frequency. Imposing information on the carrier wave and spreading it away from a pure, single-frequency sinusoidal wave is commonly done in one of several ways, e.g., amplitude modulation (AM), frequency modulation (FM), pulse modulation (an on-off, "digital" from of AM). Common sources of modulated RF include those listed below:

· Commercial TV, analogue and digital (VHF & UHF), commercial radio (AM & FM)
· Cellular telephones, pagers, messaging systems, base stations
· Microwave links for computers, television, telephone, and military
· Satellite transmissions (television, global positioning (GPS), communications)
· Aviation, marine, fire, emergency, and police dispatch radio
· Aviation, marine, police, military, and meteorological radar
· Amateur (ham) radio operators, international short-wave broadcasts
· Cordless telephones, baby monitors, wireless toys, wireless connectivity
· Computer monitors, light dimmer controls, door-openers, *etc.*
· Microwave ovens

Modulation introduces a spread of frequencies into the RF signal, but the frequency bandwidth of the net RF signal generally remains only a small fraction of the central, carrier frequency. This means that the most representative frequency range for the modulated electromagnetic waves in the RF signal is that of the (high frequency) carrier, not the (low frequency) modulation pattern. Even though the power of the RF signal may vary in step with the modulation frequency, there are no electromagnetic waves at the modulation frequency.
Characteristics of the bandwidth (BW), carrier wave (CW), and modulation depth for RF sources are summarized in Table 1.

Table 1: *Modulation Characteristics of RF Fields*

Technology	Typical modulation	Ratio, BW / CW frequency	Peak / avg. amplitude	Examples, and CW frequency
AM broadcasting	Amplitude	Very small << 1	~2	AM radio, ~ 0.001 GHz
FM radio and television	Frequency	Very small << 1	~1	FM radio, ~ 0.1 GHz
Mobile communic-ations	Pulse and frequency	Very small << 1	~10	UMTS, TETRA, GSM, TDMA, CDMA ~ 0.4 to 2 GHz
Radar	Pulse	Modest < 1	100	Airport radar ~ 4 GHz
Ultra-wideband, spread spectrum	Short pulse	Large ~1	100	Military applications ~ 2-20 GHz

From Foster and Repacholi, 2004

As Table 1 shows, parameters of potential biological significance include the frequency content of the signal (ratio of modulation frequency to carrier wave frequency), the ratio of peak-to-average RF wave amplitude, the central frequency of the RF (carrier wave), and the modulation frequency (typically ~0 to 10 KHz).

Sources of scientific data on biological effects

Information on the potential biological effects of modulated RF derives from three different lines of investigation with different strengths and weaknesses. First, at the most fundamental level is the physics of RF, which requires assessing all the sources of electric and magnetic fields that might impinge on the system of interest and determining how these fields may interfere with existing, endogenous fields. Second, in terms of animal exposure studies, their usefulness depends on accurate assessment of RF dose, establishing a dose-response curve, and ascertaining that the RF exposure was homogeneous across all the test systems (*e.g.*, all animals). Interpreting animal results requires attention to laboratory animal husbandry, physiology, toxicology, and pathology of potentially affected organ systems. Changes at the molecular, biochemical, and cellular level require knowing how to ascertain these changes accurately and verifying that no differences aside from the RF exist between the exposed and control systems. Third, observational studies of residential and occupational populations can provide correlations between variables that are surrogates of past RF exposure and disease endpoints. The validity of epidemiological studies requires using appropriate statistical analysis, avoiding bias and confounding, and interpreting results through the application of causal tests such as "Hill's Criteria."

Each of these sources of information has strengths and weaknesses. Mechanistic and "*in vitro*" analyses build on the solid principles of chemistry, biology, and toxicology, and will be described in more detail in the remainder of this paper. However, interpretation of mechanistic analyses for an intact, complex organism may be uncertain. Animal studies of RF exposure can bear directly on cause and effect, but they require assumptions about their relevance to humans. That is, animal experiments allow well-characterized RF dosimetry (and exposures at elevated levels) followed by careful assessment of pathology. Animal models, however, may not faithfully mimic the complex mixtures of RF signals to which humans are exposed over a lifetime. Epidemiology deals with humans, the most relevant species, but statistical analyses of disease risks in residential and occupational populations are difficult to interpret. Valid measures of RF exposure and dose are generally missing. Epidemiologists utilize indirect measures of an individual's past RF exposure and also cannot reconstruct the role of all other potentially important modifiers, confounders, and lifestyle factors.

The major focus is this paper will be on mechanistic considerations relevant to cancer causation, and general reviews on the biological effects of modulated RF are available (NCRP, 2003; NRPB, 2004). Two typical results from the other lines of investigation will be mentioned.

In the case of animal studies of RF tumorigenicity, Elder has recently summarized 30 available publications in this area (Elder, 2005). Table 2 shows the results of his analysis of the animal literature, grouped in this table by type of RF modulation, and with each result at a specific frequency counted as a separate study.

Table 2: Modulation Schemes Tested, Tumorigenicity in Animals Models

Modulation tested MHz frequency, – type –		**Number of tests made**	**Effect on tumour incidence**	
			Increase	No Increase
5500	UWB	1	0	1
435 to 2450	PW	3	1	2
860 to 9400	CW	10	2	8
915	AM	1	0	1
900	GSM	8	2	6
836 to 1500	TDMA	6	0	6
836 to 903	FM	3	0	3
845	CDMA	2	0	2
849	DAMPS	1	0	1
836	FDMA	1	0	1
1616	Iridium	1	0	1
Total number of tests		**37**	**5**	**32**

Several observations can be made regarding this table. First of all, there is no consistent pattern of positive results, and more recent, better-designed studies are overall negative. Second, it should be noted that even for the 5 positive results, the authors of the studies did not necessarily conclude that each positive result met criteria of validity such as dose-response, consistency, and reproducibility. Third, when testing at a p Ω 0.05 significance level, for 37 tests, about 2 positive results would be expected by chance alone. Fourth, even at face value, 2 of the 5 statistically significant results appeared in experiments that tested non-modulated RF (CW = continuous wave), and hence these results would not tend to support the idea that modulated RF is more potent than non-modulated RF. Overall, the weight of evidence in rats and mice exposed for long times, up to lifetime exposures of 2 years, at a variety of frequencies and modulations, suggests an absence of effects on carcinogenic processes, body mass, and longevity (Elder, 2005; Dasenbrock, 2005).

On the epidemiology side, a recent review of RF studies found that available evidence fell short of the strength and consistency required to establish an increase risk of cancer from RF exposure (Elwood, 2003). One of the studies that likely had high levels of pulsed RF exposure (*i.e.*, highly modulated RF) involved a 40-year follow up of 40,581 Navy veterans who were classified into low and high exposure groups, with about 20,000 sailors in the high microwave-exposure group and the rest in the low microwave-exposure group (Groves *et al.*, 2002). In the high exposure group, there were no significant excesses for all cancer (SMR=0.7), brain cancer (SMR=0.7), or testicular cancer (SMR=0.6). Standardized mortality ratios for leukaemia in the high exposure group were slightly elevated (SMR=1.1), but not significantly so. This large cohort not only had a long-term follow-up, but also had the potential for significant exposure to pulsed RF, and yet did not yield increased risks of cancer from modulated RF exposure.

Mechanistic consideration of modulated RF exposure effects

Mechanistic considerations are crucial because living organisms rely upon the same laws that govern all systems. As shown in Fig. 1 below, physics forms the basis of chemistry, which forms the basis of biology, which forms the basis of medicine. Hence, even though there is an increase in complexity as you move up this progression, each successive layer must obey the fundamental laws found to be valid for the layer below. At the most fundamental level are the laws of physics, which have been exhaustively validated by experiment and through internal consistency. The principles behind radiofrequency waves, namely Maxwell's laws of electromagnetism, are accepted to be invariant in time and space, and their accuracy in describing the interactions between electromagnetic fields and matter underlies the functioning of virtually all technology. No exceptions have been found, in spite of constant challenges. Likewise, physics has been found to be valid in complex systems, encompassing chemistry, biology, technology, and medicine. Simple conservation laws (*e.g.*, energy, motion, charge, momentum) are universally applicable, and biology is no exception.

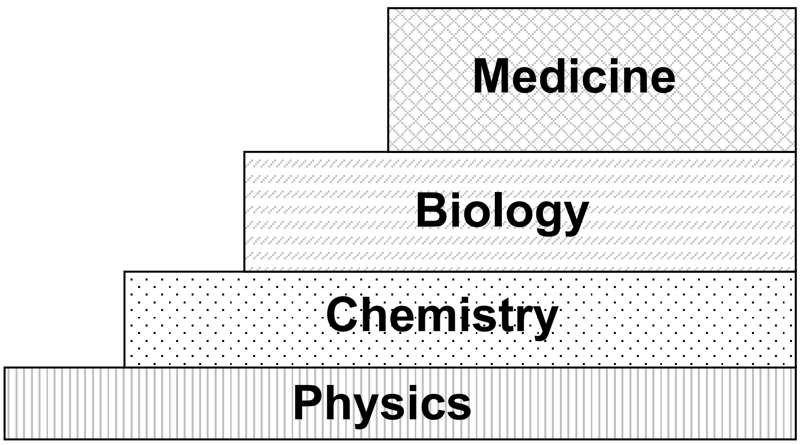

Figure 1: *Each scientific discipline rests on the underlying laws of a more basic discipline*

Ionizing *versus* Non-Ionizing electromagnetic radiation

The electromagnetic spectrum includes radio waves, light energy, ultraviolet, x-rays in a continuum, as shown in Table 3[1]. The boundary in the region between visible light, ultraviolet light, and soft x-rays is an important one because it defines different modes of molecular action.

Table 3: *Electromagnetic Spectrum*

ELF	AM Radio	FM / TV	Micro wave and Radar	Radiant Heating, Infrared	Sun Lamps, Visible Light	Medica l X-Rays	ζ-, η-, ν- Rays
ə= 3000 km ɜ = 100 Hz *E* = 0.4 peV	3 km 100 kHz 0.4 neV	3 m 100 MHz 0.4 σeV	3 mm 100 GHz 0.4 meV	30 σm 10^{13} Hz 0.04 eV	300 nm 10^{15} Hz 4 eV	3 ÷ 10^{18} Hz 4 keV	0.3 pm 10^{21} Hz 4 MeV
Dž Power lines 50 – 60 Hz		Dž Cell phones, ~ 1 – 2 GHz		Dž Human body heat ⇑ ⇑ ⇑ ⇑	Dž Vision Non-ionizing⇑	⇓ Ionizing	Dž Cosmic rays ⇓ ⇓ ⇓ ⇓
(*induced*	*currents*)	(*RF heating*	*currents*)	(*photo —*	*chemistry*)	(*molecular*	*damage*)

A crucial dividing point on Table 3 is the distinction between electromagnetic waves that can disrupt chemical bonds and those that cannot. The former are called "ionizing," and the latter are called "non-ionizing." It is instructive to compare the energy of ionizing and non-ionizing radiation, on a per-photon basis, because this tells us how the individual packets of electromagnetic radiation (known as "photons") can affect the molecules of life. Ionizing radiation can break up molecules like DNA, and hence cause mutational changes that might lead to cancer. However, non-ionizing radiation cannot break up molecules, and hence cannot affect the information content of DNA. Modulation of RF alters the energy content of the RF carrier-wave photons only very slightly – that is, to the extent that new, slightly higher or lower frequencies are introduced.

[1] Key relationships for Table 4 are: frequency (ɜ) Δ wavelength (ə) = speed of light (c);
Energy (E) = Planck's constant (h) Δ frequency (ɜ)
Example, for 2 GHz (= 2Δ10^{9}/sec), ə = (3Δ10^{8} m/sec) / (2Δ10^{9} /sec) = 0.15 m = 150 cm;
E = (4.1Δ10^{-15} eV-sec) Δ (2Δ10^{9}/sec) = ~ 8 Δ 10^{-5} eV = ~ 8 σeV
"eV" = "electron volt" = is an energy unit for atoms and molecules
1 eV = 1.6 picoerg = energy acquired by a singly charged particle accelerated through 1 V

For quantum interactions, the amount of energy (in electron-volts) that individual photons can deliver to atoms and molecules is shown below, on Table 4. Because chemical bonds have strengths of the order of 1 electron-volt and higher, photons from any portions of the electromagnetic spectrum below visible light cannot disrupt chemical bonds. In fact, we know that the chemistry of life is not affected by thermal energies corresponding to 37°C (310 K), and the energy of thermal collisions is about ~0.03 electron-volt. [2] Even so, in body fluids molecules move at ~1,000 m/sec, undergo about 10^{12} (trillion) collisions per second, and have a Brownian displacement in one second of about 15 μm. Hence, any energy added by RF waves must compete against this robust background of energetic activity. Table 4 shows that photons below the infrared portion of the spectrum do not achieve even the threshold of ~0.03 eV energies from background thermal collisions at 37°C. Modulation of the non-ionizing electromagnetic waves does not affect this conclusion.

Table 4: *Photon Energy (eV) and Interactions with Molecules Across the Spectrum*

Spectrum	Photon Energy [3]	Effect on Molecules
Soft x-rays	20,000 eV	ionize
Visible light	2.0 eV	bend (*i.e.*, isomerize)
Infrared waves	0.02 eV	disaggregate (*i.e.*, melt solids)
Millimeter radar	0.0002 eV	rotate, vibrate
Television RF	0.00000002 eV	no known molecular effects
60-Hz EMF	0.0000000000002 eV	no known molecular effects

Two important caveats to the above discussion, based on the energy of RF photons, need to be considered. One exception to the above "no-effect" conclusions occurs, of course, when the sheer intensity of the radio waves is such that the absorption of energy increases the temperature to the point where proteins and DNA are "denatured," *i.e.*, heated to the point that the molecular structure is destroyed, not by the RF *per se*, but by the energy of the collisions between molecules when colliding at velocities characteristic of elevated temperatures. The second exception occurs if the electric-field strength is sufficiently large to cause a "corona" discharge. That is, at field strengths in the 100 kV/m range, free electrons (or ionized molecules) in the air may be electrically accelerated during a one-half cycle so as to achieve kinetic energy sufficient to disrupt chemical bonds upon collision with molecules. However such high field strengths do not occur in commercial broadcasting or in cellular telephones and lower field levels are not able to accelerate electrons to ionizing energy levels.

Consideration of energy transmitted, energy intercepted, and energy absorbed

Even at the transmitter location itself, the total energy available in terms of effective radiated power from the antenna varies widely according to RF source type, as shown in Table 5.

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2 For molecules that are in equilibrium with an absolute temperature T (Kelvin units), the thermal energy of each mode of movement (translation, rotation, vibration) is approximately *k*T, where *k* is Boltzmann's constant. The size of Boltzmann's constant is such that the energy per degree T is 86 σeV. Hence 310 K corresponds to 27 meV or approximately 0.03 eV.

3 The energy of a photon of an electromagnetic wave is *E* = *h*з. where з is the frequency and *h* is Planck's constant. The size of Plank's constant is such that 1 GHz photons have an energy of 4 micro-electron volts (σeV). Millimeter radar has a wavelength of 6 mm (ә = 6 mm, з = 50 GHz), and the photon energy is 200 σeV.

Notably, cellular telephone base stations are at the low end, when considering the quantity of radiated RF power.

Table 5: *Radiated-Power Strength of RF Sources*

Cellular telephone handset	~ ½ Watt
Single light bulb (visible and infrared waves)	100 Watts
Single ham-radio antenna	1,000 Watts
Array of cellular phone base-station antennas	1,200 Watts
Typical AM radio station transmitter	50,000 Watts
Typical FM radio station transmitter	100,000 Watts
Typical UHF TV transmitter	1,000,000 Watts

More relevant in terms of energy impacts at the organism level is the amount of energy intercepted, *i.e.*, incident power per square centimetre of surface area. A comparison of energy fluxes in this regard is given in Table 6. The units are milliwatts per square centimetre (mW/cm^2). It can be seen that more energetic photons (light, infrared waves) are normally present at energy flux levels more intense than even the maximum allowable intensities in the cell telephone band. In fact, our body surfaces radiate infrared energy so vigorously that they are easily seen by "night vision" cameras.

Table 6: *Incident Energy per Unit Surface Area from Various Sources*

Source	**Energy Flux**
sunlight at noon [4]	140 mW / cm^2
3 feet from a 1,500 W electrical heater unit [5]	48 mW / cm^2
on black body surface at 37∀C ($ς_{max}$ ~ 10 σm) [6]	52 mW / cm^2
microwave oven, RF leakage standard	5 mW / cm^2
3 feet from a 100 W light bulb [7]	1 mW / cm^2
cell telephone (2 GHz) public guideline	1 mW / cm^2
cell telephone (850 MHz) public guideline	½ mW / cm^2
typical RF level adjacent to bottom of base station tower	0.005 mW / cm^2

To evaluate the potential for biological effects, the flux of RF energy per unit surface area needs to be converted to dose of RF energy absorbed within the organism, *i.e.*, watts of

4 The average amount of solar energy reaching the earth's atmosphere is defined as the solar constant. This has a value of 1370 W/m^2 which is equal to 137 mW/cm^2.

5 Assuming that a reflector behind a one-meter long heating element directs the 1,500 W of energy into the half-cylinder in front of the heater, the surface area at 1 meter radius (~3 feet) is 3.14 m^2, which works out to 1.5 million mW divided by 31,400 square centimetre, or, 48 mW/cm^2.

6 Wien's Law states that the wavelength, a͛. at which most power is radiated by a body at temperature T is a͛ = 2898/T = a͛ (μm), where T is degrees Kelvin and the wavelength is given in micrometers. The Stefan-Boltzmann Law states that the energy flux from a black body at temperature T is given approximately by ū , where ū = ů T^4 W/m^2, where ů is the Stefan-Boltzmann constant (5.67×10^{-8} $W/[m^2K^4]$).

7 Assume spherical radiation, at one meter, the surface area is 4´ r^2, and if *r* = 3 ft = 91 cm, area is 104,000 cm^2. Hence, 100,000 mW/ 104,000 cm^2 ° 1 mW/cm^2.

energy per kilogram of tissue. "Watts" is energy per unit time, and is the product of current times voltage. The dose of RF energy is called "specific absorption rate," or SAR, and it depends on the fraction of the RF electric field that penetrates into tissue.[8] That is, for certain portions of the electromagnetic spectrum, the energy incident on the body may pass through or around the body and not be absorbed. For other portions of the spectrum, the energy may reflect off body surfaces and again be unabsorbed. SAR, can be expressed in terms of the tissue (*i.e.* internal) RF electric field (E_i), the electrical conductivity of the tissue (ů $_e$), and the mass density of the tissue (ɟ $_m$).

SAR = "specific absorption rate"
= energy absorbed per unit time per unit tissue mass
= [watts / kilogram {W/kg}]
= [current {A} Δ voltage {V}] / [mass {kg}]
= [conductivity {A/V-m}] Δ [(electric field)^2 {V^2/m^2}] / [density{kg/m^3}]

Eq. (1) SAR = [ů $_e$] [| E_i |^2] / [ɟ $_m$]

RF dosimetry consists of carefully determining the magnitude of the internal RF electric field as a function of the frequency and intensity of the external RF electric field. This ratio depends crucially on the RF frequency as well as the dielectric and conductivity parameters of human tissues. Such dosimetry allows using the allowable SAR levels (Table 7) to be converted into frequency-specific RF exposure limits.

Table 7: *Power Absorbed from RF vs Power Generated by Body Metabolism and Other Sources*(a)

Source of Energy Input	Power Level
general public SAR limit on whole-body-average rate of RF energy absorbed	0.08 W/kg
occupational SAR limit on whole-body-average rate of RF energy absorbed	0.4 W/kg
Human metabolic rate, whole-body-average, when standing [a]	~1.5 W/kg
general public SAR limit, 10-g-tissue-average, rate of RF energy absorbed	2.0 W/kg
solar energy absorption rate, while sunbathing at noontime	~ 3 W/kg
heat delivery that will melt an ice cube (0∀C) to water (0∀C) in one day [9]	4 W/kg
Human metabolic rate, whole-body-average, when walking [a]	5 W/kg
Human brain tissue, metabolic rate [b]	~11 W/kg
Human heart muscle, average metabolic rate [b]	~32 W/kg
Human quadriceps muscle, exercising metabolic rate [a]	~60 W/kg
thermal energy production by individual brown fat cells [c]	~300 W/kg

Umberger *et al*. 2003 Aiello 1997[c] Matthias *et al*. 2000

8 For a frequency of 1 GHz, the wavelength (ə) (distance between crests) in air is 30 cm. Because of the increased dielectric constant in tissue, the speed of light in tissue is reduced, and ə in tissue is ~ 10 cm. Overall, the "1/*e*" penetration depth of 1 GHz into tissue is ~ 3 cm.

9 The melting of ice requires 80 cal/g (heat of fusion). 1 cal = 4.186 Joules = 4.186 Watt-sec. Hence, melting of ice requires 335 Watt-sec/g or 335,000 Watt-sec/kg. One day contains 86,400 sec, and hence 3.9 W/kg will deliver ~335,000 Watt-sec to one kg in one day.

Table 7 illustrates that the SAR safety limits on the amount of RF energy that is allowed to be absorbed by body tissues are far below the energy generation that the human body is capable of on its own. For example, the general-public RF limit on whole-body energy absorbed is 50-fold lower than the energy input required to melt an ice cube in one day, and is more than 50-fold below the whole-body energy expenditure of walking. The general-public RF limit on local, small sections of tissue is about 30-fold lower than the energy output of exercising skeletal muscle. Even smaller units of human tissue, e.g., fat-burning cells, are capable of energy output that is over 100-fold greater than the local-absorption SAR limit for RF energy. When an amplitude-modulated RF signal is absorbed in tissue, variations in the rate of heating will occur at the modulation frequency. The biological significance of such thermal changes will depend on the amount of energy deposition and the frequency of modulation. High levels of heating can irreversibly damage (and kill) cells, but lower, yet significant, levels of heating (such as taking a daily hot shower) are completely reversible. Unless a threshold of energy deposition is reached, permanent cellular damage is not known to occur from modest changes in temperature. At the whole-animal level, tissue injury can be expected only when the amount of power absorbed begins to exceed the amount of heat generated by normal body processes. For more localized heating, sensory reactions can be triggered by smaller amounts of heat energy. For example, the "microwave hearing effect" refers to audible stimuli produced by brief pulses of intense RF energy (Elder and Chou, 2003). Absorption of short bursts of energy causes a small and transient thermal expansion, leading to an acoustic vibration that is detected by the exquisitely sensitive auditory processes in the inner ear. That is, this is a "thermal" effect manifesting itself as a sound because of the short duration of the RF pulse, without perceptible change in time-averaged temperature.

Forces exerted by RF electric fields

Having examined quantum (photon) effects and energy input effects, the last mechanism to consider is the force generated by RF electric fields. It must be remembered that electric fields, by definition, exert force on electric charges, and magnetic fields, by definition, exert force on moving charges. These are the fundamental interactions of electromagnetic fields with matter, and there are no others. Hence, in order for the electric and magnetic fields in modulated RF to exert an influence on living cells, the fields must, *via* some aspect of force, modify molecules or structures in the organism. For example, the RF electric fields will exert a (rapidly alternating) force on free charges. For fixed charges in molecules that are electrically neutral overall, there may be twisting forces, or induced polarization, both of which may act to distort the molecule, and perhaps cause a shape change sufficient to modify the capabilities of the molecule. For example, because of the electric charges present in proteins or on membranes, the RF electric-field force may change a protein's configuration, and hence possibly interfere with its ability to function as an enzyme, a receptor, or an ionic gate. The argument for considering these forces is that charged ions, molecules, and structures are present in living systems. Also, at a molecular level, all molecule-to-molecule interactions are electrical in nature. Moreover, electrical phenomena are integral to normal cell function. However, the magnitude of the force is of crucial importance. It needs to be determined if the forces caused by RF be "heard" in the "noise" of existing activities and electric fields in living cells. An additional consideration is that the RF fields average to zero, and hence, even tiny force-driven displacements cannot accumulate. Finally, one needs to demonstrate how any forces exerted by RF might link to not to just biological effects, but to cell malfunction and disease.

The magnitudes of endogenous forces that are known to act at the cellular level to modify protein structures have been measured and can serve as a basis for comparison to forces produced by RF fields. Thus, the mechanistic constraints on having force-generated effects on biological systems can be appreciated by ranking electric field forces from RF signals relative to forces normally generated (or sensed) by molecules in living systems. Molecular forces generated in (and sensed by) living cells have been measured using the "atomic force microscope," "optical tweezers," and other innovative techniques. These forces are of the order of 1 piconewton (pN = 10^{-12} N) or higher. [10] Such forces, operative at a molecular level in living systems, need to be compared to RF generated forces.

For purposes of comparing electric field forces to their possible biological effect, we can use the electric field strength in tissue corresponding to a specific absorption rate (SAR) of 2 W/kg, which is the maximum level allowed for cell telephones, averaged over 10 g of tissue. If we apply Equation 1, and use the fact that the density of tissue is 1,000 kg/m^3 and the conductivity is ~ 1/ɳ -m, then the associated internal electric field is ~45 V/m at 1 GHz. For RF in the vicinity of 1 GHz, the electric field across various cell constituents is fairly uniform and does not exhibit the much higher voltage drop across cell membranes that may occur for frequencies below 1 MHz.

To estimate an upper limit to the direct field-charge interaction, consider a protein molecule that has 100 unbalanced electric charges (+ or –); the maximum force of 45 V/m on this molecule is ~0.0007 pN. This is more than 1,000-fold smaller than the smallest forces known to modify protein molecule function. Note that the electric force on 100-fold-charged molecule in the cell membrane experiences a force of ~160 pN due to the normal resting cell membrane potential (~70 mV over 7 nm), so under typical physiologic conditions, cell membrane voltages result in robust electric-field forces on cell-membrane protein, which can modify function, *e.g.* open and close ion channels.

Table 8 illustrates the results that molecular biologists and sensory organ anatomists that have been reporting, regarding the most force-sensitive aspects of biological systems. These scientists have not been able to find one sensitive to the RF electric-field levels typically found in communications technology. Not only are the RF electric field forces very low, but also biological systems have slow response times (milliseconds or longer).

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10 The size of a "piconewton" can be appreciated as follows. The force of one pound (weight) is ~4½ newtons (N), and one milliliter of water weighs ~0.01 N or ~0.035 oz. The mass of a human cell, approximately 10 σm in length on each edge would be 10^{-9} g, and would weigh (in air) approximately 10^{-11} N, or 10 pN.

Table 8: *Comparison of RF Forces to Forces Generated (or Sensed) by Biological Systems*

Biological Effect	Force	Ref.
open inner-ear hair cell ion channels	~ 1.5 pN	(a)
force of single myosin head against actin filament	~ 3 pN	(b)
force of single kinesin molecule against microtubule	~ 7 pN	(c)
mechano-receptive ion channel, skin touch sensor	~12 pN	(d)
force on protein in membrane, 10 electron charges	~16 pN	(e)
force needed to stretch DNA molecule by 10%	~20 pN	(f)
force generated by bacterial flagellum motor	~ 20 pN	(g)
DNA strand-to-strand binding force	~40 pN	(h)
Receptor-to-ligand binding force	~90 pN	(i)
Bacterial pilus motor protein	~110 pN	(j)
force of 2 W/kg RF on molecule, 100 electron charges	0.0007 pN	see text

[(a)] Hudspeth *et al*., 2000 ; [(b)] Finer *et al*., 1994 ; [(c)] Kawaguchi *et al*., 2000 ; [(d)] Sachs, 1997 ; [(e)] A typical cell membrane is 7 nm in thickness and has a resting potential of 70 mV across it. Thus, the electric field, *E*, within the membrane is 10 mV/nm or 10 million V/m. A protein with 10 charges, *q*, feels a force of $10qE$ or $[10]\ \Delta\ [1.6\Delta 10^{-19}]\ \Delta\ [10^{+7}] = 1.6\Delta 10^{-12}$ = 16 pN; [(f)] Yin *et al*., 1995; Baumann *et al*., 2000; [(g)] Berg, 1995; [(h)] Purohit *et al*., 2003; Kafri *et al*., 2004.; [(i)] Litvinov *et al*., 2005; [(j)] Maier *et al*., 2002.

Summary and discussion

Any biological interaction mechanisms capable of detecting the difference between a modulated RF signal and an non-modulated RF signal must be either be (a) fast enough to respond to and detect changes in the central RF frequency, or (b) sensitive to the RF power changes occurring at the modulation frequency. For (a), scientists have not been able to identify biological structures capable of the necessary high-frequency RF tuning or bandwidth discrimination. For (b), being sensitive to the power changes in the signal would require a "rectifying" biological structure that is non-linear at low power levels, which has not been identified by biologists or anatomists. Even if such a "rectification" occurred, it remains difficult to envision how tiny RF power modulation input, occurring at levels below existing exposure RF standards, would lead to deleterious effect on biological systems, which have considerable thermal output (Table 7) and overall thermal inertia in the intact organism. Non-thermal mechanisms relying on non-linear responses (*e.g.*, breakdown of the cell membrane), require RF-electric-field thresholds that are quite high, and would not be expected, aside from elevated RF levels which in themselves would produce hazardous tissue heating.

There are relatively few experiments with cells or animals that have been designed to examine the effects of RF exposure as a function of modulation *per se*. Evaluation of studies utilizing modulated RF do not support a reproducible bioeffect that would exist at RF exposure conditions allowed by current exposure limits (Meltz, 2003). Moreover, mechanistic considerations of the biophysical interactions between RF electromagnetic fields and biological systems, under RF exposure conditions allowed by the current limits, do not point to an overlooked hazard specific to RF modulation, with the possible exception of very short, intense RF pulses. The necessary intensity for such pulses is not encountered in the cellular telephone environment. My review and other similar reviews support the conclusion that, mechanistically, the RF energy associated with cellular telephone technology is not sufficient to cause modulation-dependent health hazards of RF fields, because there appears to be no biophysical basis on which such hazards would be expected (Challis, 2005; Foster and Repacholi, 2004; NCRP, 2003; NRPB, 2004).

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HEALTH EFFECTS

A Review of Non-Thermal Health Effects from Radiofrequency Fields Relevant to Base Station Exposure

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The aim of this review is to gather data from laboratory studies on biological and health effects of "low-level" RF exposure relevant to base station exposure. Results related to whole-body exposure of humans and animals are considered along with exposure of cell culture models. Most of the studies were done using mobile telephony signals, but other sources were also taken into consideration. Overall, there is no evidence of deleterious biological effects that could be associated with health hazards.

Introduction

This chapter reviews laboratory studies on health effects related to exposure to base-station radiofrequency (RF) sources. It addresses the potential health effects associated with electromagnetic fields, but not with effects caused by the fear of base stations!
All sources considered here (mobile telephony, WiFi, etc.) are far-field, low-level sources that contribute little to human RF exposure. They cause whole-body exposure of people in contrast to mobile telephones, which produce local exposure. This is one of the main criteria used here for assessing the scientific literature.

The main recent national and international scientific reviews of the literature that indirectly address the issue of base stations have concluded that exposure to base stations does not cause health effects (NRPB[11], AFSSE[12], SSI[13], etc.).

In order to evaluate the potential biological effects of exposure to base-station RF fields, one must consider the facts:

- exposure to these sources is often long lasting,
- exposure levels are very low (typically 10,000 times lower than exposure guidelines in the case of mobile-telephony base stations), while most of the recent research on mobile telephony has focused on the effects of mobile telephones, i.e. at high local exposure level (SAR[14] ca. W/kg), close to the thermal range.

Brief overviews of the data from various approaches are given based on their relevance to base-station exposure.

[11] Mobile Phones and Health 2004 Documents of the NRPB Volume 15 No.5 2004 http://www.hpa.org.uk/radiation/publications/documents_of_nrpb/index.htm
[12] 2005 report to the AFSSE (Agence Française de Sécurité Sanitaire Environnementale) http://www.afsse.fr
[13] Statens strålskyddsinstitut, SSI, http://www.ssi.se/english/Contact_SSI.html
[14] specific absorption rate

In the following table, the main figures from the WHO database[15] are provided for all studies related to mobile telephony

Study type	Ongoing	Completed w/Publication	Comp. w/o Pub.	Total
In vitro	42	47	28	117
In vivo	34	69	25	128
Human/ Provocation	39	39	18	96

These data are broken down below into those that can add to knowledge of the biological effects of base station signals and those that do not, based on the design of the experiments (e.g. local vs. whole-body exposure, SAR level, likelihood of thermal effects, and endpoints). The most recent findings, both negative and positive are discussed along with the relevant replication studies. Recent data on cells (genotoxicity), animals (blood-brain barrier), and humans (sleep, well-being) are also considered in terms of the weight-of-evidence approach relevant to base stations.

This review is based on articles published in peer-reviewed scientific journals prior to 2006.

Results

Human studies

Very few human studies have been done using far-field exposure. Most studies have dealt with sleep, EEG, cognitive functions, and well-being.
In sleep studies, exposure from sources away from the head was only used by a Swiss group (Hubber et al. 2002, 2003), while other groups used local exposure next to the head (e.g., Loughran 2005). The conclusion from these human studies is that there may be alterations to sleep caused by exposure, but the data are still inconsistent. Moreover, there is no known effect on health attributable to these low-amplitude alterations of sleep.
In a further study by the same group (Huber, 2005), the effects of lateral exposure to base-station-like or phone-like signals were assessed on regional cerebral blood flow (rCBF). Exposure lasted 30 min at an SAR level of 1 W/kg. Alteration of rCBF was found only with mobile-like signals. These changes, which were within the range of normal variability, are not by themselves an indication of health damage.

In 2003, a Dutch study on volunteers was made public (Zwamborn et al., 2003). These experiments were carried out at the TNO research laboratory. The volunteers were exposed to RF fields similar to those of a base station. There were two groups of subjects: one taken from a register of sensitive subjects and the other selected from people who were not affected by base-station exposure. The age and gender structures of the two groups were very different due to the difficulties in recruiting subjects. The cognitive functions were measured using the Taskomat test to evaluate reaction times, memory comparison, visual selective attention, and dual tasking. Well-being was also tested using a standardized questionnaire which gave quantitative scores for the various symptoms.
Analysis showed that low amplitude effects were observed under exposure, especially for non-sensitive subjects, particularly with regard to well-being parameters and above all with UMTS signals, rather than GSM 900 and 1800 signals. This TNO report concluded that UMTS signals had an adverse effect on well-being for both groups.

[15] http://www.who.int/peh-emf/research/database/emfstudies/

Since its publication, this study's methodology (statistical analysis, operating mode of emitters, use of well-being questionnaire, etc.) has been criticized. The way the two well-being tests were administered do not appear to have been strictly in compliance with the validated conditions, especially the fact that both tests were used successively four times each on the same day at 45-min intervals: this does not comply with the rules for such subjective tests, which are supposed to be evaluated over a period of six weeks.
However, this study constitutes a reference that is in the process of being replicated in Switzerland (Achermann et al., funded by the Swiss mobile telephony foundation).
In 2004, the EMF committee of the Dutch 'Health Council' published its conclusion on the TNO study (Knottnerus et al. 2004). It concluded that the study had been well-designed and well-performed, but that comments could be made on the interpretation of results. In terms of cognitive functions, additional statistical analysis showed that an effect appeared only for the non-sensitive group after exposure to UMTS signals in comparative memory tests. On the basis of this result, the committee did not conclude that there was a health effect. The committee strongly recommended replication of this study, advising to keep the mode of exposure as close as possible to that of the initial study, as well as to increase the number of volunteers per group, to ask volunteers if they perceived the field, and to use the same questionnaire while validating it in separate studies.
In conclusion, one must await the outcome of the Swiss replication study and other similar projects planned elsewhere.

Animal studies

Over the last years, major improvements have been made in the quality of exposure systems and in particular in terms of SAR uniformity and evaluation of the SAR in each organ (e.g., Nikoloski et al., 2005). Moreover, the thermal regulatory and thermal breakdown thresholds have been determined in mice and rats whose whole body has been exposed in restrainers (Ebert et al. 2005). This provides much more confidence in the validity of the data obtained with whole-body exposed animals. Moreover, in line with the WHO recommendations, several SAR levels were often used, allowing for a potential dose-effect relationship. Many of the investigations have been replication or confirmation experiments, and most of them are negative.

Cancer

Since the publication in 1997 of a report on an increased lymphoma incidence in transgenic 'Pim-1' mice chronically exposed to mobile telephony RF signals (Repacholi et al, 1997), none of the subsequent long-term studies in rodents have confirmed these results (see review by Dasenbrock, 2005). However, several of the follow-up co- and carcinogenicity studies are still ongoing. The quality of the most recent or ongoing studies has been greatly improved in terms of dosimetry (exposure systems, SAR estimation as a function of the age of the animals, etc.), statistical power, and comprehensive histopathology.
In order to reach a definitive conclusion, one must await the outcome of the studies performed mainly within the European 5th framework programme (Cemfec, Perform A): bioassays on mice and rats, replication of the 'Pim-1' study, and bioassays on DMBA-initiated tumours in rats. Most of these studies should be published before the end of 2006. However, the conclusion given today by most expert groups is that there is little evidence that whole-body exposure of animals leads to co-promotion of tumours at levels up to ca. 1 W/kg, which is several orders of magnitude above the environmental base-station exposure levels.

DNA damage

There are several ways to assess DNA damage. The three main ones are sister chromatid exchange, micronucleus frequency, and DNA fragmentation monitored using the “comet assay”. The first two techniques are well-validated while the third is not – even if it is often used in RF bioeffect research.

In a major 2-year investigation, pregnant Fischer 344 rats and their nursing offspring were “head-mainly”[16] exposed at 1.6 GHz (Iridium signal) for 2 hours/day, 7 days/week at 0.10 to 0.22 W/kg in the brain (Vijayalaxmi et al. 2003). This was followed by chronic exposure of male and female offspring to a near-field 1.6 GHz signal for 2 hours/day, 5 days/week, over 2 years. Exposure took place at a whole-body SAR of 0.16 or 1.6 W/kg in the brain. Bone marrow smears were examined for the extent of genotoxicity, assessed from the frequency of micronuclei in polychromatic erythrocytes. The incidence of micronuclei was not different among RF-exposed, sham-exposed, and cage control rats.

The Lai group (Lai and Singh 1995, 1996, 1997) had reported increased DNA damage in brain cells of rats exposed whole-body for 2 hours to 2.45 GHz RF signals (CW or pulsed) at SAR levels of 0.6 or 1.2 W/kg using the comet assay. However, attempts to confirm these results have failed (Malyapa et al. 1998). The two research groups used different versions of the comet assay, which might explain the discrepancy. In a more recent study, both methods were used to assess DNA damage in brain cells of rats exposed to pulsed 2.45 MHz RF fields at 1.2 W/kg (Lagroye et al. 2004). No effects were observed, suggesting that low-level whole-body exposure does not induce DNA damage.

In Croatia, the Trosic group reported transient changes in both micronucleus (MN) frequency and in counts/proportions of red blood precursor cells in blood and bone marrow of rats exposed to RF fields (Trosic et al. 2002-2004). Exposure was at 2.45 GHz (CW, 1-2 W/kg, 2 hours/day for 2, 8, 15 or 30 days). In an initial study published in 2002, MN were significantly increased in peripheral blood after the 8th day of exposure, but not with other exposure durations. In the second study, in 2004, the difference in MN frequency in bone marrow cells was statistically significant only after the 15th day of exposure. Whatever the cause of these differences, the health significance of these transient changes is unknown.

Heat-shock proteins

Heat shock proteins (HSP) are present in all species and are among the best phylogenetically conserved proteins. Heat shock proteins are categorised into several families that are named on the basis of their molecular mass (e.g., HSP70). Under physiological conditions, these proteins function as molecular chaperones or proteases that have a number of intracellular functions. Few studies have been done on HSP following whole-body exposure of animals to RF signals.

In a British study on nematode worms exposed at very low levels of RF exposure, it was reported that exposure resulted in increased hsp27 expression (de Pomerai et al. 2000). However, a recent paper by the same authors revealed that the original findings could not be replicated (Dawe et al., 2005).

[16] Such exposure in a carousel with the head of the animal pointing towards the antenna leads to exposure primarily in the head

Hsp70.1-deficient mice were exposed by a Korean group to CDMA signals at 849 and 1763 MHz at 0.4 W/Kg in reverberation chambers, twice daily for 45 min, 5 days/week , for 10 weeks (Lee et al. 2005). The aim was to determine whether such a sub-chronic RF exposure could cause constitutive induction of a stress response at a cellular and/or molecular level. Major tissues were histopathologically analysed, and immunocytochemically evaluated for cell proliferative activity. Expression level of HSP and phosphorylation of the stress-activated kinases were assayed by Western blotting. The levels of HSP90, HSP70, and HSP25 were not affected by exposure. Furthermore, RF exposure did not affect the phosphorylation status of the major stress-activated kinase (MAPK) Moreover, there was no evidence of increased proliferative and apoptotic activities.

Blood-brain barrier (BBB) permeability

The findings of the Salford group in Lund, Sweden, of an increased permeability of the BBB at low SAR levels have triggered a great deal of interest and several replication studies. A major replication study was performed at Brooks in Texas in collaboration with the Salford group. The outcome of that study was presented at the BioEM05 congress in Dublin in June 2005 (McQuade, et al. 2005), but has not yet been published. Hundreds of animals were whole-body exposed in the same exposure system as in Sweden (TEM cells), and no increase in BBB permeability was found under any exposure condition. A recent study by the Japanese Shirai group dealt with young rats (4 and 10 weeks old) exposed “head-mainly” at 1.44 GHz at 2 and 6 W/kg for 90 min/day for 1 or 2 weeks (Kuribayashi, et al. 2005). Neither BBB related genes nor permeability were affected, and this negative finding is most relevant in light of the young age of the animals.
Further evidence of a lack of effect on the BBB came from the Cassel group in Strasbourg, France (Cosquer, et al. 2005a). Rats were exposed at 2.45 GHz in cylindrical waveguides for 45 min and working memory was assessed after whole-body exposure of the animals previously treated with scopolamine methylbromide (which affects memory when it crosses the BBB). Since there was no alteration of the performance of the rats, the authors concluded that, in this very sensitive model, exposure did not induce an increase in permeability of the BBB.
While awaiting the results of a few more studies such as the American replication of the Salford group's experiment, one can presently conclude that the evidence of effects of exposure on the BBB at low SAR levels is weak. Recent studies are better-documented in terms of dosimetry and all studies published since the Salford findings, including confirmation studies, have been negative. This conclusion is in line with a recent review (Lin 2005).
The Salford group had also published observations of “dark neurons” or damaged neurons in rat brains following acute 2-hour exposures and a delay of 50 days before observation of the damage (Salford, et al. 2003). There are replications of this study being performed in several laboratories worldwide.

Rodents memory

RF exposure guidelines have been established on the basis of the effects of RF fields on animal behaviour (Review by D’Andrea et al. 2003). Further behavioural studies have been performed over the last several years, mainly on the memory of rats. In 1994, the Lai group reported that there was a learning deficit in rats exposed to pulsed 2.45 GHz in cylindrical waveguides (Lai et al. 1994). Replication studies by Cobb et al (2004) and the Cassel group (Cassel et al. 2004; Cosquer et al. 2005b&c) have failed to reproduce these results. The type of pulsed whole-body exposure used in these studies was different than that used in mobile telephony, but in view of the high SAR levels (around 1 W/kg), one can conclude that an absence of effects on rodent memory at these levels can be extrapolated to base-station levels and signals.

Cell studies

Most of the cell studies described here are related to cancer models.

Genotoxicity

Possible effects of RF exposure on the genetic material of cells have been extensively studied. This is because damage to the DNA of somatic cells can be linked to cancer development or cell death, whereas damage to germ cells can lead to genetic damage.

Several research groups have reported the absence of effects on DNA damage using the comet assay.
The Roti-Roti group exposed Molt-4 T lympho-blastoid cells to RF fields using four wireless communication signals similar to mobile phones for up to 24 h at SAR levels ranging from 0.0024 to 3.2 W/kg (Hook, et al. 2004). No statistically significant differences in the level of DNA damage or apoptosis were observed for any frequency, modulation, or exposure time.
In Naples, Italy, the Scarfi group investigated genotoxic effects in human peripheral blood leukocytes following 2-hour exposure to 900 MHz GSM signal at 0.3 and 1 W/kg (Zeni, et al. 2005). No differences were observed between sham-exposed and RF field exposed samples in terms of DNA damage and sister chromatid exchange.

Within the European Reflex project, DNA damage was observed by the Rüdiger group in Vienna, Austria (Diem, et al. 2005), in human fibroblasts and rat granulosa cells exposed to GSM-1800 and CW signals using the comet assay (4, 16, and 24 hours, 1.2 and 2 W/kg). Increased DNA strand breaks were seen in both the alkaline and neutral comet assays after 16 and 24 h exposures to all signals. The methodological limitations of these experiments have been discussed extensively and a replication study is ongoing in Ulm, Germany.
Based on several review papers, the conclusion so far is that there is little evidence that RF exposure is directly mutagenic and that the few effects that were reported result from temperature increase (review by Verschaeve, 2005). However, one cannot yet totally exclude indirect effects on DNA replication and/or transcription of genes. The variety of experimental protocols has been large. Because of poor dosimetry and low statistical power in many studies, comparison among data from various laboratories is difficult (review by Vijayalaxmi and Obe, 2004). Only large international collaborative studies could shed more light on the existence of genotoxic effects of RF exposure on cell models.

Gene expression

In 1999, it was reported that CDMA [17]and FDMA[18] signals caused small, but statistically significant increases in the proto-oncogene fos levels as C3H 10T 1/2 murine embryonic fibroblasts entered the plateau phase during exposure. No effects on Myc or Jun proto-oncogenes levels were observed in that study (Goswami et al., 1999).
A replication study was recently published (Whitehead et al., 2005) in which the expression levels of fos were measured after exposure to three modulated signals (CDMA, FDMA, and TDMA[19]) at 5 and 10 W/kg. Fos expression was measured using RT-PCR[20] . Expression of

[17] Code division multiple access
[18] Frequency division multiple access
[19] Time division multiple access

fos mRNA was not significantly different from that found after sham exposure at either SAR level for any signal modulation. Therefore, the results of Goswami et al. could not be confirmed.
The new high-throughput screening techniques of genomics and proteomics are being tested in RF bioeffects research. Once validated they may help to learn more about low-level RF exposure bioeffects.

Mechanisms

Most of the research on mechanistic models deals with possible nonthermal bioeffects of RF exposure (i.e., not caused by a temperature elevation) since thermal effects are already well-known (review by Challis, 2005). However, this is still open to discussion in the absence of a clear demonstration of the existence of nonthermal bioeffects or mechanistic models. Thermal effects are known to have thresholds, and exposure guidelines are based on this. Some scientists have suggested that SAR 'windows' may exist that ruin the guideline setting process, but there is no evidence so far of this.
Many people are concerned about the bioeffects of long-term exposure at low levels, but it is difficult to make mechanistic hypotheses as there is no evidence that long-term exposure below the thermal threshold induces adverse health effects.
Several workshops on RF mechanisms are planned in the near future that should provide further update on new models.

Conclusion

This review takes into consideration only a small part of the literature on laboratory studies related to mobile telephony, since most of the projects deal with mobile phone exposure, i.e. close to the head, for human and animal models.
Recent research activity has been mainly devoted to mobile telephones, and today most of the large research programmes have been completed (Perform A & B, Guard, Reflex, etc.), and the level of research activity is likely to decrease in the coming years, in spite of the interest new signals such as WiFi.

The paucity of data related to mobile telephony base stations and other similar sources is thus explained by the fact that the health concerns revolve more around hand-held phones which expose the head, with an SAR level close to the local exposure limit, than base stations which are located far from the body – with a corresponding whole-body SAR several orders of magnitude lower than exposure guidelines.
Most of the more previous published data on the effects of RF have been obtained at or near the thermal threshold, and are not very relevant to the present discussion. There are few results at SAR levels below the guidelines (0.08 W/kg), and all of them are negative. However, public concern is often about long-term exposure at low levels and potential cumulative effects. The fact that most of the acute high-level exposure studies are negative and that several long-term exposures of animals (bioassays in particular) are also negative points towards an absence of bioeffects for exposure at low levels.

In fact, investigations at levels comparable to base stations are impossible since the exposure history of the samples is not known and sham exposure would be difficult to perform.
All recent expert reports have concluded, based on laboratory analysis, that there are no adverse health effects from exposure to very-low-level exposure (e.g., NRPB, 2004; Moulder et al. 2005, AFSSE, 2005)

[20] real-time polymerase chain reaction

In conclusion, most of the data obtained within the framework of research programmes on mobile telephony can be interpreted in terms of an absence of effects at the levels relevant to base station exposure. However, there are still some concerns about the role of the duration of exposure in the elicitation of health effects and the subjective symptoms described by many individuals (not covered in this chapter). Since most of the large-scale studies on animals and cells have been completed, further health risk assessment will be done in the coming two or three years. This should reach the same conclusion, i.e. the absence of health effects based on experimental studies. If so, this will complement the knowledge gained from ongoing epidemiological studies dealing with mobile telephones as well as other sources (base stations, TV and radio emitters).

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Health Effects of Mobile Phone Base-Stations: Studies of Electromagnetic Hypersensitivity

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Abstract

This paper outlines some of the key factors required to investigate the health effects of mobile phone base-stations in human volunteers. Issues involved in the investigation of "Electromagnetic Hypersensitivity Syndrome" (EHS) are discussed. A brief review is provided of the current scientific literature on the effects of mobile phone technology on health in those reporting EHS. Future research needs are identified and discussed.

Keywords: electromagnetic hypersensitivity syndrome; mobile phones and health; electromagnetic radiation and health; mobile phone base-stations and health effects.

In the developed world, people are exposed to a variety of sources of electromagnetic radiation ranging from radio and TV transmitters, telecommunications links and satellite communications to mobile phones and their associated base-stations. The increasing roll out of mobile phone technology in most countries has led to an increase in the amount of background electromagnetic fields in the radiofrequency range and this has been paralleled by widespread public concern about the potential health effects of this technology. Hundreds of newspaper articles and television reports are published world-wide on a daily basis, often presenting conflicting evidence on the potential effects of mobile phones and their base-stations on human health. The scientific literature is also large and confusing, often showing inconsistent effects across different studies. The aim of the current paper is to focus on a subset of scientific studies that examine the impact of radio-frequency electromagnetic fields (RF-EMFs) on people who report that they are particularly sensitive to this type of non-ionizing radiation. This condition is generally termed "Electromagnetic Hypersensitivity" (EHS) and is not widely accepted as a medical condition. Therefore, it is vital to access the scientific literature in order to determine that the symptoms reported in EHS are indeed causally related to the presence of RF-EMFs. We outline the key criteria that a good study should have in order to assess whether RF-EMFs are causally linked to subjective health effects. We also limit our overview to human research and consider only subjective health complaints and cognitive changes, as these are most widely reported by people who report that they suffer from EHS.

A first step in any analysis of the causes of health complaints is that we need to acknowledge that specific diseases and problems can often be caused by a variety of different mechanisms. Hence, for example, skin can be burned by over exposure to the sun; contact with boiling water; contact with hot metal etc. One of the real difficulties in trying to determine the causes of EHS is that people typically report a range of non-specific symptoms such as headaches, memory impairments, difficulties in concentrating, sleep disturbances and so on. All of these symptoms can be caused by a variety of factors such as stress, worry, kidney failure, heart disease and many other physical and psychological disturbances. However, people with EHS consistently report that these symptoms are triggered specifically by weak EMFs and this needs to be taken seriously and tested under controlled conditions.

How can we investigate the health effects of EMFs?

Before setting out to study the effects of EMFs on health, we need to determine what aspect of the EMF is important. Public concern relates primarily to mobile-phone base-stations, however, is there really something special about the 900 MHz to 2.1 GHz range? Mobile phones and their base-stations usually operate within the approximate range of 900 MHz to 2.1 GHz and fall just at the beginning of the microwave region of the radio frequency spectrum. RF-EMFs (3Hz-300 GHz) carry a relatively high level of quantum energy and given enough power are able to produce health-related thermal effects. Consequently safety guidelines have been established, based on the results of extensive scientific research, to guard against this known risk of RF-EMF emissions.

Hyland (2000) has argued, however, that current safety guidelines are not comprehensive as the pulsed nature used in mobile phone technology may also cause non-thermal effects. For example, Bawin and colleagues (1975, cited in NRPB, 2002) reported an increase in calcium efflux in cells exposed to RF-EMFs modulated at 16Hz. Yet subsequent research has failed to replicate Bawin et al.'s original findings (e.g. Albert et al. 1987, ibid.) and there is still no theoretical basis for the effect of RF-EMFs modulated at 16Hz on calcium efflux.

Hyland (2000) and Johansson et al. (2001) have proposed different biophysical theories to explain how RF-EMFs may influence human health. According to Hyland, the "oscillatory similitude" between the modulated radiation and the living organism creates the possibility for non-thermal effects to occur because the living organism is able to recognise certain frequency characteristics of the radiation and thereby respond to it. Johansson and colleagues, on the other hand, have argued that some cutaneous mast cells may contain small magnetic particles of magnetite (Fe_3O_4), causing an interaction with environmental EMFs such as computer monitors resulting in the skin-related problems often reported by EHS sufferers. There is a need for further research to elucidate the nature and potential health impacts of these proposed mechanisms.

While the absence of a well understood biophysical mechanism does not, of course, indicate that such a mechanism does not exist, it does make it difficult to determine how EMFs might affect health. In this situation, it is appropriate to first establish a clear causal link between EMFs in particular frequency ranges and specific health symptoms. An important criterion for a good study is to utilize a convergent approach using multidisciplinary teams incorporating a range of expertise. Thus, investigation of the effects of EMFs from the molecular to the systems levels with input from a variety of scientific disciplines (e.g., physics, engineering, biology, neurochemistry, cognitive neuroscience and cognitive psychology) is important. In addition, given the social and cultural dimension of the public concerns input from epidemiologists and social scientists is also important.

Types of approach

1. Epidemiological Studies
   Throughout the past few decades numerous epidemiological studies have endeavoured to determine the distribution of diseases such as, cancer and heart disease associated with long term exposure to EMFs (see Ahlborn et al. 2004 for a comprehensive review of epidemiological studies in the 100kHz to 300GHz range). Epidemiological research, unlike animal studies, can provide direct information about EMF exposure on human health (NRPB, 2004a).

   Although epidemiological research is able to describe the distribution of a disease in a given population associated with EMF exposure there are many shortcomings and problems with interpreting the results of such studies. Primarily, epidemiological research by itself is unable to determine causal relationships. Only when combined with experimental research, is it possible for epidemiological studies to help test for causation. It is difficult to interpret the results of epidemiological research mainly due to the fact that it is almost impossible to determine the individual level of EMF exposure. Until instruments like a personal dosimeter are fully developed that can provide an accurate measure of the level of EMF exposure for an individual from a variety of RF sources over a period of time, human volunteer studies provide the best approach to investigate acute effects from wireless technology.

2. Human Volunteer Studies
   Many EHS sufferers claim that they experience negative health effects within a relatively short period of exposure to EMFs. Only under well controlled laboratory conditions, can scientists determine if a particular signal, such as a 30 minute 2100MHz UMTS signal can affect a variety of physiological, cognitive and health measures. Therefore, it is important to determine if specific EMFs have an effect on health and well being before looking at more complex designs that include multiple sources of EMF for example, a combined signal from computers, mobile phones, radio and television transmitters, and wireless local area networks. Human volunteer studies can also examine more long term effects such as a base-station signal on quality of sleep using EEG measurements.
   There are many complexities associated with testing EHS sufferers making human volunteer studies of this nature difficult to conduct. Many EHS sufferers are understandably reluctant to put themselves in a situation which they believe will make them ill and many EHS individuals are unable to travel to laboratories to be tested. The biggest difficulty, however, is overcoming an overall distrust of scientists among the EHS population and scepticism over the value and necessity of well conducted laboratory research.

Summary of human studies to date
A number of different reports on the potential health effects of mobile phone technology have been published, most emphasizing that the level of exposure to EMFs from base-stations is low and well below national guidelines. According to the ICNIRP Guidelines (1998), the basic restrictions for current densities for frequencies ranging from 10MHz to 10GHz for the general population are as follows: whole-body SAR (specific absorption rate) is 0.08W/kg, localised SAR (head and trunk) is 2W/kg and localised SAR (limbs) is 4W/kg. A recent NRPB report confirmed that base stations in the UK are operating at around 0.18% of the ICNIRP Guidelines and therefore well within these parameters (Mann et al., 2000). This is further supported by the latest results of the UK's Ofcom base station audit (2005). Apart

from the fact that emission levels from mobile phone base-stations are low, many reviews have also concluded that adverse health effects do not occur. For example, the National Radiation Protection Board (NRPB) in the UK concluded recently that "The widespread development in the use of mobile phones world-wide has not been accompanied by associated, clearly established increases in adverse health effects" (NRPB, 2004b).

In spite of these reviews from around the world, there is still widespread public concern which, if anything, appears to be increasing. A close analysis of the scientific studies leading to the conclusions drawn in these various reviews reveal, however, that there are often a very small number of well-controlled studies. This of course means that drawing firm conclusions is often problematic. Statistical power is a statistic that determines whether a study has sufficient "power" to detect a difference between test and control conditions that is above a certain level of chance. For instance, statistical power of .80 suggests that there is an 80% probability that the result obtained in a particular study was correct. A problem with many of the studies on the impact of RF-EMFs on health is that power is often very low, so that once again it is not clear how certain we can be about the validity of the results. There are a number of ways to increase statistical power, one of the most common being to increase the number of participants being tested. A larger sample size reduces some of the random variation introduced by individual differences leading to a more homogenous group and thereby bringing the overall result of the experiment closer to the population being estimated. It has also been argued that many laboratory studies have used artificial sources of RF-EMFs making it difficult to generalize to the normal working and living environment. Thus, one of the criteria for a good study is using an exposure system that is similar to that found in the normal environment in which people live and work.

Many factors need to be considered in the development of a good exposure system. Both the GSM and UMTS signals are extremely complex therefore, expert knowledge is necessary to develop a signal that replicates the key components utilized in commercial base-stations. For example, the GSM broadcast channel and traffic channel operate at different frequencies. While the broadcast channel is constantly sending information to all mobile phones in its cell the traffic channel transmits user data (e.g. voice transmission) through 1of 8 time division multiple access frames each slot lasting 577 μs of which there is 30.5μs of guard space before and after the data transmission. Since the traffic channel is used for user data the pattern of usage is constantly changing depending on the number of users in a cell at any given time. Therefore, an exposure system should not only include a broadcast channel, but also a realistic and reproducible model simulation of the traffic channel variation during 'busy hour' usage. Another issue to consider is establishing what power density participants should be exposed to. Similar to the traffic channel the power density from a base-station is variable depending on factors such as the number of users and the propagation of the signal. Distance from a base-station is not a good estimate of power density, because depending on the topography of the area, RF-EMFs, like visible light, can be blocked, reflected, refracted, scattered, and/or diffracted off different types on objects, such as buildings, houses, cars, signs and hills (Mann et al., 2000). Therefore, a good exposure system should produce an EMF power density that typically occurs in the natural environment across a variety of distances from base-stations.

In human studies, statistical power is an important issue to consider and this can be enhanced in a number of ways. Most commonly, increasing the number of participants in an experiment will increase the power of the experiment. However, power can also be increased by strengthening the sensitivity of the people being tested. All of the governmental reviews mentioned previously reviewed studies conducted on members of the general public without any particular sensitivity to RF-EMFs. Thus, it is possible that a more focused review of studies conducted on people reporting EHS might demonstrate the elusive link between EMFs and adverse health effects. A preliminary question concerns whether there is any evidence for an enhanced perception of EMFs in particular groups of people.

What is the evidence for enhanced perception of EMFs?

Leitgeb & Schrottner (2003) tested the perception threshold for 50Hz electric currents in 708 adults. The interesting finding was that there were large individual differences, with women generally having lower perception thresholds (i.e., more likely to detect the electric field) than men. They concluded that some people are indeed more sensitive to EMFs and that this is a necessary condition for the development of EHS. While variation in detection thresholds may well be important in the development of EHS, we note however that it is probably not a "necessary" condition as suggested by Leitgeb and Schrottner (2003). There is a large literature in experimental psychology showing that a range of physiological and neural reactions can occur to visual stimuli which are presented for such a short period (usually around 14 msec) that they do not enter conscious awareness. As an illustration, the presentation of an angry face under these subliminal conditions can lead to an increase in the galvanic skin response (Esteves et al., 1994) as well as to increased activation in the amygdale (Whalen et al., 1998), which is a sub-cortical brain area responsible for the detection of threat amongst other things. The important point is that people in these experiments cannot detect the presence of the face above chance. Thus, the fact that subliminal stimuli can influence a variety of bodily responses indicates that EHS could possibly develop even in the absence of a demonstrated increase in perception threshold. Nevertheless, the fact that people with EHS readily report that they are aware of the presence of EMFs even when they cannot see the source indicates that they may well have a lower threshold for EMFs.

Do people with EHS have a lower threshold for EMFs?

Mueller, Krueger, and Schierz (2002) tested 49 EHS participants and 14 control participants and could find no difference between the two groups in ability to detect 50Hz field exposures (100 V/m). Likewise, Lyskov and colleagues (2001) exposed 20 EHS and 20 controls for 10 minutes to a 60Hz magnetic field and found that neither group responded. However, they did find that the EHS group differed in baseline HR and electrodermal activity, and concluded that the people with EHS may have a physiological predisposition to react to physical and environmental stress. Thus, it seems that there is no evidence that people with EHS have a lower perception threshold for EMFs. However, as mentioned previously, a lowered threshold may not be a *necessary* condition for the development of symptoms. What is needed are well controlled double-blind experiments designed to assess the impact of base-station EMFs on physiological, behavioural, cognitive and neural functions, in groups of both EHS and control participants.

Characteristics of a good study

As mentioned earlier, the investigation of EMFs and health is a complex issue best tackled by multidisciplinary teams of physical, biological and behavioural scientists. There is a tremendous amount of apparent inconsistency in previous research due to a range of different exposure systems being tested, and a range of different outcome measures being used. Moreover, almost no studies have been replicated meaning that it is very difficult to draw firm conclusions across studies. Given this our suggestions for a good quality study are as follows:

1. Well controlled and realistic exposure system.
2. Electrically screened testing environment.
3. Double-blind testing conditions.

4. Measure of whether people can detect exposure and sham conditions under double-blind testing.
5. Test EHS and matched control participants.
6. Test a range of age groups.
7. Measure a variety of outcome measures (e.g., physiological, behavioural, subjective, cognitive, neural) under exposure and sham conditions.
8. Sufficient wash-out period between exposure and sham conditions.
9. Adequate follow-up measures after testing.

Surprisingly few studies meet all of these criteria, and many only meet a couple of them at best. This may be one reason why there is so much inconsistency in the pattern of results found in laboratory-based studies. Having said that, it is the case that most studies do not find clear links between exposure to EMFs and health outcomes. For example, while anecdotally people often complain that mobile phones affect their sleep a review of 14 studies on the effects on handsets and sleep concluded that “in reality no adverse health effect has been found in any published human study on the effects of mobile phones” (Hamblin & Wood, 2002). It should be noted, however, that we could find no published study examining the effects of base-station EMFs on sleep. There is, however, one double-blind study presented at the 2005 Bioelectromagnetics conference that is currently in progress. Schroettner & Leitgeb are conducting a pilot study investigating whether sleep quality of hypersensitive persons is associated with ambient EMFs.

Review of studies investigating EHS

Electromagnetic hypersensitivity provides a good opportunity to assess the acute health effects of EMFs since people with EHS generally report that their symptoms emerge within a few minutes of being exposed to an electromagnetic field. A comprehensive and systematic review of published provocation studies testing people with EHS has recently been published (Rubin et al, 2005). Therefore, we will not repeat this endeavour but instead highlight a couple of key studies and summarize the conclusions provided by Rubin et al (2005). In brief, they identified 31 double-blind experiments which tested a total of 725 EHS participants. Of the 31 studies, 24 could find no difference between exposure and sham conditions. While 7 studies did find a difference this could not be replicated by the same research teams in 2 cases, 2 of the remaining 5 studies found conflicting results (i.e., EHS participants felt better when exposed to EMFs relative to sham exposure) and the remaining 3 studies may have been due to statistical artefacts. They therefore concluded that:

> “this systematic review could find no robust evidence to support the existence of a biophysical hypersensitivity to EMF” *Rubin et al (2005)*

Rubin et al (2005) do however point out that low statistical power was a problem in many of the studies that they reviewed. One of the best controlled studies examining the effects of the EMFs emitted by GSM and UMTS base-station signals (Zwamborn et al., 2003, unpublished report) did report an affect on cognitive function and well being. Seventy-two (36 EHS) individuals were tested using a double blind nested cross over design in which all participants were exposed to the sham condition plus two out of the three exposure conditions (900MHz, 1800MHz, 2100MHz) in a semi anechoic chamber. Participants completed 4 cognitive tasks during a 20 minute exposure and a “Well Being Questionnaire” was completed after the exposure outside the testing room. The results for the cognitive tests were mixed in that some parameters showed impaired cognitive functioning (e.g. slower reaction times) while others resulted in facilitation (e.g. improved memory). These results did not show a consistent pattern for either group or exposure condition. Zwamborn and colleagues failed to control for multiple comparisons. If alpha levels are corrected to reduce the chances of type one error then these differences in cognitive performance are no longer significant. With regards to well being, both the control and EHS group reported poor levels after the UMTS compared to sham exposure; however, these differences were relative small. In addition, an un-standardized questionnaire for well being was utilized making this result difficult to interpret. Since all the testing occurred on the same day, other factors such as carry–over effects, fatigue and short exposure conditions may have contributed to the inconsistency in findings.

What can we conclude?

Overall, the majority of well-controlled published studies have indicated that EHS symptoms do not appear to be related to the presence of EMFs (see Rubin et al, 2005, for review). However, it is also the case that many studies had particular problems with power and may have therefore missed an effect that was not strong enough to be detected under the specific testing conditions investigated. In our view, while most studies indicate null effects, there is nevertheless a genuine uncertainty among the general population regarding the non-thermal effects of mobile phones and their associated base-stations on health indices, especially in those reporting EHS. There is therefore a need for further large and well-controlled laboratory studies that test both EHS and control participants under double-blind conditions. We are currently aware of 4 on-going studies around the world, which will provide important information when they are completed and published. Assuming that these studies contain enough statistical power to detect even a weak effect then the results should be relatively conclusive.

In terms of future research, the difficulties of research investigating the effects of EMFs on people reporting EHS need to be acknowledged. First, people with EHS are understandably reluctant to expose themselves to even low-level EMFs and this makes research very difficult. Second, there is a tendency to mistrust science among many EHS support groups and many studies have been undermined by these groups on spurious grounds. Third, the most severely affected individuals with EHS are unable to leave their homes and travel to the laboratory to be tested. While it is always easy to find problems with specific studies, it is important for society in general to acknowledge the importance of conducting systematic and controlled research in order to establish the causal relationship between environmental factors, such as EMFs, and health and other outcomes. It is impossible to establish that EHS is indeed caused by EMFs unless such systematic studies are conducted. In turn, scientists in this field need to be aware of the problems and fears faced by people with EHS in coming into a laboratory (travel is often very difficult) and then being exposed at least some of the time to EMFs which they strongly believe are causing their adverse symptoms. We will not gain new knowledge unless people with EHS and scientists work together in the attempt to understand the potential causes and mechanisms underlying EHS.

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Study on the Feasibility of Future Epidemiological Studies on Health Effects of Mobile Telephone Base Stations: Dosimetric criteria for an epidemiological base station study

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1. Background

The introduction of mobile phones using the digital GSM 900 / DCS 1800 standards in the 1990s led to a wide use of this technology and subsequently to an increase in the environmental exposures to RF fields, the introduction of new technologies, e.g. UMTS has intensified this process. Mobile communication networks require the use of base stations that are often situated close to dwellings or houses and have become the focus of concerns of parts of the population in recent years.
These concerns resulted in the demand for epidemiological studies on the potential health effects of the RF emissions of such base stations. Within the scientific community the usefulness of epidemiological studies to investigate health effects related to the RF fields from mobile base stations has been debated controversially due to a number of unsolved methodological problems. Up to now only a few cross sectional surveys on possible effects of base stations as well as several cluster investigations of populations residing near TV and radio transmitters were performed. These studies do not allow any conclusions and sound large scale studies are lacking. Several questions remain open, e.g. the adequate type of study design, the endpoints to be investigated, the adequate exposure metric and the methodology how to deal with the emissions from other RF sources.

2. Objective

The research project "Study on the feasibility of future epidemiological studies on health effects of mobile telephone base stations" brought together in a collaborative effort leading international scientists in RF-engineering/dosimetry and epidemiology to jointly assess the feasibility of epidemiological studies on health impacts of RF-exposure from mobile phone base stations.

3. Methodology

The feasibility study was finished in spring 2005 and consisted of two main parts:

∉ Existing epidemiological studies on RF sources and health were analysed to describe existing study designs and to identify strengths and weaknesses. Existing epidemiological and human experimental studies on base station exposure were critically and systematically reviewed.

∉ Existing exposure assessment methodologies were evaluated and the suitability for epidemiological studies was examined. The contribution from other RF sources to the total exposure is taken into account.

4. Results

4.1. Specific aspects of the field distributions in the vicinity of base stations

The determination of the exposure next to mobile communication base stations under real life conditions needs to consider several aspects. The RF field distribution depends on several environmental factors, field levels are varying in space and time. Multipath propagation and fading effects lead to scenarios that are often not easy to reproduce leading to large uncertainty budgets. Considerable variations of the field levels in the GSM 900, DCS 1800, UMTS, Broadcasting and FM frequency range were found in restricted areas, e.g. the relation between the maximum field level and the average field level within one cubic meter was found to be typically between 2 and 5, the ratio between the maximum and minimum being much larger. One approach to describe exposure scenarios is to use laws of field distribution, e.g. Rayleigh, LogNormal, Rice. Within the examined areas it was not possible to find clear relations between field scenarios defined by distance, LOS or NLOS conditions (Line Of Sight, Non Line of Sight) and Indoor versus Outdoor conditions. Preliminary results indicate that the meteorological conditions on the ground like water or snow may have an important impact on the propagation of reflected waves.

In the next subchapters variations in space and time are shortly discussed

4.1.1. **Variations in space**

The spatial variation of the field strength (fading), can be divided in two different types. The distinction is conditionally made by the cause of its origin (*Parsons, 2000)*, *Pätzold, 1999*) in *large-scale fading (also: long-term fading, shadowing*) and *small-scale fading (also: short-term fading, fast fading).*

Large scale fading is a phenomenon that happens in the range over 10 wavelengths of the propagating wave; whereas under 10 wavelengths we speak from small scale fading.
At first the field strength sways very quickly around the local mean average value. When the fluctuations happen within a wavelength the phenomenon is called *small scale fading*; and it is provoked by interference between the propagation waves, that arrive through different paths to the receiver.

If we obtain the mean average value over more than 10 wavelengths, it oscillates around a global mean average value. Shadowing effects are the reason for these fluctuations. If all these fluctuations are averaged by statistic methods, the received field strength will also be decreased monotonously with the distance to the base station. This is the case of *large scale fading*.

In the literature we can find a variety of different examples for measurements on sites with different exposure situations from base stations. The comparison and the classification are due to different measurement concepts quiet difficult. As an example of a different exposure situation we describe one typical NLOS (Non Line of Sight) situation, measured on the area of Seibersdorf. It has to be mentioned that it was so far not possible to define classes according to scenarios examined so far. Examined is a closed room without any windows, as depicted in Figure 1 and Figure 2, and at a distance within 100-150 meters from the GSM 900 base station located on the roof top.

Figure 1: *The room TOX7 (ARC Research-Austria)*

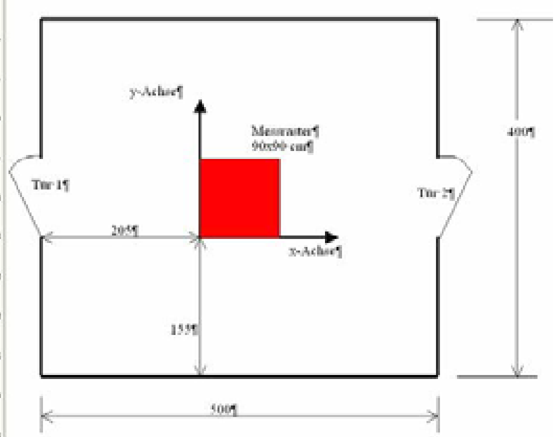

Figure 2: *Measures of the room [cm]*

The dimension of the side length of the examined field cube was 0.9 m with a grid of 0.15 m. The antenna used for the measurement was the PCD 8250 (ARC-Research) using the isotropic measurement procedure (ADD3d).

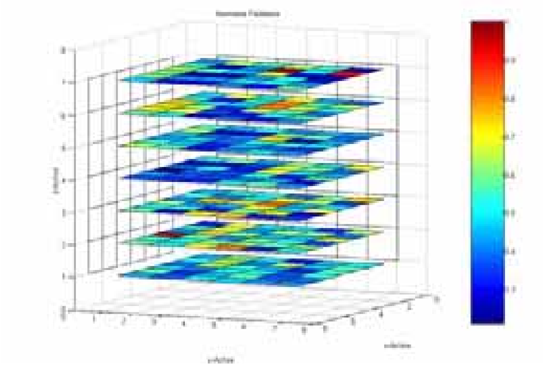

Figure 3: *Field cube with normalized values*

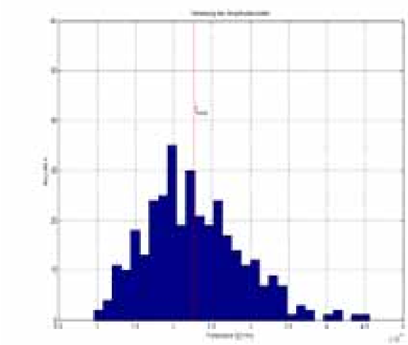

Figure 4: *Discrete amplitude distribution of the field values (PDF). One should note that the distribution fits well to an expected Rayleigh distribution*

4.1.2. Variation in time

The variation in time is a well investigated phenomenon, e.g. Figure 5. For the data transfer in mobile communications it is very important to have a reliable channel model in the time domain to estimate for example the bit error ratio in transmitted data.
While in the short range from millisecond to second good models exist for the prediction, for longer terms in the range from hours and more, it is not any more possible to find describing models. Moving objects like trees moved through the wind, persons walking or cars moving can provoke under and overestimation of the field as a highly time variant object, leading in practice to new boundary conditions every moment. The time dependence of a mobile channel with a constant power (BCCH) from a GSM 900 base station operating at the frequency f = 946.6 MHz was investigated at 6 adjacent locations, the measurements were performed over a period of 1 week.

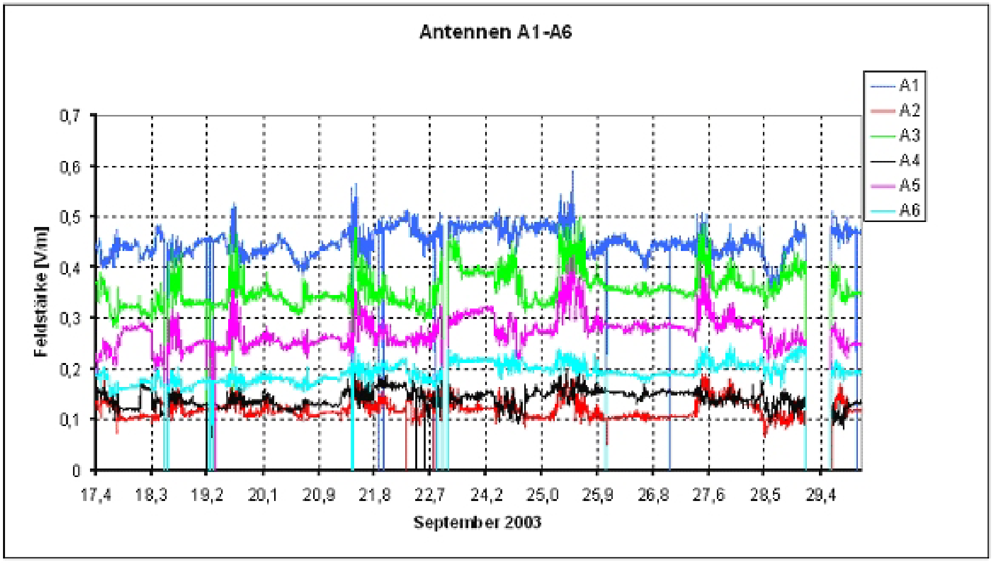

Figure 5: *Variation in time from a BCCH from a GSM 900 base station (measurement cycle: 4.5 min, transmitted with constant power)*

The short peaks with a field value of 0 V/m in Figure 5 are from short interruptions for maintenance of the measurement set-up. The variations of the received signal demonstrate very well the changes of the channel versus time mainly caused by moving objects, e.g. persons, cars, trees and changing meteorological conditions, e.g. rain or wet versus dry ground.

4.2. Available methods and equipment: numerical methods and measurement tools

4.2.1. Numerical methods

The numerical methods can be divided in two main different types based on the used physical wave propagation model: Field theoretical methods (solving Maxwell's equations; e.g. given Finite Elements (FEM), Finite differences in time domain (FDTD)) and optical methods (e.g. Ray Launching and Ray Tracing). The big difference between optical based methods and field theoretical methods next to the physical background is the different requirement to the computer hardware.
Optical methods are used for scenarios where field theoretical methods are limited because of their computer requirements.
In the literature we can find also hybrid methods. These hybrid methods are a combination between field theoretical methods and optical methods and have the advantage to consume lower computer resources. For the investigation of small areas field theoretical methods are often used, e.g. FDTD, and for large areas optical method like ray tracing are often applied.

4.2.1.1. Field theoretical based methods

The calculation of electromagnetic fields in an analytic way is only possible in a reliable way for very simple geometries. Therefore, for more complicated scenarios the use of field theoretical methods in the discrete field room is recommended. The field room is subdivided in cells (e.g. the Yee cell in FDTD) and based on this, the mathematical Methods established are described below.

All the field theoretical methods have in common, that for complex field problems because of the complex geometries in the field space, the resulting necessary discretisation requires lot of memory on the hardware (see Figure 6).

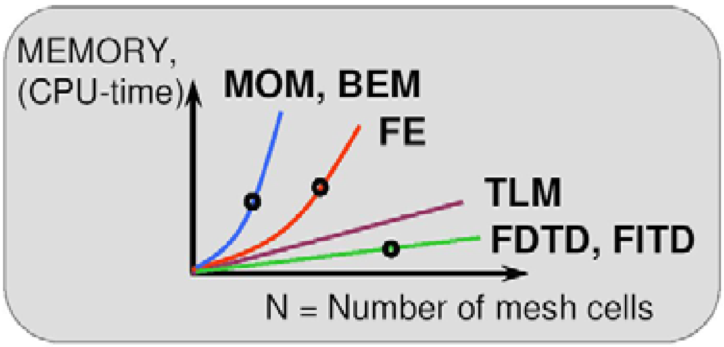

Figure 6: *Requests to the computer hardware (source: www.cst.de)*

Field theoretical methods are perfectly suitable for the calculation of complex heterogeneous structures (e.g. absorption ratio for the human body). The dimension of the calculated area is limited because of the required memory request.

4.2.1.2. Optical based methods (GTD/UTD)

(Generalized Theory of Diffraction/Unified Theory of Diffraction)
Optical based methods are very important for the estimation of electromagnetic field distributions in the environment of base stations. In situations, where due the large

dimensions of the field rooms and the resulting requirements to the computer hardware it is not anymore possible to use field theoretical methods like MoM, FEM or FDTD.

The physical background for the optical method is for the reflections and the refractions Fresnel's formula and for the geometric diffraction the geometrical theory of diffraction (GTD) and the unified theory of diffraction (UTD). The GTD/UTD model assumes that all existing waves are planar waves.

Also is presupposed that all objects are in the far field, and that all dimensions of the geometries are greater than 1 or 2 wavelengths. This theory does not consider any electric currents, so that the calculation of impedances is not possible.

The advantage from the GTD/UTD method is that there are practically no limitations considering the dimension of the object and no dependence of the simulation duration from the frequency, like for example with FDD methods.
The main application for optical methods is the calculation of large scale field distributions like e.g. the planning of mobile radio networks.

4.2.1.3. Hybrid methods

In the literature one can find hybrid simulation techniques (*Rousseau et al.,1995*, *Lautru et al., 2000*, *Mochizuki et al. 2003*, *Bernardi et al., 2002*). Field theoretical methods where combined with each other or with optical methods (GTD/UTD) like MOM with GTD/UTD, FDTD with MOM and FDTD with GTD/UTD. The concept is shown in Figure 7.

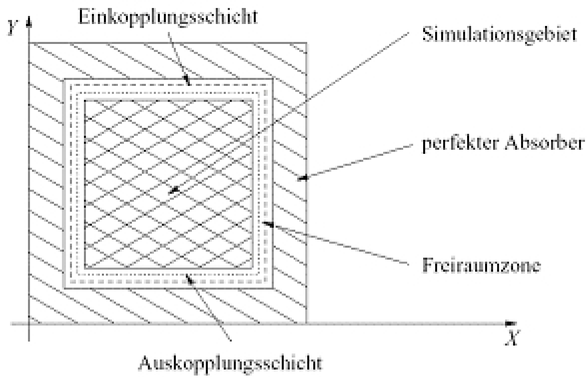

Figure 7: *Inner and outer layer for coupling hybrid methods*

The main principle is based on the idea that the large scale area is simulated with optical methods, and specific areas like the human body area are simulated using field theoretical based methods.

4.2.2. Measurement methods

4.2.2.1. Spot measurements

Measurements of radio frequency electromagnetic fields can be basically performed in two ways: broadband and frequency selective. The principal difference between both is that in the frame of broadband measurements the total contribution over a large frequency range is obtained without distinction of the contribution of different sources operating at different frequencies, which is actually obtained using frequency selective devices because they allow distinguishing between the specific contributions in the different frequency ranges. Broadband measurements are performed with probes and hand-held measuring instruments, while for frequency selective measurements spectrum analysers attached to antennas are used. Owing to their sensitivity, the broadband devices are often used for compliance assessment. With a typical sensitivity of around 0.2 V/m such measurements can be carried out with enough accuracy. Spectrum analysers can detect signals being at least 8 to 10 orders of magnitude lower as the limits specified in the guidelines, standards or other documents. Spectrum analysers are well suited for detailed frequency selective measurements.

Broadband measurements

For broadband measurements a probe, usually isotropic, and a field meter are used. The probe consists of a short-electric dipole (or loops) that detect the field. The corresponding current flows through a conductor wire (with high resistance) to the field meter. Probes can be distinguished whether they are only able to measure the fields in one direction or they are isotropic and measure the field components in the three orthogonal directions in space and calculate the magnitude of the resultant field strength, and thus facilitating the assessment procedure. On the field meter, the value obtained is shown as effective or peak value.

Obtaining a result is easy, convenient, and fast. However, minimum qualifications are needed to avoid false handling and subsequently false results. Due to the isotropic characteristic of the field probe, the unknown direction of the maximum field component and the polarization are typically not relevant. In such cases, the reading corresponds to the squared sum of the field components (*Haider et al., 2002*).

It is important to note that a typical broadband field probe is not designed to distinguish between emissions of different frequencies such as radio and TV broadcast stations, GSM mobile phones, or a base station. Therefore, the field probe provides no information as to whether the meter reading corresponds to e.g. base station's emissions or to some other signal within the probe's measurement range. In fact, the reading will correspond to the sum of several signals. A field probe can be sensitive even to out-of-band signals.

Additionally, sensitivity of the devices is also rather poor with values of about 0.1 V/m.
For epidemiological studies the use of a broadband field probe is usually not recommended (an exception might be the use of probes with filter functions) because it does not capture the contribution of every source but the total of all the sources of exposure and because such probes are often not sensitive enough. A field probe might be used only when results are confirmed by additional frequency-selective measurements showing that the signal of interest is much stronger than the other signals at the measurement location (*Haider et al., 2002*).

Frequency selective measurements

For a frequency selective measurement the following components are required:

1. Frequency analyser or a receiver.
2. Receiver antenna (according to the type of measurements)
3. RF-cable to connect the antenna to the spectrum analyser.

The antenna receives the energy of the signals at the location of investigation, these signals are feed to the spectrum analyser through the RF-cable, and the analyser will display the voltage corresponding to the field strengths in the frequency range chosen (using a filter). A typical frequency range is from 9 kHz to 2.9 GHz. For measures in the surroundings of mobile communications base stations the range must at least cover the frequencies from 900

MHz to 2.3 GHz. The most suitable antennas for this purpose are dipole antennas with low directivity, like biconical antennas.

Because the purpose of the measurement is often to obtain the maximum value of the immission, the spectrum analyser might be set to MAXHOLD function so that every maximum value measured will substitute the formerly saved maximum.

4.2.2.2. Exposure assessment versus time

Dosimeters

Dosimeters allow determining the personal exposure due to electromagnetic fields versus time. It is crucial for the evaluation in respect of the electromagnetic fields from base stations and other sources to monitor in a way that allows distinguishing between the contributions from different application, e.g. mobile phones, GSM 900 base stations or broadcast stations. One system fulfilling such requirements (Figure 8) was developed by *Antennessa* (www.antennessa.com). The sensitivity of the system is reaching 0.05 V/m, the minimum measuring cycle is 3 minutes long. A personal dosimeter is essential for characterization of the exposure in the general population, as it allows measurements being taken over a longer time period during all of a person's usual activities.

Dealing with personal exposure in usual case where general public has access the frequency band of interest are FM (88 to 108 MHz), TV (174 to 223 MHz) & (470 to 830 MHz), GSM 900 [Tx(up) (875 to 915 MHz)] & Rx (935 to 960 MHz), GSM1800 [Tx (1710 to 1795 MHz)] & Rx (1805 to1880 MHz) and UMTS [Tx (1920 to 1980 MHz)] & Rx (2110 to 2170 MHz).

Frequency bands	*9 Fixed ranges*
Sensitivity	*0.05 V/m*
Dynamic	*40 dB up to 5 V/m*
Operating conditions	*-10 °C to 50 °C*
Samples	*Over 7000 samples*
Battery life	*> / days*
Dimensions	*193 x 95.6 x 69.4 mm*
Weight	*450 g*
Protection	*IP 43*
Power Supply	*230 V @ 50 Hz*

Figure 8: *Specification of a portable dosimeter (Antenessa, France)*

The measurements carried out in Europe have also shown that the results are very often below 1 Volt per meter and rarely above 5 V/m. Therefore a measurement tools having a dynamic limited to 40 dB with a measurement range of 0.05 V/m to 5 V/m is able to record the exposure in a reliable way. In order to analyze the exposure over 1 or 2 days the system shall record each 3 minutes the exposure encountered in each frequency band of interest.

Dealing with the personal dosimetry isotropy is a key point. If the dosimeter is put on a desk or on a table the E field recorded shall be assessed with an acceptable isotropy. If the antenna is close to the body coupling occurs and than free space calibration is not adequate. In this case the person is moving and the field is coming through multi-path propagation. As a consequence an averaging over an adequate time window is able to provide an estimation of the exposure.

Monitoring Systems

Monitoring systems allow monitoring continuously the whole frequency range (monitoring mode) for all types of signals in the frequency range of interest. For monitoring methods again isotropic systems are necessary, but also additional functionality of these systems is needed. Caused by their permanent operation data base functionality for data processing is recommended. The systems have to be fail safe (e.g. if the analyzer is sending not valid data or some devices have a total error) under certain conditions weather given, air-conditioned and the systems should be able to work together in a network with other stations. It becomes essential to send an alarm to a central unit if some results were exceeding the general expected signal floor or any limits. The system has to store such events in detail (field strength, frequency, bandwidth and time) whereas for the other time period sliding average values of the selected field strength will be adequate to avoid exorbitant data volume.

Some organizations perform control of the exposure with permanent monitoring systems where the levels of exposure obtained are compared with international or national guidelines. These systems consist of an isotropic probe that captures all the contributions within a specific frequency range. The data obtained in the monitoring station are sent to a central station where they are processed and displayed in graphics.
While such systems are usually broadband devices, more sophisticated ones have also been developed like the Field Nose Complete: a frequency selective and isotropic measurement system designed for short- and long-term EMF measurements as well as for monitoring and scientific studies, created in Austrian Research Centers GmbH – ARC .

The Field Nose is based in the Add3D system and works according to the dot screening method. As can be seen in Figure 9 and 10, it consists of a spectrum analyser, a precision conical dipole antenna with positioning unit that allows measurements in three orthogonal antenna orientations, a power supply unit and a measurement controller. The antenna covers a frequency range from 80 MHz up to 2.5 GHz and is designed for a dipole-like radiation pattern. The software allows the definition of measurement setups as well as data evaluation and visualization of results.

In a few words it works as follows: the antenna is positioned sequentially in three orthogonal orientations by the positioning unit. The software calculates the equivalent isotropic field strength from three measured values with the Add3D algorithm which guarantees optimum isotropic characteristics.

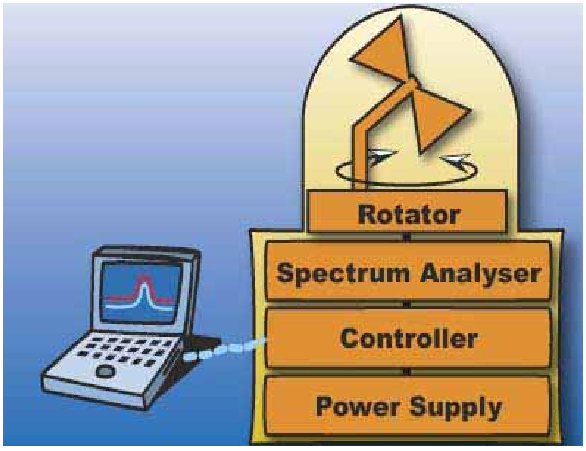

Figure 9: *Schematic of the Field Nose Complete setup*

Figure 10: *Field Nose Prototype*

5. Conclusions

One has to be aware that we are just at the beginning stages of addressing exposure and potential health problems associated with the new technology of mobile communications. More knowledge is needed mainly in development of exposure proxies and methods that minimize bias in the measures of soft outcomes. In any case, the recommendations are often outcome and study specific.

A very important first step to improve research in this field is to gain knowledge on the exposure distribution and variability of exposure in the general population from different RF sources. Exposure surveys with personal RF exposure measurements in randomly selected samples of the general population are strongly encouraged. One aim of such surveys is to estimate the contribution of the different RF exposure sources to the total exposure, in different subjects, at different points in time. A second aim is to identify characteristics that allow a valid prediction of individual exposure levels and can be used in large-scale studies.

It is not generally recommended to neglect a priori the contributions from other RF sources than mobile phone base stations. Thus, an exposure proxy has to capture all relevant sources in the RF and microwave frequency range. Systematic measurement studies in different populations are needed to obtain more data on individual’s exposure as a mixture of exposures from different sources. In terms of both cumulative and time weighted average exposure and exposure above a certain threshold it has to be investigated whether there is sufficient variability between subjects and if so, what are the main reasons, for this variability and whether it can be reliably (albeit approximately) captured in a large population. The outcome of these investigations will have significant impact on which hypothesis can be tested in the future.

The ongoing project VALEX (Validation of Epidemiological Exposure Assessment Methods) is dedicated to deal with the main dosimetric questions, e.g. evaluation of individual exposure profiles taking into account contributions from different types of RF sources. The suitability and range of application of specific exposure assessment equipment, i.e. frequency selective monitoring system and dosimeter is currently analysed in the frame of a pre-study for the project VALEX, first RF exposure assessment protocols taking into account behaviour of persons are validated.

Acknowledgements

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Laboratory and Volunteer Trials of an RF Personal Dosimeter

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Abstract

Laboratory tests and volunteer trials were carried out to evaluate a new RF personal exposure meter (PEM), which logs electric field strength in frequency bands used by certain transmitters that contribute significantly to public exposure. The laboratory tests showed the PEM had performance broadly in line with that required for its intended purpose, however it does not sum together properly the fields of multiple signals in the same frequency band. The PEM has a 50 mV m^{-1} detection threshold and data from the volunteer trials suggests that this may limit the ability to construct an exposure gradient over the range of likely exposures within a population study. Nevertheless, the PEM does seem able to discriminate the relatively high exposures of people who live near to mobile phone base station and television broadcast transmitters from those of people living elsewhere. Recommendations are made that should improve the usefulness of the PEM for validating exposure modelling techniques and as a monitor to assess RF exposure.

Introduction

There are considerable challenges in assessing the exposure of individuals in the general population to radiofrequency radiation (RF). These include the number and range of sources that have to be considered, the effect of the environment on local signal strengths, and the mobility of people. Personal use of low power devices close to the body, e.g. mobile phones, cannot be neglected because they can give higher contributions to exposure than more powerful, but distant, sources.

Published exposure data are generally in the form of spot measurements, i.e. measurements made (effectively) at a point in time and space when/where a person may be present (e.g. Mann et al, 2000; Bergqvist et al 2001; Cooper et al, 2004a). Such data have repeatedly shown that pubic exposures near to mobile phone base stations are well within the ICNIRP guidelines and, on this basis, expert groups and health authorities have concluded that the exposures are unlikely to pose a risk to health (IEGMP, 2000; WHO, 2000; AGNIR, 2003; NRPB, 2004). Nevertheless, some people believe that base stations, or other radio transmitters near to them, have affected their health. Where studies are contemplated to address such concerns, it is important to design the studies with appropriate scientific rigour.

The spot measurement data often show that, where a particular source is the focus of concern, other less visually obvious sources give greater contributions to exposure. The data also show exposures vary greatly, even at similar distances from base stations, thus confirming the considerable effect of the environment on signals through physical processes such as reflection, diffraction and mutual interference of signal elements travelling through different paths (multipath propagation). At locations where people spend most of their time, i.e. indoors, no clear trend for exposures to reduce with distance has yet been shown within the first few hundred metres of base stations. The spot measurement data would seem to challenge the suggestion that there might be such a trend.

In order to design robust studies of people's health, it is necessary to develop personal exposure estimates for the individual study subjects so that their exposures can be ranked into high/low categories. However, little information is available on personal exposures to radio waves and how they might vary with possible determining factors such as distance of residence from a base station. If a personal exposure meter (PEM) could be developed and used to reliably characterise RF exposures, this might offer a way forward for research into the health of people living near to base stations. Such an instrument could be used to assess directly the exposure of subjects in a study, or as a tool for the validation of modelling approaches.

This project aims to evaluate a newly developed personal exposure meter, the Antennessa DSP090, that is designed to be carried by people, sometimes worn on the body, and to log exposures to RF signals over time as they move around. The project comprises laboratory investigations and a volunteer trial to assess the technical performance of the instrument and the practical aspects of its use in studies. The project is supported by the UK's Mobile Telecommunications and Health Research Programme (MTHR) and the results should assist the future development of the PEM and its appropriate use in future studies.

Materials and methods

Personal Exposure Meter (PEM)
The DSP090 personal exposure meter manufactured by Antennessa was used in this project and eight units were supplied to the study. The PEM records electric field strength in the nine different frequency bands shown in Table 1 and it contains three orthogonal sensors in order to give an isotropic response. The dynamic range is from 50 mV m^{-1} to 5 V m^{-1} with a precision of 10 mV m^{-1} and the logged data have the appearance shown in Figure 1. It should be noted that the PEM gives a reading of 0.05 V m^{-1} when there is no field applied. The user specifies the recording interval and the total recording time when programming the PEM with PC software in advance of a measurement.

Band name	Active sources in the UK	Range MHz
FM	VHF broadcast radio	88–108
TV3	Digital audio broadcasting	174–223
TV4&5	UHF broadcast television	470–830
GSMtx	GSM mobile phones (900 MHz)	890–915
GSMrx	GSM base stations (900 MHz)	935–960
DCStx	GSM mobile phones (1800MHz)	1710–1785
DCSrx	GSM base stations (1800 MHz)	1805–1880
UMTStx	3G mobile phones	1920–1980
UMTSrx	3G base stations	2110–2170

Table 1: *Measurement frequency bands specified for the PEM*

Sample	Date	Time	Battery (mV)	Temperature °C	FM	TV3	TV4&5	GSMtx	GSMrx	DCStx	DCSRx	UMTStx	UMTSrx
1	12/1/2005	13:32:13	4178	19.1	0,05	0,05	0,07	0,05	0,05	0,05	0,05	0,05	0,05
2	12/1/2005	13:34:13	4155	19.6	0,05	0,05	0,06	1,03	0,05	0,05	0,05	0,05	0,05
3	12/1/2005	13:36:13	4179	19.6	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	12/1/2005	13:38:13	4187	19.9	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
5	12/1/2005	13:40:13	4182	20.1	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
6	12/1/2005	13:42:13	4158	20.3	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
7	12/1/2005	13:44:13	4193	20.3	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
8	12/1/2005	13:46:13	4174	20.2	0,05	0,05	0,05	0,05	0,05	0,60	0,05	0,05	0,05
9	12/1/2005	13:48:13	4187	20.2	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	12/1/2005	13:50:13	4189	20.1	0,05	0,05	0,08	0,05	0,05	0,05	0,05	0,05	0,05

Figure 1: *Example of logged data from the PEM*

The PEM contains filters, switches and amplifiers, which separate the signals from its three sensing antennas into the different bands. In order to conserve the batteries, each amplifier is only switched on for the part of the recording interval when it is used to make a measurement. During the periods when the amplifiers are switched on, samples are taken every 330 µs so individual GSM bursts of 577 µs duration are not missed. The maximum values from sequences of 70 samples are recorded for the GSMtx and DCStx bands and the minimum values from sequences of 20 samples are recorded for the remaining bands, other than UMTStx. For UMTStx, the average value from a sequence of 20 samples is recorded. Hence, in addition to band-pass filtering, the PEM uses special techniques to differentiate between TDMA (pulsed) signals, as from GSM mobile phones, and continuous signals, as from GSM base stations, in order to improve its band selectivity.

Exposure metrics

In many cases where the PEM was used to log electric field strength over a period of time, the resulting data sets showed the field strength was below the detection threshold of 50 mV m^{-1} for an appreciable proportion of the time. In such cases it is possible to develop numerical approaches to predict the most likely value of the mean field strength and to develop an associated uncertainty estimate.

The approach applied in this project was the same as that of Cooper et al (2004b) with occupationally acquired personal exposure records. The Uncensor 4 program, as available on the Internet from the Virginia Institute of Marine Science, was used to implement Helsel's

Robust Method. This program fits a lognormal distribution to those data samples that are above a detection threshold and then generates values at random according to the fitted distribution to replace the “censored” values below the detection threshold. Once all of the censored values have been replaced, the arithmetic mean of all the samples is evaluated.

Uncensor 4 can process a maximum of 1000 samples. Consequently, data sets from the PEM of greater than this size were sampled randomly to produce sets with exactly 1000 entries. Also, the floating point format of Uncensor 4 was fixed in the program and so the field samples (in V m^{-1}) were converted to mV m^{-1} in order to improve the precision of the program output.

Laboratory testing

A sequence of tests was designed to examine electrical aspects of the PEM performance, such as band selectivity, response to modulated and unmodulated signals, linearity and isotropy. Tests were also carried out to examine the performance of the instrument in multi-signal RF environments. Finally, testing was carried out to determine immunity of the PEM from commonly encountered electromagnetic fields in bands other than those it was designed to measure, including 50 Hz electric and magnetic fields, and domestic TV and PC monitor fields.

The RF fields used in the testing were produced in an EMCO 5311 GTEM cell using a Mini-circuits ZHL42 amplifier driven from an Agilent E4483C Vector Signal Generator. The field strength in the cell was set by positioning a fibre-optically connected Holaday HI-6005 3-axis electric field probe at the position that would be occupied by the PEM and then controlling the power into the cell to establish the required field strength prior to testing the PEM. This system was able to produce fields of precisely known frequency, strength, modulation and polarisation.
Specially shaped blocks of a low dielectric constant material (Eccostock SH2, Emerson and Cuming) were made to hold the PEM at the correct position and orientation in the GTEM cell, as shown in Figure 2. X, Y and Z orientations were defined for which a given sensor inside the PEM was directly aligned with the vertically directed electric field.

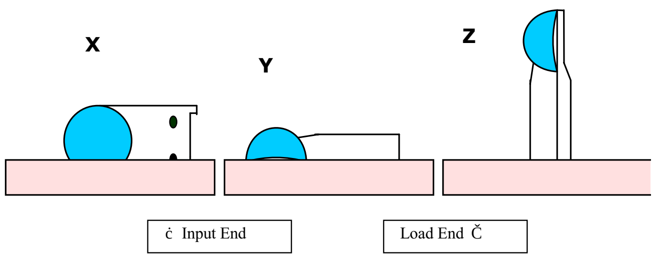

Figure 2: *Orientations of the PEM inside the GTEM cell*

A jig was prepared which allowed rotation of the PEM inside the GTEM cell in order to investigate its response in four different rotational planes. These planes are shown in Figure 3.

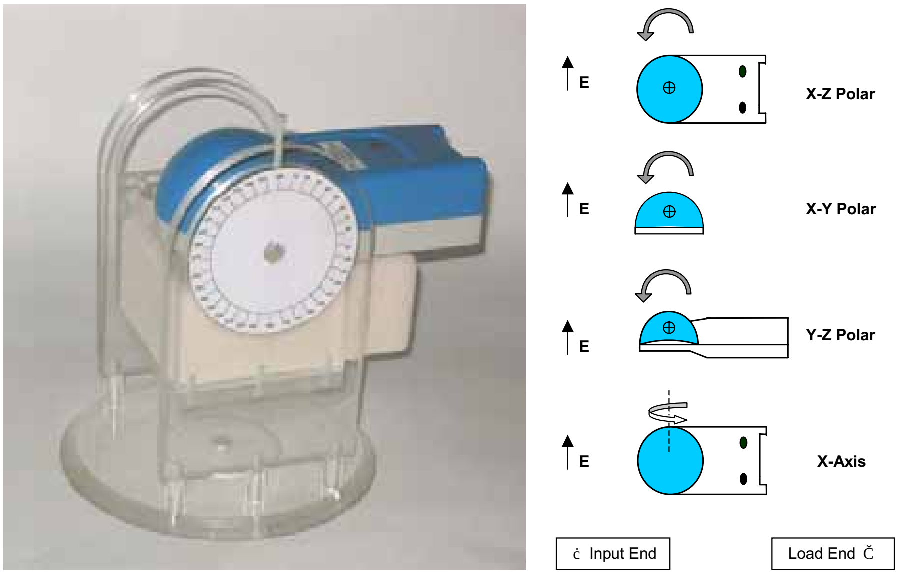

Figure 3: *Jig and rotations used to examine isotropy of the PEM response*

Volunteer trial

Ten members of staff from HPA's Centre for Radiation, Chemical and Environmental Hazards (CRCE) volunteered to use a PEM for a period of one week and to provide feedback on their experiences and perceptions. Each PEM was programmed to record every 2 minutes over the trial week – a total of 5040 measurements – and the volunteer was also asked to keep a written diary indicating where they were at a given time so this could be correlated with the recorded data.

In advance of receiving the PEM, each volunteer identified four locations where they generally expected to spend most of their time over the trial week. Typically, these locations included their office at work, and their kitchen, bedroom and living room at home. Spot measurements of signal frequencies and field strengths over the RF spectrum from 80 MHz to 2.5 GHz were made at the locations on the day of deployment and on the day of collection of the PEM. These narrowband spot measurements were made with an antenna on a tripod close to the centre of each location and the equipment is described in more detail below.

Initially, the data from these narrowband spot measurements were examined to determine whether there were any signals contributing significantly to exposure with frequencies outside the bands covered by the PEM. Then, the signal strengths were summed to evaluate the total RMS electric field strength present in each of the PEM bands, and compared with the data recorded by the volunteer's PEM when their diary showed them to have been present at the same location.

After returning the PEM, the volunteers completed a short questionnaire reporting back on their experiences and perceptions of the instrument. The questionnaire was divided into four sections, the first of which considered how much of the time the PEM had been worn and where it had been placed when not worn. The next section asked about perceptions on the design aspects of the instrument and the practicality of wearing it in various situations. The volunteers were asked to suggest any improvements for the design of the PEM and whether they felt using it had modified their behaviour in any way. The third section asked about experiences such as whether the volunteers had felt self-conscious with the instrument or whether it had attracted any attentions/comment. Finally, the volunteers were asked how long they would be prepared to use the instrument if asked to do so again, with or without a diary. Similarly, they were asked how long they felt it would be reasonable to ask a member of the public to use the PEM.

Narrowband spot measurements

The equipment used for the narrowband spot measurements consisted of an ARCS miniature biconical antenna connected to an Agilent E4407B spectrum analyser controlled from a laptop computer so that all of its settings were applied automatically. The measurement was made in 13 sub-bands, each with appropriate bandwidths, frequency resolutions and dwell times, as shown in Table 2, in order to measure the RMS field strength at each of 14788 fixed frequencies. The measurements were made in three orthogonal polarisations and at heights of 1.1, 1.5 and 1.7 m, and this took around an hour to perform.

Band	Frequency, MHz		Number of points	Resolution bandwidth	Sweep time, seconds	Notes
	Start	Stop				
1	80	154.95	1500	30 kHz	4.5	Includes FM Radio
2	155	389.9	2350	100 kHz	12	
3	390	394.998	1667	10 kHz	15	TETRA base stations
4	395	469.9	750	100 kHz	7.5	
5	470	854	1537	1 MHz	40	UHF Television
6	855	923.5	138	1 MHz	4.1	
7	924	961	1481	100 kHz	45	GSM base stations
8	961.5	1803.5	843	3 MHz	25	
9	1804	1880	3041	100 kHz	90	GSM base stations
10	1880.25	1901	416	100 kHz	13	DECT
11	1901.5	2108.5	208	3 MHz	6.2	
12	2110	2170	201	3 MHz	6	UMTS base stations
13	2172.5	2500	656	3 MHz	20	Includes WLAN

Table 2: *Spectrum analyser settings for narrowband spot measurements*

The resultant RMS electric field strength at each frequency was then calculated and spatially averaged over all three heights to reduce the sensitivity of the measurement to spatial fading. Then, a peak search algorithm was used to form tables of signal frequencies and field strengths, and experimentally derived correction factors were applied in order to account for losses due to the restricted spectrum analyser bandwidths. Finally, the signal strengths were accumulated to evaluate the total RMS electric field strength present in each the PEM bands, as defined in Table 1, and other bands of interest.

Laboratory testing results

Unmodulated signals

The PEM has nine response bands, as previously detailed in Table 1. In addition to the in-band performance, it was necessary to evaluate the out-of-band performance. Consequently, a large number of test frequencies were used. In addition to three frequencies per response band (lower, mid and upper), a number of out-of-band frequencies were also selected. The test frequencies are all shown in Table 3 with the centre frequencies of each band shown in bold.

Frequency MHz	PEM band	UK application	Frequency MHz	PEM band	UK application
49		Licence free devices	940	GSMrx	GSM900 Base Station
75		Runway ILS	**947.5**	GSMrx	GSM900 Base Station
90	FM	FM Radio Broadcasting	955	GSMrx	GSM900 Base Station
98	FM	FM Radio Broadcasting	1300		ATC Radar
106	FM	FM Radio Broadcasting	1715	DCStx	GSM1800 Handset
125		Aircraft communication	**1747.5**	DCStx	GSM1800 Handset
145		Amateur radio, Paging	1780	DCStx	GSM1800 Handset
176	TV3	PMR	1810	DCSrx	GSM1800 Base Station
198	TV3	PMR	**1840**	DCSrx	GSM1800 Base Station
222	TV3	DAB radio	1875	DCSrx	GSM1800 Base Station
380		TETRA	1900		DECT Cordless Phones
430		Amateur Radio, Licence free devices	1925	UMTStx	3G Handset
475	TV4&5	UHF TV Broadcasting	**1950**	UMTStx	3G Handset
590	TV4&5	ATC radar	1975	UMTStx	3G Handset
650	TV4&5	UHF TV Broadcasting	2115	UMTSrx	3G Base Station
820	TV4&5	UHF TV Broadcasting	**2140**	UMTSrx	3G Base Station
880	GSMtx	GSM900 Handset	2165	UMTSrx	3G Base Station
895.5	GSMtx	GSM900 Handset	2450		Ovens/WLAN/Bluetooth
912	GSMtx	GSM900 Handset			

Frequencies in bold are mid-band frequencies for each of the nine PEM bands

Table 3: *Test frequencies*

Each of the eight PEMs was exposed for 1 minute (with a 5 second recording interval) in three orthogonal orientations to each of the above frequencies. For each frequency and orientation, the mean recorded field value was derived, taking values of 0.05 V m^{-1} as zero field. Figure 4 shows a typical set of response data for one axis of one instrument.

The results of pooling the response data from the in-band tests are shown in Table 4. The mean recorded field is shown with the standard error (n=72, i.e. 8 PEMs, 3 orientations and 3 frequencies in each band) and as the difference from the actual field value in dB. The uncertainty in the right hand column of the table is the sum of the uncertainty in the exposure field and the manufacturer's figure for isotropicity.

Mean recorded field, V m^{-1}	dB relative to 2.5 V m^{-1}	Uncertainty dB
1.94 ±0.05	–2.20	1.50
2.43 ±0.08	–0.24	2.00
2.56 ±0.09	+0.19	2.60
2.90 ±0.12	+1.29	3.10
3.33 ±0.07	+2.49	3.10
2.66 ±0.06	+0.53	3.70
2.55 ±0.03	+0.17	3.70
2.55 ±0.08	+0.18	3.70
2.10 ±0.04	–1.51	3.70

Table 4: *Pooled response data from all eight PEMs*

All of the responses, except for that of the FM band, are within the expected uncertainty and the standard errors show a fair degree of consistency between responses.

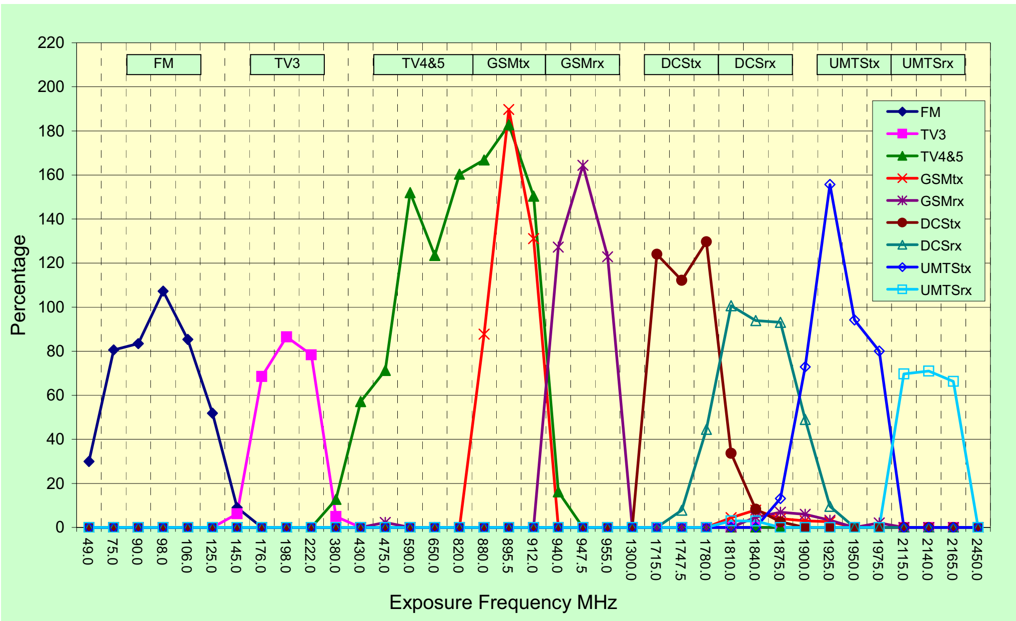

Figure 4: *Relative response of a single axis of one PEM to an unmodulated field of 2.5 V m^{-1}*

An arbitrary response level of 10% or more of the exposing field, i.e. ≥0.25 V m^{-1}, was set as a significant out-of-band (OOB) response level. There were several sets of conditions that generated OOB responses and these were as follows:

- FM band responses to 49, 75, 125 and 145 MHz
- TV4&5 band responses to GSMtx frequencies (880, 895.5 and 912 MHz)
- DCStx band responses to the DCSrx frequency 1780 MHz
- DCSrx band response to DCStx frequency 1810 MHz
- DCSrx band response to 1900 MHz (DECT)
- UMTStx band response to 1900 MHz (DECT)

These OOB responses reflect the difficulty of realising perfect band-pass filters. The FM band responses are of little consequence since they render the instrument sensitive to pager, PMR and other signals, which whilst outside the specified band, nevertheless represent actual exposure of the subject. The TV4&5 band response to GSMtx frequencies should not be a problem in practice, but the PEM relies entirely on its ability to discriminate continuous from pulsed signals in order to provide separation of signals in these bands. Similarly, the DCStx band response to DCSrx frequencies and vice versa should not be a problem in practice due to the signal discrimination aspects of the PEM.

In general, the response of the PEM should be within the intended bands with reasonable rejection of signals of other bands. However, the response of both the DCSrx and UMTStx bands to signals at 1900 MHz does pose the question of how the PEM would respond to DECT signals from cordless phones, and this topic will be considered in the results from the volunteer trial.

In-band linearity tests were performed on two instruments. For each of the nine response bands, a field of 2.5 V m^{-1} was established in the test position in the GTEM cell using the appropriate mid-band test frequency. The cell line voltage was then reduced by a factor of two to generate a field of 1.25 V m^{-1} and this process repeated a further three times, resulting in a final field of about 0.156 V m^{-1}. No significant non-linearity was seen.

A more detailed investigation of the linearity at low fields in the FM and TV4&5 bands was carried out using one instrument. This used a similar method to the earlier linearity tests, but used fields of 2.5, 0.25, 0.125, 0.10, 0.08, 0.06 and 0.05 V m^{-1}. There were difficulties in carrying out this measurement using fields close to the instrument's lower response limit. Taking account of this, no significant non-linearity was found.

Modulated signals

An extensive series of tests was conducted to determine the response of the PEM to modulated signals. In general, these were conducted with one or two instruments at field strengths of 1.0 and 2.5 V m^{-1}, using both modulated and unmodulated signals for each of the X, Y and Z orientations. Confirmation of the consistency of the RMS field between modulated and unmodulated states was obtained by the use of a thermal power meter (Rohde & Schwarz model NRS).

Responses to FM radio (98 MHz), synthetic DAB radio (198 MHz), analogue TV (CH36, with video and audio carriers at 591.25 and 597.25 MHz respectively) and synthetic digital TV (also CH36) signals were essentially identical to the responses to unmodulated signals of the same frequency.

An Agilent E4438C signal source was used to produce GSM/DCS, DECT and UMTS signals for testing. The GSM/DCS uplink signals were simulated with one out of eight timeslots active and the results confirmed the operation of the pulsed vs continuous signal discrimination functions in improving the selectivity of the bands, since the GSMtx signals were not measured in the TV4&5 band. The field recorded by the PEM represented that during the active part of the signal.

The GSM/DCS downlink signals were simulated with two carriers in the relevant band. The first carrier had between 1 and 8 active slots and was intended to represent a traffic channel (TCH) and the second was from a CW signal source and intended to simulate the Broadcast Control Channel (BCCH). If this BCCH surrogate was omitted, transmissions with up to 7 active slots were not recorded. The mean field strength recorded with the BCCH surrogate carrier alone was very slightly higher than that recorded when both carriers were present, irrespective of the number of active slots. This implied that the instrument response for multiple signals may be in error and it was investigated subsequently.

The results for UMTS uplink signals were essentially identical to the responses to unmodulated signals of the same frequency. With UMTS downlink signals, the PEM reading was around 6 dB lower when the modulation was applied.

No responses were seen with a DECT signal at 1890 MHz having one out of 12 timeslots active. An ATC radar signal was simulated at a frequency of 1300 MHz, with several pulse widths and repetition rates and with a peak field strength of 2.5 V m^{-1}. No responses were seen.

Multiple signals

A number of tests were conducted to investigate the response of the PEM to multiple signals occurring in the same or in different bands. Outputs from the signal sources were combined using an appropriate power combiner and the resultant signal fed to the amplifier and then into the GTEM cell. The fields of each individual component and of the combined signal were checked with the HI-6005 probe. In each case, the RMS sum of the individual components corresponded closely with the field of the combined signal. Finally, a spectrum analyser was used to confirm that no unwanted spurious mixing products were present.

The results where the signals were in different bands are summarised in Table 5. All signals were modulated appropriately, except where indicated. GSMrx signals were unmodulated (CW), simulating the BCCH channel.

The majority of combinations of signals in different bands showed no significant change between single-signal and simultaneous signal results. However, there was one important exception. Recorded field strength of signals in the TV4&5 band were significantly reduced, by about one third, in the presence of a GSM 900 (Base station, CW equivalent to the BCCH transmission) signal.

Tests with signals in the same band were carried out in several bands, and are summarised in Table 6. Two or three signal sources were combined using an appropriate power combiner and the resultant signal was fed to the amplifier. The fields of each individual component and the combined signal were checked with the HI-6005 probe. In each case, the RMS sum of the individual components corresponded closely with field resulting from the combined signal.

Signals applied separately				Signals applied together				Change > 10%?
Signal 1		**Signal 2**		**Signal 1**		**Signal 2**		
Band	**E, $V\,m^{-1}$**	**Band**	**E, $V\,m^{-1}$**	**Band**	**E, $V\,m^{-1}$**	**Band**	**E, $V\,m^{-1}$**	
FM	1.76	TV3	1.00	FM	1.70	TV3	0.97	No
FM	1.09	GSMrx	1.65	FM	1.10	GSMrx	1.66	No
FM	1.13	TV4&5	1.04	FM	1.11	TV4&5	1.02	No
TV4&5	1.52	GSMtx	1.43	TV4&5	1.47	GSMtx	1.41	No
TV4&5*	0.97	GSMrx	1.56	TV4&5	0.64	GSMrx	1.55	Yes, TV4&5: −34%
TV4&5†	1.43	GSMrx	1.59	TV4&5	0.96	GSMrx	1.57	Yes, TV4&5: −33%
GSMrx	1.59	DCSrx	1.28	GSMrx	1.62	DCSrx	1.28	No
* modulated ATV †unmodulated ATV								

Table 5: *PEM behaviour with two signals in different bands*

The results are shown as mean field (the mean of the recorded field in the X, Y and Z orientations) for each signal and for the recorded and predicted results. It can be seen that the instrument does not respond correctly to multiple in-band signals, the response being significantly less than the RMS sum. Thus the instrument will under-read in situations where there is more than one simultaneous transmitter in a band. This is a situation that will occur in practice, particularly with broadcast (FM, TV4&5) signals, and with multi-operator cellular sites.

PEM band	Individual signal E-fields, $V\,m^{-1}$			E-field of signals together, $V\,m^{-1}$		
	Signal 1	**Signal 2**	**Signal 3**	**Recorded**	**Predicted**	**Error %**
FM	1.66	1.98		1.77	2.65	–34%
FM	0.71	0.66		0.65	0.97	–33%
FM	0.71	0.86	0.91	1.03	1.44	–31%
FM	1.66	0.66		1.59	1.78	–11%
GSMrx	1.92	1.83		1.75	2.65	–34%
DCSrx	1.47	1.34		1.31	1.99	–45%
UMTSrx	1.63	1.65		1.73	2.32	–34%

Table 6: *PEM behaviour with multiple signals in the same band*

Response isotropy

The equipment shown in Figure 3 was used to execute the rotations also shown in the figure in order to examine the isotropy of the PEM response. The experimental method was similar to that of the previous tests, with a nominal 2.5 $V\,m^{-1}$ field. Rotational increments of 10°

were used with a recording duration of 1 minute for each position. Due to time constraints only a limited number of bands could be used; the middle frequency for the FM, GSMtx and UMTStx bands was chosen, and the response examined for rotation in the X–Y, X–Z and Y–Z planes, and about the X-axis, as shown in Figure 3. A summary of the results is shown in Table 7.

Band	**X-Z**	**X-Y**	**Y-Z**	**X axis**
FM	−0.2, −13.8 dB	+0.2, −2.3 dB	+1.4, −9.9 dB	−1.3, −2.8 dB
GSMtx	+5.3, −3.6 dB	+4.4, +1.5 dB	+4.4, −3.8 dB	+5.1, +2.0 dB
UMTSrx	−0.2, −7.8 dB	+3.4, −0.2 dB	+0.3, −11.0 dB	+2.9, −8.7 dB

Table 7: *Rotational isotropy test results compared with the PEM specification*

The results show that there are deep nulls in the polar response of the PEM for certain frequencies and directions. This is to be expected given the overall size of the PEM in relation to the wavelength and that its battery boxes and circuitry cards would have passed between its sensor and the incidence direction of the exposure field for the X-Y rotation.

Electromagnetic immunity

A parallel plate exposure system was used to establish a typical maximum environmental 50 Hz electric field strength of 5 kV m^{-1} and then a helmholtz coil system was used to establish a typical maximum 50Hz magnetic flux density of 100 μT. With both systems, the PEM was placed in the field with each of its sensors aligned in turn with the field for 1 minute, and then the logged data were downloaded. No responses were seen.

The PEM response to HF fields of frequencies of 1.8 and 27.12 MHz was examined by exposing the instrument in a TEM cell exposure system. The method was similar to that employed for the CW tests in the GTEM cell system and a field of 5.0 V m^{-1} was used. Whilst there was no response to the 1.8 MHz field, for the 27.12 MHz exposures the mean field was recorded as being 0.59 V m^{-1} in the FM band.

In order to evaluate the possibility of interference from TV receiver and PC monitor fields, PEMs were placed close to a number of PC monitors and domestic TV receivers. No responses were seen.

Volunteer trial results

Spot measurements

An initial test of repeatability of the spot measurement procedure was performed by comparing the band-accumulated data taken on deployment of the PEM with those taken on collection of the PEM. There was no guarantee that the RF spectrum would not have changed over the trial week, but even so, the data agreed with each other to within 3.4 dB (95% confidence).

Table 8a and 8b shows the spot measurement data taken on deployment of the PEM to each volunteer and the data for the 40 locations should be considered in the context of the 50 mV m^{-1} PEM detection threshold. Signals were measured in the FM band at 12 locations and in the TV3 band at 2 locations, however the field strengths in these bands never exceeded 50 mV m^{-1}. Signals were measured in the TV4&5 band in the houses of all but three of the volunteers, but the field strengths were only above 50 mV m^{-1} in the house of volunteer 5, who lived closer to TV broadcast masts than the other volunteers. Signals were rarely measured in the GSMtx and DCStx bands, and the field strength was always below the PEM detection threshold, suggesting that the signals were from distant phones, and no signals were measured in the UMTStx band. Signals were measured at 34 locations in the GSMrx band and at 24 locations in the DCSrx bands; however, the fields were only above 50 mV m^{-1} at three locations, all in the house of Volunteer 1. Signals were measured in the UMTSrx band at three locations, all in the house of Volunteer 1, and the signal strengths at two of these locations were above 50 mV m^{-1}. It is notable that Volunteer 1 lived around 300 m from a mast with TETRA, GSM and UMTS cellular antennas installed, and this was significantly closer to a mast than any of the other volunteers.

The deployment data were examined further to determine the influence of certain sources with frequencies outside the defined PEM bands. The sources of primary interest were TETRA base stations (390–395 MHz), wireless local area networks (WLANs) (2.4–2.5 GHz), and DECT cordless phones (1880–1900 MHz), and the results are shown in Table 8. TETRA signals made a measurable contribution at all but 10 of the locations, and they made a dominant contribution at the three locations in the house of Volunteer 1. DECT signals were measured in the houses of five of the volunteers and gave significant contributions to the total field. Two of the volunteers (1 and 6) had home computers with IEEE 802.11b WLAN capability in their houses and the signals from these were detected when the narrowband measurements were made in the same room as the computers, but not when the measurements were made in other rooms.

Detailed examination of the signals grouped under the “other” category showed that truncation of the TV4&5 band caused TV signals between 830 and 854 MHz to be excluded from the relevant summation. Similarly, truncation of the GSMrx band caused E-GSM base station signals in the range 925–935 MHz to be excluded. These theoretical exclusions do not appear to be a problem in practice as the laboratory testing has shown that the band filters are sufficiently wide to include these parts of the spectrum.

		Electric field strength (RMS), mV m^{-1}													
		PEM frequency bands								Other bands					Total
Volunteer	Location	FM	TV3	TV4&5	GSMtx	GSMrx	DCStx	DCSrx	UMTStx	UMTSrx	TETRA	WLAN	DECT	Other	
1	Home, Living room					**86**		**77**		39	113		36		170
1	Home, Dining room					**104**		**119**		**56**	116	72	11		217
1	Home, Bedroom					**170**		**113**		**55**	104		37		238
1	Work, Office					9		18							21
2	Home, Study room					4								5	6
2	Home, Kitchen	4				8								3	9
2	Home, Bedroom	11		11		16								6	23
2	Work, Office			14		18		7			1			26	35
3	Home, Living room			18	9						3		14	5	25
3	Home, Kitchen			16		3					1			7	17
3	Home, Bedroom	5		16	12						3		60	6	64
3	Work, Office					4		7			1				8
4	Home, Living room			8		3		23			1			11	28
4	Home, Kitchen			18		2		11						6	22
4	Home, Bedroom	7		9		11		33			2			14	39
4	Work, Office					18		37			1			16	44
5	Home, Living room	18		**69**							3		22	8	75
5	Home, Kitchen	16	15	**82**							2		36	12	93
5	Home, Bedroom	39	11	**130**	17	6					5		15	26	141
5	Work, Office					7		15							17

Table 8a: *Spot measurements of signal electric field strengths made with the narrowband measurement system, spatially averaged over heights of 1.1, 1.5 and 1.7 m, and summed across the PEM and other relevant frequency bands. Electric field strength values shown in bold face are of sufficient strength and in the correct bands to be measured by the PEM.*

		Electric field strength (RMS), mV m^{-1}													
		PEM frequency bands									Other bands				Total
Volunteer	Location	FM	TV3	TV4&5	GSMtx	GSMrx	DCStx	DCSrx	UMTStx	UMTSrx	TETRA	WLAN	DECT	Other	
6	Home, Living room					11					3			7	13
6	Home, Kitchen					5					2	102	10	4	103
6	Home, Bedroom	7				37		22			7			34	56
6	Work, Office					20		42			1			43	63
7	Home, Living room													3	3
7	Home, Kitchen													3	3
7	Home, Bedroom					5		6			4			11	14
7	Work, Office					5		7			1			10	13
8	Home, Living room			11		8		12			1		14	12	26
8	Home, Kitchen			8		4		23			1		8	11	28
8	Home, Bedroom			30		13		43						22	58
8	Work, Office			23		6								14	27
9	Home, Living room			11		28		16			13			11	38
9	Home, Kitchen	4		31		45		30			12			17	66
9	Home, Bedroom	6		13		25		28			24			9	48
9	Work, Office					4					1				4
10	Home, Living room			4		15		9			37			20	46
10	Home, Kitchen					13		7			24			20	34
10	Home, Bedroom			8		17					27			28	44
10	Work, Office	5				6		7						11	15

Table 8b: *Spot measurements of signal electric field strengths made with the narrowband measurement system, spatially averaged over heights of 1.1, 1.5 and 1.7 m, and summed across the PEM and other relevant frequency bands. Electric field strength values shown in bold face are of sufficient strength and in the correct bands to be measured by the PEM.*

Other signals frequently detected with the narrowband equipment were those used for wide area paging, around 138 and 153 MHz, and other ones of unknown origin at 469.8 and 961.0 MHz. Signals were occasionally measured at other frequencies, such as 168, 185, 206 and 453 MHz. The maximum field strength of any of these paging and other signals was 12.4 mV m^{-1} and considerably below the 50 mV m^{-1} detection threshold of the PEM. This suggests that there would be little merit in adding further bands to the PEM, beyond those of TETRA, DECT and WLAN.

Personal measurements

The records in the personal exposure data from each volunteer were assigned tag numbers based on where the diary showed the volunteer was present at the corresponding point in time. The first four tag numbers were the spot measurement locations for each volunteer, and a small number of other tag values were assigned, e.g. travelling in a car, and time spent outdoors. This allowed the recorded data to be analysed separately for each location. The data from Volunteer 10 were lost because of a battery charging problem.

The PEM records the field strength in V m^{-1} and to two decimal places. A histogram was thus formed for each volunteer/location combination, and also for the entire data set arising from each volunteer, with each of the 495 levels from 0.05 to 5.00 V m^{-1} defined as a separate bin. The data were then further processed to form curves, similar to that in Figure 5, in which the x-axis was a field strength threshold and the y-axis was the percentage of the appropriately tagged samples above that threshold.

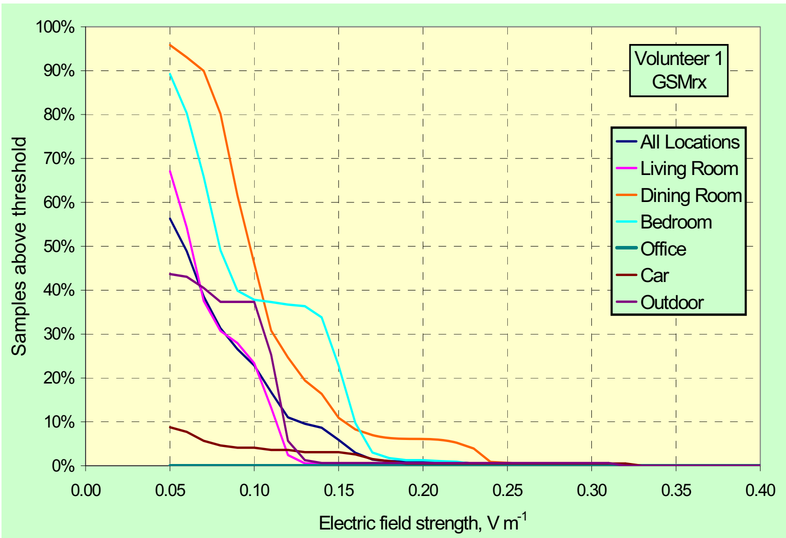

Figure 5: *Example of processed personal exposure record results for the exposure of one volunteer in the GSMrx band*

Figure 5 shows that the highest GSMrx exposures for Volunteer 1 occurred in the dining room, where the field strength of 96% of the records (i.e. 96% of the time) was above 50 mV m^{-1}. Very little of the time was the field strength for any of the locations above 250 mV m^{-1}. A set of graphs similar to Figure 5, but covering all volunteer/band/tag combinations was produced. Numerical methods described in the exposure metrics section were then used to estimate the mean electric field strengths and the results are shown in Table 10a and 9b.

The numerical methods proved unreliable where very few data were above the detection threshold and so mean field strengths were not estimated where less than ten such values were recorded. Among 43934 records taken across all the volunteers, only eight were above 50 mV m^{-1} in each of the FM, TV3 and UMTStx bands, and so these bands are omitted from the table. The GSMtx and DCStx bands were omitted from the table as there were few situations giving rise to many records above 50 mV m^{-1} and these situations are discussed below.

Volunteer number	Location number	Frequency band			
		TV4&5	GSMrx	DCSrx	UMTSrx
1	All	33 (30–35)	73 (64–84)	53 (47–61)	
	1 Living room	41 (38–45)	77 (67–88)	56 (49–64)	
	2 Dining room	42 (39–45)	104 (77–144)	68 (59–78)	
	3 Bedroom		115 (100–132)	131 (97–181)	
	4 Office (Work)				
	5 Car		38 (33–43)	25 (19–35)	
	6 Outdoor				
2	All				
	1 Living room				
	2 Dining room				
	3 Bedroom				
	4 Office (Work)				
	5 Car	14 (12–16)			
	6 Outdoor				
3	All	15 (11–21)		15 (11–21)	
	1 Living room				
	2 Kitchen				
	3 Bedroom				
	4 Office (Work)				
	5 Car	53 (39–73)	39 (29–53)	46 (34–64)	25 (22–29)
	6 Outdoor	67 (58–77)	50 (32–84)		
4	All	9.0 (6.7–12)	12 (9.2–17)	9.8 (9.1–11)	
	1 Living room				
	2 Kitchen				
	3 Bedroom				
	4 Office (Work)				
	5 Car	26 (23–30)	29 (21–40)	21 (18–24)	
	6 Outdoor	9.1 (8.0–11)	19 (18–21)	16 (15–17)	
	7 Bathroom (Home)	51 (47–55)			

Table 9a: *Personal exposure mean electric field strength estimates in mV m^{-1} (95% CI) for various volunteer/band/location combinations*

Volunteer number	Location number	Frequency band TV4&5	GSMrx	DCSrx	UMTSrx
5	All	52 (48–56)	11 (7.9–15)	18 (14–25)	8.1 (7.1–9.3)
	1 Living room	55 (51–59)			
	2 Kitchen	53 (49–57)	13 (10–19)		
	3 Bedroom	68 (63–74)			
	4 Office (Work)	26 (24–31)	49 (36–68)	40 (30–56)	
	5 Car	29 (27–32)	26 (24–28)	54 (40–75)	27 (23–31)
	6 Outdoor	530 (330–820)	63 (47–89)	47 (36–67)	
	7 Train	98 (85–110)			
	8 Study (Home)				
6	All				
	1 Living Room				
	2 Kitchen				
	3 Bedroom				
	4 Office (Work)				
	5 Car	19 (16–22)	7.6 (5.6–10)	10 (7.6–14)	
	6 Outdoor				
7	All	4.3 (3.8–5.0)	6.3 (4.7–8.8)		
	1 Living Room				
	2 Kitchen				
	3 Bedroom				
	4 Office (Work)	39 (34–45)	19 (16–21)	19 (17–22)	
	5 Car	15 (14–17)	30 (22–41)	27 (23–31)	25 (22–29)
	6 Outdoor				
	7 Train				
8	All	7.1 (5.2–9.8)	8.8 (7.7–10)	8.1 (6.0–11)	
	1 Living Room				
	2 Kitchen				
	3 Bedroom				
	4 Office				
	5 Car	30 (22–41)	36 (26–49)	36 (27–50)	19 (17–22)
	6 Outdoor	40 (38–44)			
	7 Dining Room	16 (14–18)			
9	All	13 (9.3–17)	13 (9.9–18)	17 (13–24)	9.8 (7.3–14)
	1 Living Room	15 (14–16)			
	2 Kitchen				
	3 Bedroom				
	4 Office				
	5 Music Room	100 (95–110)		56 (51–60)	
	6 Outdoor	24 (18–34)	36 (23–60)	46 (29–77)	

Table 10b: *Personal exposure mean electric field strength estimates in mV m^{-1} (95% CI) for various volunteer/band/location combinations*

A range of exposures was evident in the TV4&5 bands across the volunteers and locations, although 94% of samples taken across all volunteers were below the detection threshold. 69% of the samples above the threshold were acquired from Volunteer 5, who, as noted in analysing the spot measurement data, lived nearer to VHF/UHF broadcast radio masts than the other volunteers.

Circumstances		Electric field strength, V mī1						Ratio, dB		
		Personal measurement			Spot measurement					
Volunteer	Location	TV4&5	GSMrx	DCSrx	TV4&5	GSMrx	DCSrx	TV4&5	GSMrx	DCSrx
1	1	41	77	56		86	77		ī 1.0	ī 2.8
	2	42	104	68		104	119		0.0	ī 4.9
	3		115	131		170	113		ī 3.4	1.3
5	1	55			69			ī 2.0		
	2	53	13		82			ī 3.8		
	3	68			130			ī 5.6		

Table 11: *Difference between personal exposure mean estimates when the diaries showed the volunteers were at the spot measurement locations and narrowband spot measurements*

The data from the GSMtx, DCStx and UMTStx bands indicated that the volunteers made little use of personal mobile phones. Data above 50 mV mī1 were recorded in certain situations, for example 43% of the time when Volunteer 5 travelled on a commuter train. Another notable occasion was when a volunteer placed a PEM next to a DECT base station by their bedside. Continual recording of data just above 50 mV mī1 throughout the night indicated that the DECT signals were being measured in the GSMtx band.

In analysing the spot measurement data, it was noted that Volunteer 1 lived closer to a TETRA/GSM/DCS/UMTS mast (around 300 m) than any of the other volunteers. The personal measurements reflect this situation in that the mean field strength estimates for this volunteer are appreciably higher than with the other volunteers. The readings from the other volunteers exceeded the detection threshold for much smaller amounts of time, typically less than 10%, and mean estimates could not be constructed for many of the situations. The greatest fields seemed to be recorded when the volunteers were outdoors or in their cars, rather than inside their homes. Few records were above the detection threshold in the UMTSrx band.

The personal exposure mean estimates were compared with narrowband spot measurements taken at the same locations on the day of deployment of the PEM and the results are shown in Table 10, where values for both sets of data were available.

The only situations where data were available both from spot measurements and personal exposures were with the TV4&5 band in the house of Volunteer 5 and with the GSMrx and DCSrx bands in the house of Volunteer 1. In this limited set of cases, the data were within 6 dB of each other, suggesting that the spot measurements gave a fair representation of subsequent personal exposures at the locations.

Feedback questionnaire

The volunteers were not given prescriptive instructions about how and when they were to wear the PEM on their body, but the belt clip and the method of mounting on the waist were drawn to their attention. The volunteers were encouraged to experiment with wearing the PEM in different ways to find what suited them and their clothing style. Five of the volunteers did not use any form of bag/rucksack and reported varying degrees of success in wearing the

PEM using its belt clip. Particular difficulties reported with wearing the instrument on the waist included the clip pushing off the belt when the volunteer sat down and that the clip did not suit all types of clothing, e.g. dresses without belts. One volunteer wore the PEM inside a small rucksack behind their shoulders. This meant that the PEM did not interfere with movement when standing and walking, but the rucksack had to be removed when sitting down. There would be the possibility of the PEM rotating inside the rucksack to face the body, thus shielding its sensors, but this was avoided by hanging the PEM by its belt clip from a loop of tape inside the rucksack. Two volunteers used the PEM inside a bag strapped around their waist, which had the comfort advantages of using a rucksack and also allowed the bag to be rotated around the waist to a convenient position. The remaining two volunteers used shoulder bags, with which the loose shoulder straps allowed the PEM to be moved around the body to a convenient position, even when driving.

When the volunteers were not moving around, they generally removed the PEM and placed it nearby. When in their lounges, volunteers were usually sat on a sofa or chair and placed the PEM on the arm of the chair, or on a table next to the chair. The volunteers indicated that it was easy to forget to pick up the PEM when they went to the kitchen or bathroom, and that sometimes when they knew they would only be away for a few minutes, they chose to leave the PEM behind. On some occasions volunteers left the PEM in the living room overnight rather than taking it to their bedroom because they forgot to pick it up.

There was a clear consensus among the volunteers that the instrument was larger than ideal and that it should be made smaller if possible. One volunteer observed that a good target size would be similar to a large mobile phone. Conversely, two volunteers pointed out that the large size of the PEM meant that they were more likely to notice it and therefore less likely to forget to pick it up. Views on the weight of the instrument were split roughly equally, with only two volunteers strongly expressing that the PEM was too heavy when worn on the waist. Carrying the PEM in some form of shoulder bag would probably lessen concerns about its weight.

Using a body worn instrument, such as a personal exposure meter, inevitably causes some changes in the behaviour of the wearer. The important question is whether any of these changes in behaviour affect their exposure. The volunteers were asked whether there were any situations in this trial where they felt using the PEM had appreciably modified their behaviour. The main issues were associated with filling in the diary and keeping the PEM near the volunteer. One volunteer felt they had moved around less in their house due to the burden of knowing that they would have to complete a diary entry. Another highlighted forgetting to pick up the instrument on leaving a location, because they then had to retrace their movements and find where they had left it. Generally the volunteers did not feel overly self-conscious with the PEM, although it was regarded as better to wear it under clothes or in a bag so it was not on view. There were some situations where volunteers chose not to wear/use the PEM and these were in an aerobics class, in a nightclub, and at home on a day when they spent some time closely supervising a small child.

Questions were asked about how long the volunteers would be prepared to use the PEM in a future trial with and without keeping a written diary. Generally, a week was seen as the maximum time while keeping a written diary, with seven of the volunteers indicating this period. Without keeping a written diary, some of the volunteers would be prepared to wear the PEM for longer, so two to four weeks would seem practical.

The volunteers were then asked to consider how long they felt it would be reasonable to ask a member of the public to use the PEM in a future study. With a diary, most of the volunteers felt a week would be acceptable, but there were a number of reservations and one volunteer felt it would be unreasonable to expect a member of the public to keep a diary for any length of time. One volunteer felt that much would depend on whether the PEM could be made lighter and smaller. If a member of the public were not expected to keep a diary, again it would seem possible to use the PEM for longer, with 1–2 weeks seeming acceptable.

Discussion and conclusions

The personal exposure meters (PEMs) supplied to this project had specified measurement bands appropriate for FM broadcast radio, GSM1800 (DCS) mobile phones and base stations, and UMTS mobile phones and base stations in the UK. The bands specified for UHF television broadcast, and GSM900 mobile phones and base stations, were of insufficient width to capture all such active sources in the UK and they should be widened. The TV3 band supplied to account for VHF broadcast television transmitters in France is unnecessary for the UK, where such sources are not present. Important omissions from the PEM include the bands for TETRA base stations, DECT cordless phones and wireless computer networking.

Across all eight PEMs, the responses to appropriately modulated signals were broadly correct (within 3 dB) for individually applied signals. The calibration certificates supplied with the PEMs appeared to show generic data and it would be better if the PEMs were individually calibrated so that their readings are traceable to appropriate standards with defined uncertainties.

The PEMs do not respond correctly to multiple signals present in the same band, and give readings less than the RMS field strength of all the signals combined. This is a particular problem where multiple signals of similar strength are present, as from broadcast television stations that may produce up to five signals of similar strength in the UK. The response of the PEM to multiple in-band signals should be examined to see if it can be rectified. If this cannot be done, consideration will have to be given to the additional uncertainty introduced in any studies carried out.

The PEM sensing element incorporates three orthogonal electric monopoles mounted on the faces of a cuboid. Such a configuration is potentially able to give a fairly isotropic response; however, the PEM has circuit boards and batteries of appreciable size adjacent to its sensor and these can be expected to degrade its isotropicity. Measurements confirm that the sensor is significantly less isotropic than the ±0.5 to ±2.5 dB (according to band) claimed in its specification. Nulls of at least 13.8 dB depth and peaks of at least 5.3 dB were identified. Given the design difficulties, it is difficult to see how this situation could be greatly improved.

Much of the time, the recorded data from the volunteers who used the PEM in this project were below the 50 mV m^{-1} detection threshold, and this lack of sensitivity seems likely to limit the ability of the PEM in constructing an exposure gradient within a population study. Nevertheless, the PEM does seem able to discriminate the relatively high exposures of people who live near to mobile phone base station and television broadcast transmitters from those of people living elsewhere.

Volunteers generally found the PEM difficult to wear on their waist, and not supplying an alternative method for them to carry the PEM caused them difficulties in this trial. Several of the volunteers devised other ways of carrying the PEM on their person, such as in a small rucksack, in a bag worn on the waist, or in a shoulder bag. On balance, the shoulder bag seemed the most practical method since it could be rotated about the body when the volunteers sat down or were driving etc. With such a bag, care would have to be taken to ensure the PEM is attached inside so it cannot rotate to face the body. There was also a strong consensus among the volunteers that the PEM needed to be smaller to be used as a body-worn instrument. Weight was felt to be less of an issue than size. It is likely that concerns over the size of the PEM could be ameliorated by supplying it in some form of shoulder bag, as recommended above.

An important technical question when the PEM is taken off the body and placed nearby is where is the most appropriate position to put it in order for it to give a realistic estimate of personal exposures? It is not easy to answer this question definitively in the absence of detailed experimental testing in homes where the exposure levels are consistently above the PEM detection threshold. Poor placement of the PEM will give systematically higher or lower exposures and it may be possible to develop guidance in order to avoid poor placement. Positioning the PEM on window sills will lead to over-estimates of exposure and positioning it at floor level will lead to under-estimates. Guidance should be developed for users of the PEM in order to avoid inappropriate placement when it is not carried on the body.

It is possible to envisage two broad applications for the PEM, and the technical requirements are different for each application. First, the PEM could be used as a validation tool for exposure modelling techniques, in which case it only has to measure the field of individual signals from known transmitters. Second, the PEM could be used as a tool to measure the total exposure of subjects to all RF signals, in which case it needs to sum the signals in the context of the chosen exposure metric. With due heed given to the conclusions of this work, the PEM should be useful for both applications.

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Occupational RF Exposure from Base Station Antennas on Rooftops and Buildings

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The proliferation of radio base stations in urban environments, particularly on building rooftops and on façades, has resulted in an increasing number of RF EMF sources at different frequencies, output power levels and types. People working with antenna installation and maintenance for the network operators receive information concerning their exposure to RF fields, but it may also be the case that other workers temporarily can have their workplace in the near vicinity of an antenna system, without having received any, or limited, information about the RF exposure situation. Some examples are painters, chimney sweepers, people shovelling snow, technical staff dealing with repairing or maintenance of roof, roof-racks and gutter or with heating, ventilation and air conditioners, as well as others who could be called on to perform work on buildings.

For base station antennas, a compliance boundary can be used to describe the RF exposure and outside this boundary the exposure is below the relevant limits. The size and shape of the compliance boundaries vary with frequency, output power level and antenna type. The figure below shows a simplified compliance boundary determined with respect to the ICNIRP general public reference levels for a typical 3G/WCDMA base station antenna (14.5-18 dBi antenna gain, 60-130 cm height) with emitted output power levels up to 25 watt. For this configuration, the compliance boundary has the shape of a cylinder with a diameter of 3 m and a height corresponding to the antenna height plus 20 cm (10 cm above and 10 cm below). The cylinder starts 10 cm behind the back of the antenna. Using the basic restrictions, expressed in terms of SAR values for whole body and local exposure, it has been shown by numerical calculations with a human whole body model that the diameter of the compliance boundary is less than 1 m for the same type of base station configuration [Ref 1]. When applying the ICNIRP occupational exposure limits the size of the boundary is further decreased to some tenths of a meter. An example of such a calculation is given in Figure 2 from Ref 1.

Possible co-location of antennas at a site and additive exposure from other RF sources might change the size and dimension of the compliance boundary. Also the occasionally complex geometry of reflecting areas from roof surfaces can change the compliance boundary determined in free space although it can be shown that reflecting objects outside of the main beam of the antenna (defined by the –3 dB beam widths) only have minor effects [Ref 2]. In Europe, standards are under development describing the requirements and procedures to verify that the general public have no access to areas where the exposure, including exposure from other radio sources, might exceed the limits when a base station is put into service in its operational environment.

When considering occupational exposure it is often of interest to investigate the time-averaged exposure when, for example, a chimney sweeper need to quickly pass the area directly in front of an antenna. The ICNIRP exposure guidelines specify a six minutes averaging time and due to the high directivity of most base station antennas, which means that the radiated energy is concentrated to a main beam in front of the antenna, the time-averaged exposure is well below the limits for a person passing with normal walking speed in front of a typical antenna.

However, there could arise situations where workers need access to areas with exposure levels exceeding the general public limits. For such situations, there is a need for a careful investigation and clarification of operational procedures of control, measurements and instructions, elaborated and aimed to protect the health and safety of the workers.

Brochures or similar materials should be made available for technical staff repairing buildings, which provide relevant information about EMF exposure from base station antennas, precautions to be undertaken before and during the execution of tasks at the roof of buildings, working instructions, access restrictions and possible warnings, etc. Many network operators already provide such information to landlords and owners of the buildings on which the antennas are installed. It may be a need to standardize this type of information to workers. Additionally, it could also be needed, within this scope, to review the situation of workers wearing pacemakers, microprocessor controlled medication dosage devices, metallic prosthesis, etc.

A matter that also may need to be clarified in some countries is the one related to legal responsibilities. Although employers normally have the safety responsibility of their employees, contractual forms between various possible employers (building owners, subcontractors, etc) and workers may result in an unclear understanding on who is the one that must account for the information to the workers.

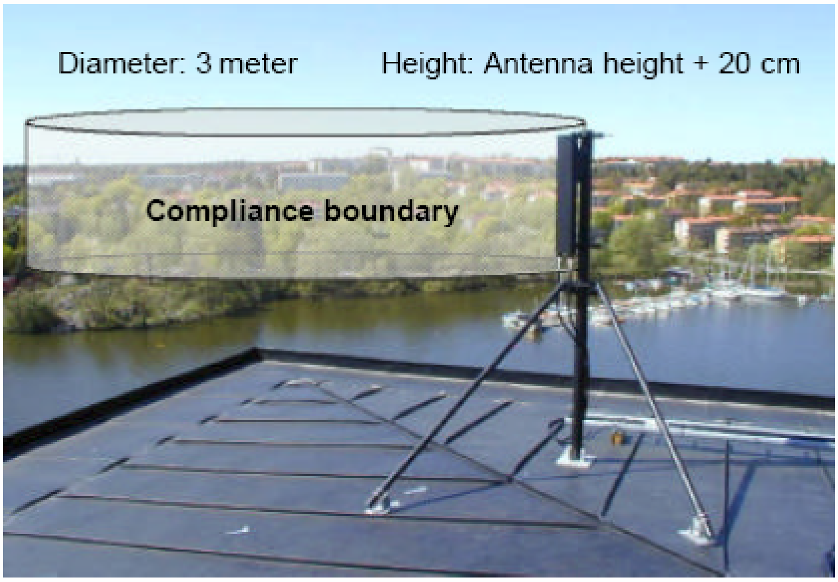
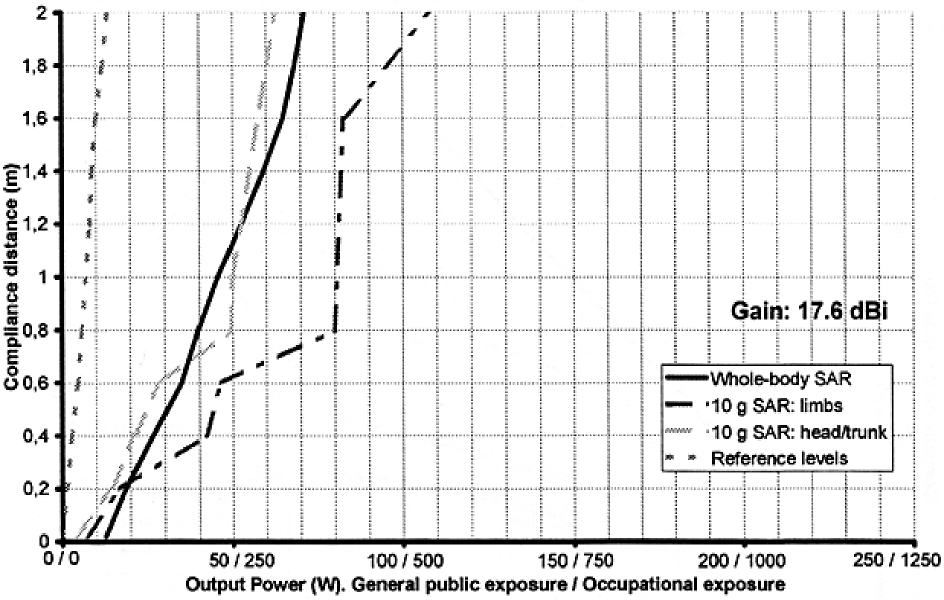


Figure 1: *Example of a compliance boundary with regard to the ICNIRP reference levels for the general public.*



Compliance distance as a function of output power for the 17.6 dBi antenna.

Figure 2: *Example of a compliance boundary with regard to the ICNIRP basic restrictions for both the general public and occupationally exposed workers. The SAR values in the whole-body, limbs and head and trunk are calculated for different output power and distance to the antenna. From ref 1.*

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POLICY OPTIONS

Regulating the risks of mobile phone base stations: a comparative study in 5 European countries

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Abstract

Based on a comparative study of risk regulation in five countries (Belgium, France, Spain, Switzerland and the UK), this chapter focuses on the impact regulatory regimes have on the construction of risk. Analyzing the process of agenda setting, scientific expertise and decision-making, it assesses the influence exerted by the institutional framework on risk regulation. The argument is that the management of emerging risks relates as much to the issue of scientific uncertainty than to the capacity political institutions show in solving highly complex problems embedded in social, economic, political and judicial uncertainties. Hence, institutional coherence and consistency between the different agents determine the content and outcome of risk regulation.

Studies of risk in the social sciences have focused on either the social construction of risk or risk regulation by government agencies and organizations. In the first case, different strands of research have looked at the role of public perceptions, culture, scientific controversies or social movements, to analyze the way in which risks are constructed, i.e. how an activity or a substance comes to be seen as presenting a risk for health or the environment[1]. In the second case, studies have been more concerned with the manner in which public authorities manage issues of uncertainty through the tools of risk analysis and the use of various regulatory instruments to reduce or mitigate risks[2].

This paper wishes to argue that these two approaches must be combined, in order to understand the inherent political nature of risk issues. We aim to show that risk regulation actually plays a part in the construction of risk, alongside in particular social movements and scientific controversies. We also wish to stress that risk regulation encompasses a wider range of organizations and agents than is usually understood, including private firms, local government, the courts and even NGOs. Finally, we want to demonstrate the determinant role played by the political institutional framework on the content of risk regulation. Risk regulation is not just about getting the science right, taking the appropriate measures to reduce whatever risk exists, and communicating to the public the information necessary to assess the risks and adopt the right behavior; it is also about managing institutional incoherence between competing agencies, ministries, local governments and experts. As Hood *et alii*[3] have shown, many risk regulation regimes are characterized by a substantial disconnection between the different components of the regulatory process. This incoherence has as much impact on the

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decisions taken and their effectiveness, than the risk assessment provided by scientific experts and the legal framework in which these decisions fit in.

Such an argument calls for a comparison of risk regimes, either in one country on various risks, or across several countries on a similar issue. Yet, comparative studies in risk regulation remain scarce although those that were produced remain highly influential. Furthermore, existing studies have often focused on known risks, such as chemicals for example, and have less frequently dealt with emerging risks. This notion refers to activities or substances which present a high degree of uncertainty. The uncertainty is not only scientific, but also economic, political, social and even judicial. In other words, the uncertainty is not only about “known unknowns and unknown unknowns” in the science, it also comprises the attitude and behavior of the various agents who are either responsible for an activity or a substance, in charge of controlling it, or concerned by its potential or actual effects. These activities or substances present a high degree of risk for public officials and private firms alike, notably in terms of liability, political legitimacy, and financial consequences.

This chapter presents the results of a comparative study in risk regulation across 5 countries[4] – after a previous study of the controversy around BS in France[5]. In all 5 countries, public officials were confronted with similar local protest movements against the erection of mobile phone base stations (BS). These movements, albeit limited in number, progressively focused on possible health effects of electromagnetic fields (EMF) – even though no such effect had been clearly demonstrated by scientists working on EMF worldwide. Hence, this was a case of regulating “unknown unknowns”, an activity for which public officials are not well prepared but which they monitor closely following recent health crises and scandals throughout Europe. Related to this was, of course, the issue of applying or not the precautionary principle to mobile phone BS.

The countries were chosen according to the levels of exposure to EMF adopted by the regulators: 3 countries followed the 1999 European Recommendation based on guidelines issued by ICNIRP (France, Spain, United Kingdom), while 2 adopted lower levels of exposure (Belgium, Switzerland). The 5 countries are quite close in terms of levels of socio-economic and technological development. We also chose them because the situation in these countries was often referred to in the French debate (either to justify existing levels of exposure or to call for more precautionary measures) and we wanted to measure the possible influence regulation in one country had on another.

The survey included interviews in the five countries with public officials (national and local), experts, mobile phone operators or their professional associations, opponents to BS and counter-experts; we analysed reports, regulatory measures and various documents published on the matter. Our purpose was to describe and analyze the process of agenda setting, scientific expertise, decision-making and implementation. Our method is based on a social constructivist approach to risks and a public policy analysis framework to regulation, stressing in particular the influence of institutional constraints on policy making.

The study was financed by the *Programme Sciences Biomédicales, Santé et Société* (CNRS, MIRE, INSERM).

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The rise of contestation

The issue of BS arose in similar terms across the 5 countries. Reactions emerged toward the end of the 1990's, when the networks were already in large part rolled-out. They were often a reaction to the densification in BS roll-out, due to the massive use of mobile handsets, the arrival of late competitors who had to build-up their own network rapidly, and the development of third generation mobile phone technologies. The densification of the networks resulted in the fact that BS became more numerous, more visible and closer to homes. Most oppositions started out as a reaction to the intrusion of these equipments in individuals' familiar daily environment. Individuals and groups protested against nuisances and aesthetic concerns, the possibility that their land or house values would diminish, or the fact that no satisfactory answers were given to their initial queries or expressions of anxiety.

The inadequacy of planning regulation

In all 5 countries, the installation of BS initially came under the planning law. This provided for authorizing a BS if it complied with rules and procedures. Local authorities were responsible for examining the application and giving (or refusing) the authorization; but the law did not allow them to refuse on the grounds of personal convenience or political motives. Operators installing a BS also had to go through a procedure of authorization with national telecommunication authorities, but this was mainly a technical matter with little negotiation. Given the fact that BS were relatively light equipments, no information of neighboring populations was provided for, and it was not requested that operators assess the possible health and environmental impacts of BS.

This initial regulatory framework was rapidly equated by local opponents with a lack of adequate protection and means to make themselves heard. They exercised strong pressure on mayors, forcing them to take measures against BS even though local authorities had no legal ground to do so. This first period thus revealed the inadequacy of existing rules and procedures concerning electronic devices installed in populated areas, and it encouraged local opponents and officials alike to fight for stricter regulation given the lack of means provided by planning law.

The organization of contestation

Protest movements were initially local and showed similar traits from one country to the other. First, they were often embedded in local issues: either pre-existing conflicts or strong social or political stakes. Second, places in which contestations arose had often undergone deep socio-demographic changes with consequences on their physical appearance (individual housing units, for example). Third, opponents to BS actively used the Internet to collect information and build up their argument. It is through this medium that they came upon data which suggested the existence of possible health effects, along with information on movements elsewhere in their country or in other countries. Links were quickly established, in particular through e-mails, and what started out as a series of local contestations slowly built up into a global movement. This process was clearly observable in France and the UK.

In some cases (France and the UK), existing NGOs took on the issue or were founded in order to coordinate local movements at the national level. In the federal States (Belgium, Spain and Switzerland), NGOs tended to be more present at the regional rather than the central level, although this did not exclude peak associations at the federal level.

National NGOs relayed the demands of local protest movements; but simultaneously, they established a link between these movements and other NGOs and counter-experts fighting against EMF for a number of years. Hence, what started out as a series of local protest movements fighting on planning issues progressively turned into a national movement against a health or environmental risk. A change in the planning law was demanded, along with stricter authorization procedures; but NGOs also undertook, using the influence derived from their capacity to speak on behalf of the numerous local movements, to request lower levels of exposure, based on the precautionary principle.

In federal States, local protest movements tended to find regional authorities more responsive, with the result that NGOs were not as strongly organized in these countries as they are in more centralized States (France and UK). Regional authorities, either under pressure from local authorities or because they saw an opportunity to demonstrate their political capacity on highly sensitive issues, were immediately sympathetic to the contestation of BS and open to the possibility of taken stricter measures against operators.

Hence, the institutional framework exerts some influence on the form taken by protest movements. These movements, along with NGOs, will tend to organize at the level at which they can hope to obtain the most results or exercise pressure. Thus, in the federal States, they will work at the regional level which is in charge of planning regulation, while this remains a national prerogative in more centralized States. Health, on the other hand, is most often a central prerogative, even though regions may have some limited means in some cases. As for telecommunications, it is systematically a central State mission.

This division, in turn, suggests that, whilst in centralized countries, public authorities will have to strike a compromise between different interests and dimensions of the problem, this is not the case in more decentralized countries in which regional authorities can easily take decisions on planning issues without having to take into consideration health or telecommunications, since these remain within the realm of central government. In other words, this makes it potentially easier for them to adopt stricter regulation on BS roll-out, while in centralized countries, the ministries in charge of telecommunications will be quick to exert pressure on their health or planning colleagues, should they be tempted by stricter rules on operators or the adoption of precautionary measures.

“Normal” contestation

Local reactions to BS come as no surprise: other infrastructures have triggered similar reactions, often easily denounced as Nimbyism, a convenient cover-up for the lack of prior information and consultation of neighboring populations. Situations where there exists some competition over the use of land, or where activities generate nuisances, can be expected to lead to local reactions. But not all reactions stem into a problem of national importance. In this respect, BS are an interesting case.

In other words, local reactions to the roll-out of thousands of BS are to be expected, they are “normal” – and actually often quite limited in number compared with the total number of BS. Rather, the question that can be raised is: why were these reactions not seen as normal (and anticipated) ? And how did they turn into a wider national health issue ?

Our hypothesis is that the response of public authorities to these oppositions amplified the dynamics of contestation: in other words, it is not so much the reactions of the local populations which constitute the problem, but rather their management by public authorities both at the national and local levels.

The national government's response to contestation

Beginning in the late 1990s, BS are caught up in a dynamics of contestation which transforms them into a public problem. This transformation follows basically the same lines from one country to the other. It results from two types of pressures exerted on national authorities.

Regarding health, the EU and international scientific bodies encourage the adoption of levels of exposure defined according to the state of scientific knowledge. These levels, which can be found in the July 1999 European Recommendation, are based on ICNIRP guidelines and research financed by the European Commission and WHO. They are part of a wider movement which stresses the need for national governments to base their decisions on sound science in order to cut short to the conditions which produced health crises and scandals in the past; and to resort to the precautionary principle only in clearly defined circumstances. In such a context, any attempt to base decisions on something else than science faces the risk of strong criticism for favoring political or special interests.

Simultaneously, local and regional authorities have often, under pressure from protest groups, adopted more restrictive measures to the installation of BS. Such decisions, although often illegal, nevertheless create difficulty for central governments: on the one hand, when based on health related motives, local and regional authorities are clearly trespassing on central government ground; on the other hand, these decisions highlight the greater responsiveness of local government whilst demonstrating national authorities' difficulty in providing a quick and satisfactory answer to growing social unrest. This difficulty being capable, in turn, of leading to a new crisis or a weakening of central authorities' legitimacy.

Turning BS into a health problem

Although different in nature, these two types of pressures result in the health issue being cut off from other dimensions of the contestation of mobile phones and BS, making it the central stake for opponents and proponents alike. National governments find themselves under pressure from both sides, with an obligation to either follow what appears to be an international consensus, or to remain in touch with local and regional authorities who appear to be more responsive.

These pressures are relayed by other agents. Mobile phone operators exert pressure on national authorities to obtain a regulatory framework that allows for the pursuit of their activity, while at the same time answering the doubts and worries of the population and the opponents' arguments. NGOs also put pressure on central government, but in favor of lower levels of exposure – based on the situation in neighboring countries or the advice of counter-experts organized at the international level. These two groups of agents establish links between local, national and international arenas.

Hence, central authorities must manage a problem whose framing largely escapes them: on the one hand, they must adopt levels of exposure, with a strong incentive to follow the recommendations of international expert groups; on the other hand, they must answer the doubts and worries of the populations living near BS. If they decide to follow the international mainstream, they will be reminded of past errors in experts' assessments of risks (asbestos or BSE, for example) and their dramatic consequences, and counter-experts will insist on the many remaining scientific uncertainties. If they decide to favor what they perceive to be their constituency's demands, they risk facing harsh criticism for taking political rather than science-based decisions. In both cases, they will fail to understand that managing risk issues under conditions of high uncertainty calls for procedures departing radically from those adapted for the management of better-known risks. Thus, to solve what they perceive to be contradictory demands, they will call upon scientific experts to produce advice. In so doing, they will loose from sight the reasons for which BS triggered local reactions and later grew into a national issue, and focus solely on what has been built up into a national problem extracted from its context.

It is at this stage that differences begin to appear between the different countries: not only is the ministry in charge not the same, but the expert advice is contrasted, leading to differentiated decisions in the 5 countries. Hence, this helps to explain the reasons for which countries have adopted different levels of exposure, but it also reveals institutional differences between countries that have adopted similar levels.

Setting the agenda

Contrary to the 3 other countries, Belgium and Switzerland already have a specific regulation on non-ionizing radiation (NIR), which specifies that everything must be done to reduce possible adverse health effects along with effects on individuals' well-being. In Switzerland, for example, the 1983 Law on Environment provides that any effect which could prove to be harmful or unpleasant must be reduced on a preventive basis and as soon as possible (following the ALARA principle). In both countries, EMF have been under scrutiny before the era of mobile phones (around problems of high-voltage power lines or short-wave radio transmitters). Hence, government officials are strongly urged to adopt low levels of exposure, even in the absence of scientific data suggesting the existence of any risk.

The 3 other countries are in a more comfortable position from a regulatory point of view, but face harder protest from local movements. These have been amplified by four phenomena: the siding of local authorities with these movements; the support of members of parliament to NGOs; decisions taken by intermediate levels of government in federal countries; the growing number of cases brought before the courts in the absence of any clear policy guidance and expert advice. This social and political amplification raises the risk of a potential health crisis, with potential dangerous effects on national authorities.

Yet, the ministry in charge of this issue varies from one country to the other. In Spain, the Ministry of Science and Technology, and more precisely the secretariat in charge of Telecommunications and Information, takes on the issue without seeing fit to consult with the Ministry of Health. In France and in the UK, the Ministry of Industry asks the Ministry of Health to provide expert advice specifically on the health dimension. In Belgium and Switzerland, it is the Ministry in charge of environmental protection which takes on the issue. The title of the ministry in charge already gives a first indication as to the framing of the problem, i.e. how central authorities understand its causes, consequences and nature. It is also a clear indication of the regulation regime within which the issue will take place.

In all 5 countries, the ministry in charge of health (or environment) must cooperate with the ministry in charge of industry, since the latter is responsible for telecommunications policy. This policy calls for, in particular, the maintenance of a competitive market between several operators, the obligation for these to offer a quality service with a good coverage of both the population and physical space, and the possibility for operators to roll-out their BS in good conditions. Often, these requirements are controlled by an independent regulatory agency.

The interests of the different ministries do not always coincide. This is a first source of conflict, since health issues tend to contradict the development of a mobile phone market.

Hence, the framing of the issue and its initial treatment vary from one country to the other:

- In Switzerland and in Belgium, the emphasis is on public health, which is recognized as a legitimate source of worry by public authorities; a ministry is more specifically in charge of the issue, articulating environmental and health concerns; BS are clearly the focus of regulation rather than handsets (hence the fact that the Ministry of Environment is in charge of the issue, not the Ministry of Health).
- In the UK and in France, the Ministry of Industry isolates the health dimension from other concerns and charges the Ministry of Health with the task to call upon scientific experts to produce advice which can lead to regulation; in this case, handsets are the object of attention rather than BS (which may explain why the Ministry of Environment is not in the picture) even though it is the latter that attract the most protest at the local level (as authorities and experts soon find out).
- In Spain, the Ministry of Industry wishes to act on its own, and it is only under pressure from the Ministry of Health that it accepts to cooperate with the latter.

The experts' conclusions

In all 5 countries, experts are called on to produce a state of the knowledge. Yet, differences are visible in the membership of the expert committees, the question addressed by government, their working procedures or their conclusions.

In 4 out of 5 countries, an expert group is brought together. Only in Belgium does the government see fit to consult with three experts individually. The Swiss group is predominantly medical. The French, Spanish and British groups are composed of a variety of scientific disciplines, but only the last also comprises lay members. Among the three Belgian experts, one is known for having adopted strong positions on the risks of EMF.

In Switzerland and Belgium, the experts are asked for a state of the science. In Spain, France and the UK, they are also asked to make policy recommendations. In 4 out of 5 cases, the experts work with very short deadlines: this implies that they must rely essentially on existing data and results, rather than attempt to produce original research. In Switzerland, the group has a longer history of publishing reports on the effects of EMF, but relies nonetheless on existing research, including non-peer reviewed results. But only in the UK does the expert group actively seek to bring in more information, from published results to non-peer reviewed data and even anecdotal evidence collected during hearings and through personal correspondences. As a consequence, only the Stewart report in the UK echoes at length the complaints of individuals and groups and the fact that these, and the ensuing problems of well-being, must be addressed by government officials.

All the reports, except for one Belgian expert, conclude that there exists, in the present state of knowledge, no proof of any adverse health effect due to BS. But only the French report and two Belgian reports clearly exclude the possibility of any such effect, given the low intensity of radiation. The other reports are more cautious and do not exclude the possibility that further research could reveal risks for health. In other words, the reports do not draw the same conclusions from their findings.

This can be explained by the way in which experts apply the precautionary principle and define health. In France, the experts clearly refuse to apply the precautionary principle to BS since they see no ground for any possible risk, now or in the future; they suggest applying this principle only to handsets, for if there is no clear indication of risk, it remains theoretically possible. But considering the wide public concern around BS, they suggest banning any installation within 100 meters of a sensitive building caught in its beam of highest intensity. In the UK, the experts recommend the use of a precautionary approach (in this case, ICNIRP guidelines), based on the scientific uncertainties along with the popular reactions to BS; and they consider health to cover issues of well-being, which in this case is at the heart of many complaints. The Swiss experts adopt a similar line of reasoning, encouraged by the fact that the law provides for the adoption of a precautionary approach, and by their predominantly medical background which makes them more responsive to problems of well-being. The Spanish report contains some advice in terms of precaution, although it recommends, as do the British, French and 2 out of 3 Belgian reports adoption of ICNIRP guidelines. The third Belgian report suggests that these guidelines be divided by 100, given the possible health effects. The French, British and Spanish reports also contain many other recommendations, in particular regarding risk communication, research and the monitoring of levels of exposure.

Hence, in all 5 countries, experts try to strike a compromise between the existing scientific knowledge, the government's expectations in terms of policy recommendations and widespread protest movements, around a shared definition of health or precaution. Yet, government officials do not always adopt the same definitions.

Contrasted regulations

National authorities, following the experts' conclusions, have adopted different levels of exposure. Spain, France and the UK decided to follow ICNIRP guidelines and the European Recommendation, while Belgium and Switzerland adopted lower levels of exposure following the precautionary principle. But French, Spanish and Swiss authorities followed the experts' advice, while in the UK and Belgium, authorities parted somewhat from the experts' conclusions. In the UK, the government followed the advice on exposure levels, but neither accepted to adopt a precautionary approach nor recognized problems of well-being. In Belgium, authorities took an intermediary position between the advice of two experts to stick to ICNIRP guidelines and recommendation by the third to reduce exposure levels, thus giving equal status to both positions and striking what appeared to be a fair compromise.

Rules defining levels of exposure were supplemented by procedures regarding the calculating and monitoring of levels of emission and immission. The methodology for these procedures often turned out to be a new source of tension, in particular in those countries that adopted low levels of exposure, since the content of the procedures could give operators some leeway in respecting the levels of exposure or on the contrary raise the degree of constraint. In all countries, they were destined to provide authorities with data and a capacity to assess possible health effects. Yet, while Spain has engaged in an effort to monitor regularly all BS, Switzerland relies on a theoretical calculation. In the other countries, a limited number of BS are monitored and the results published on the Internet.

In all 5 countries, government officials were first and foremost concerned with avoiding any potential blame, should an accident occur in the future. Having been confronted with health crises and scandals, they were careful not to reproduce the same mistakes. The paradox is that their intervention, along with the experts' advice, actually contributed to the existence of a health risk. If at the outset, the possibility of a risk for health or the environment was not always present, the consequence of the regulatory process was the confirmation that there existed doubts regarding this technology. This unintended effect has already been observed in other areas of public intervention. In an effort to prove their willingness and capacity to manage risks, public authorities actually contribute to the existence of these risks. Hence, it is up to other agents to contribute to the reduction of risk.

Supplementing national regulation

In all 5 countries, central governments have focused on the health issue. Yet, the ensuing regulation has not resolved the problem of protest against BS roll-out and, on the contrary, has often contributed to risk amplification. In those countries that adopted precautionary measures, the decisions seemed to confirm the possibility of a risk. While in those countries that followed the European Recommendation, the denial by public authorities of the existence of any risk fuelled contestation, either because experts seemed to be more cautious in their advice (UK) or openly contradictory in their recommendations (France), or because intermediate levels of government maintained the issue on the agenda (Spain).

Hence, national regulations have reframed the problem and managed the uncertainties facing central governments, but they have not treated the causes for local protest movements. This leaves mobile phone operators and local officials faced with the initial problems raised by these movements, but they have since gained a better understanding of their nature and been able to test different solutions. Nevertheless, they remain dependent upon the institutional framework and the decisions taken by central government for their capacities to act.

The management of uncertainties by the operators

The political construction of health risks related to EMF by central government presents operators with a potential liability risk, since they are accountable for the base stations. More precisely, it presents them with a two-fold answer to contestation of BS. On one side, the expert advice and regulation offers a legal protection against any blame should a risk occur. So in a sense, it reduces the regulatory and scientific uncertainties and gives them the opportunity to focus on other aspects of the problem. But on the other side, regulation and scientific advice are themselves fraught with uncertainty, in particular in countries where experts did not exclude the possibility of a risk or in which regulators put forward the precautionary principle.

In a first step, operators have undertaken to work together. This was not an easy move given the fact that they operated on a highly competitive and young market, with the necessity to fight for market shares. Furthermore, operators differed widely in size and date of entry on the market: there was hardly any incentive for a newcomer to cooperate with already well entrenched firms, especially when these were ancient State monopolies with a majority of market shares. Nonetheless, given the importance of protest movements and political reactions, they quickly understood that their interest lay in joint actions in terms of communication, monitoring and negotiations with public officials. These actions aimed at reducing four types of uncertainties besetting their activity.

Scientific uncertainty: This type of uncertainty is particularly significant in countries that adopted regulation based on the precautionary principle (Belgium, Switzerland) or whose experts called for a precautionary approach (UK). In these cases, any new scientific results showing the possibility of a risk could lead to tighter regulation. But in countries that followed the European Recommendation, this uncertainty also exists, albeit in a different manner. Experts can come under direct attack for lack of independence (France) or on the contrary their call for some measure of precaution can be used by counter-experts and NGOs to publicize studies and results which tend to prove the existence of a risk for health (UK). Operators attempt to reduce scientific uncertainty by financing research projects, at the national, European and international level, either directly or via foundations created specifically for the purpose of producing more science on EMF.

Social uncertainty: This can take several forms. The first is protest movements and NGOs that block or delay the roll-out of BS. Operators have little hold on these and can only rely on the law to push forward their project. But some initiatives have been taken. In Switzerland, for example, the three operators created a foundation on mobile communication and the environment, which provides an ombudsman to solve conflicts. In the UK, the Mobile Operators Association (MOA) organizes on a regular basis stakeholder meetings, with the participation of representatives from industry, local government and NGOs opposing BS. These meetings take place behind closed doors, in order to encourage participants to speak freely and exchange information without having to play out a role in front of an audience.

The second form of social uncertainty refers to the behavior of subcontracting firms in charge of finding sites and installing BS. Given the constraints under which they work in terms of delays, prices and objectives, they tend to adopt rather brutal methods, that often trigger or amplify local citizens' reactions. This has led in some countries operators to standardize and control more strictly the behavior of their subcontractors, or even to internalize this activity.

The third form comprises the behavior of the competition, notably the newcomers when they must in a short period of time roll-out an entire network in zones that are already covered by other operators, or operators who could be tempted to get an edge by playing on safety or environmental arguments. These risks have encouraged operators to work together, as we noted earlier, in order to convince each one of them that they would have more to lose from competition than from some sort of cooperation on issues such as health.

Political uncertainty: This category refers to the possibility that lower exposure levels be set under pressure from experts or social protest movements. But it also covers the behavior of local officials, who have often sided with protest groups rather than risk losing electoral support. Whilst operators have continuously lobbied central government and insisted on the consequences a lowering of exposures would have, they have tended to concentrate their efforts more and more on local authorities. This is the case in Spain, with limited results concerning their capacity to convince municipal and regional governments to abandon restrictive regulations. The French and British examples are more telling.

In France, following the success of charters signed between municipal authorities and operators in the three largest cities (Paris, Marseille and Lyon), the association of mobile phone operators (AFOM) suggested to the association of French mayors (AMF) to elaborate a guide of best practices to serve as a sort of general framework for future local charters. The document was signed in 2004. It rests on the assumption that informing the public and municipal officials in advance will reduce the risk of contestation and ensure the acceptability of BS; the guide also assumes that contestation results first and foremost from lack of information and transparency. The document aims at giving officials and citizens knowledge about existing antennas as well as projected BS, it is also destined to give officials some form of control over the operators' activities. It provides for the control of levels of exposure and campaigns to monitor actual EMF. On this last point, the guide is close to the code of self-regulation adopted by the Spanish operators in 2001.

In the UK, following publication of the Stewart report in 2000, MOA undertook to publish its "10 commitments" along with tools to identify sensitive places (Traffic light model) and work with local planning authorities. The MOA's strategy is one of producing soft law, rather than trying to obtain more regulation. MOA also stresses the need to inform the public as best as it can. Once again, the assumption is that clear information will help modify public perception, but only by being open and straightforward can such information achieve its goal. The documents it has published define a procedure destined to provide an acceptable roll-out of BS. But it considers public meetings to be useful only in sites with a traffic light on red, i.e. sites with a potential for contestation. Interestingly enough, these different documents have been integrated in policy guidance produced by government. In this case, regulation tends to originate in the private sector before becoming public.

Judicial uncertainty: As many decisions by operators or local authorities are attacked in front of the courts, a jurisprudence is slowly building up. In some countries, the high courts have definitely given their point of view (France and Switzerland) while in other the different parties are still awaiting a decision which will give some clear indications to the lower courts (UK and Spain). The multiplication of trials also entails longer delays in roll-out, while the many conditions imposed on operators through national and local regulations raise the probability of a flaw in the procedure which the courts will seize to refuse the operators' claims. Finally, the legal arguments tend to vary, from the precautionary principle to the right to a fair hearing. All this implies for the most part long delays in installing BS, and some risk that courts will acknowledge the use of the precautionary principle on this issue.

In all 5 countries, operators have thus been active in trying to reduce the different uncertainties they face, and which could all lead to risk or crisis with potentially dramatic consequences for their activity. They have relied on central government regulation, but have sometimes preceded it, and more often sought other solutions working directly with local government or NGOs.

Municipal governments and political uncertainty

Local authorities have been, from the start, at the forefront of protest movements, often siding with these by fear of losing electoral support, and trying to gain some control over the operators' siting operations. But with the multiplication of court decisions defeating this strategy, some authorities took the measure of their limited capacities, while others insisted in trying to block BS notwithstanding the high probability of judicial defeat. Local authorities have also often turned to parliamentary members and central government officials for help in tackling this issue, with limited success since the ensuing regulation often served to cover the central authorities' accountability all the while transferring the problem back to local officials. Hence, they still face an "ill-structured problem" and can only partly rely on national regulation to reduce the complexity of the matter. Furthermore, the pressure from local protest groups and operators alike has not abated.

Local authorities are highly dependent upon the institutional framework for resources, capacities and prerogatives. They must also take into consideration actions by regional governments in the three federal countries. Hence, local authorities are not in the same situation in federal countries and in centralized States: in the latter, they must rely on the most part on their own capacities to manage the problem, whilst in the former, they can more easily transfer the problem up to the next level or on the contrary be tempted to illustrate their autonomy vis-à-vis the regional levels.

British, Swiss and Belgian municipalities are in a situation where they find little solution in national regulation, since it does not address their specific problems concerning the installation of BS and the reactions triggered among the population. They lack the capacity to manage the problem and tend to rely on upper levels to solve the conflicts – or ultimately the courts to arbitrate. Even though they will often lose, they will be tempted to oppose the installation of a BS to satisfy their constituency, knowing that the courts and upper levels of government will then take the matter into their own hands. In the UK, local authorities find it difficult to interpret the diverging information they receive from experts, government, operators and NGOs, all the more so since the courts have not yet produced a stable jurisprudence. Whatever their decision, they are almost certain that it will be brought in front of the courts. And while the operators have gone a long way in trying to work with local

authorities, it is ultimately the judges who will decide of the outcome. In Switzerland and Belgium, the regional governments, often competent on planning issues, have sometimes provided supplementary regulation, offering local authorities with a framework more adapted to the problems they face than regulation concerned solely with exposure levels.
On the contrary, French and Spanish municipal governments have undertaken to manage this problem in political terms, albeit in very different manners.

In France, the authorities in the largest cities have taken the initiative of negotiating and signing charters with the operators. These charters define the rules operators must follow when planning the installation of new BS and impose campaigns to monitor exposure levels. Operators were all the more encouraged to enter negotiations and accept these conditions, that public authorities owned a large number of buildings on which antennas could be installed and could block any installation within 100 meters of a sensitive building caught within the beam of an antenna. But they also saw the advantage they could gain from negotiation which underpinned their good will and could serve to reduce social protest movements (who were not invited to the negotiations).

In Spain, local authorities went further and published ordinances with very strict rules concerning the installation of BS. This was possible because of the large powers communes, along with autonomous communities, enjoy in the Spanish system, notably on planning issues. Although the ordinances have been systematically attacked in front of the courts, and for the moment often defeated, they have had nonetheless a great impact on the operators' activities, in particular in terms of delays and blockages. Furthermore, 6 (out of 17) autonomous communities have also passed laws on BS. The main characteristic of these ordinances and laws is their diversity. But their common feature is an increase in the rules and procedures operators must follow to pursue the roll-out of their networks.

Judicial regulation as last resort

As mentioned several times, it often is the courts' role to arbitrate in last resort the conflicts between operators, local authorities and protest movements. When the superior courts have produced a decision, as is the case in France and Switzerland, this helps to reduce the uncertainty in the decisions of lower courts. Otherwise, court decisions can vary according to the arguments put forward and the weight of evidence. Yet, whatever the jurisprudence, the increasing influence of the courts tends to shift the focus from scientific arguments to more procedural issues.

In France and Switzerland, the superior courts in administrative justice have arbitrated in favor of the operators, as long as they comply with regulation. The French judges considered that the experts' report denied any claim for application of the precautionary principle to BS, hence eliminating the main argument used by opponents to block these installations. The Swiss judges considered that the regulation offered all the guarantees necessary, since it applied a precautionary approach, and thus did not permit for local authorities to adopt stricter rules regarding exposure levels. Hence in both cases, operators are most certain to win future cases and can only expect longer delays.

Although less clear, the situation in Belgium seems to follow similar lines. Operators remain very wary of the risk an unfavorable decision would have on their activity, but the national regulation, supplemented by the regions, have actually reduced the number of trials. When asked to arbitrate, the courts tend to consider that the regulation protects citizens well enough.

In Spain, the situation remains more uncertain and complex, given the variety of texts being attacked. Of the more than 900 ordinances adopted by municipalities, 862 have been taken to court. Few decisions have been taken, for the moment, but they are generally in favor of the operators. Nonetheless, the courts produce decisions with nuances, canceling certain parts of the ordinance while approving others. The result is an even more complex picture in which operators must find their way, case by case. Given their preference for more standardized solutions, this situation is highly unfavorable to them.

In the UK, many cases are pending trial. Opponents tend to refer to the Human Rights Act of 1998, introduced in British law in 2000, to block the roll-out of BS. The highest courts have not yet decided upon the matter, thus entertaining some level of uncertainty on the side of NGOs and operators alike. It is interesting to note that NGOs in the UK are the only ones to have adopted a judicial strategy, with the help of lawyers trying to build a case for opponents. In the other countries, NGOs and protest movements still rely mostly on political pressure.

Hence, in all 5 countries, the courts tend to have the final word, or at least to play an important role in limiting the capacities local authorities hold in regulating the installation of BS. But given the complexity of the issue, it is the superior court's prerogative to define the doctrine for the other courts; in the meantime, these can still adopt varying positions.

Conclusion

In all 5 countries, local protest movements persist, with important delays in the roll-out of second and especially third generation networks. But each country has its own specific configuration to manage this problem. As we have seen, a configuration is composed of central government, scientific experts, courts, intermediate and local levels of government, and operators. It also relies on specific definitions of precaution and health. Each configuration contributes in its own way to alleviate the level of conflict, often by externalizing the cost along with the remaining risks toward the operators.

France is a case of a stabilized configuration: the State, experts and superior administrative court are consistent and coherent in their appraisal of the lack of any risk related to BS, thus denying any claim to the use of the precautionary principle. In this context, local authorities and operators sign charters which regulate the installation and operations of BS. Even though some contestations persist, their intensity tends to diminish and NGOs are moving to the issue of handsets and children – followed by experts who also express some worries on the matter.

In Switzerland and Belgium, protest movements persist and the courts are called upon to arbitrate. Although operators tend to be favoured by court decisions, they remain under the threat of a lowering of exposure levels by national authorities who, having applied the precautionary principle, could be led to adopt stricter rules if scientific data pointed at the evidence of risk for health. This is a paradoxical situation, since regulation in both countries is clearly not based on scientific evidence; yet, scientific results such as the TNO study which tend to suggest the existence of health effects could encourage authorities to tighten regulation – although it is not clear in what way.

The Spanish situation is the most unstable, due to the strategies adopted by local and regional authorities, and court decisions which introduce still more complexity. Although government officials and experts tend to be consistent, the autonomy granted to communes and autonomous provinces provides these with opportunities to regulate on the matter with little consideration for scientific evidence, but strong concern for popular reactions. They take this opportunity to demonstrate their responsiveness, while contributing to maintaining the issue on the agenda. The result is a vary sensitive situation and lack of effectiveness for the efforts of national authorities and operators alike – in other words strong institutional incoherence.

The UK is characterized by the inconsistency between the attitudes of government officials and experts, the latter calling for a precautionary approach and a more open attitude towards the issue of well-being, the former more hesitant to engage in a road they consider hazardous and preferring to trust their regulatory agency's statements that there is no risk for health. This inconsistency has encouraged operators to adopt a clear strategy of openness towards local authorities and the public. Yet, this attitude is contested by opponents who, on the basis of the experts' conclusions, call for stricter regulation. Local authorities are left to find a solution, which in any case ends up in court. As long as a clear jurisprudence has not been produced, this situation is highly favourable to the persistence of protest movements and contestation, all the more so when experts consider that government has not followed their initial advice and openly criticize the existing regulation.

Hence, while a consistent attitude between government officials, experts and the courts contributes to alleviate the level of conflict, it is not enough. One must also take into consideration the role and capacities of intermediate levels of government. But inconsistent attitudes can also contribute to the maintenance of a high degree of instability on the issue, i.e. its persistence as a political problem with potential risk for public authorities and private firms. In other words, both the emergence of a risk issue and its settlement are determined by an institutional regulatory framework. Risk, as this case demonstrates, is not so much an issue of scientific uncertainty than it is about the capacity of political institutions to manage highly complex and uncertain problems.

The Swiss regulation and its application

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Introduction

In 1999 the Swiss government introduced an ordinance relating to protection of the general population from non-ionizing radiation in the environment (ONIR 1999). While this ordinance is applicable to a large variety of different categories of installations the present contribution is restricted to the radiation of mobile telephone base stations emitting an equivalent radiated power (ERP) exceeding 6 W. Protection is accomplished by two complementary approaches:

- Radiation which, according to scientific evidence and agreement, represents a proven risk for human health, is prohibited. The evaluation of the scientific literature on biological and health effects as undertaken by ICNIRP forms the basis. The reference levels of ICNIRP (ICNIRP 1998) for the general population were enforced in the Swiss ordinance without modification. They are applicable at all places in the environment accessible to persons, even if exposure is only of short duration.
- If radiation has a potential for adverse effects but scientific proof is lacking, it is further limited as far as technology, operational conditions and economic considerations allow. This approach is based on the precautionary principle in its interpretation of "prudent avoidance of exposure". In the Swiss ordinance this principle was put into limit values for the exposure produced by a single installation. This installation limit value is about ten times lower (with respect to field strength) than the ICNIRP exposure limit value. It is only applicable at places where persons stay for prolonged time, so called places of sensitive use.

The first approach - protection against scientifically proven and agreed risks - is internationally harmonized. The second one however - precautionary limitation of the radiation - is a Swiss innovation and has provoked both acceptance and critique. The contribution concentrates on this aspect. What were the reasons for Switzerland to adopt this approach, how was it shaped and what is the experience in applying it so far?

The ordinance relating to protection from non-ionizing radiation

When we began with the preparations for the actual regulation several years ago, the situation was the following:

- Thermal effects of RF radiation and their thresholds were known and scientifically agreed on. These effects are produced under short term exposure.
- There were indications for biological and possibly health effects at intensities far below the thermal threshold. These indications came from scientific experiments as well as observations of exposed individuals in their every day life. They point to a potential of low level radiation having adverse consequences other than thermal effects, specifically under prolonged exposure conditions.

- The Swiss law relating to the protection of the environment (LPE 1983), which is in force since 1983 and forms the legal basis for environmental protection, demands the application of the precautionary principle, specifically the precautionary limitation of exposures. It is this requirement which distinguishes the Swiss legal framework from that of many other countries. Exposures which might become harmful or a nuisance (no proof necessary) shall be limited in the sense of precaution as much as technology and operating conditions will allow provided this is economically acceptable.
- At places where persons stay for prolonged time, the radiation of base stations can be kept far below the levels necessary to avoid thermal effects without substantial inconvenience for the network operators.

This situation has not changed since. Since a potential for negative effects was identified and at the same time technical possibilities to reduce exposure existed, it was no question that precautionary measures to minimize exposure must formally be introduced in Switzerland in the protection against non ionizing radiation in the environment. The question was rather how and to what extent such measures could be defined.

The primary aim was to give unambiguous guidance for local authorities, network operators and the concerned public. To fully appreciate this, it is necessary to point to another peculiarity of the Swiss legal system: Any structure to be erected, whether buildings, roads or telecommunication infrastructures must undergo a public planning procedure prior to approval by the authority. During this procedure the intent of the applicant is published in the local newspaper, the dimension of the planned structure is indicated by posts on-site and the plans can be consulted at the local administration. Anyone who is affected by the planned installation more than the average population is entitled to formulate opposition against the project and to appeal to the courts in case the opposition is rejected. This public involvement is not special for mobile telephone masts. It is part of the Swiss direct democracy and has a long tradition.

Given the legal obligation to implement the precautionary principle and the many stakeholders involved it was indispensable to create a precautionary regulation which was as concrete and exhaustive as possible. The precautionary measures to be taken should no longer be fixed on a case by case basis but formulated for general application. Any installation which respects these precautionary limitations would be considered to satisfy the precautionary principle without further evaluation. A more flexible approach or even the complete omission of precautionary rules would inevitably have led to a wave of legal procedures claiming the evaluation of precautionary measures on an individual basis in each single case. It was the will of the Swiss government to avoid such a development and instead to offer generally applicable rules.

The following approach was finally chosen and has been applied in the authorization of some 10000 base stations nationwide:

- A precautionary limit value, the so called installation limit value, was fixed. It amounts to 4 V/m for GSM900 installations, to 6 V/m for GSM1800 and UMTS and to 5 V/m if GSM900 is combined with GSM1800 or UMTS on the same installation. It is applicable to the radiation of each individual base station (sum of all antennae for mobile telephony) when operating at full power and shall be respected at places of sensitive use, e.g. apartments, schools, hospitals, children's playgrounds, indoor work places. This limit value is not based on medical but rather on technical and economic considerations. It does not constitute a "no-effect level". It was fixed based on an extensive review of several hundred base stations and is the result of a political compromise. With the specification of this value the government declared what it considered technically possible and economically acceptable with respect to the precautionary limitation of exposure.

- When applying for a planning permit for a new base station or the substantial modification of an existing one, the network operator has to submit a declaration of the expected exposure by means of a so called site data sheet (BUWAL 2002). In this form the technical data of the antennae relevant for NIR exposure are displayed and the electric field strength at the three most exposed places of sensitive use is calculated. The calculation is simple; it is based on free space propagation with coarse consideration of the antenna diagram and attenuation of building walls. The site data sheet is public.
- The local authority controls the site data sheet and decides on approval or rejection of the demand. A project which respects the installation limit value and the other requirements set by construction laws is entitled to obtain the permit. The authority cannot refuse it.
- If the exposure at a place of sensitive use amounts to more than 80% of the installation limit value according to the calculation, a measurement of the electric field strength is performed after the base station has started operation (BUWAL/METAS 2002).

Experience

The chosen concept provides legal security for the network operators and the local authorities. The obligation for precaution is considered fulfilled if the installation limit value is respected.

The concept turns out to be reassuring for some parts of the population, but not for all. Many appreciate the government's willingness to keep exposure low. Nonetheless, according to a recent representative survey, 36% of the Swiss population expressed concern with respect to the radiation of base stations. This concern and the continuing opposition against base stations would certainly also exist in the absence of any precautionary regulation, probably to an even higher degree. It basically originates from different perceptions of the precautionary principle. While the precautionary principle in the Swiss legislation follows a technical approach - and therefore can by definition not absolutely guarantee the absence of any negative effects -, these groups demand a 100% proof of safety or at least a limitation of exposure below some no-effect-level, whatever the effect may be. This conflict is fundamental and not specific for Switzerland. If it appears to be more prevalent here than elsewhere this is due to the generous possibilities provided by the traditional planning permit procedures for individuals to submit opposition and voice their concerns.

The Swiss precautionary limit values do not undermine scientifically based exposure limits as is sometimes asserted. In contrast, the two approaches should be viewed as complementary. A contradiction would only arise if standard setting bodies would consider their scientifically based exposure limits as final and all embracing. Hardly any scientist would subscribe to such a notion. Consequently, attempts should be welcomed which, in addition to protecting from known risks, keep exposure as low as reasonably achievable.

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Base stations and health:
Government responses in Italy

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General framework of Italian regulations on electromagnetic field exposure

In Italy, responsibilities regarding exposure to electromagnetic fields (EMF) are divided between the central government and local authorities. A Framework Law issued in 2001 assigns to the State the definition of exposure limits; for radiofrequency (RF) fields, such limits were issued through a specific decree in July 2003 (the text of both the law and the decree is available, in the original Italian version and in the English translation, in the database of national standards of the WHO International EMF Project at: http://www.who.int/docstore/peh-emf/EMFStandards/who-0102/Worldmap5.htm). The same Framework Law states that the criteria for the installation of antennas are decided by regional authorities, namely regional parliaments and city councils.

Actually, some Regions had issued before 2001 their own laws, that include also exposure limits. These laws are progressively being cancelled by the Constitutional Court, and have therefore limited interest for present and future policies on the installation of telecommunication plants, including radio base stations (RBS) for mobile telephony.

However, some local authorities, under the pressure of the public, have tried to limit the environmental exposure levels of base station in an indirect way. The national law defines in fact three classes of restrictions for EMF exposure, namely exposure limits (not to be exceeded anywhere), attention levels (not to be exceeded in correspondence to residential buildings and sensitive areas), and quality goals. The definition of the latter is twofold: quality goals are on one side “the values of an electric, magnetic and electromagnetic field, set forth by the State in order to minimize gradually the exposure to EMF”, on the other “the planning criteria, town planning standards, provisions and incentives […] provided by the regional laws”. The town planning standards, for which also city councils have competence, have frequently been exploited to set *de facto* limitations to the installation of RBS. For example, the requirement of minimum distances of antennas to residential buildings and sensitive areas has used (through an appropriate choice of the distance) to limit to environmental EMF levels in these areas below a given value.

Impact of exposure limits on the installation of base stations

The attention level and the numerical value of the quality goal are set by the aforementioned decree to 6 V/m - in terms of electric field strength - for any frequency between 100 kHz and 300 GHz. Such value is well above typical levels that may be found in the vicinity of base stations for mobile telephony. To ensure good area coverage, antennas are usually installed in Italy over masts elevating from the roofs, or on the edge of terraces and pointing outwards, so that electromagnetic field intensities are below 6 V/m at any accessible point, also on the top of the building where the RBS is located. In conclusion, the precautionary exposure limit defined at the national level has no influence on the siting of base stations.

The low levels of electromagnetic fields in environments normally frequented by the public are also indicated by calculations performed with validated numerical codes: values around 1-2 V/m are usually predicted in correspondence to the nearest buildings. However, the Italian rules require that compliance must be verified through measurements if calculated values exceed 50% of the limit, i.e. .3 V/m. Since it cannot be excluded that such value could be found in the close proximity of the antenna, experimental surveys are systematically carried out, virtually on every base station, to ascertain that attention value is not exceeded even in the closest accessible point. The latest Yearbook of the Environment (ANPA 2004) reports about more than 4,000 surveys in 2003 only. Such an effort lead to identify a very limited number of cases on non-compliance: 43 over a five-year period, all with a preponderant contribution of broadcasters close to the area.

Monitoring campaigns

In addition to the measurements mentioned above, that are performed by the Regional Agencies for Environmental protection (ARPA), a nation-wide monitoring of environmental EMF levels has been promoted by the Ministry of Communication. The project, coordinated by the Ugo Bordoni Foundation, a recognized technical structure linked to the Ministry, is based on the use of about 120 broad-band and 230 selective narrow-band antennas that can be relocated at a different site after a period of continuous data logging that is typically of a few weeks. The collected data are displayed at the website of the foundation (www.fub.it).

To the date of June 2005, based on the information available at the website, about 1,500 sites had been monitored, for a total of almost 1 million hours of data logging. No global statistics have been provided by FUB so far. From a random check of data available online, environmental field levels appear well below the attention level of 6 V/m, although the measurement sites were in most cases selected among those considered "critical" *a priori.*

From the time profile of field intensity, contributions that are likely due to radio and TV broadcasters can be identified. Such analysis confirms that most of the environmental RF exposure is due to broadcasting, even in cases where the monitoring station is located in the vicinity of a RBS.

Information to the public

The framework law indicated information to the public as a key action, ad allocated about 500,000 euros per year to this purpose. However, activities in this area have been limited so far, and no action has been promoted at the national level by the government or by public agencies. Only a few regions have organized scientific symposia, published leaflets and booklets, and produced didactic material such as CDs and websites.

The Ugo Bordoni Foundation has promoted the translation of some WHO documents, including the manual "Establishing a dialogue on the risks of electromagnetic fields", that has been made available both online and as a booklet. Fifty thousand copies have been printed and distributed to national and local authorities, including the mayors of all the over 8,000 Italian cities and towns.

Another interesting activity of FUB is the so called Blubus, a bus equipped with a complete station for the monitoring of electromagnetic fields that has moved through the Country in the last couple of year visiting about 100 cities. Experts were available on site to show the measurement procedures, assist in the interpretation of results, and answer questions on exposure to electromagnetic fields and related risks.

The response to the initiative has been everywhere positive, but unavoidably confined to the city where the bus stopped, with at the best some attention by the local media.

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Local policy options for the installation of mobile telephony base stations

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Introduction

Radio base stations (RBS) for mobile telephony are low-power sources of electromagnetic fields (EMF). The characteristics of the technology require in fact that – with the only possible exception of areas in the very close proximity of antennas - the electromagnetic field levels be kept low, in order to avoid interference between cells and to allow the re-use of frequencies.

This circumstance should be reassuring, because no adverse health effects have been established for exposures to radiofrequency fields below the limits recommended by international organizations such as the International Commission on Non Ionizing Radiation Protection (ICNIRP), and field strengths around base stations are always much less than the limits. Indeed, several expert panels have unanimously concluded that the chance for RBSs to pose any health problem is negligible. Nevertheless, base stations keep creating very high concern and strong opposition within the public.

The reasons for the widespread scare of electromagnetic fields have been widely investigated in recent years, and a number of factors influencing – and often distorting – the perception of health risks have been identified. While most of these factors are common to all EMF sources, at both low- and high-frequencies, some are specific to mobile telephony: the density of antennas, the rapid and apparently endless increase of their number, the visual impact and the way – often insensitive – in which they are installed.

National governments are facing the difficult challenge of reconciling contradictory demands of the public, who asks for example for less base stations and at the same time for more effective networks. Some countries have adopted exposure limits that are lower than international guidelines, but necessarily high enough to allow operation of the technology. It has bee noted on this regard that *"even in the countries where the exposure limits have been lowered using the precautionary principle, namely Italy and Switzerland, the resulting limits of 4 – 6 V/m are not exceeded underneath base stations"* (Health Council of the Netherlands 2000). Therefore, this kind of national regulations have no practical impact on the development of networks for mobile telephony. This is a possible reason why several active groups have started addressing their claims to local, rather than national, authorities.

On the other hand, individual citizens do not oppose base station networks in general (the great majority are phone users), but rather the installation of individual antennas, with the typical NIMBY attitude.

The responses of authorities may be very different, depending on local circumstances including the intensity of social pressure, the degree of urbanization of the area, and the political colour of the local government.

Range of local options

In the variety of policies adopted in different countries and regions, some "typical" actions may be identified, namely:

- setting exposure limits more restrictive than national ones;
- setting limits on power radiated by individual antennas (emission limits);
- setting minimum distances of base stations to residential buildings or to other "sensitive" areas;
- finding an agreement between local authorities, operators, the public and other stakeholders.

The effectiveness of each action should be evaluated over the time, in the light of the specific goal at which the action aimed. More precisely, it should be considered whether the objective is a reduction of exposure – and therefore, in a precautionary approach, a reduction of potential risks however hypothetical – or rather a mitigation of public concerns and tensions.

In the following, some examples of actions actually taken in three countries, namely Austria, France and Italy, are presented and discussed.

Adoption of local exposure limits

Any authority setting exposure limits to address the specific issues of base stations should consider that such limits are meaningful only if they have a real impact, i.e. if they impose modifications of the existing networks, or restrictions on new ones. Therefore, the limits should be of the same order of magnitude as, or lower than, field levels that can be found in accessible areas near base stations.

In Italy, some regional parliaments and city councils have established their own exposure limits based on the argument that the national ones, although lower than international guidelines, are irrelevant for mobile telephony and do not introduce any precaution for this technology. Although these regulations are progressively being cancelled by the Constitutional Court (being in contrast with a general law stating that only the national government can set exposure limits), the examples are useful for a discussion on practicality and effectiveness of such measures.

Some examples of local limits set in Italy are reported in Table 1:

City or Region	Maximum E-field (V/m)	Notes
Perugia	3	
Novara	1	0.5 V/m near sensitive areas
Tuscany	0.5	To be reached by 12/01/2005

Table 1: *Selected cases of exposure limits set locally in Italy*

It is interesting to compare these limits with the findings of a monitoring survey carried out by Fondazione Ugo Bordoni (FUB), a technical institution linked to the Italian Ministry of Communication. Some representative data, available at the FUB website (www.fub.it), are shown in Fig. 1.

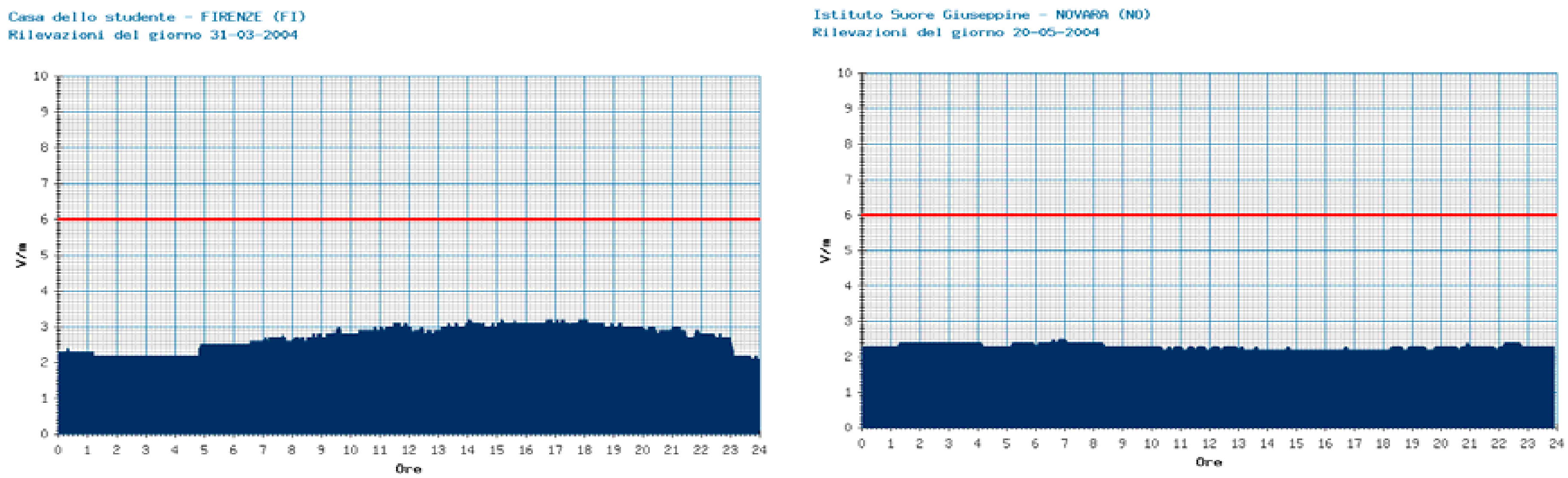

Figure 1: *Electric field strength measured through continuous monitoring near the Students' House in Florence (left), and an elementary school in Novara, Italy.*

The graphs indicate that, though being well below the Italian exposure limit of 6 V/m, the electric field strength exceeds in both cities, and at any time of the day, the precautionary levels set by local ordinances. Similar situations occur in other towns where limits of the order of fractions of volt per meter have been set: the limits are widely exceeded, with no apparent reaction by competent authorities.

By contrast, limits of the order of some volts per meter have limited effect, if any. The full data set of the experimental survey available online (relative to about 1500 sites) indicates typical exposure levels below 2 V/m. An exposure limit of the order of 3 V/m (as in Perugia), or more, is complied with in most cases without any significant impact on existing or future networks.

In conclusion, precautionary limits for base stations seem to have produced no actual reduction of environmental EMF exposure and of hypothetical health risks, while the disparity of numerical values chosen by different authorities is likely to have negatively affected public perception and worries. On this regard, an international expert group (Cognetti et al. 2002) noted the *"confusion in the public mind and stress about health effects from EMF exposure when there are different limits required by different authorities at the local, regional and national level in the same country"*.

The "Salzburg model"

Special measures to limit exposure from base stations have been implemented in Salzburg, Austria. The case has received special attention and therefore deserves some additional discussion.

Following an agreement reached with a single operator that a limited number of new antennas should not exceed a given exposure level, the Provincial Health Directorate launched the proposal to assume the same level - called the "Salzburg Protection Value" - as a limit for all new base stations.

More precisely, it was required that the power density generated by any individual RBS should not exceed 1 mW/m^2 (corresponding to about 0.6 V/m). The same directorate later stated that the value should be understood as an upper limit for the cumulated emission of all the four Austrian operators, so that each provider should keep its emission below 0.25 mW/m^2. Since two of the Austrian providers operate at both 900 and 1800 MHz, they should limit emissions to no more than 0.125 mW/m^2 for each application on a single facility.

Although the "Salzburg model" has no legal binding, the Municipal Department for the Protection of Architectural Appearance regularly refuses authorization for new installations, unless the operator provides proof of compliance with the above restrictions.

Such procedure, that has been adopted some years, has raised strong opposition on scientific, technical, and legal ground.

The Austrian Minister of Transportation, Innovation and Technology, based on the conclusions of an *ad hoc* study committed by the Office of the Federal Chancellor, officially stated that according to the scientific investigations there is no health hazard due to mobile telecommunication (Hohenberg 2000).

From the technical point of view, operators claimed that no further development of the GSM network is possible, and a technical study carried out by technical institutions officially appointed confirmed this argument. A report issued by the Swiss Federal Office of Communications (OFCOM 2002) concluded in fact that *"the measurements, as well as the exposure situations simulated using computers, indicate clearly that an exposure value of 1*

mW/m^2 cannot be complied with, for people living near antenna installations in an urban area, for technical and operational reasons”. The authors of the report also noted that *“at 8 of the total of 13 antenna sites selected at random the Salzburg assessment value of 1 mW/m^2 was exceeded by up to a factor of 40”* and evaluated that *“it would probably be very difficult to achieve exposure values lower than 100 mW/m^2 without substantial economic consequences”*.

The legal controversies are based on the consideration that in Austria the definition of exposure limits falls outside the competency of municipal or provincial councils. At the national level, a Draft standard was published in 1992 (ÖNORM 1992) and updated in 2001, based on ICNIRP guidelines. The Austrian Parliament reaffirmed in January 2002 and July 2003 that only the national standard, and not the “Salzburg model” apply anywhere in the country. A legal case for abuse of authority was also filed, with the court stating in 2002 – in agreement with the Parliament - that provincial institutions are not authorised to set 1 mW/m^2 as a limit.

In conclusion, the “Salzburg model” seems not to have been effective under any point of view. It has prevented the development of networks, with no evident health benefit for public health; at the same time, it has not settled down the controversies and probably has not reduced public concern.

Minimum distances from buildings and inhabited areas

The requirement of minimum distances of RBS to residential settings in probably the most “popular” measure that local authorities can enforce for the sake of precaution. Differently from emitted power, distances between buildings and antennas can be directly verified by citizens, and cannot change over the time.

The reported cases of municipal authorities adopting such policy are innumerable, and many examples can be found on the web. However, the criteria adopted may be very different. Many cases exist of small towns where the generic prescription is given that base stations should be located outside the inhabited area. More frequently, and particularly in large cities, local ordinances set definite distances, either to residential buildings in general or to sensitive areas. A wide range of values can be found for such distances; to make the variety even larger, also the definition of “sensitive area” changes from case to case.

Examples of minimum distances to sensitive areas in Italy range from 75 m in Monza to 100 m in Rome, 150 m in Vicenza, 200 m in Empoli and 300 m in Lecce. The town of Pieve di Cento can perhaps be considered a limit case, with minimum distances of 300 m to houses and rural buildings, 500 m to sensitive areas, and 1000 m between any two RBSs.

Contrary to the general perception of the public, such measures increase, rather than decrease, the average environmental level of EMF. A report of the French Parliament (Lorrain and Raoul 2002) mentions the case of a school in Marseille where the removal of a base station from the top of the building caused an increase of power density in the courtyard, because all other antennas nearby had increased their emissions to ensure adequate coverage of the area.

On the other hand, it is dubious that controversies and worries come down. In France, an expert group (Aubineau et al. 2001) recommended that RBSs located less than 100 m away from schools were oriented in such a way as to avoid that the radiation beam directly pointed to the building. The group clarified that the recommendation was not justified by any hypothesis of risk, but only aimed at reducing public concern. Two years later, a different expert group noted that the measure had produced the opposite effect, and the level of worry had increased (Aran et al. 2003).

Agreements between local authorities and operators

The installation of base stations always requires authorization by competent authorities. At the early times of the technology, such authorizations were granted on a case-by-case basis, with waste of time and money, scarce attention to the global impact of the networks, and possible disparities in the criteria adopted in different cases. This created in the public the sensation of a "wild" development of mobile telephony, and was probably an initial cause for opposition to new installations. On the other hand, efficient and reliable communication networks are a necessity for the society, and their development is an obligation – often legal - for both operators and authorities. It is therefore of common interest to find an agreement on criteria and rules to follow for planning and upgrading networks, and for licensing installation and operation of antennas.

The details of the many charters that have already been signed differ, depending on the specific local characteristic. Besides exposure to electromagnetic fields, other local elements should be taken into consideration, including present and future urbanization, visual impact of antennas and masts, preservation of the historical and natural landscape, etc. However, it seems evident that the adoption in a given country, or region, of agreements based on the same approach, and with similar objectives, would greatly favour the acceptability of mobile phone networks by the public.

Based on these considerations, the Italian Ministry of Communication agreed with the Council of Italian Municipalities (representing the about 8,000 city and town councils of the Country) the text of a draft Memorandum of Understanding between local authorities and operators of mobile telephony. The document indicates the main obligations of each party, in rather general terms; it can therefore be seen as guidance for developing, on a common basis, specific agreements tailored to the local situations.

Although the agreement was signed in December 2003, its application has been so far rather limited, and apparently not very successful. While it is possible that the bureaucratic procedures for authorization of new installations have been speeded up, there is no clear evidence, on a national scale, of a decrease of controversies and opposition to base stations.

Local exceptions however exist, the case of Genoa being probably the most significant. The so-called "Genoa Charter" was signed already in 2000, well before the memorandum of understanding, that was probably motivated also by the success of that experience. The document came after a long process of information, training, and involvement of different stakeholders. It was signed in fact by the Mayor, the presidents of all councils of city quarters, representatives of the University of Genoa, the Regional Agency for Environmental Protection, environmental associations, and action groups. The charter defines specific rights and duties for each of these parties.

It is also important to note that the agreement is not limited to the definition of rules to install new base stations and to check compliance for existing ones. Continuous actions of information and training are carried out, and all parties are regularly involved in discussions on future development of the network. Thanks to this wide participation, the opposition to mobile telephony, that was very strong in the past, seems to have greatly softened.

The Paris Charter

Much attention has been devoted to the agreement reached in 2003 between the City Council of Paris and the French operators of mobile telephony. The general framework of the "Paris Charter" does not differ from similar documents issued in France and other countries. However, several points are peculiar, and deserve attention.

Some basic concepts are clearly stated in the preamble to the charter: the scientific consensus that no evidence exists of health effects from exposure to base stations is explicitly recognised; the very low emission levels are noted; the adequateness of the French regulations on exposure to RF fields (derived from ICNIRP guidelines) is also remarked; both parties recognise the opportunity to take measures to limit exposure to EMF from base stations, but stress that such measures are motivated by public worries and the high density of antennas, not by any health risk.

The "Paris Charter" was signed in March 2003, for a period of two years, after which it had to be revised in the light of its impact. Operators took the pledge to develop their networks in such a way that the average EMF level existing at the time of the agreement were not increased, and to keep exposures below 2 V/m in terms of electric field strength. This limit refers however to an "effective " exposure, being the electric field strength intended as measured indoor, and averaged over a 24-hour period.

Such restrictions are rather soft, and the charter received some criticism for leaving the situation unchanged. Indeed, a survey carried out on more than 500 installations showed that the electric field strength was below 2 V/m in 98% of cases, with 83% of antennas not exceeding even 0.5 V/m.

According to reports of the media, the agreement was overall well accepted by the public, and probably stimulated other similar charters in various parts of France (e.g. Lyon, Nancy, Hauts de Seine, Chantilly). Differently from Paris, these do not define any exposure limit. However, common to all is the recognition of the adequateness of the national standard (and therefore of ICNIRP guidelines), and the recognition of lack of scientific evidence of long term effects.

All charters mention that anyway, as a precautionary measure, an effort should be made to minimize exposure, i.e. to reduce EMF to the lowest levels compatible with a good quality of service. Such statements, that appear also in many ordinances and legal acts of local authorities, may however be ambiguous because "minimization" and "quality of service" are not well defined. A clarification of these concepts is therefore appropriate.

Minimization of exposure and quality of service

The declared objective of many local policies is base station networks that create the lowest possible level of environmental EMF, with the implicit assumption that this would minimize public exposure. However, people are normally exposed also to EMF from mobile phones whose emissions are not independent of the network.

In modern digital phones the emitted power is dynamically determined by the Adaptive Power Control. To prevent interference, and to extend battery life, the power is automatically reduced to the minimum needed for good communication with the RBS. The technique allows in principle reduction up to 30 dB, i.e. a factor of 1,000; the actual reduction depends however on the quality of the connection, that in turn depends on the distance to the antenna, the presence of obstacles and the density of phone traffic in relationship to the capacity of the network.

In order to optimize traffic, an active communication can be switched during the call from an antenna to another, possibly more distant or less favourable from the point of view of signal quality. If the capacity of the network is low, switching can be very frequent. Since at every handover (transfer of communication) the emitted power is reset to the maximum, this mechanism can lead to significant increase of user's exposure, which typically is *per se* two or three orders of magnitude higher than any possible exposure from base stations. Research carried out in Rome showed for examples that, in spite of the big potential of APC, the average reduction is less than a factor of 2, with phones working at maximum power 40–60% of the time (Ardoino et al. 2004).

Limiting the number of base stations, or locating them away from high-traffic areas, for the sake of precaution may therefore have limited impact, if any, on environmental EMF levels, but may largely increase individual exposure of users and – given the universal use of mobile phones – also increase overall exposure of the public.

Conclusions

The experiences reported in previous sections refer to a limited number of cases and cannot be generalized. Nevertheless, they provide some clear indications.

Local authorities are more sensitive than national governments to public pressure, and more available to adopt precautionary policies to cope with it.

Regulatory actions that establish very low exposure limits, minimum distances to buildings, or other restrictions on the networks seem poorly effective in lessening public concerns. At the same time, only marginal reductions of environmental EMF levels can be expected, while the overall exposure of individuals might even increase.

Policies based an agreement between all involved parties have proven more successful. They offer in general more participation and transparency, and favour trust in authorities. To this purpose, it is essential that the bases of local agreements are consistent with those of national and international health policies.

It should be noted however that no easy and universal solution exists. Any option represents a compromise between competing factors, including exposure levels, quality of service, visual impact, etc. While it is important that all these factors are taken into consideration, their relative importance may differ between countries, regions, and groups of the society.

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Wireless Networks - Regulatory Good Practice

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Abstract

In the course of 2002, mobile phone lines exceeded fixed lines and at the end of 2004 there were more than 1.7 billion subscribers to mobile networks. The social and economic benefits of mobile wireless services are well recognised. Future wireless networks are likely to be more complex and use antennas that are likely to be smaller, possibly more numerous and generally of lower power. The typical levels of exposure from existing and newer wireless networks are very low and the consensus conclusion of expert groups is that there is no convincing evidence of a public health risk. Deployment of cellular wireless networks has been accompanied by controversy linked to concerns about possible effects on health, visual amenity or property values compounded by a perceived lack of dialogue between local authorities, network operators and communities. Major delays in network deployments have been observed in countries where there is significant organised opposition and regulatory uncertainty. Countries with the most effective environments for network deployments base their regulatory approach on science based human exposure standards, clear planning guidelines, appropriate consultation processes and the existence of an independent resolution body. A stable and transparent framework that is outside political interference provides the best regulatory approach to ensure community acceptance and the growth of wireless services with the consequent social and economic benefits.

Introduction

In the course of 2002, mobile phone lines exceeded fixed lines [ITU, 2002] and at the end of 2004 there were more than 1.7 billion subscribers to mobile networks around the world.[26] The social and economic benefits of mobile wireless services in both the developed [Lewin, 2004] and the developing world are well recognised [Vodafone, 2005]. Geographical targets for coverage set by governments shaped the pace of initial network deployments but subsequent development has been a response to the growth in customer numbers and the desire for anytime, anywhere contact. Future wireless networks are likely to be more complex, with designers considering a topology that combines cellular networks with elements of wireless local area networks (WLAN), peer-to-peer networks and distributed antenna systems and use new modulations [Tachikawa, 2003]. These wireless networks will deploy transmitters that will be smaller, possibly more numerous and generally of lower power. Accompanying the growth of mobile communications has been has been concern in some countries about possible health risks, with much of the interest directed at antenna sites rather than handset usage [Rowley, 2005]. Government and industry has responded in various ways to this concern with the most effective frameworks based around science-based standards,

[26] http://www.gsmworld.com/news/statistics/index.shtml

auditing of compliance, community consultation and independent planning bodies. This paper discusses a number of such regulatory responses and identifies key principles that support good regulatory practice.

Wireless communications networks

As shown in Figure 6 there are many different wireless access technologies in use or under development today that provide different combinations of range, data rate and mobility. In the past radiofrequency (RF) access technologies tended to be used singly, however, many future applications use combinations in the same device. For example, a Bluetooth link may exist between a headset and a device carried on the body, which uses an in-building WiFi service for email or voice access and which automatically switches to a cellular wireless network to maintain a call when the person leaves the building. Supporting these services are the network of transmitters that may be managed by a central system or which may use peer-to-peer protocols to form a mesh network. The frequency and intended range of operation play a significant component in determining the physical size of the antenna infrastructure, with higher frequencies and shorter range (lower transmit power) requiring smaller antennas.

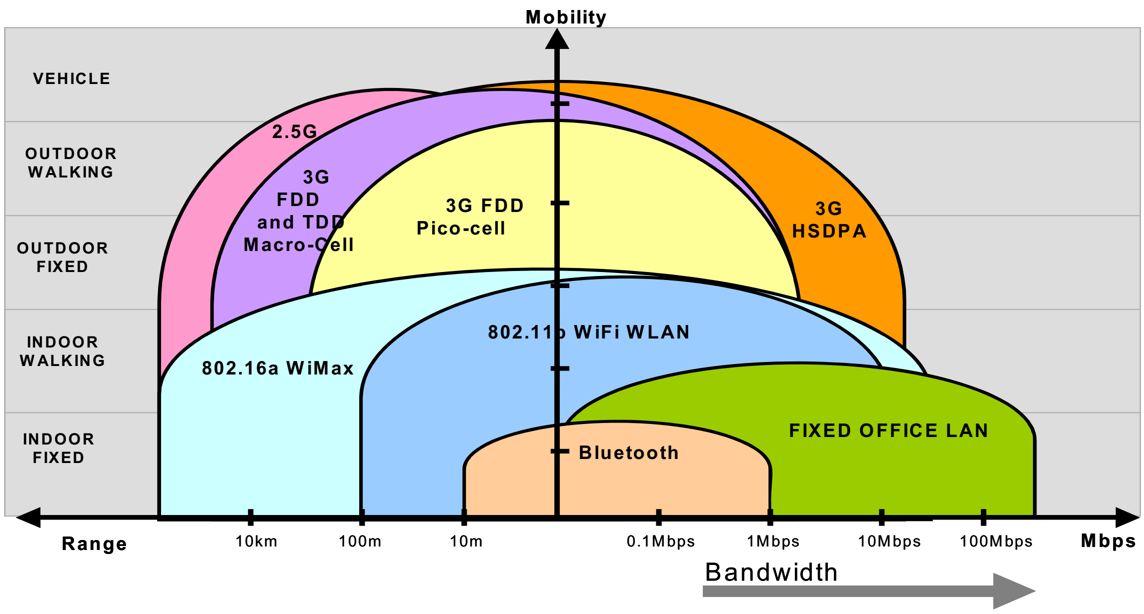

Figure 6: *A view of radio frequency access technologies showing performance relative to range, data rate and mobility.*

In the early stages of cellular network deployments, geographical coverage is the main requirement and so base station antennas may be located on high buildings or freestanding masts. As the network matures and capacity, i.e., the ability of more people to make calls increases in importance, the network will be redesigned with lower power transmitters, directional antennas and smaller cell sizes. The size of a cell can vary in size from 100m or less to 10km or more depending on location and the number of calls to be carried. A small cell will transmit at a low power, often similar to the power transmitted by a mobile phone.

In order for services to be seamless there must be no gaps in coverage with transmitters located where customers want to make or receive calls. For cellular mobile communication systems this means that the required geographic coverage area is divided up into a continuous irregular grid of adjoining "cells" (often pictured as honeycomb-shapes) with frequency, operating powers, antenna orientation and other network parameters selected to ensure quality of service. When a mobile phone user is on the move, calls are 'handed over' from one base station to the next, so that there is no break in the call and this requires the radio coverage from individual base stations to overlap.

Once an area has been identified as needing a new site, detailed investigations are undertaken to work out the available locations. This generally involves consulting with local authorities, conducting a detailed environmental assessment, and considering the feasibility of site sharing with other telecommunication providers. Mounting antennas on an existing building or mast is generally more acceptable than erecting a new mast. However, site sharing may not always result in the most visually acceptable structure because each additional set of antennae usually increases the height by between four and six metres and may require a stronger structure to carry the additional weight. In selecting the best site several factors are taken into consideration including: the number of people requiring service, local topography, obstacles that may block clear radio signals, and the concerns of people who live and work nearby. As the visual appearance of the antennas may contribute to their acceptance by planning authorities and communities, network operators may paint the antennas to improve blending or place the antennas behind facades that are transparent to radio signals and plant bushes to screen equipment shelters. The final design is often a compromise between aesthetic appearance and achieving network coverage objectives.

It is important to understand that cellular networks are not static. Mobile network operators continually monitor their networks to determine the level of customer demand and to identify areas where coverage is unsatisfactory. One capacity limit is that each base station can carry a limited number of simultaneous voice calls, typically of the order of 10-50 per cell. In addition, higher data rate services, e.g., remote email access, may require smaller cell sizes to ensure that the energy per bit of information transmitted by either the handset or the base station is sufficient for reliable communication. A major activity in network evolution is the process of splitting existing cells, whereby omni-directional antennas are replaced by directional antennas to give a sectored site. Over time each sector may be further reduced in operating area by down tilting antennas and reducing transmitter powers. The redesign of the network will also include new frequency assignments to limit interference between sites. From a regulatory perspective, it is usually desirable that site permissions allow for operators to make changes, within specified parameters, to antennas, transmitter powers, frequencies, etc without needing new authorisations.

RF exposures from wireless networks

Public cellular mobile networks

In relation to mobile communications base stations, exposures are generally whole body, effectively 24 hours and potentially throughout a person's life, such as is presently the case with radio and TV broadcast. RF measurement surveys generally show maximum levels from GSM base stations in publicly accessible areas that are less than 1% of the international guidelines [Mann et al, 2000], that the levels vary throughout the day in response to call traffic [Neubauer et al, 2005] and that mobile communications signals are only a small part of the total environmental RF exposure [Line et al, 2000]. Radio frequency surveys have been undertaken in several countries with some results for GSM base stations operating at 900 MHz summarised for illustrative purposes in Figure 7.

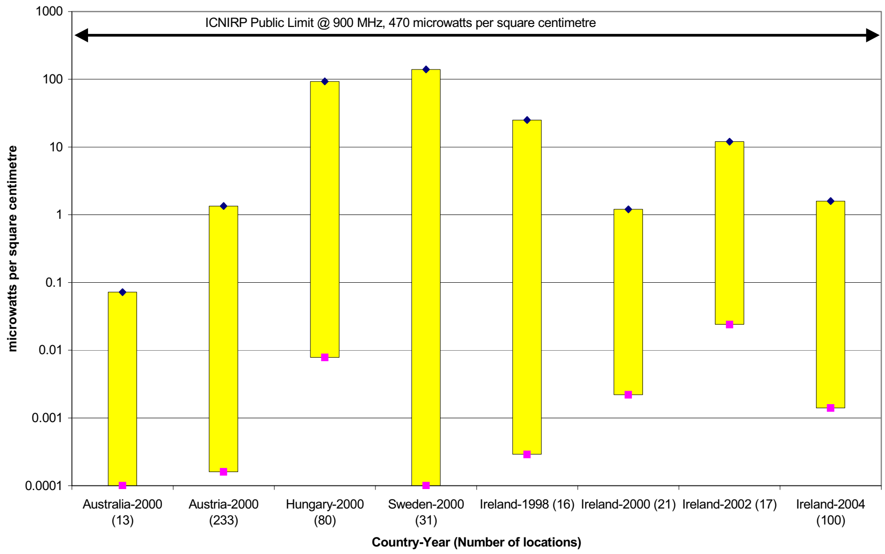

Figure 7: *Plot of minimum and maximum reported [Line et al, 2000; Berqvist et al, 2000; OTDR 1998, 2000, 2002; COMREG, 2004] values for GSM signals at 900 MHz in a sample of countries. The report year is indicated after the country name and the figure in brackets is the number of measurements.*

Note: due to differences in survey measurement methods the comparisons are relative rather than absolute.

It should be emphasized that due to differences in measurement techniques inter-country comparisons are relative rather than absolute. The data shows that population exposures may vary over 6 orders of magnitude within a single country, with average exposures below 1 $\mu W/cm^2$, about 0.2% of the ICNIRP limit at 900 MHz. Ireland is the only country for which RF survey data was available over a period of years. From this limited data, there would appear to be a trend downward in the maximum level and upwards in the minimum level. This would be consistent with maturing GSM networks operating on lower powers from individual base station sites but providing wider geographic coverage. Microcell and picocell wireless systems are also widely used to ensure service in urban areas and within buildings. Despite their greater closeness to people, the RF exposures are similar to those of larger base station sites due to their much lower operating powers [Cooper et al, 2004a].

Private wireless networks
It is becoming increasingly common for business, educational institutions and even individuals to operate private wireless networks, often to support nomadic access to computer networks. Typically RF exposures are very low [Somerset County Council, 2003] and the compliance framework is often equipment based, for example, through management of output power or by incorporating radiating elements in radomes that prevent access to areas above allowable public exposure levels. The end-user needs clear information on recommended installation practice and any conditions on usage, in particular about proximity to the body. In hybrid public-private situations, such as, a school wireless LAN, additional information may be needed for school authorities to address the questions of parents and comparative data on exposures relative to common products and services may be helpful.

Occupational exposures
Two broad classifications of workers may be required to work close to wireless network antennas. The first, persons who install antennas and transmission equipment, will generally have some training and understanding of safe working around radio transmitters. They may also have access to personal protective equipment, such as RF hazard monitors and can be expected to have received information about exposure levels and compliance zones around antennas. However, even for such persons routine RF exposures are generally low [Cooper et al, 2003]. The second group, persons such as building maintenance staff, may have little or no awareness of radio transmitters. These persons (and the building owner for a rooftop site) are likely to need easily understood information, including diagrams to indicate accessible areas. In some situations, signs or physical barriers may be appropriate. From a site management point of view, policy decisions about allowable exposure to public or the higher occupational RF limits will be needed and then implemented.

Even with good hazard management processes, suspected or real instances of exposure to RF levels above the relevant limits are possible. An appropriate investigation will usually be needed to determine if an over-exposure actually occurred and at what level. In addition to the importance for occupational safety, this exercise can provide significant reassurance for the exposed individual. Due to the significant safety factors incorporated in the standards, especially at radio frequencies, detectable harm is unlikely expect in the case of RF burns. There is no specific test for an RF injury and COMAR [2002] has published guidance for physicians, emphasising the importance of providing reassurance.

Wireless network deployments - good regulatory principles

Deployment of second generation (2G) and third generation (3G) networks has not been without controversy, with concerns about possible effects on health, visual amenity or property values compounded by real or perceived lack of dialogue between local authorities, network operators and communities. The public in general, whether or not they are mobile phone users, show limited understanding of the needs of wireless services to have antennas located close to where people want to use their phones. In countries where there is significant organised opposition and regulatory uncertainty, major delays in network deployments have been observed [GSMA, 2004a]. Through the last decade of deploying cellular wireless networks a number of principles have emerged that can guide the development of good industry and regulatory practice.

RF exposure standards based on international scientific consensus

The human exposure guidelines of the International Commission for Non-Ionizing Radiation Protection [ICNIRP, 1998] are based on a thorough review of all published scientific literature. They are the basis for the recommendation of the Council of the European Union [European Council, 1999] and have been adopted in many parts of the world [WHO, Undated]. The WHO says of these guidelines [WHO, 2005]:

> 'To date, all expert reviews on the health effects of exposure to RF fields have reached the same conclusion: There have been no adverse health consequences established from exposure to RF fields at levels below the international guidelines on exposure limits published by the International Commission on Non-Ionizing Radiation Protection [ICNIRP, 1998].
>
> 'The ICNIRP guidelines were developed to limit human exposure to electromagnetic fields (EMF) under conditions of maximum absorption of the fields, which rarely occurs, and the limits incorporate large safety factors to protect workers and even larger safety factors to protect the general public, including children. Thus, the limits in the ICNIRP guidelines are highly protective and are based on all the available scientific evidence.'

Some national authorities have adopted human RF exposure standards that are more restrictive than the ICNIRP recommendations on the basis of providing additional protection against health effects that are regarded as non-established by ICNIRP [BUWAL, 2003]. In addition, local authorities and individual scientists have recommended values differing from the ICNIRP guidelines, however, it has been argued that such actions have increased public perception of risk [Burgess, 2002]. In a recent experimental study Wiedemann and Schütz [2005] tested the effect of precautionary limits on perception of risk and found a statistically significant increased perception of risk. The authors conclude that:

> 'Precautionary measures implemented with the intention of reassuring the public about EMF risk potentials seem to produce the opposite effect. They may amplify EMF-related risk perceptions and trigger concerns…'

The authors go on to reference the WHO advice [2000] that '…science-based exposure limits should not be undermined by the adoption of arbitrary cautionary approaches' and add:

> '…any precautionary policy should consider possible countervailing risks such as increasing fear and unnecessarily spreading anxieties. These adverse impacts of precaution should be brought to the attention of policy makers.'

Other national authorities have chosen to align their national exposure standard with the international guidelines, even when this could be interpreted as a relaxation of exposure limits at certain frequencies. In some cases this has been coupled with a recommendation that 'low or no-cost measures should be applied in order to avoid or reduce exposures' [Ministry for the Environment, 2000]. It is clear that local authorities are not the place to develop human exposure standards for RF exposure. The adoption of arbitrary reductions of the international guidelines, often applied discriminately to mobile communications services, is likely to result in co-location problems, additional sites, greater local authority costs and delays in site deployment with no measurable benefit to human health [GSMA, 2004b; Bornkessel and Stöcker-Meier, 2003].

Transparent and accountable siting process for public wireless networks

Public wireless communications is an important business, but it is also a critical national infrastructure providing personal and societal benefits in times of emergency and disaster. Fragmented local authority rules may delay network deployments and lead to gaps in coverage. National governments have developed planning frameworks and industry has adopted codes designed to provide for consistent planning policies in regard to siting of base stations [ODPM, 2002; ACIF, 2002]. These frameworks contain a number of similar underlying principles.

- *Siting rules that take account of physical characteristics*. Generally, the requirements needed to obtain approvals increase as the size of the proposed radio base station. Under these rules, small installations such as microcells or roof-top sites, may require no local authority approvals, while larger mast sites may be subject to the full planning process.
- *Consultation processes consistent with other infrastructure*. In recognition of public concern about based station siting, there is usually some requirement for notification of nearby residents and there may be a requirement for additional local consultation in the case of expressed public concern. Distribution of letters, notices in newspapers, small meetings and public drop-in sessions are generally more effective than large-scale meetings in addressing concerns. In general, the requirements should be similar to those of other infrastructure developments of similar size.
- *Transparent planning approval and appeals process*. It is important for all parties to a base station siting decision that the decision-making process be fair, transparent and free from political influence. In some countries judicial review of local authority decisions is possible while in others there are separate environment courts.

As was noted previously, the radio signal levels from mobile base stations in publicly accessible areas are very low. Hence, planning conditions that require commissioning measurements or on-going monitoring are not of great value only as they only serve to confirm compliance. There may be circumstances where audits of a sample of radio transmitter sites can be a useful component of a programme to build public trust.

Recommendations and conclusions

Given the variables of technology, politics, geography and social considerations, it is unlikely that any one approach will be suitable for all network deployments in all countries. Nevertheless, the experience gained from the deployment of existing wireless services provides several key lessons for national authorities, the WHO and industry stakeholders that can facilitate the rollout of newer wireless systems.

Recommendations for national authorities

It is clear from the example of several countries that fragmented national regulatory authority provides an environment in which controversy and political action becomes more likely [Burgess, 2002]. Health and telecommunications policy are properly the role of national government, while planning approvals are generally a matter for local authorities. The national regulatory framework should be based on a health policy of limiting RF exposures consistent with the international scientific guidelines. As effective mobile communications is increasingly a key national infrastructure, the framework may also contain provisions aimed at providing for a consistent approach by local authorities to the evaluation of base station applications, for example, specifying exempt installations or the timescales for decisions. Local authorities in turn should focus on planning aspects (e.g., aesthetics, site access, etc) and not seek to determine health policy. Public notification or consultation requirements should be appropriate to the proposed development and aimed at providing a real forum at which concerns can be effectively discussed in a non-confrontational manner. The national and local policy and processes need to be transparent and underpinned by an impartial body that can adjudicate in the case of disputes and make decisions that are binding on the parties.

Recommendations for the World Health Organization

The World Health Organization has an important role in providing impartial and authoritative advice on health policy to national authorities. Many stakeholders rely upon WHO statements and so there is a need to ensure that recommendations are clear and free from scientific caveats wherever possible. The WHO can provide significant reassurance by bridging the gap between the reality of low scientific uncertainty and the public perception of greater risk evoked by phrases such as 'the jury is still out.' Future WHO information should be inclusive of the full range of emerging radio technologies and aim to improve public understanding of the relationship between base station antennas, phones and services. The importance of audience specific information has perhaps been underestimated to date. General fact sheets and policy advice to governments serve many uses, however, concerned persons will often contact their family doctor if they fear harm from proposed antennas. At present these doctors are underserved with factual information, deriving much of their understanding from media reports. This stakeholder group would benefit from a concise brief or awareness raising activity from the WHO via national medical associations or medical journals.

Recommendations for the mobile communications industry

The mobile communications industry has learned many lessons from the deployment of existing wireless networks. The key message is the need to develop and maintain a relationship of trust with local communities. These lessons have been incorporated in voluntary or mandatory codes of conduct and agreements with local authorities in several countries, see Table 1.

Country	Code or Agreement
Australia	Australian Communications Industry Forum - Deployment of Mobile Phone Infrastructure Code
Austria	Forum Mobilkommunikation-Agreement Between the Österreichischer Gemeindebund and the Mobile Telephony Providers
Canada	Industry Canada - CPC-2-0-03: Environmental Process, Radiofrequency Fields and Land-Use Consultation
France	L'Association Française des Opérateurs Mobiles - Good Practices Guide between Mayors and Operators
Germany	Informationszentrum Mobilfunk e. V - Mobile Communications Industry Initiative
Italy	ANCI MoU with Ministry of Communications: Installation, Monitoring, Testing and Rationalisation of Radio Base Station Equipment
Netherlands	Netherlands Antenna Bureau - MoU under the National Antenna Policy
Portugal	Autoridade Nacional de Comunicações (ANACOM) - Code of Conduct and Good Practice for the Installation of the Equipment which generates Electromagnetic Fields
Spain	Spanish Association of Electronics and Telecommunications Industry (ANIEL) - Self-Regulatory Code for Mobile Communications to Guarantee Security of Service
UK	Mobile Operators Association – Ten Commitments To Best Siting Practice

Table 1: *Codes of Practice or Agreements on Network Deployments in a Sample of Countries*

These documents have varying legal weights and levels of detail. Some were developing by operators in consultation with other stakeholders, especially national and local authorities, and others are government led actions. The UK and Australian approaches were among the first adopted with the former developed on a voluntary basis by industry and the latter via a formal committee process involving representatives of industry, local authorities, government and the community, leading to adoption as an enforceable regulation.

The GSM Association recognises that there is public concern about the siting of radio base stations. This public concern is in contrast to a number of independent expert reviews that have concluded that there is no convincing scientific evidence of a link between public exposure to low level radio signals generated by mobile telecommunications systems and adverse human health effects [Sienkiewicz and Kowalczuk, 2005]. The wireless industry acknowledges that there is a responsibility on it, with central and local government, to address community concerns about radio base stations. The GSM Association developed guideline principles [GSMA, 2002] to assist Members, especially in developing countries, learn from the experience of other operators, Table 2.

- The GSM Association and its Members welcome continuing independent, high quality and objective research and are currently supporting research recommended by the World Health Organization to address scientific uncertainties. On-going research will ensure that policy can be based on substantiated scientific evidence and will provide the basis for on-going review of exposure guidelines.
- The GSM Association believes that all existing and new radio base stations should be designed to comply with relevant national radiofrequency exposure guidelines. The GSM Association supports national exposure guidelines that are based on sound scientific evidence and are subject to on-going expert review. We encourage international harmonisation of standards. The GSM Association opposes the imposition of local unscientific restrictions on siting that discriminate against mobile communications.
- GSM Association members should consider the appropriate form for a declaration of compliance with radiofrequency exposure guidelines. This would support openness and improve the confidence of local communities in the compliant operation of base stations.
- The GSM Association believes that the provision of technological information to regulatory and planning authorities is an effective means of raising awareness and understanding of the deployment issues confronting Members.
- Improved dialogue with local authorities and other key regulatory stakeholders will increase understanding of network infrastructure development requirements and the impacts of local planning frameworks. The consultation process should take into account planning, environmental and community issues.
- GSM Association Members should consider whether communication with regulatory and planning authorities could be improved through the use of clear and consistent supporting documentation.
- Site sharing with other radio installations or existing structures, where technically feasible and in line with competition law and licensing conditions, should be factored into decisions on the most environmentally appropriate radio base station solution.
- Appropriate siting and design that reduces the visual profile of antennas can help allay public concerns. The GSM Association recognises that, where reasonable and practical, measures can be taken to minimise the environmental impact of radio base station developments.
- The GSM Association supports clear processes to respond to enquiries about radio base stations and that the information provided to the public needs to be of a high standard.

Table 2: *GSM Association Guideline Network Deployment Principles*

The main elements of these guidelines include clear information exchange with local authorities and other key stakeholders, proactive operator site sharing initiatives when feasible, environmental sensitivity considerations, and more efficient and detailed availability of data. The key health and safety aspects include operator provision of declarations of network infrastructure compliance with relevant national or international guidelines. These guidelines are consistent with voluntary commitments made by GSM Association members in

Australia, the UK, other countries and with the GSM Europe (GSME) 'best practice' recommendation on network rollout adopted in late 2001.

Independent expert public health groups have concluded that there is no convincing scientific evidence of a health risk from the low level signals from wireless networks in publicly accessible areas, however, as long as there remains a need for major wireless infrastructure developments, there are likely to be localised instances of opposition to base station siting. A stable and transparent regulatory framework that is outside political interference provides the best regulatory approach to ensure community acceptance, to build an environment of trust and to support the growth of wireless services with the consequent social and economic benefits.

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Precautionary measures for base station siting - reaching a consensus between providers, local authorities and public to protect public health

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Abstract

Due to the actual procedure in base station siting and the growing number of base-stations needed for the still developing mobile services, citizens protests against base stations are ongoing and a solution to assure mobile telephony services, public health and social peace is urgently needed. We analysed the different already experienced solution models trying to deduce a "best possible way to act" recommendation instead of facultative measures varying from city to city and from country to country.

Keywords: Public health, precautionary measures, consensus for base station-siting and building, long-term-exposure-minimization.

Introduction

Due to the actual procedures in base station siting, long-term health effects cannot be excluded and are even plausible, considering the following facts as well as the WHO health definition: "a complete physical, mental and social well being and not merely the absence of disease or infirmity".

∉ The precautionary approach prevailing the WHO/IRPA document of 1981 has been almost fully abandoned, as well as the reservations of the EU Parliament in 1998.
∉ Absence of public involvement and (right of) information in the planning and building phase, as well as after siting, e.g. concerning the actual and expected additional EMF exposure etc.
∉ Property devaluation, due to visual impacts, and fears due to potential long-term risks.
∉ WHO briefing pamphlet no.32 *Local authorities, health and environment: Electromagnetic Fields:*- "No standards-setting body has set exposure guidelines to protect against long term health effects, such as a possible risk of cancer".
∉ International re-insurance companies explicitly exclude coverage of potential EMF health risks.
∉ No obligation to prove that site and antenna configuration have been chosen in view of public exposure minimization.
∉ No obligation for exposure control after siting (e.g. 24h-control of emitted power) and therefore unknown exposure situation of the public.
∉ No data collection of loss of well being reports and no attempt to clarify these reports about loss of well being after installation of antennas.
∉ Still considerable scientific concerns (and disagreements) concerning:

- interpretation of studies, possible effects and potential health risks of EMF, especially long-term effects;
- what constitutes an "established" health effect;
- the great variation in limit values applied in different countries;
- the rationale behind the different exposure standards;
- the consequences when applying the Precautionary Principle to EMF's;
- the mechanisms that may be responsible, as well as a poor understanding of the basic interaction mechanisms, between EMF's and the organism;
- whether the SAR is the right factor to consider.

∉ ICNIRP and EU recommendations exclude protection of people with medical and metallic implants.

∉ EU regulation concerning EMF working exposure defines everyone as worker instead of only those who are professionally exposed (difference to other pollutants)

∉ Same situation as for base stations concerning Wireless Networks.

Discussion

Some countries or cities have already adopted legally Precautionary Measures for EMF's, for example there are regulations in Switzerland, Italy, and France.

Example Italy:
Based on their Constitution and art. 174 / Precaution – Treaty of Amsterdam,
1998 = Ministerial Decree DM 381/98 – art.4, comma 1: "Minimization as low as possible to guarantee the service" 2001 = law no. 36 "Exposure minimization" and redevelopment of existing installations.

2003 = DPCM 08.07.2003 "Attention value – quality criterion 6 V/m for all those areas where people are more than 4 hours/day". This long-term-exposure-precautionary measure allows, however, the use of the mobile-phones themselves = short-term exposure. **ICNIRP should adopt this distinction!**

Region of Alto Adige (South Tirol/Italy): the providers have to present their plans to the regional government on 30 January of each year. Then the regional government transmits the projects to the communities, where the public involvement should be implemented. After return of all community-statements to the Regional Government, the Regional Government approves the plans and looks for an agreement with the providers.

We have to raise the questions:

How exposure-minimization can be reached in the most effective way?

∉ by avoiding base station installation nearby/in kindergarten and schools while siting near residential homes is not called into question?

∉ with innovative technical solutions, e.g. microcells and picocells, e.g. combined with optical fibbers, instead of "maxi-antennas"?

∉ with wireless homes, W-LAN in schools, public areas, hotels etc., Bluetooth?

∉ or if exposure minimization can be better reached using connections with cables, avoiding WLAN accesses where people can stay for longer time (e.g. work place), etc.

and why,

∉ for all other pollutants than EMF, the exposure-limits are distinguished for workers whose job implies exposures to the pollutant and other workers who are considered to be "general public"?
∉ while only for EMF's the standards suggest the same limits for workers professionally involved with EMF exposures and also for the others, being considered "public" in the case of other pollutants?

Objective

To reach a consensus between the Government, the industry/providers, local authorities and the citizens, there are, from PMI's point of view, the following necessities:

∉ **legally based public involvement instead of facultative options**, varying from one city/country to another. Some examples have already been experienced in practice:
  - Round-tables in Venice (Higher Institute of Prevention and Work Safety), Bologna, Empoli, etc.
  - Germany: Munich etc.
  - Agreement of Paris (2 V/m)
  - Switzerland-regulation
  - Israel-law 21.12.2005

∉ **exposure-minimization** (as low as possible to guarantee the service): low exposure-levels have been demonstrated to be technically and financially achievable with 3 years measurements in Styria – Austria, Salzburg = siting and round-tables for about 2 years (public relation award 1998), measurements in Carinthia and Vienna – Austria, Italian attention level of 6 V/m (sum of the whole RF-spectrum).
∉ **publication of the documentation proving that the site has been chosen in view of exposure-minimization** (as low as possible to guarantee the service…) and those different siting-options have been considered and evaluated. Exposure evaluation before siting can be done with experienced software (e.g. BAKOM software supported exposure and field distribution evaluation in the city of Salzburg, Austria - www.bakom.ch)
∉ **control** of long-term exposure/emitted power after siting including data-publication on the internet.

PMI-recommendations for BTS-siting to reach a consensus Providers – Local Authorities – Public and for public-health protection:

1. ICNIRP should adopt the Italian regulation which distinguishes between long-term exposure from base stations and short-term exposure from the mobile phones themselves; a distinction which allows the use of the mobiles despite lower long term exposure values.
2. Exposure minimization to the minimum needed to maintain the quality of the service as quality criterion.
3. Broadband applications via cables.
4. Base station siting with public and local authority involvement, taking also in consideration different siting options.
5. Take into account the local health situation.

1. Public information about existing and expected exposure values / computer-simulation including consideration of existing HF EMF sources.
2. Open-minded discussion about different technical solutions.
3. Exposure/emitted power control via 24hour monitoring.

4. Publication of calculated and measured exposure-values via internet.
5. Publicly accessible database
6. Redevelopment of existing sites.
7. Collect citizen-reports about well being problems after base station sitings.
8. Solve the insurance and property devaluation problem
9. Cell phones: good visible publication of the SAR-values, avoid publicity for children’s use.

RISK PERCEPTION AND COMMUNICATION

Understanding Public Responses to Precautionary Action and Advice

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Introduction

Thus far, there has been little research that has addressed the impact of precautionary approaches to risk management on people's appreciation of technology, its possible risks and benefits, and on their attitudes to those responsible for risk management. This is a subject however that is of increasing interest to policy makers and those responsible for risk management. In particular, the World Health Organisation (WHO) have recently been grappling with the production of a framework intended to guide WHO member states in the way that precautionary approaches might be applied to developing health policies around areas of scientific uncertainty. As part of this, drafts of this developing advice have considered how public concern might be relevant to the development of precautionary responses.

Recent academic explorations of the development of precautionary approaches have suggested that it is unhelpful and unproductive to align science based regulation and precaution against each other (Stirling, 2002). One ongoing debate in this area thus centres around the way in which lay perspectives might shape the adoption of precautionary approaches. Stirling suggests that precaution is best understood as a process of engaging lay perspectives in dealing with uncertainties. The crux of this proposal is that 'the social appraisal process be as open to the perspectives of those who stand to be affected by a course of action, as those proposing it'. Clearly this represents a much broader perspective on lay input than simply focusing on the role that lay concerns might have in motivating precautionary approaches. However, in large part stimulated by a book by Burgess (2004), one focus of the debate around electro-magnetic fields and mobile telecommunications has been upon the role which public concern plays in driving the adoption of precautionary approaches and whether precautionary actions and advice reduce public concerns or rather have the effect of intensifying or even producing concerns.

Precaution and public concern about mobile telecommunications in the UK

Examination of the regulatory framework within the UK for managing the possible health risks of mobile telecommunications illustrates how a precautionary framework has emerged in response to public concerns, and importantly, has been seen as a means to address those concerns.

This can be traced through the initial statement by Tessa Jowell, the Minister for Public Health

> *"In April 1999, the Minister announced that, in response to recent research publications, the now widespread use of mobile phones and "the heightened public concern about health effects from mobile phones", the NRPB had been instructed to establish an Independent Expert Group on Mobile Phones to assess rigorously the current state of research into the health impacts of mobile phones"* (House of Commons, 1999)

The IEGMP was duly established and in the resulting report (IEGMP, 2000) prefaced their recommended series of precautionary measures by saying,

> *" We recommend that national and local government, industry and the consumer, should all be actively involved in addressing concerns about possible health effects of mobile phones." (para 6.40).*

In accepting the recommended precautionary approach, the government response to the IEGMP report was explicit in anticipating the expected effects of a precautionary approach (Department of Health, 2004):

> *"The report makes helpful recommendations on measures to reduce public concern about the health impacts of MT technologies."* (para 1.2).

It seems then that one of the primary motivations expressed for recommending precautionary actions and advice around MT was to attenuate public concerns.

Research around public concern and precaution

What do we know about the effect of precautionary action and advice upon public concerns? The research that has been carried out to this point tends to the conclusion that precautionary actions and advice do not reduce concern but rather exacerbate it. This position has been most strongly stated by Burgess (2004). He argues that mobile telecommunications can be considered a 'phantom risk', that is, one that has no basis in scientific reality and that "precautionary advice and activity itself can animate risk perceptions" (2004:90). He suggests that precautionary advice can confirm and cohere the individual's initially diffuse anxieties and that it signals to the public the existence of risk, which in turn instigates and intensifies concern. This work is attuned to a wider perspective articulated by Durodie (2003) and Furedi (1997), which suggests that precaution can promote a culture of fear and that official responses to 'perceived problems' can become the driver of 'real problems'.

The relationship between precaution and public concerns was also addressed in a recent essay by Peter Sandman (2004). He draws attention to the lack of existing research, and, drawing on his experience of risk management and the existing risk perception and communication literature, explores a range of possible mechanisms that might increase or reduce concern. Weighing this evidence he concludes on balance, that government adoption of precaution would be more likely to exacerbate worry. Importantly however he draws attention to the likelihood of important variations between people and between responses to different types of precautionary action or advice.

Weidemann and Schütz (2004) used an experimental design to explore the effects of precautionary advice upon perceptions of risk, the sufficiency of scientific knowledge about the risk and trust in those managing the risk. (They did not focus upon factors that might determine variation in responses to precaution.) Across their two studies they found that precautionary advice tended to heighten perceptions of the risk, and, that it was associated with lowered trust that the health protection of the public was assured.

In summary then, it would seem that there is some evidence to suggest that precautionary measures can have the effect of *increasing* public concerns. There seems no empirical evidence thus far that a precautionary position has the effect of reassuring the public and assuaging their concerns.

Current MTHR research

The main focus of our work in the UK, funded by the Mobile Telecommunications Health Research Programme[27], has been to explore public responses to uncertainty, and in particular to precaution. Thus far we have addressed this issue using both qualitative[28] and quantitative approaches. Initially we explored the way in which people make sense of precaution in a series of focus groups. This qualitative approach was used to allow us to document people's understandings of uncertainty and precaution and to discover how they made sense of the possible health risks of mobile telecommunications. Following this, as part of a module of questions that we included in the Office of National Statistics Omnibus Survey we asked people about five specific pieces of precautionary action and advice.

Focus groups

The qualitative work (reported more fully in the article noted in footnote 4) consisted of a series of ten focus groups conducted in two areas of the UK. The groups were purposively sampled and included those that expressed negligible and strong concerns about the possible health risks of mobile phones as well as those that had been part of protests about base station siting. Each group lasted for between 60 and 90 minutes and were structured in three stages:

> (i) General discussion of the benefits, risks and regulation of mobile phones and masts with no mention of precautionary approaches.
>
> (ii) Discussion/introduction of the notion of a precautionary approach to MT in the UK
>
> (iii) Discussion introduction of the nature of precautionary advice in the UK

The analysis of the interview transcripts identified four important themes

(1) Little awareness of precautionary approach to MT risk management in the UK

The benefits of MT were considerably more salient than any potential health risks. There was clear recognition of the existence of scientific uncertainty around these risks but little acknowledgement that this uncertainty had been recognised by the government or that there was any government action linked to this. Participants surmised that the likely government approach was to 'wait and see' with no change of approach in the meantime.

(2) A precautionary approach is unlikely

Participants suggested that it was unlikely that the government would take a precautionary approach – partly because it was thought to be an admission of liability should the risks become more established over the years. Industry were also seen to have a strong role in constraining government admissions of uncertainty. The view was also expressed that if there was no evidence that there was a risk of health effects then it was contradictory to take a precautionary stance.

(3) Different concept of precaution from government

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[27] http://www.mthr.org.uk/

[28] An article based on the qualitative work (Managing the Possible Health Risks of Mobile Telecommunications: Public Understandings of Precautionary Action and Advice) has been submitted to 'Health, Risk and Society'.

When the concept of precaution – care in the face of uncertainty – had been introduced participants noted a range of evidence that this was not in fact the case. For example, continuing controversy around mast siting of masts – operator secrecy and lack of public information - was taken as indicative of a lack of care about uncertainties about health impacts. Participants held quite different conceptions of precaution than those embodied in the IEGMP report.

(4) Making sense of precautionary actions and advice

In the final stage of the focus groups the facilitator introduced the specific precautionary advice that had been given in the UK as outlined in the DoH leaflets (DH, 2000a; DH 2000b). It was clear that there was no simple or single type of response to these in terms of producing concern or providing reassurance. There were certainly instances of information being used to validate existing concern and of the provision of information about precautionary actions providing reassurance. In addition some reassurance was contingent upon the provision of information *per se*. However one of the clearest strategies for making sense of the details of precautionary advice was to be sceptical. Here precaution is seen as a way of regulators hedging their bets and avoiding accountability. The rhetoric of precaution was thus seen to prepare the way for a government justification of 'well, we told you so', at a later date should fears about possible health risks of MT prove to be justified.

Survey work

The focus groups thus provided rich data where complex reasoning around risk and precaution was evident. This contrasts with the approach taken in the quantitative work where, when asked about precautionary advice or action we simply asked people to say whether each piece of advice reassured or increases concerns (or neither). This was done with a nationally representative survey (n = 1800). The picture that emerged was similar across all five questions – by and large people responded by saying that the precautionary advice or action increased concern rather than reassured. These results are summarised in Figure 1 below. On each question about half of those answering said that the advice caused at least some degree of concern.

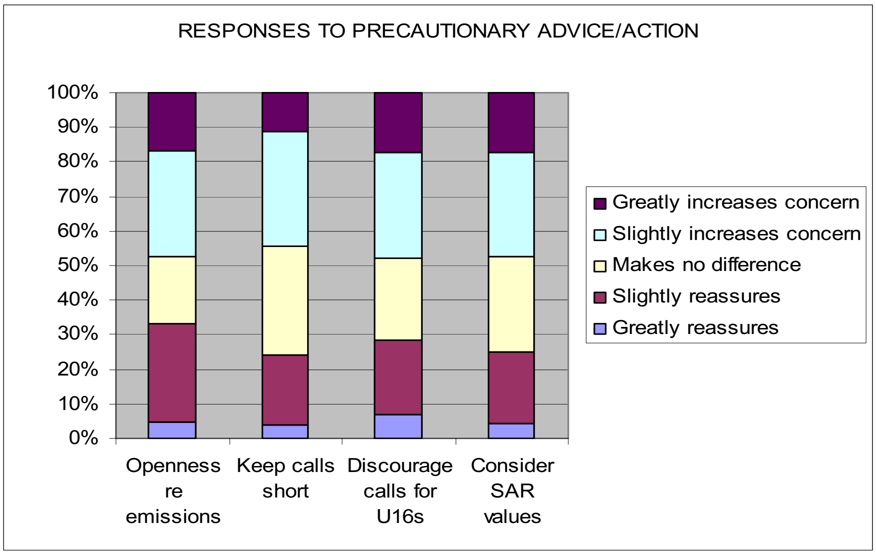

Figure 1 *Responses to Precautionary Advice and Action*

However, there was some variation between people in the degree of concern that people reported that this advice caused. For example, people who reported low frequency of phone use were more likely to be reassured by the advice, as were those who agreed that the government provides all relevant information about health risks. Figure 2 below illustrates that there were also differences in relation to people's initial levels of concern about the possible health risks of mobile phones.

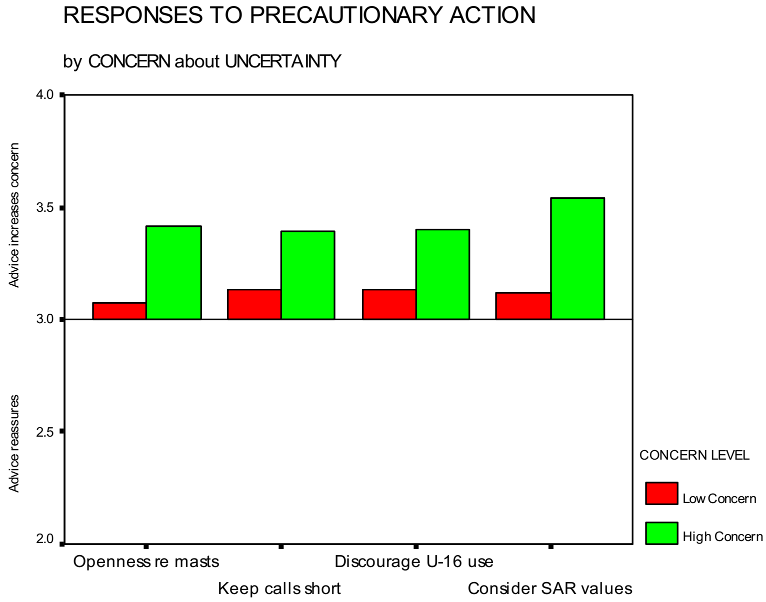

Figure 2 *Responses to Precautionary Advice and Action: the role of Concern*

Discussion

Taken together these results suggest that when people are given the opportunity to consider and to make sense of the relatively unfamiliar concept of precautionary action and advice (as they were in the focus groups) they draw on existing meanings and experiences to highlight different interpretations of precaution. Here there was no strong theme that precautionary advice initiated concern or heightened existing concerns. In contrast, our survey results paint a similar picture to the findings of Weidemann and Schütz – where the dominant response to precaution was that it was linked to concern rather than to reassurance.

It might be argued that in the comparatively context free environment provided by the survey, risk and precaution were conflated and that precaution was thus seen to signal risk. Participants are sensitive to the presence or absence of cues provided by the research environment itself (Schwartz and Sudman, 1992; Houtkoop-Steenstra, 2000) and certainly the predetermined and constrained response options of the survey provide quite a different context for responses than the wide ranging discussion of both the benefits as well as the possible risks (health and otherwise) of mobile telecommunications evident in the focus groups. We are currently in the process of collecting experimental data that will systematically explore how variations in the context within which precaution is presented affect evaluations of precautionary action and advice.

Where precaution is used as a response to public concern, the motivation by implication is that precaution is likely to attenuate those concerns. In contrast, the research reported here offers some support for the previous finding that precaution may intensify pre-existing concerns. It does however also suggest that much greater understanding is needed of the contexts in which precaution is more or less likely to be interpreted as cause for concern. Our exploration of this is ongoing.

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