Mobile Telecommunications and Health Research Programme

Report 2007

MTHR Programme Management Committee

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Chairman: Professor Lawrie Challis OBE

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Contents

Executive Summary

The report describes the progress of the UK Mobile Telecommunications and Health Research (MTHR) Programme. It was established in 2001 on the recommendation of the Independent Expert Group on Mobile Phones (Stewart Committee) with initial funding of £7.36 million provided by government and industry on a 50:50 basis. Further contributions later raised this to £8.8 million. In order to ensure that none of the funding bodies can influence the outcome of the MTHR Programme, it is run by an independent programme management committee. This includes some members of the Stewart Committee and additional specialists to provide a broad range of expertise. It has four overseas members, including a representative of the World Health Organization, and was initially chaired by Sir William Stewart. He was succeeded by Professor Lawrie Challis in November 2002.

The first of the 28 research projects supported by the Programme started at the end of 2001. To date, 23 studies have been completed and the results of many have been published in peer-reviewed scientific journals (23 papers so far). The report describes this latter research and places it in context with work going on in other parts of the world. Information on the progress of the unpublished MTHR projects is also given and further details can be found on the MTHR website: www.mthr.org.uk. Having assessed the outcome of the research funded by the Programme, the Committee has identified priorities for future research to be supported by a second phase of the Programme, MTHR2.

Cancers of the brain and nervous system

The MTHR Programme has contributed to the UK component of a large multinational epidemiological study on the use of mobile phones and the risk of cancers of the brain and nervous system. The result of the UK component and pooled analyses with other North European countries showed no epidemiological association for short-term exposures (less than ten years). However, the situation for longer exposure times is less clear and the Committee has identified a need for further work in this area. This is discussed in greater detail below.

Brain function

The set of volunteer studies of brain function is one of the largest that has been carried out anywhere and covers possible reactions to exposure to radiofrequency (RF) fields from changes in response times and memory to blood pressure. However, none of these studies shows that brain function is affected by RF exposure and the Committee has concluded that there is no need for further studies on adults at the present time.

Electrical hypersensitivity

The Programme has supported the largest and most robust studies of electrical hypersensitivity yet undertaken anywhere and these have offered no convincing support for the hypothesis that the unpleasant symptoms experienced by sufferers result from exposure to mobile phone or base station signals. Whilst the Committee does not believe that there is any need for further studies in relation to mobile phones and electrical hypersensitivity, it recognises that the signal from the TETRA radios and base stations used by the emergency services have raised specific concerns and it will be supporting additional work in this area as part of the second phase of the Programme.

Biological mechanisms

The Programme supported studies to investigate two of the possible cellular effects identified in the Stewart Report: stress protein production and calcium signalling. A very careful study of stress protein production demonstrated that the previously observed effect was probably due to heating. In the light of this and other recently published studies, the Committee considers that there is no need for further investigation of these phenomena. In the absence of convincing new evidence of robust cellular effects, the Committee does not propose to support further work in this area.

Base stations

The Programme has supported further investigation of exposures from microcell and picocell base stations. These have provided additional reassurance that exposures are low, but have revealed that exposures in the immediate vicinity of the installation may be higher than those at the same horizontal ground-level distance from macrocell installations. The Programme has also supported important work on the evaluation of a personal exposure data logger. This appears to offer a promising new approach to exposure assessment that may eventually make possible epidemiological studies of risk from base station exposure. The Committee is aware that work on the further development and application of personal exposure data loggers is currently in progress elsewhere in the world. It does not, therefore, propose to fund additional work in this area at the present time, but will keep developments under review.

Risk communication

Work supported by the Programme in the area of risk communication has revealed that the reaction of people to the precautionary advice issued by the government varies enormously and is influenced by complex networks of prior attitudes and beliefs. This may help to explain the finding that the penetration of precautionary advice to the public is limited and suggests that policy makers may need to adopt alternative strategies for risk communication. The Committee believes that this is an area that is poorly understood and that there is a need for significant additional research effort to be applied in a systematic study.

Mobile phones and driving

It is well established that using a mobile phone while driving impairs performance and increases the risk of an accident. A new volunteer study supported by the Programme offered no evidence that this impairment was more pronounced than that due to other in-car distractions such as conversations with passengers or adjustment of interior controls. There were, however, suggestions that use of a mobile phone may draw on greater cognitive resources than other distractions.

Research recommendations

The Programme has highlighted some gaps in our knowledge that need to be filled. The absence of an association between exposure to mobile phone signals and cancers of the brain and nervous system for exposures of less than ten years is encouraging. However, cancer symptoms are rarely detectable until ten to fifteen years after the cancer-producing event and, since few people have used their phones that long, it is too early to say for certain whether mobile phones could lead to cancer or indeed to other diseases, such as Alzheimer's and Parkinson's diseases, which have not been studied at all. Another gap concerns the effect of RF exposure on children. The reactions of children to environmental agents, such as lead, tobacco smoke, ultraviolet radiation, and ionising radiation, may be different and/or stronger than those of adults. It is therefore possible that the same could be true of exposure to mobile communications signals and very little has been done so far to investigate whether this is the case.

These two issues – a cohort study on adults and research on children – are the main priorities for the recently announced extension to the Programme, MTHR2, for which funds of around £6 million have already been committed. Funding has again been provided by government and industry on an equal basis. The report describes the other areas where further work is planned.

Overall conclusions

The MTHR Programme was set up to resolve uncertainties identified by previous evaluations of the possible health risks associated with the widespread use of mobile phone technology. None of the research supported by the Programme and published so far demonstrates that biological or adverse health effects are produced by radiofrequency exposure from mobile phones. Reassuringly, no epidemiological association was found between short-term mobile phone use (less than ten years) and cancers of the brain and nervous system. Studies on volunteers provided no evidence that brain function is affected by exposure to the signals emitted by mobile phones or the TETRA radios used by the emergency services. Similarly, studies on electrical hypersensitivity have offered no convincing support for the hypothesis that the unpleasant symptoms experienced by sufferers result from exposure to signals from mobile phones or base stations. An extremely careful study suggested that a previously reported cellular effect was probably due to heating.

The Programme has also supported work on the measurement of base station emissions and these have confirmed that exposures are low, although it appears that exposures in the immediate vicinity of microcell installations may be somewhat higher than those at the same horizontal ground-level distance from the larger macrocell installations. A study on risk communication found that the penetration of precautionary advice to the public is limited and suggested that policy makers may need to adopt alternative strategies for the delivery of messages in this area. Finally, a study supported by the Programme confirmed previous observations that the use of a mobile phone while driving, whether hand-held or hands-free, impairs performance and increases the risk of an accident. However, in this particular study, the impairment appeared to be similar to that from other in-car distractions.

The Committee has recognised that, while many of the concerns raised by the Stewart Committee have been reduced by the Programme and work done elsewhere, some still remain. It has therefore proposed a further programme of work to address these. Priorities will include work to assess whether long-term exposure (greater than ten years) increases the risk of developing cancers of the brain and nervous system. In addition, work to assess whether exposure to mobile phone signals in children is associated with a different, or enhanced, symptomatology is also considered a priority.

1

The MTHR Programme

This report describes the progress so far of the UK Mobile Telecommunications and Health Research (MTHR) Programme. The first of the 28 research projects supported by the Programme started nearly six years ago at the end of 2001. To date, 23 projects have been completed and the results of many of them have been published in peer-reviewed scientific journals (23 papers so far). The report describes this published work in some detail and places it in context with work underway in other parts of the world. Information on the progress of the unpublished MTHR projects is also given. An extension to the Programme has recently been announced, MTHR2.

Background

The Independent Expert Group on Mobile Phones (Stewart Committee) was set up by government in 1999 to examine possible adverse health effects from mobile phones and base stations. Its report (IEGMP, 2000) included a recommendation for a major UK research programme operating under the aegis of a demonstrably independent panel. The Programme was to investigate health aspects of mobile phones and related technologies and it was intended that it would complement work sponsored by the European Commission and other national programmes. The Stewart Committee also recommended that the research should be financed jointly by the mobile phone companies and the public sector.

These recommendations were supported by government and industry and led to the establishment of the MTHR Programme, with initial funding of £7.36 million. Funding by government and industry was initially on a 50:50 basis. In order to ensure that none of the funding organisations could influence the outcome of the Programme, an independent programme management committee was set up to decide on research priorities, select projects and manage the research. Sir William Stewart originally chaired the Committee, which included some members of the Stewart Committee and additional specialists to provide a broad range of expertise. There are four overseas members, including a representative of the World Health Organization. Some change in membership has occurred over the years and Sir William was succeeded as chairman by Professor Lawrie Challis in November 2002.

In determining research priorities, the Committee has built on the recommendations outlined in the Stewart Report. The Programme has focused largely on establishing whether or not biological or adverse health effects occur in people as a result of radiofrequency (RF) exposure below guideline levels. Five of the projects were epidemiological studies, eight were volunteer studies (including three exploring reported hypersensitivity to signals emitted by mobile phones or base stations), and one dealt with risk communication. It was, however, also noted in the Stewart Report that a small number of experiments suggested biological effects were occurring in cells or animals and the Committee decided that further work on three of these experimental areas was needed. The rest of the projects were dosimetry or related studies assessing the interaction of RF fields with the human body.

The research has expanded somewhat beyond its original objectives to address public concerns in relation to mobile phone base stations including the newer 3G stations, and to respond to the introduction of the TETRA emergency services radio system. The (then) Department of Trade and Industry* funded three additional projects that fell outside the immediate priorities of the Programme and some further projects have been supported using new funds provided by the Home Office, the Department of Health, and the private sector. This all increased the total funding available to approximately £8.8 million, which represents a substantial proportion of UK and European

* DTI functions have been transferred to the Department for Business, Enterprise and Regulatory Reform.

research funding in this area. Publications arising from the Programme are detailed in Appendix A and a list of the projects that have not yet been published is given in Appendix B to this report. Further details can be found on the MTHR website: www.mthr.org.uk.

It was noted in the Stewart Report that the area of research on the possible health effects of mobile communications signals had not been well funded. This situation had been detrimental to the overall quality of research activity in this area, with some notable exceptions, and inevitably therefore some of the research results receiving attention by the media were of questionable reliability and validity. It has been the aim of the Committee from the outset to provide sufficient resources to allow high quality research to be undertaken and to encourage high calibre scientists to become involved with the Programme. In particular, we have encouraged collaborative working between specialists in different disciplines such as radio engineering and cell biology.

Selection and monitoring of projects

The Committee issued its first call for proposals in February 2001. As for all subsequent calls this was published in the national press, major scientific journals, and on the Internet. The selection process was scientifically rigorous and only 16 of the 82 proposals initially received as outline proposals were actually funded. In most cases initial proposals that met basic criteria were discussed in detail with the applicants to ensure that they addressed the scientific research priorities of the Programme, and were capable of providing statistically robust results. In December 2001, the Committee issued a second, more specific, call for proposals to address areas not adequately covered in the first call. A third call was made in November 2002 to cover a few remaining areas.

Once projects were underway, they were regularly monitored and reviewed by the Committee. This selection and subsequent review process has been, and continues to be, a key element in ensuring the quality of the research undertaken. Other important factors have been the development of standard exposure systems for volunteer studies and the provision of expert advice on experimental dosimetry for all laboratory studies. The Committee has also organised workshops and four annual two-day research seminars where all researchers supported by the Programme get together to report on progress and exchange ideas.

Study design

The signals emitted by mobile communications equipment (mobile phones and base station transmitters) are not pure RF waves of constant amplitude: electric and magnetic fields oscillating to and fro at one single frequency. The single frequency signals have to be modified (modulated) to carry information: speech, text, pictures, etc, and also have to satisfy certain technical constraints. The signals from GSM phones and TETRA radios use time division multiplexing: the RF emissions are switched on and off at regular intervals so that they are transmitted in a sequence of bursts or pulses. This allows a radio channel to be used by a number of handsets (eight for GSM and four for TETRA). The timeslot (pulse) rates for GSM and TETRA signals are 217 and 17.6 Hz respectively (see Appendix C).

Epidemiological studies collect observational (rather than experimental) data on groups of people or populations and are therefore concerned with exposures from real mobile communications equipment but this is not possible for the volunteer and biological experiments. These need to be carried out using signals as similar as possible to those emitted by mobile communications equipment. However, they also have to allow the experiments to be carried out ‘blind’ so that neither the volunteers nor any people in direct contact with them or who are involved with the analysis of the data are aware whether the volunteer is being exposed to the transmitter signal or to a control signal which could be either a pure RF wave or no signal at all (a ‘sham’).

Similar considerations apply to those carrying out biological experiments. It was not possible therefore to use commercially available transmitters and the experiments were all carried out using specially designed and built RF sources (most used the standard phone exposure system – see box). There is a large number of mobile phones available and the maximum exposure from the different models varies appreciably. The standard phone system was designed to give an exposure below but approaching the greatest exposure

Standard Phone Exposure System

Dr Phil Chadwick of MCL was commissioned to design a system producing exposures representative of those to real phone users. This was to be used for all the volunteer studies. The resulting device was modified from a commercially available phone and produced in two variants, one simulating a 900 MHz GSM mobile phone and the other a TETRA radio (this was also used in TETRA studies funded directly by the Home Office). In both cases the waveform of the emitted fields contained all the significant characteristics of a real signal.

The system had a headset that enabled it to be mounted in one of the standard positions used to assess the exposure from real phones. Each phone was capable of producing three different exposure conditions: CW (constant RF); modulated (RF that varies in the same way as a mobile phone signal); and sham (ideally no RF but, in practice, an exposure at most 100 times less than that in the other two conditions). The various output modes were selected using hexadecimal codes so that neither researchers nor subjects knew which exposure condition had been selected. The exposures were assessed using the standard procedure for mobile phones. The maximum SAR was 1.3 W/kg averaged over 10 g.

GSM mobile phone exposure system
(photograph courtesy of Dr Phil Chadwick, MCL)

anyone might receive. In practice, the average exposure from real phones is usually less than the maximum, so it is unlikely that people would receive larger average exposures from these than from the standard phone system. (The measure of exposure is the specific energy absorption rate (SAR) which is the power absorbed in a 10 g volume of tissue.)

It was recognised in the Stewart Report that there were considerable uncertainties regarding possible effects of mobile phone signals on people. Many of these uncertainties have arisen through limitations in the design of earlier studies. To avoid these problems the Committee insisted that all MTHR provocation studies should conform to the following set of basic principles.

a Studies investigating effects of mobile phone signals should employ a standard exposure system based on a real mobile phone held in a fixed position against the head (see box). This provided a known realistic exposure that was the same for all studies so that comparisons could be made between studies.

b Participants should each receive three different exposure conditions, sham (no RF emitted), continuous wave or CW (a constant RF signal at the same frequency as a mobile phone), and modulated (an RF signal that varies in the same way as a signal from a GSM phone or TETRA radio). This design was intended to allow researchers to distinguish possible effects of RF exposure from possible effects of distraction, discomfort, or stress arising from wearing the phone. It also enabled researchers to see if there was anything special about exposure to a mobile phone signal compared with exposure to an unmodulated RF signal at the same frequency.

c All studies should have a randomised double-blind design. This means that the three different exposure conditions discussed above have to be delivered in a random order. It also means that neither the participant nor the researcher can know what the exposure conditions are at the time of testing. To satisfy the last condition, the output modes of the exposure systems were selected using codes that were not known to the researchers.

d Dosimetric support should be provided by the National Physical Laboratory, which maintains the primary reference standards for the UK.

e All studies should have adequate statistical power (probability of detecting a meaningful effect). This means that studies would have to test a sufficiently large number of participants to be able to distinguish with reasonable certainty any effect of exposure from chance variation.

Projects selected

The majority of projects funded by the Programme are concerned with mobile phones – only five projects relate to base stations. We are of course aware that many members of the public are more concerned about the possibility of health effects from base stations than from phones. However, the Programme's responsibility is to look for possible health effects from the RF signals involved in this technology and, to do that, the situations chosen must be those judged most likely to lead to detectable effects. The exposures to the head are thousands of times greater from phones than those from base stations so exposure from phones is considered much more likely to lead to effects in volunteer and biological experiments. The situation is less immediately clear in epidemiological studies since exposure from phones is normally for a much shorter time than that from base stations. The appropriate measure of the 'dose' that would determine the effect of RF exposure on people, if any, is not known. However, if 'dose' equalled exposure multiplied by time, for most people this would certainly be greater from a phone than it would from their nearest base station.

Even so, in view of public concern, the Committee wished to support epidemiological studies involving base stations. Unfortunately it is not yet technically feasible to carry out robust studies on adults since it is not possible to obtain sufficiently reliable measurements of their average exposure. Exposures vary greatly from place to place and also from year to year since new stations are built and people move house or change their jobs or leisure activities. A further complication with adult studies is that most adults use mobile phones. The Programme is, however, funding an epidemiological base station study on young children (under five years old) since they are normally less mobile throughout the day than adults so it easier to obtain a reliable measure of the average exposure in their environment and they do not use mobile phones.

2

Cancers of the Brain and Nervous System

Background

The Stewart Committee (IEGMP, 2000) noted that few epidemiological studies had been undertaken to assess the possible health risks associated with mobile phone use. Only two studies had reported on the risk of brain cancer at that time.

One was a cohort (see Box 1) or follow-up study (Dreyer *et al,* 1999; Rothman *et al,* 1996). In this study the mortality in one year was examined among 250,000 phone users in the USA. Numbers of brain tumour cases (a rare form of cancer) arising in the cohort over this period were small so, although no significant excess in deaths was found among phone users, the Stewart Committee concluded that important effects could not be ruled out.

The second study available at that time was a case–control study carried out in Sweden (Hardell *et al*, 1999). This showed that the overall risk of brain tumours did not appear to be elevated in people who used mobile phones, either analogue or digital, even if their use was relatively heavy. In subsequent analyses (Hardell *et al,* 2001), an association was observed between the incidence of some brain tumours and reported usage of analogue phones *on the same side of the head.* However, since the association on the opposite side of the head was reduced, this suggests possible bias in reporting (Rothman, 2000): people may be more likely to remember that they had used their phone on the same side as the tumour than was actually the case. It has also been suggested that the way in which the cases and controls were recruited might have resulted in bias (AGNIR, 2003; Ahlbom and Feychting, 1999; IEGMP, 2000).

The Stewart Committee concluded that there was a pressing need for further case–control studies and it recommended that these should focus on cancers of the brain and of the acoustic nerve (acoustic neuroma) since these are the organs/structures normally most heavily exposed to radiofrequency signals from phones.

In addition, because of the methodological limitations of case–control studies, the Stewart Committee recommended that a large cohort study of mobile phones and cancer should be carried out, initially as a pilot study.

New evidence and current state of knowledge

Since the establishment of the MTHR Programme, about a dozen case–control studies (Auvinen *et al,* 2002; Christensen *et al,* 2004, 2005; Hardell *et al,* 2002, 2005, 2006a; Hepworth *et al,* 2006; Inskip *et al,* 2001; Lahkola *et al,* 2007; Lönn *et al,* 2004, 2005; Muscat *et al,* 2000, 2002; Schoemaker *et al,* 2005; Schüz *et al,* 2006a) and one cohort study (Johansen *et al,* 2002; Schüz *et al,* 2006b) have reported results on the risk of brain cancers and acoustic neuromas related to mobile phone use. One further study (Warren *et al,* 2003) investigated the risk of intratemporal facial nerve tumours. Most of the recent publications in this area have been from the Interphone study, a large European collaborative case–control study of mobile phone use and brain cancers/acoustic neuroma (Christensen *et al,* 2004, 2005; Hepworth *et al,* 2006; Lahkola *et al,* 2007; Lönn *et al,* 2004, 2005; Schoemaker *et al,* 2005; Schüz *et al,* 2006a). Two UK research groups led by Professor Anthony Swerdlow (Institute of Cancer Research) and Professor Tricia McKinney (Leeds University and NHS Scotland) have contributed to the Interphone study with work in the southeast and north of England that was partially funded by the Programme.

These Interphone studies focused mainly on whether there was a risk of malignant brain tumours (glioma), benign brain tumours (meningioma) or acoustic neuromas associated with the use of mobile phones. The UK studies focused on methodological issues concerning recall of mobile phone use (Parslow *et al,* 2003; Vrijheid *et al,* 2006) and risks of glioma (Hepworth *et al,* 2006; Lahkola *et al,* 2007) and acoustic neuroma associated with mobile phone use (Schoemaker *et al*, 2005).

BOX 1 *Epidemiological Study Designs and Measures of Association*

Cohort studies

In cohort or prospective studies, the average exposure (eg mobile phone use) is determined in a group of people who are then followed up to see who later develops disease and to investigate whether there is a relationship, or association, between the exposure and the disease.

Case–control studies

In contrast, case-control studies look back at previous exposure patterns (eg mobile phone use) among a sample of disease cases and a control group of people without the disease. In general, case-control studies are attractive as they are usually quicker than cohort studies because it is not necessary to wait for disease to develop in the study cohort, and less expensive because the number of people is usually much smaller than in a cohort study. However, case-control studies are more prone to bias that can distort study findings and either inflate or reduce the estimates of risk. For this reason, greater weight is usually placed on the results of cohort than of case–control studies.

Measures of association in epidemiological studies

The measure of association commonly used is called the odds ratio (or relative risk), which gives a measure of how many times greater (or less) the risk of the disease is among exposed people (eg users of mobile phones) compared with unexposed people (eg non-users or infrequent users). An odds ratio of 1.0 means that exposed and unexposed people are equally likely to get the disease (ie no association between exposure and disease), while an odds ratio above 1.0 implies that exposed people are more likely to get the disease than unexposed people. If the odds ratio is less than 1.0, exposures are apparently protective of the disease.

The effect that chance can play on the odds ratio obtained in a study is usually expressed by the 95% confidence interval (CI), which is the range of odds ratios consistent with the data allowing for statistical variations. The 95% CI indicates that, if 100 similar studies were carried out, the odds ratio found in 95 would be expected to lie within the CI, while in 5 they would lie outside by chance. In general, if the CI includes 1.0, the results are said not to be significantly different from 1.0, ie not statistically significant: no convincing evidence of a statistical association between use of mobile phones and risk of disease.

For glioma, an excess risk was found for reported phone use on the same side of the head as the tumour, although this was balanced by a corresponding deficit on the opposite side of the head, suggesting reporting bias as a likely explanation (Hepworth *et al,* 2006). No significant increase in risk of brain cancer was found for people who had used their phone for more than ten years, although, since the number of these was small, the ability to detect any increase (if present) was limited. No overall excess risk of glioma or meningioma was found in the German Interphone studies (Schüz *et al*, 2006a), although for glioma, long-term use (at least ten years) was associated with an odds ratio of 2.2. This result, based on only twelve cases, is not, however, statistically significant (see Box 1) as the 95% confidence interval (CI) of 0.9 to 5.1 includes 1.0. An increase was also found for reported phone use on the same side of the head as the tumour but this was balanced by a deficit on the other side, suggesting again the increase is the result of reporting bias.

The pooled analysis from five north European countries (Denmark, Finland, Norway, Sweden and the UK) also found no overall excess risk of glioma (Lahkola *et al,* 2007). However, long-term use was associated with an increased risk (odds ratio of 1.39) on the same side of the head as the phone had been used. This is of borderline significance as the 95% CI excludes 1.0, but only just (1.01–1.92). The authors concluded that their findings 'leave open the possibility that long-term mobile phone use may increase the risk of gliomas in the more exposed hemisphere'.

A significantly increased risk with use of analogue phones (which emit at higher power than the newer digital phones) was indicated in the two most recent studies carried out by Hardell *et al* (2002, 2006a,b). These studies also tended to show greater risk with long-term use (ten years or more). However, Lahkola *et al* (2007) found no difference in risk between use of analogue and digital phones.

As with all case–control studies, issues of study design, potential biases in the selection of cases and controls and the collection of data, need to be carefully considered in the interpretation of results (AGNIR, 2003; Ahlbom *et al,* 2004). Cohort studies are generally less prone to bias, especially reporting biases. A cohort study that linked cancer incidence data with mobile phone subscriber information for

the whole of Denmark found no significant increase in the risk of brain cancer (Johansen *et al,* 2002). A later follow-up study on the same cohort provided further reassurance that short-term use did not increase the risk of brain cancer (Schüz *et al*, 2006b). However, this study failed to provide convincing evidence against an effect of long-term use, and has been criticised because the lack of data on actual mobile phone usage, and the healthy nature of the cohort compared to the general population, may have led to attenuation of possible risks associated with mobile phone use (Ahlbom *et al,* 2007).

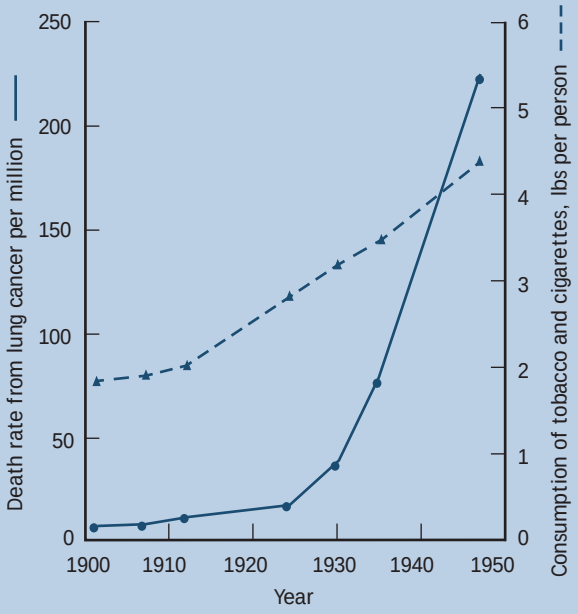
For acoustic neuroma, most studies also found overall odds ratios close to or below 1.0. Two studies in Sweden (Hardell *et al,* 2002, 2005) did find increased odds ratios, although there did not appear to be a stronger relationship with increased duration of use, which might be expected if the association were causal. A somewhat different picture appears when considering long-term phone use (more than ten years) reported on the same side of the head as the tumour. In the study of Lönn *et al* (2004), presenting results from the Swedish part of the Interphone study, an odds ratio of 1.9 was found (95% CI 0.9–4.1). A much larger study incorporating the Swedish Interphone data, as well as those from Denmark, Finland, Norway and the UK, obtained an odds ratio of 1.8 (95% CI 1.1–3.1) (Schoemaker *et al,* 2005). Since the 95% CI in these two reports either includes or only just excludes 1.0, neither of these results is convincingly significant, however, bearing in mind also the possibility of bias. Results of analyses combining data from all the Interphone studies are still to be published.

In addition to looking at possible associations of mobile phone use with cancers of the brain and nervous system, a few studies have also reported on risks associated with use of cordless (DECT) phones, which have output power similar to that of mobile phones. The output power from a DECT phone is fixed, but that from a mobile is continuously variable (see Appendix C). Hardell *et al* reported excess risks for use of cordless phones and brain tumours located in the temporal lobe in their second Swedish study (Hardell *et al*, 2002, 2003), and both acoustic neuroma and glioma in their third study (Hardell *et al*, 2006a,b). However, the German Interphone study (Schüz *et al*, 2006a) found no excess risk of either glioma or meningioma associated with use of cordless phones.

BOX 2 *Latency*

Latency is a term used to describe the delay between exposure to an agent or event that causes an illness and the development of the illness itself. For some diseases, such as cancer, this delay may be tens or even many tens of years.

This effect can be most easily seen where there has been a rapid increase in exposure to the causative agent. For example, in the years following 1914 there was a rapid increase in the use of tobacco and cigarettes. This was followed about 10-20 years later by the start of a substantial increase in the number of lung cancer deaths. For this disease, patients rarely survive long after the appearance of symptoms (the measure of incidence) so that in this case a similar pattern would be seen for both incidence of lung cancer and mortality.



Comparison of lung cancer deaths and consumption of tobacco and cigarettes (redrawn from Doll and Hill, 1950)

Mesothelioma, caused by exposure to asbestos, provides another example. In this case, mortality occurs at least 20 and in some cases up to 50 or 60 years after the exposure that causes the cancer.

In summary, overall most of the epidemiological studies to date appear reassuring with respect to short- to medium-term risk of cancers of the brain and nervous system in relation to mobile phone use. However, an inherent limitation of these results is that only a small proportion of people studied have used phones for more than ten years so that there is rather little information on risks from long-term use. This is an important deficiency since the symptoms from many diseases, including most cancers, only become apparent many years after the event that produced them, an effect known as latency (see Box 2). If the use of mobile phones did carry an increased risk of brain or nervous system cancers, the length of any latent period would be unknown. However, given that the latent periods for cancers are often many years, it seems entirely plausible that an increase in incidence would not be detectable less than ten years after the first exposure. As noted above, at present, very few people have used mobile phones for more than ten years, so it is not possible at present to rule out the detection of an association at some future date.

Future research needs

Since the Interphone studies will not resolve issues of effects from long-term exposure, a further case–control study of brain cancers and acoustic neuroma in adults may need to be considered in a few years once a larger proportion of the population has been exposed to mobile phone use over a prolonged period (more than ten years). A case–control study on brain cancers in children is also underway in Sweden and other countries. However, such studies are still prone to possible biases associated with the case–control design, and of course they do not deal with possible effects of mobile phone use on other diseases.

The Programme Management Committee therefore fully endorses the view of the Stewart Committee, which had noted the importance of establishing a new cohort study in the UK to deal with potential longer-term effects of mobile phone use and possible effects on diseases other than brain cancer, such as Alzheimer's and Parkinson's diseases. It funded a pilot study to examine the feasibility of carrying out a full cohort study of mobile phone subscribers in the UK and Sweden and this was successfully completed by Professors Paul Elliott (Imperial College London) and Anders Ahlbom (Karolinska Institute, Stockholm) and colleagues. The pilot was later extended to Denmark and Finland (and also to Germany) and results from this (Hillert *et al,* 2006) and from Interphone studies (Parslow *et al,* 2003; Vrijheid *et al*, 2006) have guided design issues concerning estimation of exposure to mobile phones from billing records and questionnaire data. A study of at least 200,000 people (90,000 in the UK) has recently been started in four countries, the UK component being funded by MTHR2.

3

Brain Function

Background

Concerns over possible effects of mobile phone signals on brain function arose soon after the widespread introduction of mobile telephony. The position of the mobile phone close to the head means that the brain could be subjected to relatively high levels of radiofrequency exposure. At the time the MTHR Programme started, some studies had reported that mobile phone exposure led to faster reaction times in simple cognitive tests (Koivisto *et al*, 2000a,b; Preece *et al*, 1999). These studies attracted widespread public attention since they suggest that RF signals from mobile phones produce direct effects on brain function at exposure levels that are currently considered safe. The possibility that this could have implications for health could not be ruled out and this was identified by the Stewart Committee (IEGMP, 2000) as a factor justifying a precautionary approach.

The Stewart Committee also recognised that a mobile phone placed against the side of the head might influence the cardiovascular centres of the brainstem or the carotid body receptors and thereby affect blood pressure or heart rate. This possibility had been highlighted by a high profile study undertaken by Braune *et al* (1998) but since there were a number of problems with the design of this study, the Stewart Committee recommended that a larger and better controlled study should be carried out to resolve the issue.

New evidence and current state of knowledge

In order to address some of the uncertainties identified by the Stewart Committee, the Programme included a number of studies to extend and improve previous investigations of RF effects on brain function. Much of the uncertainty surrounding existing data related to limitations in the design of the earlier studies. It was clear from the outset that the design of the MTHR studies would have to avoid these pitfalls. It was decided therefore that all volunteer studies supported by the Programme should comply with the same basic principles (see Chapter 1).

A major study by Professor Riccardo Russo and colleagues (University of Essex) was designed to replicate and improve the earlier work suggesting that GSM mobile phone signals affect reaction times in simple cognitive tests (Koivisto *et al,* 2000b). Several different tests were used to investigate possible effects on a range of different cognitive functions. The results of the experiment showed no statistically reliable difference between either of the RF exposure conditions (GSM or continuous wave) and sham exposure, for any of the tests (Cinel *et al*, 2007; Russo *et al,* 2006). Since this study was larger (168 participants) than previous studies, and also incorporated several methodological improvements, it provided important evidence regarding the effects of mobile phone signals on the brain. Specifically, it found no evidence for direct effects of mobile phone signals on cognitive function. This suggests that previous positive findings may have involved methodological artefacts. This is consistent with results from other studies on adults published while the MTHR study was underway and since its completion (Besset *et al*, 2005; Haarala *et al*, 2003, 2004, 2007; Krause *et al*, 2007). Although less comprehensive, studies on children (10–14 years old) suggest that cognitive function is similarly unaffected by exposure (Haarala *et al*, 2005; Preece *et al*, 2005).

The roll-out of a TETRA-based radio network (see Appendix C) for the emergency services during the current decade has prompted concern about the possible effects of exposure to the pulse-modulated fields produced by the handsets. Even though much of this concern arose from early reports on cellular effects that were not subsequently confirmed (see Chapter 5), it was felt that more work was needed to determine whether TETRA exposure of the head could

lead to direct effects on brain function. As a first step to understanding possible effects, the Programme supported work by Dr Peter Dimbylow (Health Protection Agency) to characterise the deposition of energy in the head from a TETRA handset (see box).

The next stage was to investigate the effects of exposure on brain function. Dr Stuart Butler (Burden Neurological Institute, Bristol) assessed this using a range of cognitive and electrophysiological measures in healthy volunteers who were observing visual stimuli, listening to auditory tones, or receiving sensory stimuli to the skin. The brain activity associated with these sensations was recorded from the scalp using standard electroencephalographic (EEG) techniques. Special care had to be taken to rule out direct effects of RF fields on the sensitive recording equipment used. Analysis focused on whether the brain activity evoked by these three types of external stimulus was affected by exposure. Additional experiments investigated effects of the same exposures on the background EEG pattern, on reaction times, and on brain activity evoked by stimuli under different cognitive load conditions.

A further experiment in this study investigated whether TETRA exposures could directly evoke brain responses rather than simply modifying the response to recognised environmental stimuli. As brain responses to stimuli occur very rapidly, the exposure system was modified to produce short bursts of exposure that could be synchronised with recordings of brain activity. Results from this study have been submitted for publication.

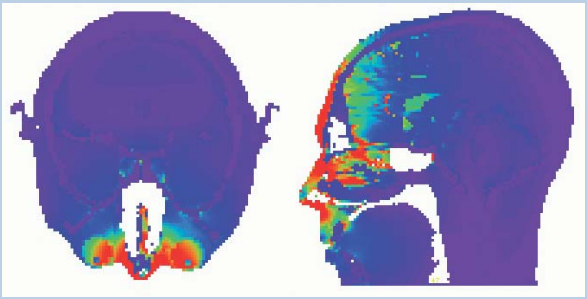
Work on the consequences of exposure to TETRA signals has also been undertaken as part of the TETRA research programme run by the Home Office. A team led by Dr Sarah Bowditch (Defence Science and Technology Laboratory) used the MTHR TETRA exposure system (see Chapter 1) to examine the effects on 40 volunteers who performed a battery of cognitive tests and completed a self-assessment of mood-state, anxiety and workload. Results from this study have been submitted for publication.

In order to assess possible effects on brain centres controlling the cardiovascular system, Professor Tony Barker (Royal Hallamshire Hospital, Sheffield) and colleagues monitored the blood pressure and heart rate of 120 healthy volunteers during exposure to RF fields. Data were collected on circulating catecholamine levels in order to assess any underlying changes in nervous system activity and ambulatory blood pressure was also measured for 24 hours following each exposure. No effects of exposure to either GSM or TETRA handset signals were found (Barker *et al*, 2007). A small decrease in blood pressure of about 0.7 mm Hg was observed when volunteers underwent sham exposure from the

Absorption of TETRA Signals in the Head

Most of the signal emitted by a mobile phone spreads out in the general environment, but a proportion of it will be absorbed by the head of the user. This absorption has been extensively studied for mobile phones as the amount of energy deposited in different brain structures may give clues to possible effects on brain function. However, at the start of the MTHR Programme similar information was not available for the TETRA handsets that were due to be issued to the police. The Programme therefore supported work by Dr Peter Dimbylow (Health Protection Agency) on computer modelling the interaction between a TETRA handset and a human head.

The work involved creating a computer model of a TETRA handset and then assessing the deposition of energy in the head of NORMAN, an existing computer model of a person. TETRA handsets were available with two basic types of antenna, a simple monopole and a helix, and models of both were created. Measurements of the fields emitted by real handsets were used to check the validity of the computer models. Energy deposition was then modelled with one or other of the handsets placed in various positions close to the head of NORMAN. The results from this work provide an indication of the likely level of exposure to the heads of TETRA users (Dimbylow *et al*, 2003).



SAR modelling of TETRA handset
(figure courtesy of the Health Protection Agency)

GSM handset. The reason for this is not understood at present but it is evidently not caused by RF exposure. Overall, these results are consistent with other recent studies investigating effects of RF fields on acute changes in blood pressure (Braune *et al*, 2002; Nam *et al,* 2006; Tahvanainen *et al*, 2004), and suggest that further studies on this topic are not necessary.

Studies to examine possible effects of RF exposure on aversive symptoms by Professor Simon Wessely (King's College London) and of hearing and equilibrium effects by Professor Linda Luxon (National Hospital for Neurology and Neurosurgery, London) will be described in Chapter 4. No effects were found in either electrically hypersensitive volunteers or a control group.

Future research needs

On the basis of preliminary studies, the Stewart Committee identified possible effects of mobile communications signals on brain function as an area for further research. However, more recent published results, including those from work funded under the Programme, have not replicated these initial findings. Mobile phone signals were found to have no significant effects on either cognitive measures, such as reaction times, or other measures of brain activity. At present there appears to be no need for further studies of cognitive performance or brain activity in healthy adult volunteers. However, this view should be revised if a mechanism for direct effects of RF exposure on brain tissue is identified. Detailed knowledge of any mechanism could allow better targeting of future investigations of effects on brain function.

The MTHR projects reported here have focused on healthy adult volunteers. Some groups merit special consideration. Studies on people who report hypersensitivity to mobile phone signals are discussed later in this report (see Chapter 4). Finally, the Stewart Committee particularly mentioned possible effects of mobile phone signals on children. Current results do not suggest that brain function in children is particularly sensitive to mobile phone signals (Haarala *et al*, 2005; Preece *et al*, 2005), but this area remains relatively under-researched.

4

Electrical Hypersensitivity

Background

A small proportion of mobile phone users report that phone use is associated with the development of unpleasant symptoms such as headache, dizziness and tingling. These reports are examples of the more general phenomenon often described as 'electrical hypersensitivity'. Affected individuals experience a range of symptoms such as those described above, which they attribute to exposure to a source or sources of weak electromagnetic fields. These sources can include computer monitors, televisions, power lines and mobile phone base stations, in addition to mobile phone handsets. Individuals vary in respect of the sources to which they attribute their symptoms. Previous studies in other countries have estimated the prevalence of self-reported electrical hypersensitivity at around 1% to 4% of the adult population. No prevalence study, however, had previously been conducted in the UK.

New evidence and current state of knowledge

With support from the MTHR Programme, Professor Elaine Fox and colleagues (University of Essex) developed and validated a questionnaire that permits identification of individuals reporting symptoms consistent with the syndrome of electrical hypersensitivity (Eltiti *et al,* 2007a). The questionnaire was subsequently employed in a large-scale postal survey of a population in Southeast England. In total, 20,000 individuals were randomly selected from the electoral role, approximately 3600 of whom returned a completed questionnaire. After allowing for possible bias associated with the probability that affected individuals would be more likely to comply than unaffected individuals, the authors estimated that the prevalence of reported electrical hypersensitivity was between approximately 1% and 4% of the population, with approximately twice as many women as men affected. Thus, the syndrome is reported by a significant fraction of the general population.

While the reality of the symptoms, and the accompanying distress, experienced by many electrically hypersensitive individuals is not in doubt, this does not mean that the symptoms are necessarily caused by exposure to electromagnetic fields. The most effective way to assess whether this is the case is through provocation studies, in which sensitive individuals, and, ideally, a control group of non-sensitive individuals, are exposed to an electromagnetic source on one occasion, and, at another time, are subjected to a sham exposure. The studies need to conform to the same basic principles adopted for those on healthy volunteers (see Chapter 1), including the need for the experiments to be double-blind to prevent any possibility of bias in either the reporting or the recording of symptoms. Given such a study design, it is possible to assess whether the symptoms reported by electrically hypersensitive individuals are in fact associated with exposure to electromagnetic fields. If this is the case, then more symptoms will be reported in the true than the sham exposure sessions, and this should occur predominantly in hypersensitive rather than control individuals.

Numerous provocation studies along these general lines have been conducted during the past 25 years or so, although not all adhered fully to the methodology described above. The studies employed a wide variety of electromagnetic signals, although most did not correspond to those emitted by modern mobile phones. With support from the Programme, these studies were recently the subject of a comprehensive review by Dr James Rubin and colleagues at King's College London (Rubin *et al*, 2005). These investigators reported that, regardless of the nature of the signals employed, the great majority of studies failed to find any evidence that the symptoms of electrical hypersensitivity are caused by exposure to electromagnetic fields. This conclusion is consistent with earlier reviews (see, for example, papers in Hansson Mild *et al*, 2004) and Rubin *et al* therefore concluded that the electrical hypersensitivity syndrome is unlikely to be related to the presence of such fields.

The Committee considered it a high priority to investigate the question of electrical hypersensitivity further, specifically in relation to exposure to radiofrequency fields emitted by the current generation of GSM mobile phones. The signals transmitted by these phones use TDMA (see Appendix C) so that they are emitted in a sequence of bursts or pulses, raising the possibility that the generally negative results obtained from previous studies employing continuous or differently modulated signals may not translate to mobile phone exposure. The studies supported in this area used the GSM standard phone exposure system and complied with the general principles for volunteer studies discussed in Chapter 1.

The Programme supported a large provocation study by Professor Simon Wessely's research team at King's College London. As noted earlier, the exposures received by volunteers from the standard system were as high as any they would be likely to receive from a phone and, in each session, the volunteers were exposed continuously for fifty minutes, longer than would typically be the case with real phones. The three exposure conditions were tested in separate sessions at least one week apart.

Two groups of volunteers were recruited. One group was composed of people who reported that they developed headache-like symptoms within twenty minutes of using a mobile phone. The second group was composed of individuals who reported that they did not experience symptoms when using mobile phones. Sixty volunteers in each group completed the full study. Prior to each session, then at several times during the session and on the day after, volunteers assessed the severity of a range of subjective symptoms.

Volunteer undergoing testing at King's College London
(photograph courtesy of Dr James Rubin, King's College London)

As might be expected, sensitive individuals reported more symptoms overall than did controls (Rubin *et al*, 2006), and in both groups the severity of reported symptoms increased as the sessions progressed. There was, however, no evidence to suggest that the symptoms were influenced by exposure condition in either group.

The findings from this study – one of the largest and most rigorous of its kind to date – offer no support for the notion that the aversive symptoms attributed to mobile phone signals by hypersensitive individuals are caused by exposure to such signals. This finding is consistent with the results of other published work in this area (Hietanen *et al*, 2002; Oftedal *et al*, 2007; Radon and Maschke, 1998; Wilen *et al*, 2006). These studies leave open the question of the origins of the symptoms experienced by sufferers, and the mechanism by which they become attributed to mobile communications signals. Importantly, the findings provide evidence that this mechanism is unlikely to involve biological effects of electromagnetic fields.

Professor Wessely's team also carried out an analysis of the differences between three groups: those who associate their symptoms with fields from electrical equipment in general; those who ascribe their symptoms only to mobile phones; and those who do not report symptoms. This found that members of the first group experience substantially worse health than either of the other two groups (Rubin *et al,* 2007).

Many of the symptoms reported by electrically hypersensitive individuals (including headache, disorientation and nausea) may be associated with disruption of inner ear function. Given the close proximity of the phone to the structures of the inner ear, it was considered important to see if exposure to a mobile phone signal could stimulate these structures and produce changes in hearing or equilibrium. Professor Linda Luxon and colleagues (National Hospital for Neurology and Neurosurgery, London) used a number of standard, highly sensitive tests of auditory and vestibular function before, during and after exposure to GSM signals on each side of the face. Participants in the study included nine volunteers who reported that they

experienced specific symptoms after prolonged mobile phone use and twenty subjects who reported that they did not. All volunteers had normal hearing.

No significant RF-dependent effects were found for either class of volunteer (Bamiou *et al,* 2007). One test associated with balance produced small differences but this was unrelated to exposure (and was attributed to the weight of the handset pulling on the side of the head). These results are in general agreement with the results of animal studies reported by Aran *et al* (2005), Kizilay *et al* (2003) and Marino *et al* (2000).

Taken together with earlier evidence, the new results from well-designed studies supported by the Programme offer no support that the unpleasant symptoms experienced by electrically hypersensitive people result from exposure to RF signals emitted by mobile phones. The power and design of the MTHR-funded work mean that it would be difficult to justify further work in this area in relation to mobile phone emissions.

Many people with electrical hypersensitivity have attributed their symptoms to mobile phone base stations and a previous study had reported that exposure elicited small effects on well-being (Zwamborn *et al*, 2003), although the interpretation of these results has been questioned (Health Council of the Netherlands, 2004). Although the effective exposure that base stations produce is very small, it is continuous. Therefore, the Programme investigated the possibility that such exposures could have adverse effects on some people, through a study undertaken by Professor Elaine Fox and colleagues (Essex University).

The researchers recruited volunteers who reported electrical hypersensitivity symptoms, and matched volunteers who did not report such symptoms. The volunteers were exposed to either a mixed GSM (900/1800) signal, a UMTS (3G) signal, or no signal at all (sham signal condition). The exposures were selected to be at the upper end of the range of everyday exposure scenarios. In an initial session, volunteers were given an opportunity to experience each of the three signals, and were told which signal they experienced. They were then exposed to each signal without being so informed, and asked whether the base station was 'off' (sham signal condition) or 'on' (ie GSM or UMTS conditions). Neither the electrically hypersensitive group nor the control group was better than chance at identifying whether the base station was on or off (Eltiti *et al*, 2007b).

In three subsequent sessions, the participants were exposed to the three signals in random order, and responded to a range of health and well-being questionnaires during each test. The tests were double-blind: neither the participant nor the experimenter knew which signal was presented in each session. Electrically hypersensitive participants generally reported lower levels of well-being than controls, but most measures of well-being did not differ significantly between the signal types, in either group (Eltiti *et al*, 2007b). An interesting exception was that participants with electrical hypersensitivity reported higher levels of arousal when exposed to a UMTS signal than to sham signal. However, this result should be interpreted with caution: it could have arisen because the random ordering of conditions resulted in a large number of electrically hypersensitive participants performing the UMTS test first, leading to generally high levels of arousal in that test, irrespective of exposure. In addition, no other measures of well-being were affected. Simultaneous monitoring of heart rate, skin conductance and blood volume pulse showed no differences between sham and UMTS conditions which could explain the increased arousal. Finally, a similar independent study in Switzerland (Regel *et al*, 2006) found no effects of UMTS signals on well-being in electrically hypersensitive participants. Therefore, although the MTHR study cannot exclude possible effects of base station signals on some individuals, it did not find compelling evidence to attribute electrical hypersensitivity symptoms in general to base station signals.

In addition, the researchers administered cognitive tests to the participants while they were exposed to each of the three signals. The results of the cognitive tests are currently being prepared for publication.

Future research needs

The MTHR-supported programme of work on electrical hypersensitivity is by far the largest carried out anywhere. However, one area that has not yet been adequately investigated is exposure to the signals that are typical of the TETRA technology currently being used by the emergency services. In this system the

signals from handsets and base stations are different: the RF transmission from handsets usually employs only one timeslot, so is emitted in a sequence of pulses, whilst that from base stations occurs in all timeslots, so is continuous. It will be important, therefore, to assess their effects separately. Two studies on handsets are now underway, one funded by the Home Office and one supported by MTHR2 – the recent extension to the Programme referred to in Chapter 1. In addition, MTHR2 is also supporting a TETRA base station study.

Professor Adrian Burgess and colleagues (Imperial College London and University of Swansea) are undertaking the study supported by the Home Office. Police officers, including both those who experience symptoms when using TETRA radios and those who do not, are exposed in a double-blind fashion using the TETRA version of the MTHR standard exposure system (see Chapter 1). The volunteers complete a battery of psychomotor and attentional tests to assess cognitive function and electroencephalographic measures of brain activity are recorded during some of the tests. The brain function measures are also being related to questionnaire measures of general well-being, and to history of TETRA handset use.

Professor Simon Wessely's team at King's College London has started work on a double-blind provocation study for MTHR2. Two groups of volunteers are being drawn from serving police officers – one consisting of those who report that they experience symptoms when using TETRA radios and one consisting of those who do not. The volunteers take part in three separate testing sessions, covering sham, continuous wave and modulated exposures. The volunteers are asked to self-assess the severity of a range of symptoms prior to, at intervals during, and following exposure.

Professor Elaine Fox and her colleagues at the University of Essex are undertaking the TETRA base station study with support from MTHR2. As for the other two TETRA studies, there will be two groups of volunteers – one consisting of people who experience symptoms that they attribute to base stations and one consisting of people who do not. All of the volunteers will be exposed to TETRA base station signals in a randomised double-blind fashion. The exposures will occur in a screened room that greatly reduces the intensity of other environmental radio signals. All the volunteers will be asked to self-assess the severity of a range of symptoms.

The three TETRA studies described above are currently in progress and it is too early to comment on the likely outcome. It is therefore possible that one or more of these studies may raise issues for further investigation. However, unless this happens, the Committee does not propose further studies on the effects of mobile communications signals on electrical hypersensitivity since it does not believe these would add significantly to the work it has already supported. It is possible though that this situation may change if significant new evidence becomes available.

5

Biological Mechanisms

Background

If responses were detected in volunteer or epidemiological studies, the focus of attention would turn to establishing the mechanisms causing them. This is challenging because there is only a limited repertoire of non-invasive techniques such as MRI (magnetic resonance imaging) scans and EEGs (electroencephalograms) that can be applied to people and it may well be that these techniques are not able to detect the underlying responses in cells and tissues. However, there are many reports in the literature of responses to RF exposure in isolated cells and tissues under laboratory conditions.

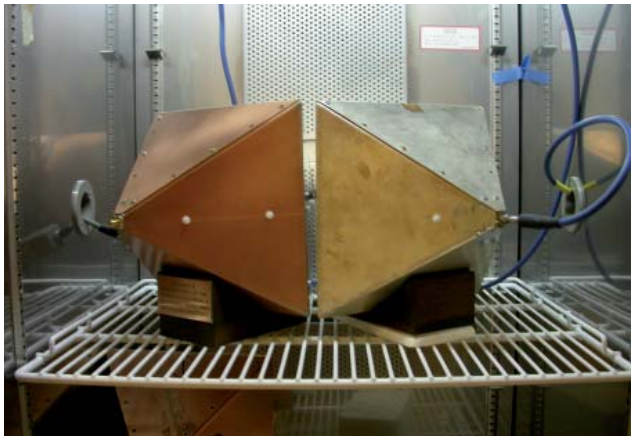
It would be much easier to unravel underlying mechanisms in these systems by applying the analytical techniques of molecular biology and physiology, if the responses were reproducible. The problem is that there is a very extensive range of possible cell and tissue responses that could be examined and selection requires some guiding principles. One useful guide is that the most extensive examination of changes in cells and tissues can be made where the whole DNA sequence of the organism has been determined and all of the genes that control the properties of the cells in the organism are known. A second guide is to look for responses that are known to result from other types of stress. The selection of research projects followed these underlying principles, but was also influenced by the conclusions of the Stewart Committee (IEGMP, 2000), which had highlighted two potentially interesting observations: effects on gene expression in nematode worms, *Caenorhabditis elegans*, and effects on calcium efflux from isolated brain tissue.

C elegans satisfies the first criterion. It is about 2 mm long and is frequently used to examine fundamental processes in cells, partly because genes can easily be inserted or deleted to determine whether or not other genes are being activated (expressed) by, for example, stress. Dr David de Pomerai's group (University of Nottingham) inserted a gene that can indicate if the worm is being stressed by heat and this showed that stress could also be produced by RF exposure at levels well below guideline values. The group's report on this in *Nature* (de Pomerai et al, 2000) attracted much attention because it offered the prospect of an important type of cell response to RF exposure that was likely to be reproducible. Subsequently, genetic manipulations might be used to establish the underlying mechanisms by which the non-thermal cellular stresses were caused. It would then be possible to determine if such responses could also be detected in isolated human cells and tissues in culture. In view of the potential value of this approach, it was very important to see if the work could be replicated.

New evidence and current state of knowledge

The MTHR Programme funded Dr de Pomerai's group to undertake a painstaking extension of its initial study and this led to the puzzling observation that the measured response to RF exposure of *C elegans* was not always the same. It was comparable in some experiments to the effect reported previously but much smaller or negligible in others. A careful re-evaluation of the physical characteristics of the RF exposure system in collaboration with the National Physical Laboratory led to the conclusion that there was a small power loss into the RF exposure chamber. A series of experiments showed that, although the power loss resulted in a rise in temperature in the RF-exposed samples of only about 0.2°C, the reporter gene was sufficiently sensitive to detect this effect and this accounted for the stress response previously attributed to a non-thermal mechanism (Dawe *et al*, 2005).

The work of Dr de Pomerai and his team in tracking down the source of the observed response has been exemplary. It required a high level of experimental competence and integrity to correct the original interpretation of the reported effect and will undoubtedly save wasted effort and resource by others.



Twin TEM cells used for microwave exposure of nematode worms (photograph courtesy of Dr David de Pomerai, University of Nottingham)

The search for a robust effect in an amenable biological system that is widely reproducible – and therefore a basis for mechanistic studies of RF effects – continues.

Two other responses that are produced by a number of different types of stress are the activation of calcium signals inside the cell and the generation of bursts of free radicals, highly reactive species that are associated in the development of many pathological processes involving inflammatory responses, including cancer.

To investigate whether these responses could result from RF exposure, advantage was taken of the expertise of Dr Martin Bootman's group (Babraham Institute, Cambridge). The group has constructed an automated imaging system to measure the concentration of calcium or free radicals in cells. The concentrations are proportional to the intensity of the fluorescence emitted from chemical indicators introduced into the cells so the group is able to look for any changes in these indicators in individual cells when they are exposed to pulsed RF fields similar to those produced by mobile phones. Mammalian tissues are used, including cells from the brain and from blood vessels, to cover a representative range of cell types that would be exposed during mobile phone use. The automation of the high-throughput imaging technology permits a large number of samples to be processed and so minimises the possibility of experimental bias. The results of this work have yet to be published.

Cells and tissues in culture also allow a specific feature of a mobile phone signal to be investigated. The most noticeable way in which this signal differs from a pure RF signal is that it is pulsed – its RF emission is switched off and then on at regular intervals as part of the TDMA modulation. It is important to know whether this has any effect on the interaction of the RF field with biological tissue.

The effect of the modulation is to add a series of waves (sidebands) whose frequencies lie above and below that of the RF carrier wave by the pulse frequency (217 Hz for GSM and 17.6 Hz for TETRA) and its harmonics. However, since these sidebands only differ in frequency from the carrier wave by around one part in a million or less, it seems most unlikely that the interaction of the modulated RF fields with tissue could differ appreciably from that of the original wave. Differences in interaction could arise, however, if the electric (or magnetic) properties of biological tissue varied with the amplitude of the RF fields. The signals would then be 'demodulated' resulting in weak electric (magnetic) fields or currents in the tissue at 217 Hz and harmonics (434 Hz, etc). Since biological tissue, particularly the central nervous system, is known to be very sensitive to low frequency electric fields, it was decided to investigate whether demodulation could occur.

Demodulation takes place in electronic devices such as diodes. In these, the current is not proportional to voltage (Ohm's law) but is non-linear. Experiments to see whether analogous structures to diodes exist in biological tissue are presently underway in a collaboration involving the Universities of Bradford and Maryland and the Health Protection Agency using an approach suggested by Balzano (2002).

Another project, involving closely co-ordinated work between Dr Zenon Sienkiewicz (Health Protection Agency) and colleagues at Bristol University and Dstl, Porton Down, searched for evidence at three different levels of biological organisation that RF fields could cause changes in brain function. Following controlled, head-only exposure, gene and protein expression in selected areas of the brain was assayed using gene chip microarray and protein technologies, electrophysiological responses were explored using brain slice techniques, and effects on learned behaviour were investigated using learning and attention tasks. Effects were compared using three frequencies, corresponding to TETRA, GSM and UMTS signals, a range of exposures, and between single and repeated exposures.

If changes were to occur, say in behaviour, then this approach would be able to see if corresponding changes occurred in the excitability of brain cells associated with that behaviour, and then to see if changes could be confirmed at the molecular level. This would give great credibility to any observed effect. While each of the approaches may have its own particular strengths and weaknesses, together they can provide powerful and compelling evidence about the likelihood of biological effects. This work has yet to be published.

Radiofrequency fields penetrate the body to an extent that decreases with increasing frequency. To understand the effects this might have on biological tissue, the magnitudes of the fields need to be determined within the various parts of the body that are exposed. This requires a knowledge of the two main electrical parameters, permittivity and conductivity, of different types of body tissue. These parameters were known to be frequency dependent and there was some evidence that they also depended on age.

To obtain better information in this area, the Programme funded Dr Camelia Gabriel (MCL) to make measurements of the electrical parameters of skin and of seven other types of tissue over the frequency range 50 MHz to 20 GHz. While measurements could be made of the skin of human volunteers, it was evidently not possible to study the other tissues. So, since the electrical parameters of porcine tissue are known to be quite similar to those of humans, *in vivo* and *in vitro* studies were made on a number of pigs aged about 35, 100 and 600 days, corresponding approximately to human ages of under 5, around 12–15, and over 25 years.

The present work confirmed earlier results showing that the electrical parameters of various types of tissue have approximately similar frequency dependencies but rather different magnitudes. It also showed there were appreciable differences in the age dependencies which were determined for four of the tissues (Gabriel and Peyman, 2006; Peyman *et al*, 2007). No measurable age dependency was found in grey matter and a small but measurable decrease found for dura seemed attributable to a change in thickness with age. However, the parameters for white matter showed a systematic decrease with age of nearly 30% and a somewhat greater decrease, over 30%, was found for spinal cord. It seems very likely therefore that the electrical parameters for children are different to those for adults and need to be allowed for in calculating the distribution of RF fields in children. However, the effect is not likely to be large for whole-body exposure, whilst for localised near-field exposures (eg for a phone held against the head) the difference in SAR is likely to be modest compared with that arising from changes in the position of the phone.

Future research needs

Technical approaches to the detection of responses in cells and tissues *in vitro* have developed rapidly in the last few years. It is possible to assay simultaneously for changes in the activity of all of the 30,000 or so genes in the human genome in a sample of cells or tissue (genomics). It is also possible to determine simultaneously changes in the levels of up to several thousand proteins in the same cells or tissues (proteomics). Most recently, technologies for the analysis of very large numbers of cellular and serum metabolites have developed rapidly, using combinations of analytical technologies (metabolomics). Research using these approaches is distinct from classical hypothesis-driven studies: the collection of very large data sets prompts entirely new hypotheses that can be tested subsequently by conventional biochemical and molecular cell biology techniques. For this reason the new technologies are being intensively applied to the diagnosis of disease and to generate new hypotheses for pathogenic mechanisms. This approach is also well suited to the controversial area of response to RF exposure in cellular systems.

A very important feature of these technologies is that they can also be applied directly to human volunteer studies. Any response found to short-term RF exposure (a few hours) of human cells *in vitro* can also be examined in human white blood cells in the circulation. The critical question of whether any *in vitro* effects can also be detected in people could therefore be addressed directly by these new technologies. The Committee does not see this work as a priority at the present time, but it does consider that if further work on cellular mechanisms was to be undertaken in the absence of a clearly defined and robust effect on people, then this is the approach that should be adopted.

6

Base Stations

Background

The Stewart Committee considered the issue of exposure of members of the general public to the emissions from mobile phone base stations (IEGMP, 2000). This was essentially restricted to a consideration of exposures from macrocell base stations (see Appendix C) as these have been the most common and emit the highest powers. It was noted that the antennas may be mounted on free-standing towers, on short towers on the top of buildings, or on the sides of buildings, and that they will generally be at heights of 10–30 m. The main beam from the antennas would normally be tilted down so that it would reach ground level at a distance of around 50–200 m from the base of the support structure. By making generalisations about emitted power and antenna gain, and by applying the inverse square law, it was estimated that the maximum power density of a beam reaching ground level 50 m from an antenna mounted at a height of 10 m would be around 100 mW/m^2.

The Stewart Committee was also able to draw on the results of measurements that had just been completed at 17 base station sites by Dr Simon Mann and colleagues at the National Radiological Protection Board (now part of the Health Protection Agency) (Mann *et al,* 2000). These results indicated that at the publicly accessible locations examined, power densities were typically between 0.01 and 1 mW/m^2 and did not exceed 10 mW/m^2 (equivalent to around 0.2% of the international guideline values) at any location. It was recognised that this was a relatively small sample, but it provided evidence that actual exposures were likely to be somewhat lower than those estimated from worst case assumptions.

No epidemiological studies specifically addressing the effects of base station exposure had been published at the outset of the MTHR Programme. The balance of evidence from studies addressing residential exposure from other types of transmitter did not indicate a hazard, but it was recognised that these studies generally had major limitations that weakened the conclusion that could be drawn. Overall, the Stewart Committee concluded that the balance of evidence indicated that there was no general risk to the health of people living near to base stations on the basis that exposures were expected to be small fractions of internationally accepted guideline values. It was also recognised, however, that there could be indirect adverse effects on people's well-being in some cases.

Given the limitations inherent in the available evidence and the level of public concern about the possible effects of emissions from mobile phone base stations, it was clear that there was a need for the Programme to support additional work in this area.

New evidence and current state of knowledge

One area in which there was little evidence was in relation to exposures from microcell and picocell base stations (see Appendix C). Dr Simon Mann and his colleagues at the HPA undertook a series of measurements close to a sample of 20 base stations selected at random from a list of installations that met basic criteria for microcells and picocells. For ten of the installations, a series of detailed measurements was made to assess how the fields fall off with distance. Interestingly the results showed that for distances less than about 50 m from a base station at ground level, power densities from microcells were likely to be higher than those from macrocells (Cooper *et al*, 2006). The main reasons for this appeared to be the lower mounting height of microcell antennas and the greater vertical beamwidth, which meant that the emitted beam reached ground level closer to the antenna. At greater distances from the base station, the trend was reversed. Exposures from microcells in public areas were generally in the range of 0.002–2% of the international guideline values, with the highest measurement representing 8.6%.

Measurement of fields emitted from microcell base station (photograph courtesy of the Health Protection Agency)

One of the recommendations contained in the Stewart Report was that the government should set up an independent audit of mobile phone base stations to determine if exposures met international guidelines. This was taken forward by the Office of Communications (Ofcom, formerly the Radiocommunications Agency), which has been measuring emissions from around 100 sites per year. This represents a large sample (currently in excess of 1% of all the base stations in the country) and has confirmed that data presented in the Stewart Report were representative. In addition, the HPA has now completed measurements at over 80 sites and has an ongoing project to summarise these on its website (www.hpa.org.uk). These measurements have typically been made over a wider frequency range than those made by Ofcom, and have demonstrated that RF exposures arise not only from local base stations, but also from a wide variety of other sources (see below).

Measurements of emissions from mobile phone base stations provide some confidence that exposures to members of the public are low, but do not in themselves reveal whether there are any adverse health consequences of those low exposures. To investigate this, it is necessary to undertake epidemiological studies of individuals with varying exposure status. The outcome of such a study would be critically dependent on the ability to assess and classify exposure. However, this is far from straightforward, as for most people RF exposures will be made up of many components including emissions from base stations, mobile phones (both those used by the individual and those used in close proximity to the individual, eg phones used by other passengers on a train or bus), cordless phone systems, professional radio communications systems, broadcast TV and radio, pagers and radar installations. To complicate matters even further, all of these exposures, including those from mobile phone base stations, will change throughout the day as people go about their daily lives and move from location to location. As a result of these problems with exposure assessment, it is generally accepted that epidemiological studies of adults in relation to base station exposure are not currently feasible.

One way to address some of the problems with epidemiological exposure assessment might be to use a personal exposure meter capable of logging exposure to different types of emission throughout the day. Early in the Programme it became apparent that such an instrument was being developed by Antennessa. This instrument appeared to have suitable characteristics. It measures electric field strength in nine frequency bands with a wide dynamic range and is designed so that the measurement will be relatively independent of its orientation. The instrument is capable of making repeated measurements and logging the data during the period of wear.

The Committee arranged to borrow eight of the instruments and commissioned Dr Simon Mann and his colleagues at the HPA to undertake a technical assessment of the performance of the instrument. The first part of the study was a laboratory assessment of the response of the instrument to known fields, both within and outside the nine frequency bands it is designed to measure. The second part of the study was a trial during which ten volunteers each wore an instrument for a period of a week, with data logged every two minutes. The volunteers kept a diary of their activity during the measurement and detailed narrowband measurements were made at the four locations where they spent most of their time. Although some problems with the instrument were identified, it performed broadly in line with expectations

(Mann *et al,* 2005). It was noted that the detection threshold may be rather high for the range of likely public exposures, although the meter was able to discriminate the higher exposures of those living near to base stations from those living elsewhere. Subject to further development, the meter appears to offer a promising route to base station epidemiological studies.

As indicated above, in the absence of a reliable means of assessing personal exposure it has not been considered feasible to carry out a base station epidemiological study on adults. Nevertheless, the Programme has pursued a study on children. Professor Paul Elliott and his colleagues at Imperial College London are carrying out a case–control study of risk of childhood cancers in relation to residence near mobile phone base stations. Exposure assessment is less problematic with younger children (under five years old) as they are likely to spend most of their time in one or two locations. In addition, there will be no direct exposure to mobile phones in this age group (although use of mobile phones by older siblings or carers may result in significant exposures). This study is in progress and expected to be completed later this year.

In addition to the childhood cancer study, the Programme has also supported a study of electrical hypersensitivity in relation to base station exposures. This has been discussed in Chapter 4.

Future research needs

It was noted during the selection of sites for the microcell measurement project that around 6% of base stations with antennas mounted at heights of less than 10 m had maximum radiated powers greater than 5 W (the upper limit used to define a microcell in this study). Clearly these higher power installations may give rise to higher exposures and there is a need to investigate this aspect further. With this exception, which might usefully be addressed through existing measurement programmes, additional studies of base station exposure do not appear warranted at the present time.

Although the scientific justification for epidemiological studies on the adverse effects of base station exposures is not strong, there is still significant public concern on this issue that may in itself have an adverse effect on well-being. Hence there would be benefit in undertaking a well-designed study providing there was confidence that the outcome would be meaningful. The Committee does not believe that this stage has yet been reached. Nevertheless, it believes that further work to develop and validate the use of the personal exposure meter would be valuable. It notes that such work is already underway in other countries.

7

Risk Communication

Background

There is uncertainty concerning the risks, if any, associated with the use of mobile phones and emissions from base stations. Despite this uncertainty, communication about the risk of mobile communications technology is commonplace. Risk communication encompasses:

a informing people (whether lay or expert) about the nature, severity and likelihood of potential harm,

b providing advice or direction on safety or precautionary measures that should be adopted (whether by individuals, communities or other interested parties, eg the mobile communications industry or government agencies).

Risk communication on this topic is not the preserve of government. There are many competing risk messages available to the public (eg from pressure groups, from the industry, and from disparate scientific experts).

The important questions concerning risk communication on this topic are:

a What is being communicated, to whom, when and by whom?

b What impact is this communication having upon knowledge, levels of concern (ie anxiety or fear), and behaviour (eg choice of type of mobile phone, level of usage of the phone, or willingness to support base station siting)?

c Could the content and/or methods of communication be improved so as to enhance public safety and sense of security?

At the inception of the MTHR Programme there had been no systematic, comprehensive examination of the structure or efficacy of risk communication regarding mobile communications. There were few data on the way mobile phones were being used (ie frequency, length or purpose of use). Records of usage were available to network providers but the analysis of these was rudimentary. Validated methods for determining baseline individual mobile phone usage were not developed and this made assessment of the impact of any risk message upon behaviour suspect. Since the functions offered via mobile phones have been rapidly changing over the last five years, the task of assessing changes in usage specifically consequent upon risk messages is even more complex.

Early studies tended to focus upon risk perception not upon risk communication. For example, Siegrist *et al* (2005) surveyed the perception of risks associated with mobile phones, base stations and other sources of electromagnetic fields (EMFs). Participants rated high voltage transmission lines as the most risky source of EMFs, while mobile phones and base stations received lower risk ratings. Trust in 'authorities' (scientific and governmental) was negatively correlated with perceived risks. People who reported using their mobile phones frequently perceived lower risks associated with them than people who used them less frequently. People living closer to base stations did not differ in their estimates of risks associated with them from people who lived further away.

The responsiveness of perceived risk to information designed to be precautionary has been explored. Wiedemann *et al* (2006) investigated the effect of information about specific energy absorption rate (SAR) values on judgements about the safety of mobile phones. The vast majority of people did not know the SAR value of their own phones. Even after SAR precautionary safety limits were explained, people believed safety increased as SAR values were reduced and that no level was 100% safe. In fact, there is some evidence that attempts to introduce precautionary measures amplify EMF-related risk perceptions (Wiedemann and Schütz, 2005). This may happen because the recipients of the precautionary advice are alerted for the first time to the existence of the hazard.

Alternatively, it may be because they are alerted for the first time that those providing advice do not actually know for sure what would be safe and can only guess at what might be safe.

New evidence and current state of knowledge

In work supported by the Programme, Dr Julie Barnett and colleagues (University of Surrey) focused upon the effects of the precautionary advice offered by the Department of Health in its leaflets *Mobile Phones and Health* and *Mobile Phone Base Stations*. Acknowledging the difficulty in assessing the impact of precautionary advice on behaviour if good measures of behaviour are not available, these researchers first sought to establish a valid and reliable self-report measure of mobile phone use. They compared self-reports of frequency and duration of usage with actual usage (derived from phone bills). A paper describing the results of this work has been submitted for publication.

Parslow *et al* (2003) reported results comparing questionnaire data with billing records and found that people tended to overestimate their use of mobile phones. This study suggests that data based on self-reports of phone usage must be treated with great caution. Research examining solely the behavioural impact of risk communications should probably not rely upon self-report measures of behaviour.

Dr Barnett and her colleagues also recognised that little is known about public understanding of uncertainty and precaution. Timotijevic and Barnett (2006) conducted a series of focus groups to assess appreciation of the extent of scientific uncertainty regarding the effects of mobile communications technology and to gauge the understanding of precautionary approaches. They found people knew of the uncertainties relating to mobile communications but they did not think that government was willing to acknowledge that uncertainty. There was little awareness that there was a precautionary approach to managing the possible health risks of mobile phones or base stations. Timotijevic and Barnett also suggested that simplistic notions that precautionary advice either provokes concern or provides reassurance fail to appreciate that the response is conditioned by complex networks of prior attitudes and beliefs. Sometimes the response is affected by self-interest and the perceived possibility of personal gain or loss (eg with regard to the siting of base stations). Different people will thus react very differently to the same precautionary advice. While unsurprising, this conclusion leads to practical problems for policy makers who wish their precautionary advice to have a common impact. The solution might be more targeted messages, tailored for specific audiences. Unfortunately, there is currently insufficient detailed understanding of the factors that differentiate between audiences that would be necessary to allow such customised message-construction.

Barnett *et al* (2007) used a survey of a representative sample of 1742 people in the UK to examine the impact of the precautionary advice in the Department of Health leaflets on mobile phones and base stations. Of the sample, 15% had seen the mobile phone leaflet and 10% had seen the base stations leaflet. When questioned about the nature of government advice in this area, 53% did not recognise any of the items of government advice. Only 9% recognised that consideration of SAR values was part of government advice. The data also suggest that people hold inaccurate beliefs about the precautionary measures they might take to improve their own safety. Penetration of the precautionary advice to the public seems limited. Sadly, the study tells us nothing of why there is limited penetration. Not all of the data from this work are yet available in the public domain. Subsequent publications may throw light on this question.

Future research needs

Key issues include:

a role of multiple sources of risk information and the effects of conflicting risk information upon behaviour,

b factors influencing the interpretation of risk information that is generated during significant conflicts (eg from opposite sides in a dispute about base station siting),

c real-time impact of new risk information on behaviour (particularly upon choice of mobile communications technologies),

d role of pricing regimes in changing use patterns for mobile phones,

e structure of risk information messages that have a targeted impact on different audiences.

These, and other, issues can only be addressed usefully by conducting systematic, large-scale studies relying upon better behavioural measures and clearly described samples of participants. In addition, research on risk communication would be more valuable if the researchers worked with those responsible for developing risk messages so as to understand thoroughly the strategic or tactical purpose of the communications used before attempting to evaluate their efficacy.

8

Mobile Phones and Driving

Background

Mobile phones can have detrimental effects on public health that are unrelated to any emissions from the phone or base station. In particular, the use of a phone may affect the ability of a user to concentrate on a concurrent task such as driving or operating machinery. The consequences of mobile phone use whilst driving are well established and were reviewed by the Stewart Committee (IEGMP, 2000), which found that there was compelling evidence from both experimental studies and epidemiological research that using a mobile phone while driving impairs performance and increases the risk of an accident. This impairment appears to be greater than that associated with merely listening to a radio or engaging in a relatively 'automatic' task such as repeating back words heard over the phone. It is evident during casual conversations and increases with the mental workload imposed by the conversation. It is also greater in elderly drivers.

As might be expected, placing calls with a hand-held phone results in a transient impairment in the ability to control a vehicle. However, the greatest contribution to the risk appears to result from the more sustained 'central' effects due to the cognitive load imposed by a conversation, which are shared by both hand-held and hands-free operation. At the start of the MTHR Programme it was believed that these central effects might be less significant for conversations with passengers than they were for the more 'remote' phone conversation. However, there was little in the way of hard evidence to support this assumption.

New evidence and current state of knowledge

The Programme commissioned Andrew Parkes and colleagues at TRL Ltd to investigate how the impairment to driving performance associated with mobile phone use compares with the effects of other common in-car distractions, such as conversation with a passenger or adjustment of interior controls.

The study contrasted numerous measures of driving performance in a highly realistic driving simulator as a function of four experimental conditions. These comprised a no-distraction control condition, a condition in which the driver continuously adjusted the radio and heating controls, and two in-car conversation conditions. The content of these conversations, in which the driver responded to verbal puzzles, repeated sentences, and generated a short monologue, was the same whether the conversation was with another person present in the car, or via a hands-free phone set. The quality of the conversations in these two different conditions, as assessed through metrics such as speech rate, time to respond, and repetition accuracy, was contrasted with a third control condition comprising a face-to-face conversation outside the simulator.

Compared with the control condition, the three in-car activities impaired performance on most measures of driving performance (Parkes *et al,* 2007). For almost all cases, the level of impairment was statistically indistinguishable. On only one measure, reaction time to a 'target' road sign, was there a hint of a disproportionate effect for the phone condition relative to the passenger conversation and control adjustment conditions. This effect only reached statistical significance when assessed with a 'one-tailed' test that assumed that, if there was any difference between the conditions, it would take the form of worse performance under the phone condition. The basis for this assumption is not clear, and the effect does not attain statistical significance when assessed with a more appropriate two-tailed test. Together with the large number of individual tests that were conducted, and the consequently high probability of a false positive result, the frailty of this effect offers little evidence of a disproportionate effect of phone use on driving performance.

Use of a driving simulator to assess distraction from use of a mobile phone while driving
(photograph courtesy of Mr Andrew Parkes, TRL Ltd)

Although phone conversations had little or no disproportionate effect on driving relative to passenger conversations or other in-car activities, driving while conversing on the phone was rated by the subjects as requiring more mental effort than for the other conditions. In addition, phone conversations were associated with a slower talking rate, more pauses, and slower response times to questions than were conversations with a passenger. Unfortunately, since no assessment was made of conversational performance over a mobile phone in a no-driving condition, it is not possible to determine the extent to which these effects on conversational fluency resulted from phone use *per se*, rather than the combination of phone use and driving.

Moreover, under real driving conditions, phone conversations could result in an increased risk of an accident relative to conversations with passengers as the latter are likely to stop talking in potentially hazardous situations. Similarly, drivers are less likely to adjust controls when confronted with hazardous driving conditions.

These findings confirm the deleterious effects of a hands-free phone conversation on driving, but offer no evidence that the effects are more pronounced than those arising from a comparable conversation with a passenger. The finding that subjects rated phone conversations as requiring more effort than passenger conversations raises the possibility, however, that use of the phone requires more cognitive resources than does talking with a passenger, leaving fewer resources 'in reserve' to cope with an unexpected event on the road. The finding that conversations over the phone were less fluent than those with a passenger may also point to greater competition for cognitive resources between conversing and driving when using a phone than when talking to a passenger. As already noted, however, the absence of a crucial control condition makes this last finding difficult to interpret.

Future research needs

The dangers arising when driving from the distraction caused by both hand-held and hands-free mobile phones are well established and it seems likely that machine operators will be similarly affected. There is a clear need to investigate the extent to which drivers and machine operators are aware of the effect that use of a phone has on their performance and whether this awareness results in them using a phone less. The results of this work should inform efforts to reduce the use of hands-free as well as hand-held phones.

At present the use of hands-free phones while driving is legally permitted, despite research demonstrating that the risk is similar to use of hand-held phones; the distraction is similar. Since they are legally permitted it is important to see if there are ways of reducing the distraction (although this should not be seen as an alternative to preventing their use). It will be important to have an objective means of assessing if the distraction has been reduced. It is considered that there is a need to establish a standard battery of tests that could be used to evaluate strategies for reducing distraction.

9

Research Recommendations

The Programme Management Committee has considered the results obtained from the studies funded in the first phase of the MTHR Programme and believes that whilst much has been done to resolve the uncertainties identified by the Stewart Committee, there are some gaps in knowledge that still need to be filled. It has therefore determined research priorities for a second phase of the Programme, MTHR2.

In doing this, the Committee undertook a critical assessment of the research priorities identified by bodies such as the WHO, AGNIR, NRPB (now part of the HPA), EMF-NET and COST 281. It was also mindful of the research that is currently in hand in the UK, and elsewhere in national programmes in France, Germany, Italy, etc, together with work now largely completed in European projects such as the Interphone study.

The radiofrequency section of the WHO research agenda on possible health effects of electromagnetic fields developed in the 1990s has been extensively revised and updated in recent years. These revisions have taken account of the outcome of three specialised international workshops held in 2004 and 2005 that examined possible health effects in relation to children, electrical hypersensitivity, and base stations. The current version of the WHO research agenda for RF fields was published in 2006 and is available at www.who.int. The Committee has also kept in mind issues of particular public concern in the UK and its research priorities include some topics that lie outside the WHO research agenda, which is restricted to possible health effects arising directly from RF exposure.

As a result of this exercise, the Committee has identified a number of key areas where it believes that further research is necessary, but is not currently in progress. These were first discussed during the open session of the MTHR research seminar in November 2004 and have since been refined. The main areas identified are given below:

a a UK component for an international cohort study of mobile phone users,

b epidemiological studies to look for associations between RF exposure and childhood diseases,

c volunteer studies of electrical hypersensitivity in relation to TETRA radios and base stations,

d high resolution modelling of RF electric fields in tissue (microdosimetry),

e studies aimed at understanding and improving risk communication,

f studies related to the risks of driving or operating machinery whilst using a mobile phone.

Further details of the rationale for these recommendations are given below, along with information on the types of study currently envisaged. Projects have already started in two of the areas as part of MTHR2, whilst a call for proposals in the remaining areas will be published shortly.

Cohort study of mobile phone users

The epidemiological studies conducted in recent years, including those supported by the Programme, have provided reassurance that short-term (less than ten years) exposure to mobile phone emissions is not associated with an increased risk of brain and nervous system cancers. However, there are still significant uncertainties that can only be resolved by monitoring the health of a large cohort of phone users over a long period of time.

The symptoms from many diseases, including most adult cancers, only become apparent many years after the event that produced them, so the possibility of an association with long-term exposure cannot currently be ruled out. Moreover, until recently, there were

relatively few people who had used their phones for much more than ten years, which means that until now it has been difficult to study the effects of long-term exposure with adequate statistical power. In addition, none of the recent studies has examined possible associations with other diseases, such as Alzheimer's and Parkinson's diseases.

The Committee is convinced that the best way to address these uncertainties is to carry out a large cohort study of mobile phone users, an approach that has also been rated as a high priority by the WHO. In order for the study to be appropriately powered, a large sample size will be required (preferably at least 200,000) and this can best be achieved through a major international collaboration. The Committee has therefore been very active in encouraging support for an international cohort study that builds on the results of the pilot study carried out in the UK and Sweden with support from the Programme. It has now been agreed that the UK group from Imperial College that carried out the pilot study will collaborate with research groups from three other countries (Denmark, Finland and Sweden), with the UK providing the largest contribution to the cohort.

The pilot study funded by the Programme suggested that the most fruitful approach would be to employ sampling based on operator records of contract phone users. Once established, the cohort will be followed into the future and the study should be capable of identifying effects on a whole range of head and neck diseases.

Sensitivity of children to mobile phone signals

One of the key conclusions in the Stewart Report was that, if there were unrecognised adverse health effects of exposure to mobile communications signals then children may be more vulnerable. Although the Committee wanted to support research in this area during the first phase of the Programme, volunteer studies were viewed as ethically unacceptable, and research was consequently limited to work on the assessment of age-related changes in the dielectric properties of different tissues and a study of childhood cancers in relation to residence near mobile phone base stations.

The Committee believes that the potential sensitivity of children remains one of the key areas of uncertainty in relation to the possible health effects of exposure to mobile phone signals. It therefore attaches a high priority to further research in this area, a view that is consistent with priorities identified by the WHO. In order to understand better the research needs in this area, and in particular to avoid unnecessary duplication of work already in progress elsewhere, the Committee organised an international workshop on mobile phones and children's health at the Royal Society in June 2007. As a result of the workshop, the Committee considers that MTHR2 could make the most useful contribution by supporting one or more epidemiological studies. The types of study are discussed further below.

Brain tumours

Although recent epidemiological studies have provided reassurance that short-term exposure to mobile phone emissions is not associated with an increased risk of adult brain cancer, none of these studies has examined the risk in children. There is greater variation in tumour type for childhood brain tumours compared with those in adults. Moreover, latency is very much shorter for paediatric tumours. As a result of these and other fundamental differences in the nature of adult and childhood tumours, it is not possible to extend conclusions from the adult studies to infer a lack of association in children.

The Committee welcomes current work on CEFALO, an international case–control study on brain tumours in children and adolescents, which will provide much needed data in this area. However, it also recognises that the low incidence of childhood brain tumours will limit the power of the CEFALO study. It will therefore give consideration to supporting proposals to carry out a similar study in the UK to add to the international effort. It would not be possible simply to add another component to the existing CEFALO study as this will be nearing completion by the time the UK component would start. Hence any UK study would have to be separately powered and in order to achieve this it is likely that at least 500 cases would be required.

Childhood illnesses

There is currently relatively little information available on whether exposure to signals emitted by mobile phones can cause symptoms such as headaches, migraine, dizziness, anxiety, loss of concentration, or sleeplessness. The Committee is aware of work underway in this area in Germany, but considers that there would be merit in supporting additional work in the UK.

The Committee will give consideration to supporting proposals to set up a cohort study to examine whether there is any association between childhood illnesses such as those discussed above and exposure to mobile phone emissions. As a result of the far higher incidence of these childhood illnesses, the size of the cohort could be considerably smaller than that proposed for the study on adult brain cancers. It may also be possible to include a sub-study to investigate whether cognitive function is affected by exposure history, ethical considerations permitting. This might add to information obtained from the MoRPhEUS study currently nearing completion in Australia.

Electrical hypersensitivity and TETRA emissions

The roll-out of the TETRA emergency services network has brought increasing numbers of reports of symptoms following exposure to emissions from TETRA handsets and base stations. Although similar issues have been addressed in relation to mobile phone signals during the first phase of the Programme, it is recognised that the signal from the TETRA radio system used by the emergency services has raised specific concerns. Hence, although this is an area of work that falls outside the WHO research agenda, the Committee believes that work is needed because of the degree of public concern in the UK and elsewhere in the world, and the resulting effect on the well-being of those concerned. Two studies are already underway in this area as part of MTHR2.

During the first phase of the Programme support was provided to Professor Elaine Fox and colleagues to carry out a volunteer study at the University of Essex to investigate whether exposure to emissions from mobile phone base stations caused the disagreeable symptoms experienced by some people. The base station exposure system at the University of Essex has now been modified to produce a TETRA signal and testing will shortly be underway. Experience gained from the mobile phone base station study should enable the design of the TETRA study to be refined.

The Programme also supported Dr James Rubin and colleagues at King's College London to investigate whether exposure to signals from a mobile phone could elicit a range of self-reported symptoms in volunteers. Although this study did not find any evidence that the symptoms suffered by volunteers were due to exposure to mobile phone signals, many police officers have reported similar symptoms following the introduction of the TETRA radio system. A second study is therefore being conducted by the same research team to test whether the signals from TETRA radios can cause symptoms. Volunteers are being drawn from police users of the TETRA system.

High resolution modelling of fields in tissue

Most of the present knowledge of the deposition of RF energy into human tissues has been determined at fairly low resolution. In order to understand better the interactions that occur, the Committee considers that it would be helpful to develop techniques in microdosimetry.

Risk communication

The study on risk communication funded under the first phase of the Programme found that the penetration of precautionary advice to the public was limited and suggested that policy makers may need to adopt alternative strategies for risk communication. The Committee believes that there is a need for additional research in this area aimed at improving the communication of information about the risks of exposure to mobile communications technologies. A number of key research issues have been identified by the Committee and it is felt that these can only be addressed usefully by a systematic, managed programme of large-scale studies with clearly described samples of participants. It is recommended that researchers should work with those responsible for developing risk messages.

Risks of driving or operating machinery whilst using a mobile phone

The dangers arising when driving from the distraction caused by both hand-held and hands-free mobile phones are well established and it seems likely that machine operators will be similarly affected. The Committee believes that there is a clear need to investigate the extent to which drivers and machine operators are aware of the effect that use of a phone has on their performance and whether this awareness results in them using a phone less. It will give consideration to supporting further work in this area, which should be aimed at improving strategies to reduce the use of hands-free as well as hand-held phones.

At present the use of hands-free phones while driving is legally permitted, despite research demonstrating that the risk is similar to use of hand-held phones; the distraction is similar. Since they are legally permitted it is important to see if there are ways of reducing the distraction (although this should not be seen as an alternative to preventing their use). It will be important to have an objective means of assessing if the distraction has been reduced and the Committee considers that there is a need to establish a standard battery of tests that could be used to evaluate strategies for reducing distraction.

Work falling outside the research priorities of MTHR2

Developments in technology

The Committee recognises that mobile communications technology is an area of rapid development and that it will be important to keep abreast of likely future developments in order to ensure that studies are relevant. However, this is not seen as an area where research could usefully be carried out. Information on new technological developments is available within the mobile phone industry and it is therefore proposed that the industry should be asked to provide periodic updates.

Biological mechanisms

The Committee recognises that molecular biology and physiology offer powerful techniques for understanding the mechanisms underlying responses seen in people. However, these techniques are only applicable where responses are well established and robust, which has not so far been the case in relation to possible effects of exposure to mobile phone signals. Consequently, the Committee does not consider it appropriate to fund further work in this area at the present time.

The Committee does, however, recognise that recent developments in analytical approaches offer the possibility of research that is distinct from classical hypothesis-driven studies. Instead, it is now possible to collect data on a very large number of cellular changes and use these to prompt entirely new hypotheses for using classical biochemical techniques. Such an approach could be applied to human volunteers and would be much better suited to studying possible effects of exposure to mobile communications signals than other *in vitro* approaches. The Committee does not see this work as a priority at the present time, but it does consider that if further work on cellular mechanisms was to be undertaken in the absence of a clearly defined and robust effect on people, then this is the approach that should be adopted.

Base station measurements

The Committee considers that there is now adequate information about 'typical' exposures from base stations and, in general, does not see any need for further work in this area. One possible exception to this may be the issue of higher power (greater than 5 W) installations with antennas mounted at heights of less than 10 m that were noted in the study carried out for the Programme by Dr Simon Mann and colleagues at the HPA. However, the Committee considers that this could be addressed through routine measurements of the type carried out by organisations such as Ofcom and the HPA. It does not, therefore, see any need to fund specific work in this area.

10

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Glossary and Abbreviations

Glossary

Ambulatory blood pressure blood pressure as measured during normal daily routines, rather than in a clinical environment.

Attentional tests tests used to assess ability to maintain attention.

Auditory stimulus external event eliciting a nerve response via the ear.

Bias any process at any stage of inference that tends to produce results of conclusions that differ systematically from the truth.

Brainstem lower part of the brain adjoining the spinal cord.

Calcium efflux process of rapid release of soluble calcium from cells or tissues.

Calcium signalling change in intercellular or intracellular calcium concentration used as a means of initiating a change in cellular processes.

Cardiovascular connected with the circulatory system.

Carotid body cluster of receptors located in the carotid artery that monitor chemical and physical properties of blood.

Case–control study an investigation into the extent to which a group of people with a specific disease (the cases) and comparable people who do not have the disease (the controls) differ with respect to exposure to putative risk factors.

Catecholamine chemical compound derived from the amino acid tyrosine and used by the body as a neurotransmitter and hormone.

Cognitive function higher processes of the brain involving the processing of information.

Cognitive testing a general name for tests measuring speed and accuracy of people's mental performance. These can include reaction times and tests of perception, attention and memory.

Cohort group of people identified in an epidemiological study so that they can subsequently be followed up to see who develops disease.

Cohort study an investigation involving the identification of a group of people (the cohort) about whom certain exposure information is collected, and the ascertainment of occurrence of diseases at later times. For each person, information on prior exposure can be related to subsequent disease experience.

Confidence interval a range calculated from data when making inferences about an unknown parameter. In hypothetical repetitions of the study, the interval will include the parameter in question on a specified percentage of occasions (eg 95% for a 95% confidence interval).

Dosimetry measurement of the absorbed dose or dose rate by an object.

Double-blind design a stringent way of conducting an experiment in an attempt to eliminate subjective bias on the part of either the experimental subject or the researcher. In a double-blind study neither the subject nor the researcher knows the exposure conditions until all the data collection and processing have been completed.

Electroencephalogram (EEG) a laboratory technique for measuring the electrical activity of the human brain via recording electrodes placed on the scalp.

Electrophysiological electrical properties of biological cells and tissues, deriving from changes in the membrane potential of nerve cells.

Epidemiology (epidemiological) study of factors affecting the health and illness of populations.

Fluorescence process whereby absorption of a photon of light results in emission of another photon at a longer wavelength; used as the basis of many extremely sensitive biochemical assays.

Free radical an atom or molecule possessing an unpaired electron in its outermost shell. In general, free radicals are highly chemically reactive.

Genomics study of all the genes in an organism's genome. The genome of an organism is the totality of the information encoded in its genetic material.

In vitro biological process occurring in a controlled environment outside the organism.

In vivo biological process occurring within an organism.

Latency term used to describe the delay between exposure to an agent or event that causes an illness and the appearance of symptoms.

Metabolomics the systematic study of the unique chemical fingerprints resulting from specific cellular processes.

Modulation Process of varying a pure waveform for the purpose of encoding information.

Nematode small worm-like organism.

Pulse modulation see TDMA.

Odds ratio Ratio of the odds of disease occurrence in a group with exposure to a factor to that in an unexposed group: within each group, the odds are the ratio of the numbers of diseased and non-diseased individuals.

Psychomotor performance the mental operations involved when people respond to stimuli, typically studied in controlled laboratory experiments. Reaction time is a well-established measure of psychomotor performance.

Proteomics large-scale study of proteins. The proteome of an organism is the set of proteins produced by it during its life.

Somatosensory stimulus external event eliciting a nerve response via pressure sensors in the skin.

TDMA (time division multiple access) system that divides each frequency band into a number of timeslots, each allocated to a single user. It allows several users to operate on the same frequency band. The effect on the transmission is often referred to as pulse modulation since the signal is emitted in bursts or pulses.

Temporal lobe part of the cerebrum, lying at the side of the brain and involved in auditory processing.

Ultraviolet radiation electromagnetic radiation with wavelengths between 100 and 400 nm. It is the most energetic and damaging form of non-ionising radiation.

Visual stimulus external event eliciting a nerve response via the eye.

Vestibular sensory system located in the inner ear that provides the dominant source of information about the movement and orientation in space of an individual.

Abbreviations

AFHSS	Adaptive frequency-hopping spread spectrum
APC	Adaptive power control
BCCH	Broadcast control channel
CDMA	Code division multiple access
CI	Confidence interval
CPICH	Common pilot channel
CW	Continuous wave
DECT	Digital enhanced cordless telephone
DNA	Deoxyribonucleic acid
DSSS	Direct sequence spread spectrum
DXT	Discontinuous transmission
EDGE	Enhanced data for GSM evolution
EEG	Electroencephalogram
EMF	Electromagnetic field
FCCH	Frequency correction channel
GPRS	General packet radio service
GSM	Global system for mobile communications
HSCSD	High speed circuit switched data
OFDM	Orthogonal frequency division multiplexing
PAN	Personal area network
RF	Radiofrequency
SAR	Specific energy absorption rate
TCH	Traffic channel
TDMA	Time division multiple access
TETRA	Terrestrial trunked radio
UMTS	Universal mobile telecommunications system
WLAN	Wireless local area network

Appendix A

Publications Arising from the MTHR Programme

Bamiou D-E, Ceranic B, Cox R, Watt H, Chadwick P and Luxon LM (2007). Mobile telephone use effects on labyrinthine function: a case–control study. *Bioelectromagnetics* [e-pub in advance of print].

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Appendix B

Research Not Yet Published

A number of research projects that have been supported by the MTHR Programme are either still in progress, or have only recently been completed and have not yet been published. Where relevant, the work undertaken in these projects has been briefly discussed in this report. However, it has not been possible to discuss results in detail where these have not yet been published. Projects that are ongoing or have only recently been completed are listed below. Further details on the projects are available on the MTHR website, www.mthr.org.uk. All publications resulting from the Programme are listed on this website and in due course final reports on each project will also be published there.

Project title	Lead researcher	Start	Finish
Epidemiology			
A case–control study of risk of leukaemia in relation to use of mobile phones	Professor Anthony Swerdlow	November 2002	March 2008
Case–control study of cancer incidence in early childhood and proximity to mobile phone base stations	Professor Paul Elliott	April 2003	September 2007
Volunteer studies			
Detection of effects of microwave radiation on the electrical activity of the brain	Dr Stuart Butler	July 2003	December 2004 *completed*
Mechanistic studies			
The effects of radiofrequency radiation on brain physiology and function	Dr Zenon Sienkiewicz	February 2002	December 2005 *completed*
Non-linear and demodulation mechanisms in biological tissue	Professor Peter Excell	September 2004	December 2007
Exposure and dosimetry			
Interaction of emerging mobile telecommunication systems with the human body	Dr Stuart Porter	April 2002	June 2006
Traceability for MTHR Research Programme (TMTHR) (measurement of emissions from commercial mobile phones)	Mr Bob Clarke	December 2001	March 2003 *completed*
SAR testing of hands-free mobile phones	Dr Stuart Porter	July 2002	January 2003 *completed*
International EMF Dosimetry Project	Dr Phil Chadwick	March 2002	February 2006 *completed*
Supporting projects			
Traceability for MTHR Research Programme (TMTHR) (dosimetry in support of the Programme)	Mr Bob Clarke	December 2001	End of programme
Experimental system and dosimetry for the MTHR system	Dr Phil Chadwick	March 2002	March 2006 *completed*
Development of base station exposure system	CDS Europe	August 2004	October 2004 *completed*

Appendix C

Mobile Communications Systems

Cellular networks

The current generation of mobile communications involves the transmission of information (voice, text messages or data) that is digitally encoded in a radio signal between a handset and a base station. Signals transmitted from the handset to the base station are called uplinks and are transmitted at slightly lower frequencies than the corresponding downlink (base station to handset) signals. In order to work, every handset has to be able to establish a radio link with an appropriate base station, and as both the handsets and base stations have limited range, each operator has divided the UK into a network of cells. An ideal network would consist of a mesh of hexagonal cells, each with a base station at its centre. However, in practice, local topography will affect the propagation of radio signals, with features such as hills, buildings and vegetation attenuating the signals and reducing coverage. Moreover, each individual base station is limited in the volume of call traffic it can handle, and as a result a higher density of base stations is required in areas with more users, such as city centres. Hence, in practice, the size and shape of cells varies enormously, with smaller cells in urban compared with rural locations. In general, base stations serving smaller cells will transmit at lower power than those serving larger cells.

In general, mobile phone network operators divide large cells (macrocells) into sectors and the base stations serving them are normally configured to transmit different signals into each of these sectors. Often there will be three sectors with equal angular coverage (120°) as this is a convenient way to divide a hexagonal cell. However, where the number of users is distributed unevenly in the surrounding area (because the base station serves a busy motorway, or because it is at the edge of a shopping centre) then the sectors may be uneven and there may be more or less than three. These base stations are normally connected to directional antennas that are mounted on the roofs of buildings or on free-standing masts. The signals emitted from these antennas usually spread out much more in the horizontal than the vertical plane in order to provide coverage across a sector. In addition, the operators will normally apply electrical or mechanical downtilt to the antennas so that the signals are directed down towards ground level. The point at which the main beam reaches ground level will depend on both the height of the antennas and the degree of downtilt, but is typically around 50–300 m from the base of the mast of other supporting structure (Figure A1).

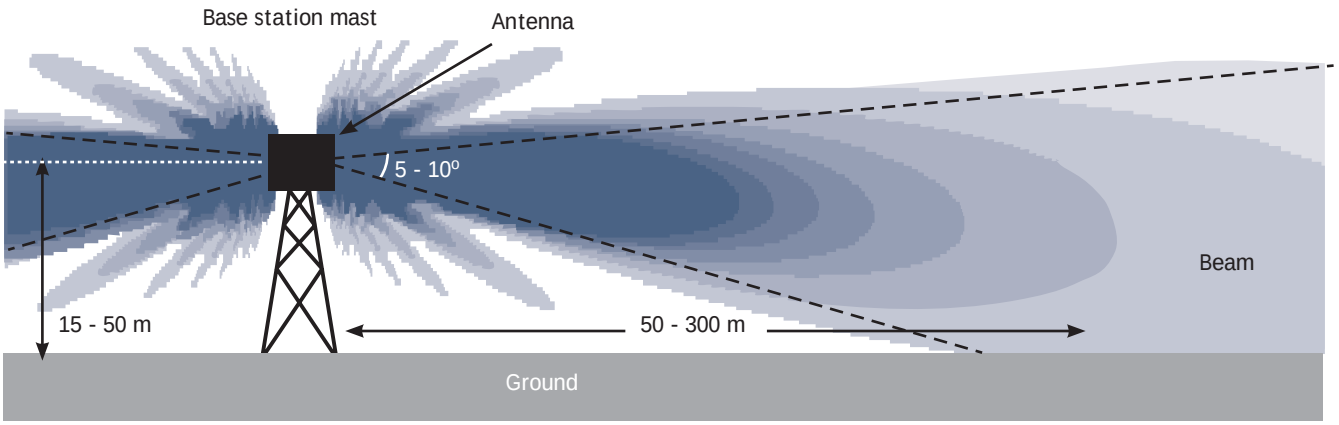
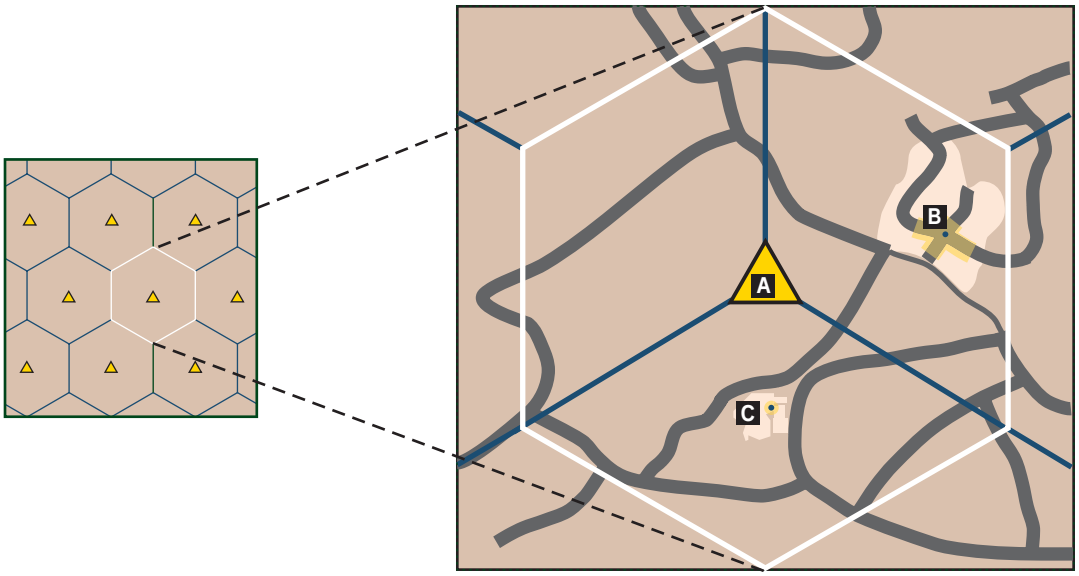


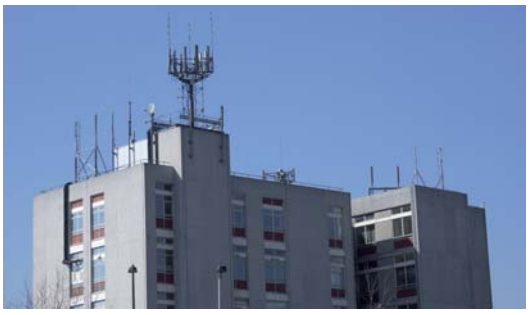
FIGURE A1 *Propagation of 'main beam' from antenna mounted on a mast (figure courtesy of the Health Protection Agency)*

In busy town or city centres network capacity is often stretched and under these circumstances mobile phone network operators may overlay the macrocell network with one or more smaller cells (microcells). These are usually served by base stations transmitting at relatively low power, with signals emitted from small antennas mounted fairly low down on the sides of buildings or enclosed within signs or street furniture. In general, the antennas used for these installations are much less directional and there is no subdivision of the cell into sectors (Figure A2).

Sometimes there is a requirement for mobile phone coverage within buildings such as office blocks, either because the structure of the building results in poor signal strength, or because there is inadequate capacity for the number of users. In these situations very low power installations may be used to provide local coverage within a limited area (picocell) such as a floor or an open plan office. As for microcells, the antennas that emit signals are not usually directional and there is no subdivision of the area into sectors (Figure A2).

The cellular structure used for TETRA emergency services radio communications is generally simpler than that used for mobile phone networks. The antennas employed are usually somewhat less directional than those used for mobile phone macrocell installations and there will often be no attempt to divide cells into sectors. Although cell sizes will be smaller in areas of high demand, the requirement to ensure the security of installations means that the use of microcell and picocell installations would not be appropriate. However, where the established network provides insufficient coverage or capacity in a particular area, mobile repeaters may be deployed to relay signals back into the main network. These normally operate at powers similar to those of other vehicle-mounted radios.





Microcell providing extra capacity in town centre

Picocell providing coverage in shopping centre

FIGURE A2 *Arrangement of cellular networks showing macrocell, with microcell and picocell base stations used to provide additional coverage (figure courtesy of the Health Protection Agency)*

Mobile communications technologies

At present in the UK there are three mobile communications technologies that are used to provide national networks. Two of these (nine networks in total) provide coverage for mobile phones, whilst the third (a single network) is designed to provide secure and resilient communications for the three emergency services. Most phones currently operate according to the Global System for Mobile Communications (GSM) protocol, which is widely used throughout Europe and most of the rest of the world. However, newer 3G phones operate according to the Universal Mobile Telecommunications System (UMTS) protocol. Emergency services radio is based on the Terrestrial Trunked Radio (TETRA) technical standard. All three systems use the cellular approach described above and the principal technical features of each are described below.

In addition to the three main types of cellular network, there is also a widespread and growing use of other radio communications technologies, particularly cordless phones using the Digital Enhanced Cordless Telecommunications (DECT) system, Wireless Local Area Networks (WLANs), and Personal Area Networks (PANs).

GSM networks

GSM networks operate in one of two frequency bands around either 900 MHz (Vodafone and O2) or 1800 MHz (Vodafone, O2, Orange and T-mobile). Both of these bands are divided into a number of frequency channels, each of which is 200 kHz wide, with uplink and downlink channels paired together. Network operators need to avoid interference between users in different cells, so a relatively small number of channels will be available in each cell and cannot be used in any other cell nearby; where the cell is divided into sectors the available channels will be divided between them. Given the limited number of channels available, a technique called time division multiple access (TDMA) is used to divide each of them in time to give eight timeslots. Each phone making a call will be allocated a particular timeslot within specific uplink and downlink frequency channels and information to be transmitted will be compressed into these timeslots. The network may vary allocations to achieve the most efficient use of the available resources.

In practice, most base stations will have some spare capacity most of the time so that new calls can be established and so that capacity is not limiting in peak periods. Where timeslots are not allocated there will be no transmission and the average power transmitted by the base station will be lower than if all timeslots were occupied. Similarly, where the volume of traffic is low (at night, for example), it is possible that a base station will not transmit at all in some or most of the frequency channels allocated to it. However, every GSM base station will always transmit all timeslots of one channel in each sector at its maximum power. This signal carries the broadcast control channel (BCCH) in one of the eight timeslots and this is used by mobile phones trying to establish a connection to the network. Once the call is established, communication will occur using traffic channels (TCH) which may be carried on any of the available frequencies.

Figure A3 illustrates the variation in output with time for GSM base station BCCH and TCH carriers and for a GSM mobile phone. It can be seen from this that the handset emits a regular pulse of output power once every 4.6 ms and this is equivalent to a frequency of approximately 217 Hz. More recent evolutions of GSM, the so-called 2½G technologies such as GPRS (general packet radio service), EDGE (enhanced data for GSM evolution), and HSCSD (high speed circuit switched data), provide higher bandwidths for data transmission but may allow a single user to occupy more than one timeslot.

UMTS networks

The UMTS networks that have recently been established by all five of the UK mobile phone network operators (Vodafone, O2, Orange, T-mobile and 3) operate in a somewhat different way to the GSM networks. The licensed bands for UMTS are at frequencies around 2000 MHz, and the frequency channels are much wider (5 MHz), but there are fewer of them (only two or three per operator). Instead of using the TDMA system to allow users to share a frequency channel, UMTS networks use a system called code division multiple access (CDMA). Essentially the signals from each handset and each base station are encoded so that signals from different base stations and different handsets can be transmitted simultaneously in the same frequency channel without interfering with each other. There is still a requirement for control information

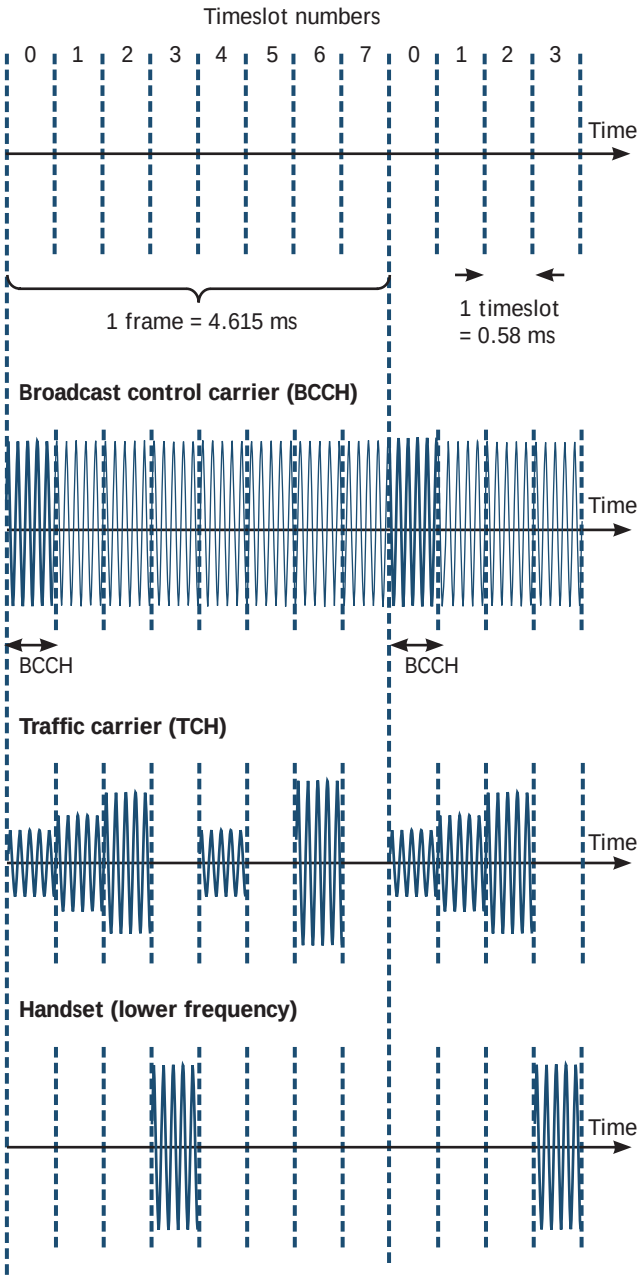


FIGURE A3 *Arrangement of timeslots for GSM networks, showing how outputs vary with time for different types of base station channel and handsets*

equivalent to that carried by the BCCH in the GSM network and this is transmitted in a common part of the transmitted signal called the common pilot channel (CPICH). Hence, as for GSM networks, the output of the base station may vary between a minimum with just the control data being transmitted to a maximum with the base station carrying call traffic at full capacity, but most of the time it will be somewhere between these extremes.

The UMTS network offers users the potential for wide bandwidths that can be used for high data applications such as video and internet access. However, there is a limit to the total bandwidth that is available from each individual base station, so that as more users share a base station, the bandwidth available to each falls. In order to maintain the availability of high data rates for multiple users, cell sizes shrink with anticipated demand and UMTS cells are expected to be generally smaller than those for GSM; smaller cell sizes will require a higher density of base stations. All five national network operators are currently offering 3G services and have constructed networks to support these. However, the number of 3G users is still relatively low compared with 2G users and the networks are still under development. It is expected that the number of base stations will increase from 47,000 at present to at least 50,000 by the end of 2007, largely in support of 3G services, but the final number of 3G base stations will be dependent on the take-up of 3G services.

TETRA emergency services radio

Two TETRA networks have been constructed in the UK. The first was constructed by Dolphin to provide private business radio services for commercial subscribers. However, this network was not commercially viable and was switched off at the end of July 2004. A second TETRA network was constructed by O2 Airwave to provide national radio coverage that was both secure and resilient. Although O2 Airwave was initially contracted to provide a service for use by the police, agreements have now been reached with a number of other organisations, including the Highways Agency, the ambulance service in England, the fire services in England, Scotland and Wales, and most recently the RSPCA. The emergency services TETRA system operates at frequencies just below 400 MHz, and the available band is split into 200 frequency channels, each 25 kHz wide, with uplink and downlink channels paired together, as they are for the public mobile phone systems. The system uses TDMA so that each frequency channel can be used by up to four users (see Figure A4). This means that, as for GSM mobile phones, the output from the handset is pulsed; in this case the frequency is 17.6 Hz.

However, the way that base stations handle traffic channels is somewhat different between GSM and

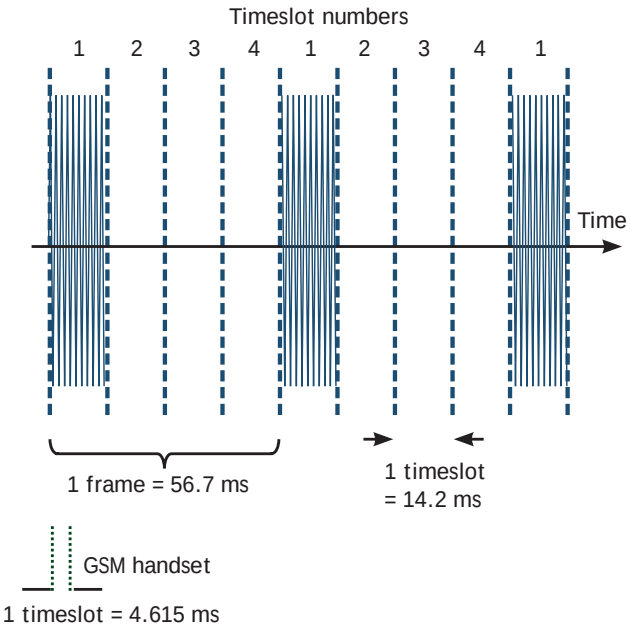


FIGURE A4 *Arrangement of timeslots for TETRA systems*

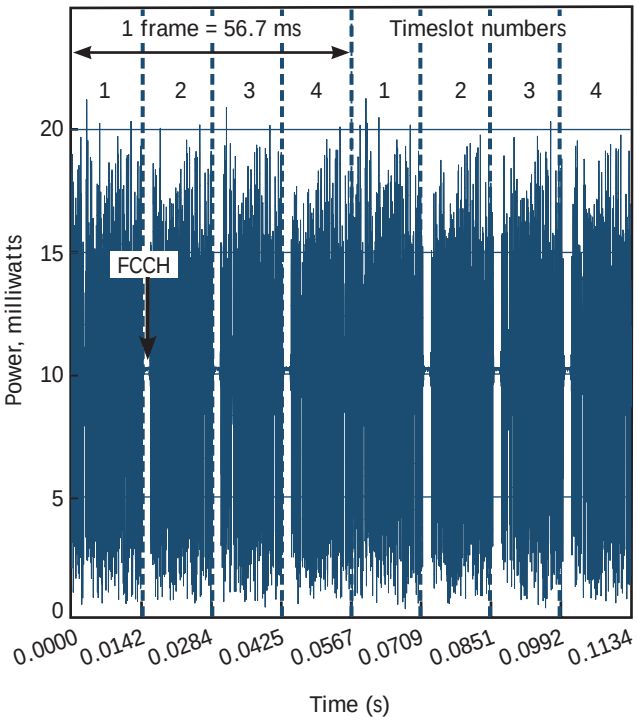


FIGURE A5 *Recorded output from a TETRA base station demonstrating the frequency correction channel at the beginning of three timeslots in every frame*

TETRA. GSM base stations do not transmit channels if they are not required to carry traffic, whereas TETRA base stations for the emergency services transmit all their available channels (normally no more than four) continuously, regardless of the volume of call traffic. In addition, GSM base stations do not transmit during timeslots that are not in use, whereas the TETRA base stations operated by O2 Airwave are configured to transmit into all timeslots, regardless of the number of users. The output from a typical TETRA base station is shown in Figure A5 and the individual timeslots can be clearly seen as bursts of variable output power (caused by modulation of the signal to carry speech or data). It can be seen from Figure A5 that for a brief period (1.78 ms) at the beginning of timeslots 2, 3 and 4, the power output becomes constant due to transmission of a frequency correction channel (FCCH). The output power during these FCCH transmissions is approximately equal to the average output power during the variable pulses. This means that although the output power from TETRA base stations is variable, it is quite unlike the handset output because it is continuous.

DECT systems

Cordless phones are widely used in both commercial and domestic environments. Although some of the older analogue phones may still be in use, particularly in the home, most recent phones are likely to operate according to one of the digital standards, such as the digital enhanced cordless telecommunications (DECT) standard, as these offer performance advantages including both greater privacy and protection against interference. As for the other communications technologies discussed above, the system consists of one or more base stations and associated handsets. However, in this case the range of both base stations and handsets is limited and the intention is to provide local coverage, eg within a home or office.

DECT systems operate at frequencies just below 1900 MHz, and the band is split into ten frequency channels, each 1.7 MHz wide. As for GSM mobile phones and TETRA, DECT uses TDMA to allow users to share frequency channels. In this case, each frame is divided into 24 paired timeslots, with one timeslot in each pair for the uplink and one for the downlink (see Figure A6). This means that the outputs from both base stations and handsets are pulsed. For handsets the frequency is 100 Hz. The situation for base stations is slightly different as it can vary from a single occupied timeslot, to several, if more than one phone is communicating with it. Each DECT base station will transmit a constant signal in at least one channel, and the handset monitors the strength of all the detectable base station signals to determine which will provide the best reception.

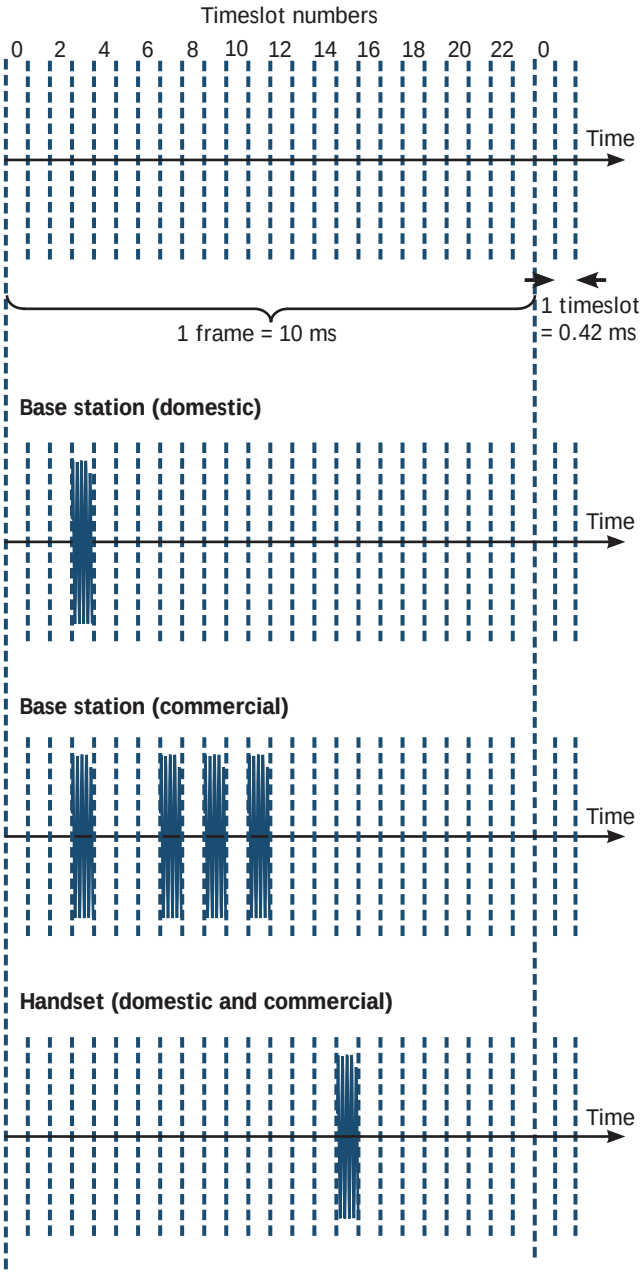


FIGURE A6 *Arrangement of timeslots for DECT systems, showing how outputs vary with time for base stations and handsets*

Wireless local area networks (WLANs)

The use of wireless local area networks for data transmission has grown enormously in recent years, largely as a consequence of dramatic reductions in hardware costs. As a result, WLAN systems are now a viable option for home use and public networks are increasingly common in major cities. Hence the growth in the use of WLAN technology appears to be a trend that is set to continue for some time to come. Most of the WLAN systems currently in use are based on so-called WiFi technology. In fact this is not a single technology, but a series of related technologies described in the US IEEE 802.11 series of standards. These systems are usually used in a point-to-multipoint configuration, which involves a single access point communicating with multiple clients. The access point is essentially a base station that provides the connection to a fixed wired network, whilst the clients are mobile radio devices that allow individual computers to communicate with the access point.

The most commonly used WiFi equipment operates at frequencies just above 2400 MHz, which is split into 14 overlapping frequency channels, each 22 MHz wide. This frequency band is shared with many other non-licensed applications and there is consequently considerable potential for interference from other users. To overcome these problems, systems based on the early IEEE 802.11b standard use a technique known as direct sequence spread spectrum (DSSS), which is similar to the CDMA systems used in 3G mobile phones. Essentially, in order to minimise interference from signals transmitted over very narrow frequency ranges by other equipment, data are encoded and then transmitted in a single very broadband signal that occupies one of the available 22 MHz channels. As a result of good data rates and low production costs, these early systems rapidly gained widespread popularity. However, with the growth in the speed of computers, the data rates available with this technology soon became too slow and an updated version was introduced. These products are based on the IEE 802.11g standard and offer high data rates through the use of a coding technique called orthogonal frequency division multiplexing (OFDM), which is also used for digital broadcast radio and television. These devices still transmit in the same frequency channels, but instead of a single very broad signal, the data are split between a large number of narrow sub-channels transmitted at precise frequencies spread evenly across the full channel. The system will monitor interference in each sub-channel and can reduce transmission in those where it is unacceptably high. In order to provide compatibility with the older technology, this equipment can also transmit at lower data rates using DSSS coding.

A third type of WiFi system operates at higher frequencies just above 5150 MHz. These systems are based on the IEEE 802.11a standard, which also uses

OFDM coding. There are technical advantages to using equipment in this frequency band as there is less competition from other users and there are more channels available to start with.

Access points used to provide public connections, and many of those used in commercial environments, will be capable of operating in any of the modes discussed above.

WiFi systems transmit data in packets or frames, each of which contains a standard duration of control signals, followed by a variable amount of data. Hence the duration of each burst of transmission may vary up to a maximum of 16.4 ms. The number of frames transmitted will depend on the volume of data to be communicated. However, in general it is common for larger volumes of data to be downloaded from the access point to the client, and so there will generally be more transmission from the access point.

Personal area networks (PANs)

Personal area networks are used to provide very short-range connections between electronic devices such as wireless hands-free kits, printers, keyboards, mice and personal digital equipment. In Europe, PANs use low power Bluetooth technology, which transmits in the unlicensed spectral band around 2450 MHz. As with WLANs, the problem with using this band is interference from other users. Bluetooth gets around this problem by using a technique called adaptive frequency-hopping spread spectrum (AFHSS). The available frequency band is divided into 79 channels, each 1 MHz wide. The device then changes frequency channel up to 1600 times a second.

Emitted powers from mobile communications systems

The exposure of an individual from a particular communications device will depend on a number of factors including: output power of the transmitter, gain of the antenna, directionality and orientation of the antenna, and distance between the antenna and the individual.

All of these factors will be variable to some extent, although the antenna characteristics will be fixed for specific items of equipment or installations. For example, mass-produced devices such as mobile phones will have standard characteristics for a particular model, although there may be considerable variation between models. In contrast, each macrocell base station installation will be individually designed to optimise performance and so sites will vary enormously in the characteristics, direction, and mounting height of the antennas. In general, the sector antennas deployed on mobile phone macrocell base stations have higher gain (typically 15–18 dBi) and are more directional than the antennas typically associated with any of the other equipment (typical gains of a few dBi) discussed in this appendix.

In much the same way, the maximum output power of devices such as phones is standardised, whereas the maximum output from individual base stations will be adjusted to provide good coverage without producing excessive interference in other cells. However, discussion of maximum output powers may be misleading as many communications systems, including both mobile phones and their base stations, are capable of adjusting their output according to conditions. In general, all systems that are capable of adjusting their output powers will reduce them as far as possible to prolong battery life (where appropriate) and reduce the risk of interference with other users.

Output powers from portable devices

All of the portable communications devices discussed in this section are designed to conform to international standards, and amongst other things these specify the maximum output powers. In addition, output powers in particular frequency bands are usually restricted by local regulations in order to prevent interference with other radio users. The maximum permitted output powers for a variety of portable devices are shown in the table.

It should be noted that the output from some devices, such as mobile phones, is variable and controlled by the network using a technique called adaptive power control (APC). Essentially the output power from the phone is continually adjusted to ensure that the signal is strong enough to maintain a good connection whilst minimising emissions to reduce interference with other users and prolong battery life. In the most common mode of operation TETRA radios employ a similar

Maximum permitted output powers for portable devices

Device	Operating frequencies (MHz)	Maximum peak output power (W)	Maximum average output power (W)
GSM 900 mobile phone	890–915	2	0.25
GSM 1800 mobile phone	1710–1785	1	0.125
UMTS mobile phone	1920–1980	0.125	0.125
TETRA handset (class 3)	380–390	3	0.75
TETRA handset (class 4)	380–390	1	0.25
DECT cordless phone	1880–1900	0.25	0.1
WLAN (IEEE 802.11b and IEEE 802.11g)	2400–2484	0.1	*
WLAN (IEEE 802.11a)	5150–5350	0.2	*
WLAN (IEEE 802.11a)	5470–5725	1.0	*
WLAN (IEEE 802.11a)	5725–5850	2.0	*
Bluetooth (class 1)	2402–2480	0.1	*
Bluetooth (class 2)	2402–2480	0.0025	*
Bluetooth (class 3)	2402–2480	0.001	*

* The output from devices such as WLAN and Bluetooth varies depending on the volume of data to be transmitted, so that a simple estimate of average power is not possible.

approach. In addition, phones employ discontinuous transmission (DTX), which ensures that the phone only transmits when the user is speaking. Cordless phones do not feature power control.

The situation is rather complicated for WLAN equipment as the units only transmit during transfer of data. Hence average output powers are likely to be considerably lower than the peak values indicated in the table. However, as the transmission time depends on the volume of data to be transmitted, average power output will depend on the number and size of files to be transferred.

Output powers from fixed devices

For mobile phone base stations, the maximum output power will vary from site to site and will depend on factors such as the area to be covered and an assessment of coverage at locations within that area. In addition, the total output will depend on the number of transmitters in use. The maximum number of transmitters installed will depend on the operator's assessment of demand in a particular area, whilst the number in use will depend on actual demand from mobile phone users at any particular time. It follows that it is not possible to provide definitive values for the power emitted by a mobile phone base station, but in general values of a few tens of watts per sector are fairly typical for macrocell installations. Maximum emitted powers from microcells will be somewhat lower and generally less than 5 W (although the MTHR study described in Chapter 6 indicated that around 6% of installations operated at higher power), whilst picocell transmitters will operate at even lower powers.

In addition, a base station will require connection to the communications network infrastructure by means of a radio, fibre or wire connection. Where this is provided by radio, this will be done by means of a highly directional microwave signal over a line-of-sight path.

As for mobile phone base stations, the output from TETRA base stations will vary depending on the nature of the coverage required. However, the situation is somewhat more predictable as they will normally be configured with up to four transmitters per base station and the transmitters all operate continuously. The total emitted power is likely to be a few tens of watts.

For the other devices discussed in this section, the output power of the base unit, where there is one, will be the same as for the portable unit.

Appendix D

Membership of the MTHR Programme Management Committee

In order to ensure the independence of the Programme, an independent programme management committee was set up to decide on research priorities, select projects and manage the research. Sir William Stewart originally chaired the Committee, which included some members of the Independent Expert Group on Mobile Phones (Stewart Committee) and additional specialists to provide a broad range of expertise. There was also strong international representation, with overseas members and a representative of the World Health Organization. In November 2002 Sir William was succeeded by Professor Lawrie Challis as chairman. Some new members have also been appointed to maintain the level of experience needed for effective management of the Programme.

Chairman

Professor Lawrie Challis OBE

Lawrie Challis is Emeritus Professor of Physics at the University of Nottingham. His university education and the first years of his academic career were at the University of Oxford (1951–1959); he then moved to the University of Nottingham. He was appointed to an established chair in 1971, was Pro-Vice-Chancellor before his retirement in 1998, and then held a Leverhulme Emeritus Fellowship for two years. He was Vice-chairman of the Stewart Committee and a member of the Home Office's Health and Safety Management Committee of TETRA and is presently a member of the HPA Advisory Group on Non-ionising Radiation and a trustee of the EMF Biological Research Trust.

His previous research interests were on the properties of low-dimensional semiconductors. He has published 230 papers and, in 1994, was awarded the Holweck Medal and Prize for his research by the Institute of Physics/French Physical Society. In 1996 he was awarded the OBE for services to scientific research. He has chaired the Royal Society Grant Board for Mathematics and Physics, the Physics Committee of the Science and Engineering Research Council, the Solid State Division of the Institute of Physics, and the European Commission Evaluation Panel for Access to Research Infrastructures.

Vice-chairman

Professor Les Barclay OBE FREng

Les Barclay was Deputy Director at the Radiocommunications Agency, responsible for research and radio technology. He is now a consultant in radio regulation, spectrum management and radio propagation, and is a visiting professor at the universities of Lancaster and Surrey. He has been chairman of the study group on radiowave propagation within the International Telecommunication Union, of the Scientific Committee on Telecommunications within the International Union of Radio Science, and of the DTI Measurement Advisory Committee. He is a Fellow of the Royal Academy of Engineering and of the Institution of Engineering and Technology. He has been awarded the OBE and the Polar Medal.

Members

Professor Glynis Breakwell

Glynis Breakwell took her PhD from the University of Bristol and her DSc from the University of Oxford. She was Prize Fellow at Nuffield College Oxford before moving to the University of Surrey where she became Professor of Psychology in 1991 and Pro-Vice-Chancellor of the University in 1995. In September 2001 she became Vice-Chancellor of the University of Bath.

Throughout the 1980s and 1990s her extensive research achievements led to awards and recognition from academic and professional bodies; she has authored or co-authored more than 250 refereed journal articles and conference papers, authored or co-authored

10 books, edited or co-edited a further 11, and has authored more than 60 book chapters and monographs.

Professor Breakwell has been extensively involved in issues of research and enterprise and university management. She has remained an active researcher, focusing upon the application of social psychology in areas of risk management and in military performance.

Her recent extramural appointments include the HEFCE psychology advisory group, Fast Stream assessor for the Civil Service Selection Board, and member of the joint UUK/HEFCE steering group on costing and pricing, and the transparency review sub-group. She has been an adviser to DEFRA and the FSA as well as the MOD and DERA. Her contributions gained her the coveted Myers Award from the British Psychological Society in 1995.

Professor Paul Elliott FRCP FFPHM FMedSci

Paul Elliott trained in mathematics and medical sciences at Cambridge University, and clinical medicine at University College Hospital Medical School, London. He then worked as a medical epidemiologist at the London School of Hygiene and Tropical Medicine and was Head of the Environmental Epidemiology Unit (1990–1995). In 1995 he was appointed Professor of Epidemiology and Public Health Medicine at Imperial College London where he heads the Department of Epidemiology and Public Health and is Director of the UK Small Area Health Statistics Unit.

He was elected Fellow of the Academy of Medical Sciences in 2000 and acted as specialist advisor to the House of Lords Science and Technology Sub-committee on Human Genetic Databases, which reported in 2001. He was a member of the Royal Society Pharmacogenetic Working Group, which reported on the future of personalised medicines in 2005. He is currently a member of the DEFRA Science Advisory Council, MRC Physiological Systems and Clinical Sciences Board, HPA Sub-committee on Radiation, Chemical and Environmental Hazards, Wellcome Trust Populations and Public Health Strategy Committee, and the UK Biobank Steering Committee.

Professor Edward Grant

Edward Grant has been studying the interaction of microwaves with biological material for 50 years. He served in the Physics Departments of three London teaching hospitals before joining Queen Elizabeth College, and subsequently King's College London, where he was Head of Department from 1992 to 1994. He retired in 1996 and is now a Director of MCL. He was a member of the Board of the NRPB from 1989 to 1997 and was a member of the (then) NRPB Advisory Group on Non-ionising Radiation for 11 years. Professor Grant is also Chairman of the BSI GEL 106 Committee concerned with the development of international standards to assess human exposure to electromagnetic fields.

Professor Patrick Haggard

Patrick Haggard is a researcher in cognitive neuroscience at University College London. He trained at the MRC Applied Psychology Unit in Cambridge, and then at the University Laboratory of Physiology in Oxford. He has worked at UCL since 1995, using behavioural and physiological methods to study sensory and motor functions of the brain.

Professor Kjell Hansson Mild

Kjell Hansson Mild is Professor at the Swedish National Institute for Working Life and at Örebro University, where he carries out research on the biological effects of electromagnetic fields. He has been working in this area since 1976. In the last five years the research has been mainly associated with mobile phone use.

Professor Hansson Mild has a background in physics and theoretical physics, and presented his thesis in 1974 on problems on cell membrane permeability and the state of water in the cytoplasm. He has published over 200 articles and 170 conference abstracts. He was the first person from Europe to serve on the Board of the Bioelectromagnetics Society and was President from 1995 to 1996, and was associate editor of the journal *Bioelectromagnetics* from 1988 to 1996. At present, he is the chairman of Commission K of the Svenska Nationalkommittéen för Radiovetenskap (SNRV).

Professor Niels Kuster

Niels Kuster was born in Olten, Switzerland, in June 1957. He received his master's degree in electrical engineering and his doctoral degree in technical science from the Swiss Federal Institute of Technology (ETH) in Zurich. In 1993, he was elected as Professor in the

Department of Electrical Engineering of the ETH. In 1999 he was appointed Director of the Foundation and Laboratories for Research on Information Technologies in Society (IT'IS), Zurich. In 1992 he was invited professor at the Electromagnetics Laboratory of Motorola Inc. in Florida, USA, and in 1998 at the Metropolitan University of Tokyo, Japan.

His research interest is currently focused on the area of reliable and safe on/in-body wireless communications and related topics. Professor Kuster is the author of over 150 publications (books, journals and proceedings) mainly on measurement techniques, computational electromagnetics, dosimetry and exposure assessments as well as on biological effects studies. He is a member of several standardisation bodies and has acted as consultant for several government agencies around the world on the issue of the safety of mobile communications. He also serves on the boards of various scientific commissions, societies and journals.

Dr Alastair McKinlay

Alastair McKinlay heads the Physical Dosimetry Department in the Radiation Protection Division of the Health Protection Agency.

He has been a member of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) since 1992 and was elected as its Chairman in 2000. He has been active in the International Commission on Illumination (CIE) for many years and was elected President of the United Kingdom National Committee. In 1996 he chaired a European Union Expert Group on Mobile Telephony and Human Health whose report set out a comprehensive European research agenda. He is a founder member of the European Society for Skin Cancer Prevention (EUROSKIN) and is currently its President. He is currently also a member of the WHO International EMF Programme Advisory Committee.

Professor Jim Metcalfe

Jim Metcalfe has been Professor of Mammalian Cell Biochemistry in the Department of Biochemistry, University of Cambridge, since 1996 and was Sir William Dunn Reader in Biochemistry in the same department from 1975. From 2001 to 2006 he was Deputy Head of Department and Director of Research and Development and was seconded part-time to the Cancer Research Campaign as Chairman of the Scientific Committee from 1995 to 2000. He is currently chairman of the scientific advisory committee for the EMF Biological Research Trust, which has the remit of evaluating any biological effects of power-line frequency electromagnetic fields that may affect human health.

His current research interests are in laboratory and translational clinical research studies on the role of cytokines, particularly the transforming growth factor beta family, in the aetiology of metastatic tumours and coronary artery disease.

Professor Michael Rugg FRSE

Michael Rugg obtained his PhD in 1979. Following a postdoctoral year at the University of York, he was appointed to a lectureship in psychology at the University of St Andrews, where he became Professor of Psychology and Head of School in 1992. In 1998 he moved to the Institute of Cognitive Neuroscience, University College London, as Professor of Cognitive Neuroscience and Wellcome Trust Principal Research Fellow.

His principal research interests are the cognitive and neurological basis of human memory and the non-invasive investigation of human brain function through the use of electroencephalography and functional neuroimaging. During 1998 and 1999 he served on the Department of Health Working Group on Organophosphates.

Dr Zenon Sienkiewicz

Zenon Sienkiewicz obtained his PhD from Queen Mary College, University of London, for research into the neurobiology of memory. Following postdoctoral work at the University of Oxford, he joined the NRPB (now part of the Health Protection Agency) in 1985.

His research interests include the neurophysiological and behavioural effects of magnetic fields and radiofrequency radiation. He has written a wide variety of scientific papers, reviews and articles on these topics. He is a consulting expert of ICNIRP and a member of a number of other groups and committees concerned with the effects of non-ionising radiation.

Former members

Professor Sir William Stewart FRS FRSE (Chairman 2001–2002)

Sir William Stewart is currently Chairman of the Health Protection Agency. He is a former President of the Royal Society of Edinburgh and Chairman of the Microbiological Research Authority. He served as Chief Scientific Adviser to the Prime Minister and to the Government (1990–1995). He is a biologist by training. He was the first Head of the UK Government's Office of Science and Technology and has served on various advisory committees including the Royal Commission on Environmental Pollution and the Natural Environment Research Council. He was Chief Executive of the Agricultural and Food Research Council, a former Vice-President of the Royal Society of London, and former Chairman of Tayside University Hospitals NHS Trust.

Professor Colin Blakemore FRS (2001–2003)

Colin Blakemore studied medical sciences at the University of Cambridge and completed his PhD at the University of California, Berkeley, in 1968. He taught at the University of Cambridge for 11 years and in 1979 took up the Chair of Physiology at the University of Oxford. He is also Director of the Oxford Centre for Cognitive Neuroscience, and was President of the British Association for the Advancement of Science for 1997–1998. He has worked as a visiting professor at the Massachusetts Institute of Technology, New York University, the University of California and the Salk Institute, and also in Japan, Switzerland, Italy, France, the Czech Republic and China. He holds the degree of DSc from the universities of Cambridge and Oxford, honorary doctorates from Aston and Salford Universities and an honorary fellowship from Cardiff University. He is a Fellow of the Royal Society, the Academy of Medical Sciences, and the Institute of Biology, a member of the Academia Europaea and a Foreign Member of the Royal Netherlands Academy of Arts and Sciences.

His research has been concerned with many aspects of vision and the early development of the brain. His awards include the 1996 international Alcon Prize for vision research and the 1989 Royal Society Michael Faraday Award for the furtherance of the public understanding of science. He is a former member of the (then) NRPB Advisory Group on Non-ionising Radiation. Professor Blakemore retired from the MTHR Programme Management Committee in 2003, following his appointment as Chief Executive of the Medical Research Council.

Professor Clair Chilvers FFPHM (2001–2005)

Clair Chilvers is Head of Research and Development in the Midlands and East of England Directorate of Health and Social Care.

She was appointed Regional Director of Research and Development at NHS Executive Trent in October 1999. Nationally, she is Director of the Mental Health Research and Development Portfolio and the National Forensic Mental Health Research and Development Programme. She is also a member of the National Mental Health Task Force taking forward objectives of the NHS Plan.

Previously she was Professor of Epidemiology at the University of Nottingham and from 1996 was Dean of the Graduate School. She was a member of the Department of Health Committee on Carcinogenicity of Food, Consumer Products, and the Environment from 1993 to 2000 and a member of the Royal Commission on Environmental Pollution from 1994 to 1998.

Dr Simon Gerrard (2001–2003)

Simon Gerrard is Deputy Director of the Centre for Environmental Risk at the University of East Anglia. His particular area of research is in risk communication. Dr Gerrard has been an expert advisor to the WHO and FAO on risk perception and communication matters and was the first Director of the WHO-inspired European Risk Communication Network funded in part by the UK Electricity Association.

He is the project leader for the risk communication and trust element of the Programme on Understanding Risk, funded by the Leverhulme Trust. His research within that Programme focuses on three main case study areas: waste disposal (including radioactive wastes); mobile phones; and climate change. The key themes within these areas are the communication of uncertainty and its impact on trust; the evaluation of risk communication initiatives; and the role of risk communication within the strategic development of open decision-making. Dr Gerrard is involved in the UK element of the HERMES research project which is seeking to develop a European perspective on the management of base stations.

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