



**Mobile Telecommunications and
Health Research Programme**

Report 2012

MTHR Programme Management Committee



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MTHR Programme Management Committee
Chairman: Professor David Coggon OBE

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Executive Summary

In this report we discuss the results of research funded by the Mobile Telecommunications and Health Research (MTHR) Programme and published since 2007. The MTHR Programme was established in 2001 as part of the government's response to the recommendations of the Independent Expert Group on Mobile Phones (Stewart Committee), and the research supported has focused on addressing the uncertainties identified by that committee. The Programme has had total funding of approximately £13.6 million provided jointly by government and industry. In order to ensure that none of the funding bodies could influence the outcome of the research, projects were selected and monitored by an independent Programme Management Committee (PMC).

Over a period of 11 years, the MTHR Programme has supported 31 individual research projects that between them have resulted in almost 60 papers in peer-reviewed scientific journals. All but one of the research projects is now complete, and the Department of Health has decided that this is an opportune time to bring research on mobile phones and health into its mainstream research portfolio. Accordingly the Programme has been wound up and future research will be commissioned and managed on behalf of the current funders through the Department of Health Policy Research Programme.

It is now seven years since the publication of our last report, which summarised the results published in the first six years of the MTHR Programme, and it is appropriate to report on the remaining completed projects. This report effectively marks the end of the Programme, but rather than summarise all the outcomes here, it is our intention that this report should be read in conjunction with our 2007 report so that together they form an overview of the Programme in its entirety. Our focus in this report is to present an overview of the results that were not in the public domain when our 2007 report was published. We also discuss the projects we funded to ensure that project

teams working in the life sciences had expert help with radio engineering and dosimetry.

Epidemiological studies of cancer

In this report we discuss the work we supported to investigate whether maternal exposure to base station emissions during pregnancy could affect the risk of developing cancer in early childhood. A second project investigated the risk of leukaemia in relation to mobile phone use. Neither of the studies identified any association between exposure and an increased risk of developing cancer. These findings appear to be consistent with the results from other recent studies examining similar endpoints. We have also set up the UK component of an international cohort study of mobile phone users (COSMOS), which has the potential to help resolve many of the remaining uncertainties relating to the health risks of mobile phone use. This is necessarily a long-term study that is expected to continue for many years. Its management will now be taken forward by the DH Policy Research Programme and we look forward to seeing the results of this study published in due course.

Effects of exposure to TETRA signals

There has been considerable public concern about the possible adverse effects of exposure to signals produced by the TETRA radio system used by the emergency services. We supported three well-designed studies to investigate whether exposure to TETRA signals from hand-held radios or base stations could affect a range of responses in volunteers. Importantly the experiments were all carried out 'double blind' so that neither the experimenter nor the subject knew whether the exposure was real or sham. None of the studies provided any evidence that TETRA signals produce specific adverse effects in those exposed to them.

Importance of signal modulation

A key question in this area is whether the modulations applied to radio signals to enable them to carry voice and data communications can elicit specific effects that are different from those of the carrier frequency alone. We supported three projects to examine this issue in different ways, including one that tested whether a wide range of cells and tissues could demodulate the signal. None of the projects found any evidence that modulated signals produced different effects from the carrier frequency. When taken together with the findings from the provocation studies we supported, which also compared modulated signals with carrier frequencies, we believe that these results constitute a substantial body of evidence that modulation does not play a significant role in the interaction of radiofrequency fields with biological systems. This conclusion has extremely important implications and should facilitate the pooling of data from different studies and allow conclusions to be drawn with greater confidence.

Assessing exposures

We supported work that demonstrated conclusively that wired hands-free kits can be used to reduce exposures from a mobile phone, provided the phone is positioned away from the user's body. We also funded the development of assessment methodologies that could be used to investigate exposures from new types of mobile telecommunications devices and provided funding towards the development of new UK standards and standard assessment protocols to be used for assessments of exposures. In addition, we supported work to assess the emission of low frequency magnetic fields from mobile phones. These field strengths are much lower than those that are known to have effects in excitable tissues.

Experimental exposures

In order to standardise exposures in provocation studies, we commissioned phone and base station exposure systems. We explain in this report our thinking behind the selection of these systems and the exposure levels used in the provocation studies we supported. Technical descriptions of the systems and details of their calibration are provided in appendices to the report.

Future arrangements

As indicated above, in the future research on mobile phones and health will be taken forward as part of the DH Policy Research Programme. Under these new arrangements the independent Advisory Group on Non-ionising Radiation will assume responsibility for drawing research needs to the attention of the UK health departments.

In the meantime we have shared our views on research priorities with the UK health departments. We see no need for further research in any of the areas addressed by the research that is summarised in this report. However, we have identified several other areas of uncertainty regarding mobile telecommunications and health, in which the UK has well-established research expertise and could make a significant contribution.

Introduction

The Mobile Telecommunications and Health Research (MTHR) Programme was set up in 2001 as part of the government response to the recommendations of the Independent Expert Group on Mobile Phones (Stewart Committee), and was formally wound up in 2012. During the 11 years of its existence the Programme used funds provided jointly by government and industry to support 31 research projects that resulted in almost 60 publications in peer-reviewed journals, along with many conference papers. Each completed project also generated a final report for publication on the MTHR website (www.mthr.org.uk).

In September 2007 we published a report on the outcomes from the first six years of the Programme (MTHR PMC, 2007). This explained the contribution made by the Programme in relevant areas of research. However, we were only able to discuss research results that had been published, and therefore our report was effectively restricted to just over half of the 31 projects supported by the Programme.

It is now six years since the publication of our 2007 report and, given that the Programme has been wound up, it is appropriate to report on the remaining completed projects.

Background

The Independent Expert Group on Mobile Phones (Stewart Committee) was set up at the request of the Minister for Public Health to examine the 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 the health aspects of mobile phones and related technologies, and it was intended that it would complement work sponsored by the European Union and other national programmes of work. 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. Over the course of the Programme, core funding amounted to approximately £12 million, provided in approximately equal share by government and industry. Additional funding of around £1.6 million was provided by the then Department of Trade and Industry, the Home Office, the Department of Health and the private sector, and used to support additional research work that fell outside the priorities set for the core funding.

In order to ensure that none of the funding organisations, whether industry or government, could influence the outcome of the Programme, an independent Programme Management Committee (PMC) was set up to decide on research priorities, select projects and manage the research. Sir William Stewart originally chaired the PMC, which included some members of IEGMP, along with additional experts, who together provided a broad range of expertise. Some change in membership occurred over the years and this is summarised in an appendix to the report. Professor Lawrie Challis became chairman on Sir William's retirement in November 2002, and was succeeded as chairman by Professor David Coggon in January 2008.

In determining research priorities, the PMC built on the recommendations outlined in the Stewart Report. The Programme focused largely on establishing whether or not biological or adverse health effects occur in people as a result of exposure to radiofrequency (RF) fields below guideline levels. It was noted in the Stewart Report that research on the possible health effects of mobile telecommunications 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 that received attention

by the media were of questionable reliability and validity. It was the aim from the outset to provide sufficient resources to allow high quality research to be undertaken and encourage high calibre scientists to become involved with the Programme. In particular, we encouraged collaborative working between specialists in different disciplines, such as radio engineering and cell biology.

2007 and 2012 reports

It is our intention that the 2007 and 2012 reports, when taken together, will form an overview of the MTHR Programme in its entirety. Many of the fundamental elements of the Programme have already been described in detail in the *MTHR Report 2007*. For example, the 2007 report gives details of the approach taken by the PMC to the selection and monitoring of projects, and explains the elements of good practice in the design and execution of projects that research groups were required to follow as

a condition of their funding. The 2007 report also summarises the results of those projects that had been published at the time of its preparation. The focus of the 2012 report is to present an overview of results that were not in the public domain at the time that the 2007 report was prepared. Full, final reports on all completed projects have been published on the MTHR website (www.mthr.org.uk), which will be archived to ensure the contents remain available.

This report also discusses the supporting projects that were put in place to ensure that research teams with expertise in the life sciences were able to produce consistent and quantifiable exposures to realistic mobile telecommunications signals. Appendices to the report provide technical descriptions of the exposure systems commissioned specifically for use in the provocation studies we supported. Other appendices provide a full list of almost 60 peer-reviewed publications produced by the various project groups, and the biographical details of all those who were members of the PMC during the 11 years of the MTHR Programme.

Epidemiological Studies of Cancer

Background

In May 2000 the Stewart Committee noted that there had been few epidemiological studies of cancer in relation to mobile phone use (IEGMP, 2000). The two studies that were reviewed in the Stewart Report were found to have major limitations. In the absence of any studies specifically relating to emissions from mobile phone base stations, the Stewart Committee examined the small number of studies that had investigated residence close to broadcast transmitters. However, it considered that these were also subject to major limitations, particularly in relation to exposure assessment and their 'ecological' study design.

The Stewart Report consequently identified a pressing need for a range of epidemiological studies designed to overcome many of the limitations of the existing work. In particular, it identified a need for case-control studies to investigate whether leukaemia and cancers of the brain, acoustic nerve and salivary gland were associated with mobile phone use. (For an explanation of case-control and other epidemiological study designs see Box 1, page 10, of the *MTHR Report 2007*.) The emphasis was placed on studies of mobile phones, reflecting our understanding of how people are exposed to mobile phone signals; exposures from mobile phones are substantially higher than those from base stations. A secondary reason for prioritising studies on mobile phones was the considerable difficulty associated with reliably assessing and classifying exposures from base stations (see the box).

Exposures from mobile phones are not uniform, with the head the most highly exposed part of the body when the phone is used in traditional speech mode. It follows from this that any increase in risk is likely to be highest for cancers of the brain and nervous system. We supported UK studies to investigate these cancers as part of an international research project called Interphone, and the results of these studies are discussed in Section 2 of the *MTHR Report 2007*.

Classifying Exposure from Base Stations

People are exposed to RF fields from many environmental sources, including broadcast TV and radio, cordless phone systems, professional radio communications systems, pagers and mobile phone systems.

Even if consideration is restricted to mobile phone signals, exposures may arise from an individual's use of a phone, the use of phones by other people close by, and base stations. Of these, the base station exposure is by far the weakest, although it is normally more or less continuous.

With the exception of broadcast TV and radio transmitters, all the sources have variable output and, in addition, an individual's personal exposure will vary as they go about their daily routine, travelling towards or away from sources, going indoors or outdoors, or moving so that buildings or vegetation are between the source and the person.

All of this makes it very difficult to characterise exposure from mobile phone base stations while distinguishing it from other sources of exposure that may be similar in frequency.

We supported work to characterise a personal exposure meter in an effort to resolve some of these problems, and this was discussed in the *MTHR Report 2007*. Nevertheless, we remain cautious about the classification of exposures in base station studies.

We are more confident about the classification of exposure from mobile phone use, although we recognise that even this has limitations.

In this section we focus on those epidemiological studies that we were unable to discuss in the previous MTHR report because the results were not available at that time. These three studies address the remaining priorities of the Stewart Committee: studies on children; a case-control study of the risk of leukaemia; and a large UK cohort study of mobile phone users.

New evidence

The Stewart Report noted that if there were unrecognised health risks, children might be more vulnerable for a number of reasons. Having given consideration to the issue, we decided that we could not ethically support provocation studies on children, but that we could support epidemiological studies on children who had already been exposed. We therefore decided to fund a case-control study by Professor Paul Elliott and colleagues at Imperial College London to investigate if exposure during pregnancy affected the risk of developing cancer in early childhood. By assuming that the mother had resided at the birth address during the pregnancy, the study team was able to assess exposure during pregnancy rather than at diagnosis, thus overcoming one of the previously identified limitations of residential studies. The issue of latency (the time between a causative event and the cancer being diagnosed – see Box 2, page 11, of the *MTHR Report 2007*) often complicates the interpretation of epidemiological studies in this area, but is minimised when the study is restricted to young children, as latency is necessarily much shorter.

The project team identified almost 1400 cases of cancer in children aged up to four years old from across the UK. The team then selected four controls for each case on the basis of sex and date of birth. Three separate measures of exposure were assessed for each of the mothers: distance from the nearest macrocell base station; total output of base stations within 700 m of the address; and an estimate of power density at the birth address. Power density was calculated from technical parameters of the base station as well as distance. This model was more sophisticated than the simple estimates based on distance used for earlier studies and was validated by field measurements. There was no correlation between any of the three measures of exposure and the incidence of any of the categories of cancer examined: brain and central nervous system;

leukaemia and non-Hodgkin's lymphoma; and all cancers combined. While exposure classification was better than for many earlier studies, it did suffer many of the limitations commonly associated with base station studies (see the box) and, in particular, it was not possible to take account of RF exposure from sources other than the base station or to estimate exposure within the home.

The results of this study need to be viewed in the context of other studies that have been carried out elsewhere since the publication of the Stewart Report. There have been no studies examining childhood cancer in relation to base station emissions, but a number of studies have investigated whether childhood cancer is associated with exposure from broadcast transmitters. One of these (Michelozzi *et al*, 2002) suffers many of the limitations identified for other 'ecological' studies in the Stewart Report. The remaining studies (Ha *et al*, 2007, 2008; Merzenich *et al*, 2008) are better in terms of both study design and exposure assessment, and also provide no material evidence for an increased risk of childhood leukaemia or brain cancer from residential RF exposure. All of these studies were limited in their ability to detect small increases in risk.

We noted above that exposures from the use of mobile phones are highest in the head and that we had therefore supported studies to investigate possible associations with cancer of the brain and nervous system. The skull and jaw contain approximately 13% of the body's active bone marrow and so it is relevant to investigate also if use of a mobile phone could affect the risk of leukaemia. As the latency for leukaemia is typically much shorter than that for solid cancers such as brain tumours, effects on the incidence of leukaemia might be detectable sooner after first use of a mobile phone. This could be important given the relatively short period for which mobile phones have been in widespread use.

We therefore decided to support Professor Anthony Swerdlow (Institute of Cancer Research) to carry out a large case-control study to investigate whether the risk of acute and non-lymphocytic leukaemia is associated with mobile phone use. Just over 800 people diagnosed with leukaemia between 2003 and 2009 were identified for inclusion in the study. They were matched to around 600 controls selected on the basis of age and residence criteria from non-blood

relatives of those with leukaemia. Participants in the study were interviewed by a research nurse who collected information on their mobile phone use, together with other possible risk factors such as smoking history, occupational history, medical history and family history of medical conditions.

The study found no association between regular use of a mobile phone and the risk of leukaemia. There was also no evidence of a trend of increasing risk with the time since a mobile phone was first used, total years of use, cumulative number of calls or cumulative hours of use. Although there was a suggestion of an increased risk of acute myeloid leukaemia with long-term phone use (more than 15 years), this was not statistically significant and appears unlikely to be real, given the normally short latency for this cancer. There was no evidence of a higher risk related to the use of analogue or digital phones.

The results from this study are consistent with those from a cohort study of mobile phone subscribers in Denmark (Schüz *et al*, 2006); the Danish study found no increase in the risk of leukaemia with long-term use and no evidence of a trend with length of use. A much smaller case-control study from Thailand (Kaufman *et al*, 2009) had various limitations and provides little in the way of additional evidence.

Future directions

Taken together, the studies discussed in this section and those in Section 2 of the *MTHR Report 2007* do not suggest that exposure to mobile phone signals is associated with an increased risk of cancer. Given the short time that mobile phone use has been widespread, none of these studies has been able properly to investigate risk in relation to long-term phone use. In addition, we recognise that all these studies have

other limitations. In particular, the case-control design inevitably requires retrospective assessment of exposure, which is problematic, especially if reliant upon the participant's memory, and so a possible source of bias. Many of these problems can be circumvented by a cohort study design as exposure can then be assessed during the progress of the study. The major disadvantages of cohort studies are the cost, the time required to obtain meaningful results, and the risk of losing touch with participants as the study progresses.

Given the advantages of the cohort design, the Stewart Committee was convinced of the value of putting in place a cohort study of mobile phone users. However, because of the logistic challenges that it would entail, the Committee also suggested that a pilot study should be undertaken first. We endorsed the view of the Stewart Committee and supported Professors Paul Elliott (Imperial College) and Anders Ahlbom (Karolinska Institute, Sweden) to carry out the pilot study. This was discussed in Section 2 of the *MTHR Report 2007*.

The pilot study demonstrated the feasibility of a cohort study, and we therefore funded Paul Elliott to set up the UK component of a large multinational cohort study (COSMOS) based on the methodology of the pilot study. The study has recruited over 100,000 participants in the UK and, together with similar studies in Sweden, Denmark, Finland and the Netherlands, there are around 160,000 participants in all. For each participant, information is being collected on health, mobile phone use and other possible risk factors. A key element of the exposure assessment will be information on mobile phone use supplied for each participant by the companies that provide mobile phone services (mobile operators). With the closure of the MTHR Programme, oversight of this long-term study in the UK will be taken forward by the Department of Health Policy Research Programme on behalf of all the funders.

Effects of Exposure to TETRA Signals

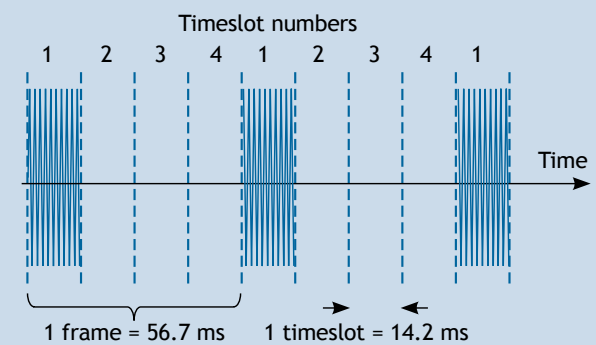
Background

The pulsed nature of TETRA handset transmissions has been a source of significant concern for the public and certain occupational groups – notably the police – and, to a lesser extent, those working in the other emergency services. The Stewart Committee had noted reports that exposure to radiofrequency fields could increase the release of calcium ions from brain tissue, an effect that appeared to be specifically associated with amplitude modulation at frequencies around 16 Hz. On this basis the Stewart Committee recommended avoiding amplitude modulation around 16 Hz in future signal coding as a precautionary measure. This suggestion gave rise to understandable concerns in TETRA users, given the similarity between this amplitude modulation frequency and the pulse repetition frequency of 17.6 Hz generated by TETRA handsets (see the box).

Recognising these concerns, we decided to fund research to examine aspects of the effects of exposure to TETRA and other pulsed fields. Some of this work related to fundamental interactions of RF fields with biological tissues, including research to investigate if pulsed RF fields can alter cellular calcium metabolism. Another project examined the potential for biological systems to detect low frequency modulations of RF fields. A third project explored the effects of a variety of modulation regimes, including TETRA, on exposed nervous tissue and examined responses at the molecular, cellular and behavioural levels. As these studies all have application beyond TETRA, they are discussed separately (see Section 4). In addition, the MTHR Programme supported work by Professor Tony Barker (Royal Hallamshire Hospital, Sheffield) to assess possible effects on the brain centres controlling the cardiovascular system in healthy volunteers. This work is discussed in more detail in the *MTHR Report 2007*.

Characteristics of TETRA Signals

It is a characteristic feature of the TETRA communications system that the signals from base stations and handsets are fundamentally different. In order to increase spectrum efficiency, TETRA employs time division multiple access (TDMA), with each frequency channel divided into four timeslots.



Each communicating handset transmits into just one of the four available timeslots, with the result that the handset transmits for approximately one-quarter of the time. This has two significant effects on exposures from handsets:

- a** average exposures are approximately one-quarter of peak exposures,
- b** the exposure is pulsed, with a pulse repetition frequency of 17.6 Hz.

The transmissions from base stations are also divided between the four available timeslots. However, in contrast to handsets, the base station may well be communicating in more than one timeslot. Indeed, even where there is no communications traffic in a timeslot, the base station still transmits. Hence the output from base stations is quite different to that from handsets, because although instantaneous power necessarily varies with time, owing to the effect of encoding information, the average power over the duration of a timeslot or longer is essentially continuous and not pulsed. Further technical details of TETRA and other communications systems are given in Appendix C of the *MTHR Report 2007*.

New evidence

This section discusses the results of three studies that examined the effects of exposure to TETRA signals on the responses of volunteers.

We supported two studies that were designed to investigate whether exposure to TETRA signals characteristic of handsets could elicit detectable responses in volunteers. Both studies used a randomised double-blind design and conformed to the basic principles for provocation studies set out in the *MTHR Report 2007*. They both used the TETRA variant of the MTHR mobile phone exposure system described in more detail in Appendix A.

In the first of these studies, Stuart Butler (Burden Neurological Institute, Bristol) and Professor Alan Preece (University of Bristol) carried out a thorough assessment of the effects of exposure to a TETRA signal or the unmodulated carrier frequency on brain function. Cognitive and electrophysiological responses were measured 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 exposure 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. The study found no statistically significant changes in any of the responses assessed during exposure to either type of signal.

A further experiment investigated whether TETRA exposures could directly evoke brain responses rather than simply modify the response to recognised environmental stimuli. As brain responses to stimuli occur very rapidly, the standard exposure system described in Appendix A was modified to produce short bursts of exposure that could be synchronised with recordings of brain activity. There was no evidence that exposure to RF pulses directly evoked detectable electrical activity in the brain.

In addition to investigating direct effects on brain function, we considered it a high priority to explore whether the particular modulation characteristics of TETRA emissions could affect the symptoms of electrical hypersensitivity. Professor Simon Wessely's team at King's College London carried out a large randomised, double-blind study using essentially the same design that the team had previously employed to investigate the effects of mobile phone exposure (described in Section 4 of the *MTHR Report 2007*).

As in the earlier study, there were two groups of volunteers, one consisting of people who reported experiencing symptoms when using TETRA radios and one comprising people who did not. Both groups were almost exclusively police personnel. All volunteers who completed the study participated in three 50-minute 'exposure' sessions: sham; carrier frequency; and TETRA signal. All the participants were asked to self-assess the severity of a range of symptoms prior to, at intervals during, and following exposure. The study found no evidence for adverse effects of exposure to TETRA signals, although there was some evidence that exposure to the carrier frequency alone decreased skin symptoms (itching, tingling, stinging and numbness) in sensitive participants.

A few other studies have examined the effects of exposure to TETRA handset signals. Consistent with the results of the two MTHR-funded studies, a randomised double-blind study of emergency services workers found no evidence for effects on cognitive performance or subjective symptoms (Riddervold *et al*, 2010). Outside the MTHR Programme, the Home Office has provided support to Adrian Burgess (Imperial College London and Aston University) to carry out a further study on police officers. It will be interesting to see how the results of this study compare with the MTHR-funded work.

We were aware that the specific concerns about the possible effects of the pulsed signals emitted from TETRA handsets had resulted in widespread public concern about exposure to emissions from TETRA base stations. Much of this concern appeared to be based on a misunderstanding, as the output from TETRA base stations is quite different to that from handsets and is not pulsed. Nevertheless, given the level of public concern and numerous anecdotal reports of symptoms typical of electrical hypersensitivity, we felt there was a need for a provocation study.

Professor Elaine Fox (University of Essex) investigated self-reported symptoms, physiological responses and performance in cognitive tests using a study design that was similar to that of her earlier study on mobile phone base stations (described in Section 4 of the *MTHR Report 2007*). Two groups of volunteers were recruited: one consisted of individuals who reported sensitivity to electromagnetic fields and the other was made up of people who said that they were not sensitive to electromagnetic fields. The subjects were 'exposed' to sham or TETRA signals in a screened room that greatly reduced the intensity of other radio signals present in the general environment. Both groups participated in three testing sessions.

The first session included an open provocation consisting of 15-minute 'exposures' during which both subjects and researchers were aware of whether the condition was sham or TETRA. This was followed by a short double-blind test consisting of four five-minute exposures (two sham and two TETRA) separated by two-minute gaps. The volunteers were asked to say whether they thought the base station was 'on' or 'off'. They were asked to make similar judgements at the end of the main double-blind provocations in the second and third sessions (see below). When taken collectively, neither group was able to identify the exposure condition better than would be expected by chance, although two sensitive and three control subjects correctly judged exposures in all six trials. With the large number of subjects (180 in total) in the study, a few would be expected to show a high success rate by chance alone.

The second and third sessions involved randomised double-blind exposures with one exposure condition per session. Blood volume pulse, heart rate and skin conductance were measured throughout each 50-minute session. In addition, the participants completed health and well-being questionnaires every five minutes during the first 40 minutes, followed by cognitive testing and a judgement of whether the field had been on or off. The study found no evidence that exposure to a TETRA base station signal affected any of the measures of health or well-being in either the sensitive or the control groups, although the sensitive group generally reported a greater number and severity of symptoms than the non-sensitive group, regardless of the exposure condition. Exposure to a TETRA signal did not elicit any differences in cognitive performance or physiological responses in either group of subjects (Wallace *et al*, 2012).

Future directions

None of the studies supported by the MTHR Programme provided any evidence that TETRA signals produce specific adverse effects in those exposed to them. There have been few other systematic studies of exposure to TETRA signals and the results published to date appear to be consistent with the findings from the MTHR Programme.

Should positive findings emerge from currently unpublished work these may provide a basis for further investigation. However, in the absence of significant new data we feel there is no need for further research into the specific effects of TETRA signals.

Importance of Signal Modulation

Background

A key issue in interpreting the scientific evidence for possible adverse health effects from exposure to mobile telecommunications signals is whether different types of signal can elicit specific effects.

All radio communications systems start with a carrier wave at a specific frequency or frequencies and this is then modified or ‘modulated’ to enable information to be encoded in it. The transmitter (phone or base station) modulates the carrier to encode information, while the receiver (again phone or base station) demodulates it to extract the information, which may be audio, video or data. In addition to the encoding of information, the transmitted signal may be further modified to improve the efficiency of spectrum usage. For example, both GSM mobile phones and TETRA radios employ a technique called time division multiple access (TDMA). When a user speaks into a GSM phone, the information is compressed into little packets, each lasting 580 millionths of a second. The phone transmits these packets at intervals of around 4.6 milliseconds. As each phone is transmitting for only one-eighth of the time, eight phones can simultaneously share the same frequency channel. However, in consequence, the carrier signal from the phone is pulsed. Technical constraints imposed by international communications standards often result in further modification of signals. More information about the technical characteristics of individual communications technologies is given in Appendix C of the *MTHR Report 2007*.

As a result of modulation, the signals produced by different technologies can be very different. For example, the signals produced by a GSM 1800 MHz mobile phone will be very different from those produced by a 3G phone, even though both operate with carrier frequencies close to 2 GHz. A fundamental question that follows from this is whether biological effects are dependent on specific modulations or solely on carrier frequency. To help resolve this question we made it a basic principle in the design

of MTHR provocation studies that subjects should be challenged with sham, carrier wave and modulated exposures (see Section 1 of the *MTHR Report 2007*). However, we recognised that these studies would not necessarily provide definitive evidence on their own, particularly if no effects of RF exposure were observed. We therefore decided that additional studies should be supported to investigate specifically the effects of modulation, and determine whether a mechanism existed by which biological tissues would be able to demodulate signals.

New evidence

All three studies discussed in this section explored the effects of modulated signals on nervous tissue as this is known to be sensitive to low frequencies such as those used for modulation.

Zenon Sienkiewicz (at the Centre for Radiation, Chemical and Environmental Hazards of the then Health Protection Agency) co-ordinated a multicentre project team to investigate the possible effects on brain tissues of carrier frequencies and modulations representing three common communications systems: TETRA, GSM and UMTS. Other members of the multidisciplinary project team included Professor James Uney (Bristol University Research Centre for Neuroendocrinology) and John Tattersall (Defence Science and Technology Laboratory). By applying the latest gene chip and related technologies alongside standard neurophysiological recording techniques and well-established assessments of learned behaviour, it was possible to investigate the effects of exposure at different levels of biological organisation. When used in isolation, each of these approaches has its own strengths and weaknesses that influence the interpretation of results. The great advantage of this study was to combine the three different approaches in an integrated way so that each consolidated the conclusions from the others.

Overall the study found no evidence of consistent changes in learned behaviour, the electrical activity of memory cells or gene expression following brain exposure to any of the carrier frequencies or modulated signals. A small number of isolated changes were observed, but false positive results are always likely with such a large and complex study. The isolated changes showed no consistent pattern and were not supported by similar changes in related endpoints, suggesting that they simply reflected experimental variability. The results from this project, when viewed collectively, provide powerful evidence that modulations characteristic of common communications systems do not engender significant biological effects on brain tissue.

Short-term changes in cytosolic calcium ion concentration are well established as important signals controlling a wide range of cellular activities in many different cell types. They were investigated in a second MTHR-funded study. Intracellular calcium concentrations are very carefully regulated and short-term increases in cytosolic calcium associated with cellular signalling may be generated by the release of calcium ions from stores within the cell, or by influx from outside the cell through the activation of specific calcium channels within the cell membrane.

The Stewart Report highlighted the possibility that amplitude-modulated RF signals might induce calcium release from brain tissue, but noted that the evidence was contradictory and the implications unclear. In part, the difficulties in interpretation relate to the advances in scientific understanding that have occurred since the original calcium efflux studies were conducted. While calcium is well established as an important cellular signal, the signalling involves increases in cytosolic calcium, not release of calcium from cells to the extracellular fluid. Moreover, a major limitation of the early studies was the use of tissue that had almost certainly died by the time the effect was observed.

Despite the limitations of this earlier work, it has engendered considerable concern, particularly in relation to TETRA signals, and we therefore considered it important to support a study that would examine meaningful measures of calcium signalling using modern techniques. The Babraham Institute in Cambridge specialises in studying cell signalling processes, so Martin Bootman and his colleagues from that institute

were considered to be ideally placed to carry out this work.

Calcium responses were studied in two types of cultured nerve cells and a cell line derived from human blood vessels, which is a well-established model for calcium signalling. Cultured cells were 'exposed' to sham, 900 MHz carrier frequency or GSM-modulated signals, and calcium ion concentrations within the cells were studied using state-of-the-art real-time imaging of fluorescence from a calcium indicator dye. The automated high-throughput imaging technology permitted large numbers of samples to be analysed.

Images of cells were captured at 30-second intervals for 90 minutes; 'exposure' occurred during the middle 30 minutes of this period. No effects of exposure on resting or spontaneous calcium concentration were found for either the carrier frequency or the modulated signal in any of the three cell types tested.

A second type of experiment tested the effects of exposure during provocation of cultured human blood vessel cells. In these experiments cells were treated with chemicals known to stimulate the release of calcium from cellular stores, or to deplete intracellular calcium ultimately leading to its re-entry from outside the cells. None of the exposure conditions produced any significant differences in the responses of the cells to the chemical treatments.

The results from this study are broadly consistent with those from other recent studies. For example, a study at the Defence Science and Technology Laboratories found no effect on intracellular calcium ion concentration measured with fluorescent indicators in cultured brain cells or cardiac muscle cells during exposure to a TETRA-modulated signal (Green *et al*, 2005). Similarly, a study at the University of Bologna, Italy, found no effect of exposure to a 900 MHz carrier frequency or a GSM-modulated signal on the movement of ions through voltage-gated calcium channels across the membranes of cultured brain cells (Plantano *et al*, 2007). In contrast, a study at the University of Illinois, USA, found evidence that spontaneous spikes in cytosolic calcium ion concentration were increased by exposure of cultured nerve cells to carrier frequencies between 700 and 1100 MHz (Rao *et al*, 2008). However, the effect did not depend on the intensity of exposure, and modulation was not investigated.

As noted above, carrier frequencies can be modulated in various ways. These include amplitude modulation and frequency modulation (AM and FM), commonly used in broadcast radio. Many digital communications systems make use of phase modulation and many introduce an element of pulse modulation, as in GSM and TETRA. While these modulation regimes are all different in detail, in general they all have the effect of introducing new components into the frequency spectrum of the transmitted signal. However, in practice these new frequency components are generally very similar to that of the carrier wave and so it seems rather unlikely that they could interact in a novel way with biological tissue or elicit appreciably different effects. Hence we consider that the most likely means by which a modulated signal would produce a novel effect would be if biological tissues were able somehow to demodulate the signal and extract the low frequency component. This would be important because cells, particularly nerve cells, can be sensitive to low frequency fields of sufficient intensity.

In electronic circuits, such as those that form the basis of radio receivers, demodulation is achieved through the use of a detector. There are many designs of detector, depending on the sophistication of the device and the type of signal to be demodulated, but in general there is an element of non-linear response, usually achieved by incorporating semiconductor devices such as diodes into the circuits. Similar, non-linear processes are likely to be required in order for biological tissues to demodulate signals. It is a characteristic of these non-linear processes that they will produce a new frequency component, called a second harmonic, which has a frequency of exactly double the carrier frequency. This led Professor Quirino Balzano of the University of Maryland, USA, to propose a new test of the potential for biological tissues to demodulate a signal.

The experimental design recognised that biological systems might be rather poor at demodulation so that the resulting second harmonic signal could be very weak. The experiment was therefore based around a doubly resonant cavity (see the figure) that was designed to trap the energy of any second harmonic component generated. This was coupled with very sensitive detection equipment so that the experiment would be capable of detecting extremely weak second harmonic components. The cavity was constructed in

Maryland and then shipped to Simon Bouffler's team at the then Health Protection Agency to carry out the actual assessment of biological materials. Dosimetric support was provided by Professor Peter Excell of the University of Bradford.

As expected, positioning a Schottky diode within the cavity resulted in the generation of a strong second harmonic response. Similar experiments with seven different cultured cell lines (adherent and non-adherent) and thin slices or sections of eight different tissues did not produce detectable second harmonic responses; all the cells and tissues were tested to show they were still alive at the end of each exposure.



Loading the doubly resonant cavity in preparation for an exposure (photograph courtesy of Public Health England)

Future directions

The three MTHR projects discussed in this section represent different state-of-the-art approaches to investigating the possibility that modulated signals might elicit different effects from unmodulated carrier frequencies. However, none of the experiments provided any evidence that this was the case. Taken individually, each project provides clear evidence in relation to specific endpoints. All three studies included an examination of excitable nerve cells as these are considered to be particularly sensitive to externally applied low frequency electric fields. Of the three projects, we consider that the demodulation project is particularly compelling as it addressed the fundamental process of demodulation with a sensitivity unrivalled by other studies.

While the three projects each provide evidence in relation to specific endpoints, we believe there is merit in considering the results of all three projects collectively to bear on the fundamental question of whether modulated signals interact differently from

carrier frequencies. In doing this it is also important to view these results in the context of the findings from the provocation studies discussed both in this report and in the *MTHR Report 2007*. We made it a requirement of provocation studies supported by the MTHR Programme that they should compare the effects of modulated signals with those of the corresponding carrier frequencies. Taken together, we believe that the results from these eight studies constitute a substantial body of evidence that modulation does not play a significant role in the interaction of RF fields with biological systems. This conclusion has extremely important implications as it provides a reasonably high degree of confidence that the results obtained with a modulated signal characteristic of one communications system can be extrapolated to exposures from other systems operating at similar frequencies. This should facilitate the pooling of data from different studies and allow conclusions to be drawn with greater confidence.

On the basis of the results discussed in this section we do not consider that further investigation of the effects of modulation should be a priority.

5

Assessing Exposures

Background

As noted in previous sections, the single largest source of exposure to radiofrequency radiation for most people is their own phone. As the radio signal emitted by a phone spreads out in all directions, exposure of a user can be reduced by increasing the distance of the phone from the body. The Stewart Committee (IEGMP, 2000) noted in its report that in principle it should be possible to achieve such a reduction through the use of an appropriately designed hands-free kit, provided the phone is moved away from the body and not simply shifted from the head to the torso.

However, the Stewart Committee also noted that as hands-free kits had not been designed for this purpose there was a possibility that for wired devices the cable might itself radiate or carry radio signals to the ear rather than reducing exposure. A *Which?* report published in April 2000 (Consumers Association, 2000) contained results indicating that the use of a wired hands-free kit could actually increase exposure of the user, although other results obtained around the same time appeared to contradict the *Which?* findings, demonstrating a large reduction in exposure. The Stewart Committee concluded that as neither report contained an adequate description of how the tests had been conducted, it could not form a clear view on the matter.

We believe that while there is continuing uncertainty over the possible effects of mobile phone signals, users should have clear information on the options available to them to reduce their exposures should they wish to. We therefore commissioned new work to investigate this issue properly and provide a definitive answer.

Just as the use of a hands-free kit could alter the pattern of exposure, many of the new ways of using mobile phones that have become popular over the last decade might also result in different patterns and levels of exposure relative to the traditional approach of holding the phone next to the ear. Many of these

changes have been dependent on the technological development of phones that we could not have reliably predicted. Nevertheless, from the outset we recognised that the evolution of communications technology would result in new exposure scenarios and we therefore commissioned work to develop assessment techniques appropriate for these novel situations.

The confusion that existed in May 2000 over whether hands-free kits increased or decreased exposures of users illustrates the importance of having standardised approaches for assessing exposures. When two teams making measurements of the same situation obtain very different results, it suggests that important aspects of the measurement procedure have not been properly considered by one or both teams. We therefore supported two projects that aimed to develop and make available to research teams resources to standardise aspects of exposure assessment.

It is well established that some cells, particularly nerve cells, can be sensitive to low frequency fields of sufficient intensity. We explained in Section 4 how we supported work to investigate whether biological material can demodulate mobile phone signals to generate these low frequency components. There is, however, another potential source of low frequency components and that is the electronic circuit in the mobile phone. Most work on exposures from mobile phones has concentrated on the RF emissions, so we decided that additional work was required to measure the low frequency fields generated by mobile phones.

New evidence

One of the studies described in this section examined exposures during the use of hands-free kits. Three others were concerned with the development of standard exposure assessment methods. The final study examined low frequency fields from mobile phones.

The procedures used to assess exposure arising from the use of a mobile phone placed against the ear are complex, but well established. Factors such as the exact position of the phone are extremely important as small changes in distances can have large effects on the magnitude of exposure. In practice, different people hold their phones differently and even individual users will move the phone about – so, to overcome this variability, internationally agreed assessment protocols use a standard position for the phone. This allows comparisons to be made between different makes and model of phone and gives a representative measure of exposure, but obviously does not necessarily indicate the actual exposure received by any individual user.

The situation for the assessment of exposures while using a hands-free kit is potentially more complicated owing to the wide variety of possible positions in which the phone and hands-free kit cable could be placed. Consequently any assessment would need to establish which realistic arrangement would give the maximum exposure. Stuart Porter and his colleagues at the University of York approached the problem by first assessing the layout of the hands-free cable relative to the phone that induced the highest power in the cable. They then established the orientation of the hands-free cable relative to the user that resulted in the highest deposition of energy in the head.

The team made measurements of the RF current induced in the hands-free cable and of the energy absorbed inside an artificial head (phantom) filled with tissue-equivalent material (see the figure). Measurements were made with a range of hands-free kits and phones, and currents induced in the cable in the presence of a realistic phantom were verified using a person in place of the phantom.

The work established that exposures were strongly dependent on the layout of the cable relative to the phone, and whether the cable ran across other parts of the body, which reduced exposures to the head. The proximity of the cable to the head was only moderately important in affecting exposure, although it was more important for phones operating at higher frequencies. The specific type of hands-free kit had a relatively minor influence, although it could affect the position of peak absorption. The frequency band also had a minor effect on the exposure.



Head phantom and robotic arm used to make specific energy absorption rate (SAR) measurements

Importantly, all of the combinations tested resulted in a sizeable reduction in head exposure compared to using a phone alone. The size of the reduction relative to the small differences observed between different hands-free kits gives confidence that this will be the case for all wired hands-free kits. It was also possible to show that a ferrite bead placed around the hands-free cable could further reduce exposures.

Stuart Porter and his colleagues undertook a second study to investigate exposures resulting from the use of new mobile telecommunications technologies such as more sophisticated handsets, hands-free devices, laptops and wearable devices. At the time the study was commissioned, most mobile telecommunications still involved the relatively simple situation of a user holding a GSM mobile phone in the traditional position against the ear. However, we recognised that the rapid evolution of mobile telecommunications technologies would generate a need to develop new assessment techniques that would try to anticipate these advances. It was expected that new technologies would make use of a wider range of frequencies, signal characteristics and antenna types, and would result in exposure of other parts of the body.

The project team started by undertaking a survey of developing technologies and from this identified five frequency bands corresponding to private mobile radio, mobile telecommunications systems and WiFi/Bluetooth. It was considered that the systems might make use of a range of different antenna types and could give rise to exposures in five broad areas of the body: the shoulder, chest, waist (side), waist (back) and groin. Given the combinations of antennas, frequencies and wear positions, the team considered 45 different exposure scenarios. Assessments were carried out using both physical phantoms and computer modelling. For the physical measurements, the team constructed generic communications devices that incorporated onboard monitoring functions to allow the behaviour of the device to be determined in the presence of the body.

There were no clear trends in the results with regard to wear position, frequency band or antenna type. However, the study did demonstrate that truncation of computer models could be used to reduce the time needed to run simulations, while for physical measurements a flat phantom generally provided a reasonable estimate of worst-case exposure.

It is often important to be able to compare measurement results obtained by different researchers working in different locations. Such comparisons can only be meaningful where it is known that the instruments being used produce similar results when exposed to the same field. This depends on the calibration of the instruments and is something generally taken for granted when using, for example, a ruler or thermometer. This is because manufacturers put a lot of effort into ensuring not only that all their products have the same calibration, but also that they have the same calibration as other manufacturers' products. This is achieved by ensuring that all calibrations are traceable to a standard. In the UK the National Physical Laboratory (NPL) maintains a wide range of primary standards, including those for specific energy absorption rate (SAR), the quantity used to assess RF exposure. We provided funds to help Ben Loader and colleagues at NPL establish a new national standard for SAR at the frequencies used by TETRA systems. The team was also able to extend the existing NPL calibration facilities at GSM frequencies to improve characterisation of probe responses. These developments directly benefited research

projects within the MTHR Programme that involved SAR measurements. In addition, they have provided a national resource for both research and industry.

In addition to having good calibration of instruments, it is also important to ensure that the correct measurement procedures are followed to ensure that exposures are properly assessed. This area is relatively specialised and expertise resides in a small number of individuals. We therefore commissioned Phil Chadwick of MCL to co-ordinate leading experts from around the world to write a measurement manual known as the *EMF Dosimetry Handbook*. A large number of chapters were produced, each authored by an expert in that aspect of measurement.

While a great deal of effort has been put into the measurement of RF exposures from mobile phones, relatively little work has been undertaken to quantify exposures to low frequency magnetic fields. These magnetic fields are produced by the flow of electric current from the battery and through the electronic circuits of the phone. For devices operating with a pulse-modulated RF output (see Section 4), the current flow from the battery to the transmitter circuit is also pulsed and produces a magnetic field that is pulsed at low frequency. As noted in Section 4, it is well established that cells are sensitive to low frequency fields of sufficient intensity, and so we considered it important to establish the intensity of the low frequency magnetic fields produced by mobile phones.

Michael Hall and his colleagues at NPL used a sensitive magnetic field probe to measure the fields produced by two GSM mobile phones and two TETRA emergency services radios. In all cases the highest fields were measured at the rear of the handset, suggesting that they were produced by current flow in the battery or nearby circuits. In all four cases, low frequency magnetic flux densities were a few microtesla in the direction of the head, but higher in other directions. These field strengths are much lower than those known to have effects on excitable tissues. In addition to the low frequency fields, all the handsets produced static magnetic fields that were somewhat more intense. Movement of the phone relative to the head during use could effectively convert this to a low frequency exposure that would be higher than that resulting from pulse modulation of the transmitter output.

Future directions

The work we supported resolved once and for all the question of whether hands-free kits could be used to reduce exposures. The magnitude of the reduction was sufficiently large relative to differences between individual hands-free kits that we are confident that a general principle has been established. It was also shown that a ferrite bead, correctly positioned around a hands-free cable, would further reduce exposure. The research team responsible for this work kindly made the data available to the appropriate standards committee and we see no need for further work on this issue.

Most of the other work described in this section was to establish resources that could be used to improve

assessments in the future. Further development work will doubtless be required in time, but we feel this would best be taken forward by standards committees and organisations such as NPL. We feel that in the future, the mobile communications industry should be best placed to assess exposures from novel technologies as the industry is aware of what is being developed and can carry out assessments long before products come to market.

The work on low frequency magnetic fields demonstrated that these fields are relatively small, particularly when compared with fields from other appliances held near the head, such as electric razors and hairdryers. We do not see further work in this area as a priority.

6

Experimental Exposures

As recommended by the Stewart Committee (IEGMP, 2000), we made provocation studies on volunteers a major component of the MTHR Programme. However, we were aware that one of the difficulties in the interpretation of the results from previous studies had been the wide range of exposures and exposure systems used. We felt very strongly that all the projects funded by the Programme should, so far as possible, use the same exposure systems and the same exposures. Hence although each individual research team had proposed to use its own exposure system, we resolved that all exposure systems would be commissioned, maintained and calibrated centrally.

We recognised that this placed a significant responsibility on us to ensure that the exposure systems we provided were fit for purpose. We therefore established a subgroup of the Programme Management Committee to agree the specification. The subgroup took advice from external expert advisers and also discussed the designs with the research teams that would be using them.

Mobile phone exposure systems

We decided that the system chosen would have to satisfy a number of key criteria:

- a** dosimetry should be thoroughly characterised,
- b** exposures should mimic mobile phone use,
- c** the system must be simple to use,
- d** the time frame for delivery should be reasonable as delays would hold up a number of projects,
- e** the system must incorporate blinding.

After considering a number of options, we concluded that a system enclosed within the casing of a mobile phone handset offered the best solution. This would most closely mimic the distribution of exposures found for a real phone and would have the added advantage

that subjects would perceive the test situation as relevant to effects of mobile phones, a concept known as ‘face validity’.

Any exposure system would need to be mounted with respect to the subject’s head as separation distance and positioning could have a large effect on exposures. We concluded that the use of a headband would be more acceptable to subjects than alternatives such as a helmet arrangement.

We decided that for mobile phone exposures we would concentrate on 900 MHz GSM signals as these had been used in the majority of the previous studies. There was also a need to provide TETRA exposures, but differences, particularly in transmission frequency, meant that both signals could not be produced by the same units. We therefore commissioned a TETRA variant of the exposure system, and in due course this was also selected for use by the Home Office TETRA Programme.

We had already decided that all the mobile phone provocation studies should involve exposure to modulated, continuous and sham signals. The sham signal was to be produced by diverting the signal from the antenna into a load within the phone. This was important to minimise any possibility that either a researcher or subject could recognise whether the phone was in sham or expose modes from subtle cues such as heating or noise. Thermal imaging of the first exposure systems by Professor Tony Barker (Royal Hallamshire Hospital) revealed differences in temperature distributions in the different operational modes and the units were subsequently modified to address this problem.

The question of which signal would be diverted to the internal load during sham operation was also an important consideration. Modulation of the output results in generation of a low frequency magnetic field from the battery (see Section 5). If the modulated field were diverted to the internal load then the unit would not emit an RF signal, but would generate the low

frequency magnetic field. This could have complicated the interpretation of results, and we therefore decided that during the sham condition it would be a continuous signal that was diverted to the internal load.

The exposure systems were to be used in double-blind studies, and it was therefore essential that the output mode could be selected without revealing which mode had been chosen to either the experimenter or the volunteer. After consideration of the blinding controls originally proposed, we asked for the design to be modified to make the blinding more sophisticated. We decided that the blinding codes would be released to the research teams at the outset, but should not be revealed to those actually carrying out the testing.

As the studies involved volunteers, we did not want exposures to exceed international guidelines for public exposure (2 W/kg for localised specific energy absorption rate (SAR) in the head) and, given a 30% uncertainty in measurement values, we specified that the exposure systems should produce a spatial peak SAR of 1.4 W/kg. After some discussion we opted to set this target in terms of rms time-averaged SAR; we recognised that this would result in a higher peak SAR during operation in the modulated mode compared with the continuous mode. We also commissioned NPL to characterise the low frequency magnetic fields generated.

Another issue we discussed was whether the exposure systems should be capable of simulating operation in discontinuous transmission (DTX) mode. Phones operating with DTX only transmit when the user is speaking (this is done to prolong battery life). We did not think there was a need to use DTX in MTHR provocation studies because other research had reported effects in the absence of DTX. Moreover, it would be necessary to select a pattern of transmission that represented DTX operation during a 'typical' phone conversation. Nevertheless, we decided to have a DTX capability built into the phones so that this could be used in future studies, if needed.

Base station exposure system

Exposure from a base station is rather different to that from a mobile phone. Exposures from phones are highly localised, typically to the head, and much higher than those from base stations. Base station exposures are generally more uniform across the body due to the distance from the base station.

The much lower exposure means that environmental signals are a potential confounding factor. We therefore recognised very early on that if we were going to support base station provocation studies, they would have to be carried out in a screened room. This would effectively eliminate exposure to environmental signals from both phones and base stations. In addition, it would prevent signals generated by the exposure system from escaping into the environment and so simplify the licensing arrangements. We concluded that the screening would need to achieve 40–60 dB of attenuation. In the end we were able to acquire a suite of screened rooms that had previously been used at NPL but were no longer required. Some modification of the rooms was necessary in order to adapt them for use in provocation studies.

We recognised that the final design of the exposure facility would be a compromise between the requirements for ideal exposures and the comfort of the subjects. The subjects needed space to be able to move and not feel claustrophobic. In addition, it was important that they did not feel intimidated by the antenna producing the exposure or by the presence of absorber material necessary for the function of the room. It was also considered helpful for there to be a screened window that would allow contact with the world outside the exposure chamber. As tests would take some time to complete, it was considered essential that volunteers should be able to sit down. It was also necessary to achieve a satisfactory separation between the subjects and the radiating antenna so that exposures would be uniform and far field, like those encountered from a real base station.

After some consideration of the matter, we decided that GSM signals would have to include both a broadcast control channel (emitted at constant power) and a traffic channel (emitted at variable power with partial occupancy of the timeslots normally assigned to different users, as described in Appendix C of the

MTHR Report 2007). We also agreed that the GSM signal should be a mix of 900 MHz and 1800 MHz GSM signals so as to simulate real exposures. The UMTS signal was modulated to simulate traffic on the channel using an industry-standard model.

We also spent some time considering an appropriate exposure level and decided that the exposure should be towards the upper end of the range of exposures from a networked base station as measured in publicly accessible areas. We concluded that each of the

exposure conditions should generate a power density of 10 mW/m^2 at the position of the subject. For the mixed signals, this power density would be the total power density from all components.

Having commissioned the mobile phone base station exposure system, we had this system modified to produce TETRA signals when we commissioned a TETRA base station study. The general design considerations were therefore the same, and the TETRA system also produced a power density of 10 mW/m^2 at the position of the subject.

Future Arrangements

In 2012 the Department of Health, as the government department with lead responsibility for the MTHR Programme, reviewed the arrangements for supporting research into the possible health effects of mobile phone technology in the context of the changing research landscape. It was recognised that a substantial number of important studies had been commissioned, overseen and disseminated through the Programme. Moreover, the research supported by the Programme had helped to allay anxieties about the health impact of mobile phones and addressed many key questions.

DH acknowledged that the MTHR Programme Management Committee had played a highly important and successful role in developing the evidence base in a complex area during a period of considerable uncertainty and public concern. Nevertheless, there was concern that the role of the PMC as selector, reviewer and manager of research was no longer consistent with current research governance arrangements for the management of externally funded research.

Following consultation with ministers and other sponsors of the MTHR Programme, DH decided that it wished to bring research on mobile phones and health into its mainstream research portfolio. It was therefore decided that in future the research would be commissioned and managed on behalf of all the current funders by the DH Policy Research Programme (PRP). The PRP is a national funding programme of independent research, commissioned using high quality processes, and with the use of independent experts on the commissioning group and as peer-reviewers.

The PRP has now taken on the management of the only ongoing project, the COSMOS study (see Section 2). This is currently funded until March 2014, when a final report for this phase of the study will be produced. Under the new arrangements, the Advisory Group on Non-ionising Radiation will assume responsibility for drawing research needs to the attention of the UK

health departments and other research funders. In the meantime we have shared our views on future research priorities with the UK health departments and these have been used to inform an invitation to tender issued by the PRP. We have reproduced our advice below.

Advice on future research priorities

In arriving at these recommendations, we assessed research already funded in the UK and elsewhere in the context of the research priorities identified in the *WHO Research Agenda for Radiofrequency Fields 2010* (WHO, 2010). In our view, there are important areas in which the UK has well-established research expertise and could make a significant contribution.

We consider the following to be priority areas:

- a** studies of long-term behavioural/neurological outcomes in children and/or adolescents in relation to mobile phone usage,
- b** provocation studies on children,
- c** provocation studies to identify neurobiological mechanisms underlying possible effects of mobile phone signals on brain function, including sleep and/or resting EEG,
- d** studies in suitable animal models of the effects of early-life and prenatal exposure on development and behaviour,
- e** studies in suitable animal models of effects on ageing and neurodegenerative diseases.

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Glossary and Abbreviations

Glossary

Amplitude modulation encoding of information by varying the magnitude of the carrier waveform.

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

Broadcast control channel frequency channel that permanently transmits identification and control information from a base station.

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

Carrier frequency frequency of the radio wave on to which information is encoded through a modulation process.

Carrier waveform waveform on to which information is encoded by modulation.

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

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

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

Cohort a group of people identified in an epidemiological study and 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 ascertainment of the occurrence of disease(s) at later times. For each person, information on prior exposure can be related to subsequent disease experience.

Confidence interval an interval 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).

Discontinuous transmission facility that allows transmission only in the presence of speech; used to prolong battery life.

Dosimetry measurement of the power or energy deposited in 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 subjects 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 has been completed.

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

Electrophysiology (electrophysiological) study of the electrical properties of biological cells and tissues that result from changes in membrane potential.

Epidemiology (epidemiological) study of the distribution and determinants of health and illness in populations.

Face validity extent to which a test *appears* (when taken at face value) to measure what it is intended to measure.

Far field region of an electromagnetic field where there is a simple relationship between the electric and magnetic field components of a propagating wave.

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.

Frequency modulation encoding of information by varying the frequency of the carrier waveform.

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

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

Near field region near an emitter where the relationship between the electric and magnetic components of an electromagnetic field is complex.

Phase modulation encoding of information by varying the phase of the carrier waveform.

Pulse modulation regular interruptions to transmissions through which a carrier frequency may be shared by multiple users, eg 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 to non-diseased individuals.

Sham exposure replication of exposure conditions where the radiofrequency energy does not reach the target site.

Specific energy absorption rate (SAR) rate of absorption of electromagnetic energy in a unit mass of tissue; usually expressed in W/kg.

Time division multiple access (TDMA) 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 because the signal is emitted in bursts or pulses.

Traffic channel frequency channel that is used to transmit call information from a base station to the user(s). Output will vary with the number of users.

Transmission movement of radiofrequency energy away from a source.

Waveform temporal and spatial structure of an electromagnetic wave.

Abbreviations

AM	Amplitude modulation
APC	Adaptive power control
BCCH	Broadcast control channel
CDMA	Code division multiple access
CPICH	Common pilot channel
CW	Continuous wave
DTX	Discontinuous transmission
EEG	Electroencephalogram
EMF	Electromagnetic field
FM	Frequency modulation
GSM	Global system for mobiles
RF	Radiofrequency
rms	root mean square
SAR	Specific energy absorption rate
TCH	Traffic channel
TDMA	Time division multiple access
TETRA	Terrestrial trunked radio
UMTS	Universal mobile telecommunications system

Appendix A

MTHR Phone Exposure System Specification

As we were supporting a number of provocation studies we decided that it would aid the interpretation of results if all exposures were made with standardised exposure systems. The Home Office TETRA Programme, which was set up shortly after the MTHR Programme, also decided to standardise on the TETRA version of our phone exposure system.

The considerations underlying our choice of exposure system design and the exposure conditions used are explained in Section 5 of the report. Brief descriptions of the exposure systems have been published in research papers and final reports from individual projects. However, we are aware that no detailed description of the phone exposure systems has yet been published and so we are providing one here. A detailed description of the base station exposure system is provided in Appendix B.

The phone exposure systems were commissioned from Dr Phil Chadwick at MCL, who also arranged ongoing maintenance and calibration. The general description of the system and information on dosimetric assessments given below were adapted from information provided by Dr Chadwick. MCL subcontracted the construction of the devices to the University of York. Professor Myles Capstick (now at the IT'IS Foundation in Zurich) who led this work kindly provided the technical description below.

General description of the phone exposure system

The exposure system consisted of a self-contained, headband-mounted generic handset. There were no external connections and the devices required no RF expertise for operation. The handsets were capable of radiating power with GSM/TETRA modulation (depending on variant), or without modulation (continuous wave, CW mode). DTX capability was also provided for the GSM handsets, but there was no

intention to use this in the studies initially supported by the MTHR Programme.

It was possible to divert power in either variant to an internal load to provide sham RF exposure conditions with heating and low frequency magnetic fields similar to the exposure modes. The power could also be diverted, via approximately 20 dB of attenuation, to a power monitoring port (an SMA socket on the top of the handset), where power in either CW or GSM/TETRA mode could be measured with a suitable power meter. A GSM handset is shown in Figure A1; the TETRA handset



FIGURE A1 (a) front, (b) back and (c) control switches of the GSM phone exposure system

looks identical apart from the antenna, which has to be longer as a result of the lower frequency of operation.

There were 27 possible different emission modes: 100% power, 50% power and 25% power; three possible modulation regimes (GSM/TETRA, CW and DTX); and three routes for the power (antenna, internal load or power monitoring port). These modes were randomly and multiply assigned to various hexadecimal values. There were 10 hex values for each mode, apart from the power-monitoring modes, which each had a unique hex value. The hex modes were set using the two rotary switches on the back of each handset, labelled MSB and LSB. Each hex value had the form nn , where n in each case was a number between 0 and 9 or a letter between A and F. So to set the hex value 1F, for example, the left-hand (MSB) dial was set to '1' and the right-hand (LSB) dial was set to 'F'.

The mean power in the GSM and CW modes was the same: this was to ensure that exposures did not exceed the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines in CW mode. However, the consequence of this was that the radiated power in CW mode was approximately one-eighth of the peak power in GSM mode (one-quarter for TETRA). The mean radiated power of the handsets was 250 mW; the peak radiated powers were 1 W for the TETRA units and 2 W for the GSM units.

In GSM/TETRA mode, the signals produced by the exposure system had the lower frequency modulation components arising from the super- and hyper-frame structure as well as the frame-related burst modulation. More detail on the output of the systems is given in the technical description below.

The currents drawn by the handsets in GSM/TETRA and CW modes were matched so that the heating of the cases was comparable. Tests by MCL and the University of Sheffield indicated that the case temperatures were similar to within 1° celsius.

An audible battery warning sounded when there were only a few minutes of useful battery life left. The output of the handset was stable to within ± 0.5 dB between three minutes from switch-on of a new battery and three minutes after the battery warning. The research teams were advised to leave units switched on for around three minutes after fitting a new battery to

allow them to 'settle' before generating exposures, so that the SAR levels would remain stable.

Three spare batteries and one charger were supplied with each handset.

Mounting the exposure systems

The magnitude and spatial distribution of deposited energy from the exposure systems are critically dependent on the position of the unit relative to the head (as it would be for a mobile phone). In order to make the results of studies meaningful, it is obviously important to standardise exposures between:

- a different trials with the same subjects,
- b different subjects within a trial,
- c different trials within a study,
- d different studies.

Standardisation of exposure was partly achieved through the use of identical and properly calibrated exposure systems. However, it was also important to ensure that the systems were always mounted in the same position. This was achieved through the use of a cradle that fitted around the subject's head and held the phone in position.

The cradle permitted the exposure systems to be mounted in either right- or left-handed positions. It was designed to facilitate positioning of the unit against the subject's head in the CENELEC 'cheek' geometry, one of two standard assessment geometries for mobile phones. For the left side of the head, this has the antenna touching or within a few millimetres of the head, above and slightly behind the ear, as illustrated in Figure A2.

The mounting bracket on the headband incorporated different position settings so that the exposure system could be placed in the CENELEC 'cheek' position for different subjects. Guidance was provided to the research groups to enable them to correctly position the units.

As the exposure systems were not symmetrical, it was necessary to use a slightly different positioning system when mounting on the right side of the head. In this case a spacer kit was used to displace the unit by approximately 40 mm.

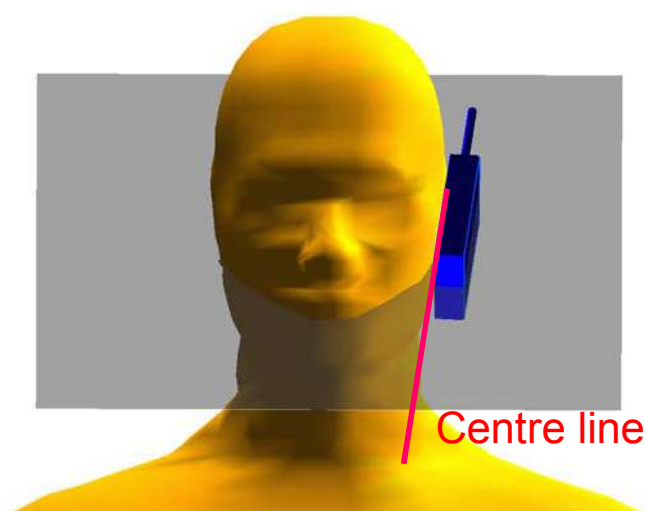
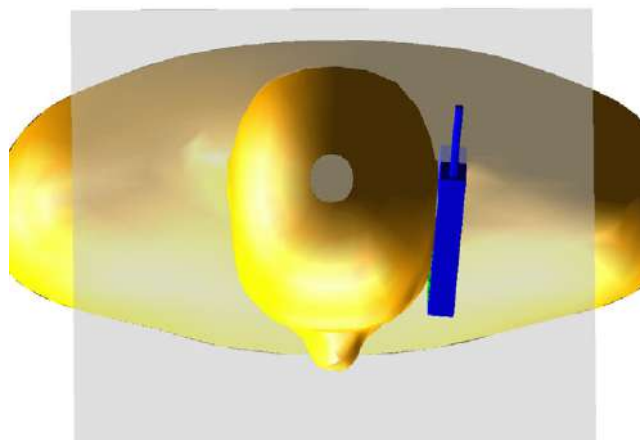


FIGURE A2 CENELEC 'cheek' geometry

Technical description of the phone exposure system

The requirement was for an exposure system solution to provide controlled exposure of volunteers with characteristics representative of a real mobile phone handset. Previous exposure system solutions involved a rack of equipment connected to a test antenna placed near the subject's head. However, a key feature of a mobile phone is that it is physically small and this constrains the antenna element counterpoise dimensions, it being important to remember that the antenna is not only the helical (or other element) but also the rest of the phone against which it is fed. The connection of a cable to any antenna can therefore dramatically alter the current distribution because the cable artificially extends the counterpoise. Therefore, we set about developing a range of representative devices built into mobile phone enclosures that could provide specified power levels corresponding to given specific energy absorption rates (SAR) with GSM and TETRA type signals or continuous wave (CW) signals. In addition, these modulated or CW signal powers were to be delivered either to the antenna, an internal load or a test port (to allow regular measurement of output power and hence verify continued operation) (Table A1). An additional requirement was that the handset should have the same power dissipation whatever the mode of operation, so that the exposure mode could not be determined from the temperature of the handset. For the GSM phone a discontinuous transmission (DTX) mode was also included for future use. The particular mode of operation was set by the operator using two hexadecimal switches allowing



256 possible mode numbers which were allocated randomly to the modes of operation. In this way the experimenter could have no knowledge of the mode of operation being selected. The DC power consumption was to be identical whatever the mode, so that the operating temperatures would be identical whatever the mode (except for the unused DTX mode).

TABLE A1 Overview of mode and output destination options for GSM and TETRA versions of exposure systems

System	Mode	Destination
GSM	CW	Antenna
	DTX	Internal load
		Test port
TETRA	CW	Antenna
	DTX	Internal load

For the GSM handsets, modes were mapped to all destinations giving nine possible operation modes. The three test port modes were used only for diagnosis and were mapped to only one mode number on the hexadecimal switches. For the TETRA handsets, modes were mapped to all destinations, giving six possible operation modes. The two test port modes were used only for diagnosis and were mapped to only one position each on the hexadecimal switches.

The output power was tuned in the GSM, TETRA and CW cases to be at the ICNIRP limit for SAR but never above, when all uncertainties were taken into account.

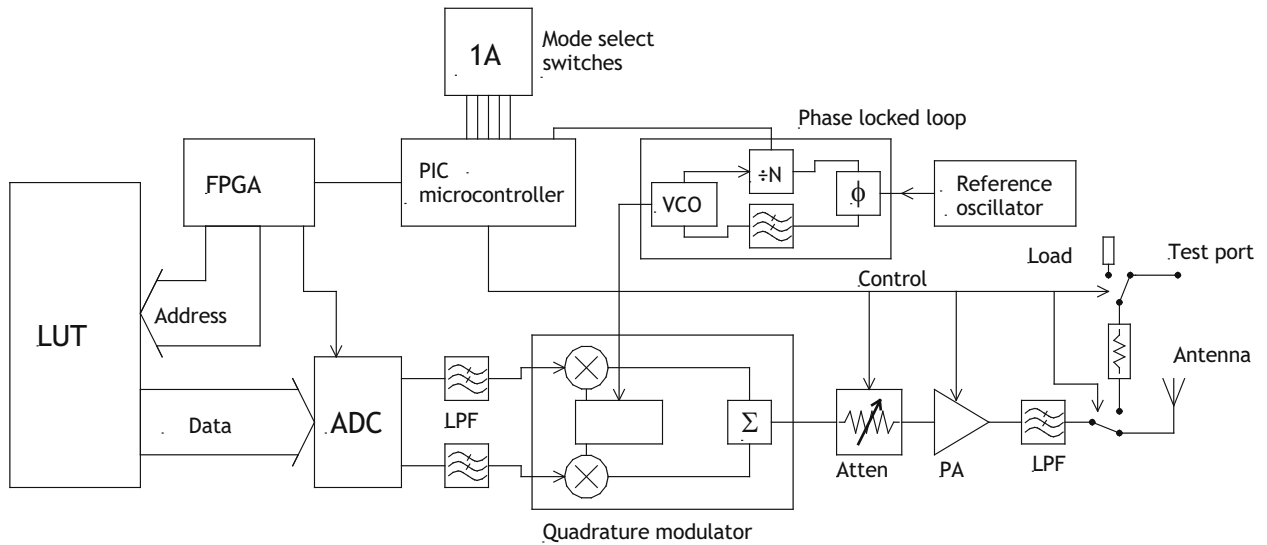


FIGURE A3 System architecture for phone exposure systems

All devices were measured at the same accredited laboratory to maintain consistency between them. The DTX mode pulse power level was the same as for a single pulse in the GSM mode.

System architecture

Both devices used essentially the same architecture (Figure A3) involving a look-up table (LUT) feeding an analogue-to-digital converter (ADC) producing in-phase and quadrature signals for direct modulation of the carrier. The modulated carrier level was then set and the output amplified up to the required level.

The key differences between the two handset variants were the different frequencies of operation and hence RF components and different data in the LUT, sample rates for the ADCs and anti-aliasing filter bandwidths.

Modulation and look-up tables

GSM modulation can be facilitated using two common methods. The first is direct modulation of the transmit VCO using Gaussian filtered data, and the second is a quadrature method using the property that frequency is the rate of change of phase. The second method is much more easily controlled and was adopted for the GSM transmitter here. The modulation process is shown in Figure A4.

Representative data were generated and the in-phase (I) and quadrature (Q) signals calculated by integrating and then filtering the signals to obtain a phase angle

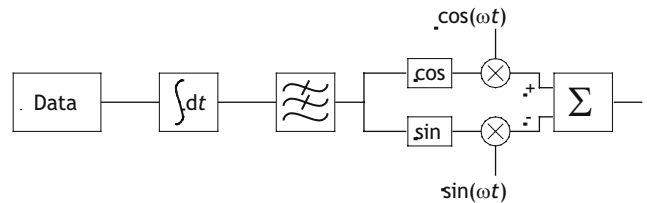


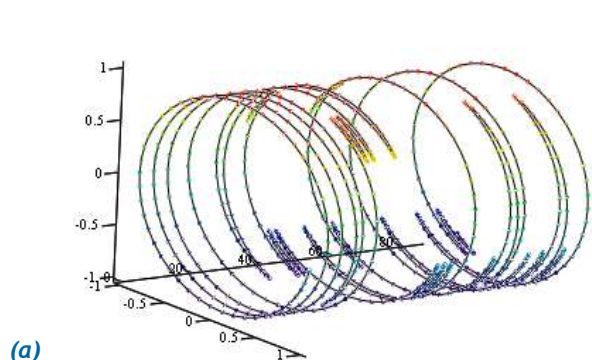
FIGURE A4 Modulation process

which was then used as the argument for sine and cosine functions to calculate the I and Q values. The resultant constant amplitude modulating signal can be seen in the phasor diagram (Figure A5).

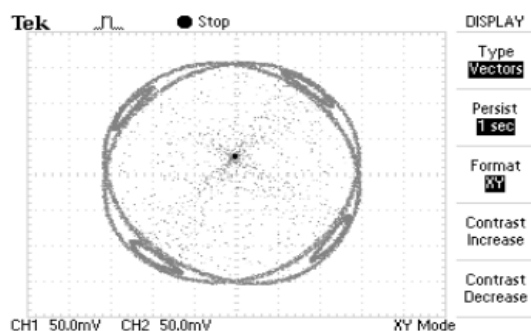
The I and Q values required to produce the modulation were stored in the LUT in the handset in blocks equal in length to one timeslot. The data in each block were conditioned to provide the ramping function at the start and end of a slot as given in the GSM specification, to ensure there were no transient spectral components outside the nominal channel.

In the case of $\pi/4$ DQPSK modulation, a pseudo-random bit stream was generated and each pair of bits used as the index to a 2×2 matrix indicating the differential phase shift such that $\Delta\phi$ was given by

$$\Delta\phi = \begin{pmatrix} \frac{\pi}{4} & \frac{3\pi}{4} \\ -\frac{\pi}{4} & -\frac{3\pi}{4} \end{pmatrix}$$



(a)



(b)

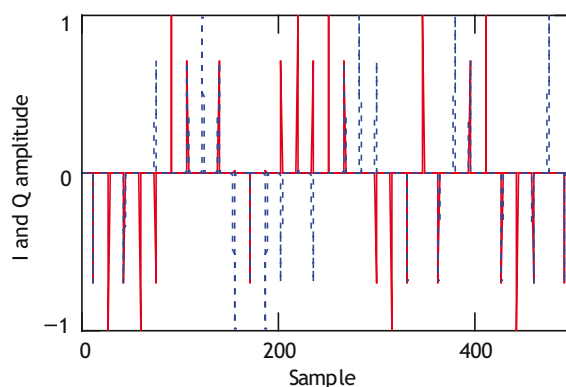
FIGURE A5 Constant amplitude modulation signal, as: (a) 3-dimensional and (b) 2-dimensional phasor diagrams

During any given symbol period k , ϕ was calculated as $\phi_k = \phi_{k-1} + \Delta\phi_k$ and from this the nominal limiting values of the in-phase and quadrature amplitudes were calculated. The nominal I and Q amplitudes were multiplied by impulse trains at the symbol rate to produce impulse trains of the correct I and Q amplitudes (Figure A6). These impulse trains were then convolved with the impulse response of the root-raised cosine filter with $r = 0.35$. The filter impulse response was given by

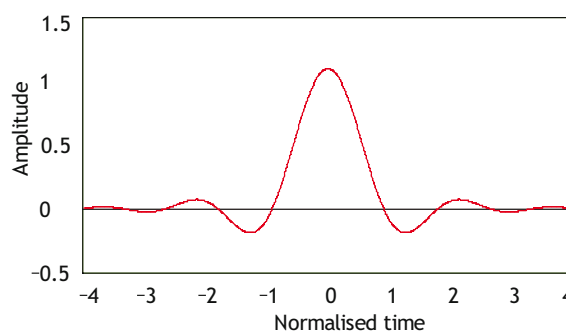
$$h(t) = \frac{\sin\left[\pi(1-r)\frac{t}{T}\right] + 4r\frac{t}{T}\cos\left[\pi(1+r)\frac{t}{T}\right]}{\pi\frac{t}{T}\left[1 - \left(4r\frac{t}{T}\right)^2\right]}$$

The whole modulation process is illustrated in Figure A7.

The resultant modulating waveforms are shown graphically in Figure A8. It is these calculated modulation waveforms that were stored in the LUT in the exposure system in blocks equal to one timeslot. The data in each block were conditioned to provide the ramping function at the start and end of a slot as given



(a)



(b)

FIGURE A6 (a) variation in I and Q amplitudes and (b) the same data transformed and shown in the time domain

in the specification, to ensure there were no transient spectral components outside the nominal channel.

Exposure system spectra and bursts

The spectral content of the handsets when in the modulated modes were measured and compared to the spectral masks for the standards (Figures A9 and A10 for GSM and TETRA, respectively). The GSM simulated signal source conformed well to the standard and the TETRA handset exceeded the permitted levels for a real device when the signal was lower than 1/200,000th of the peak level. This was mainly due to spurious sidebands on the phase-locked loop synthesiser output. Both handsets were passed by Ofcom for use within the MTHR project.

Antennas

For both the TETRA and GSM handsets, external helical antennas were used so that SAR levels towards the top of the allowable range could be readily achieved with the peak RF powers available. The helical antennas were tuned such that they were well matched in proximity to the head of a user. The antennas showed typical return losses better than 10 dB, and not worse than 7 dB. However, the exact match was dependent on the precise positioning of the handset with respect to the head.

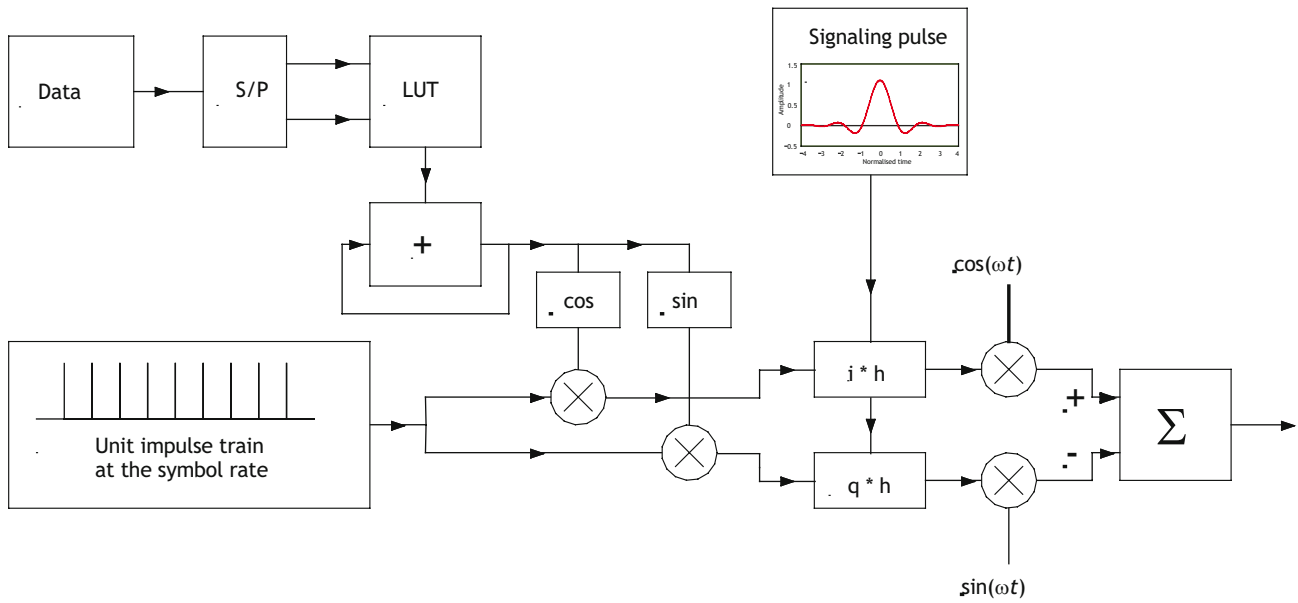


FIGURE A7 Modulation process

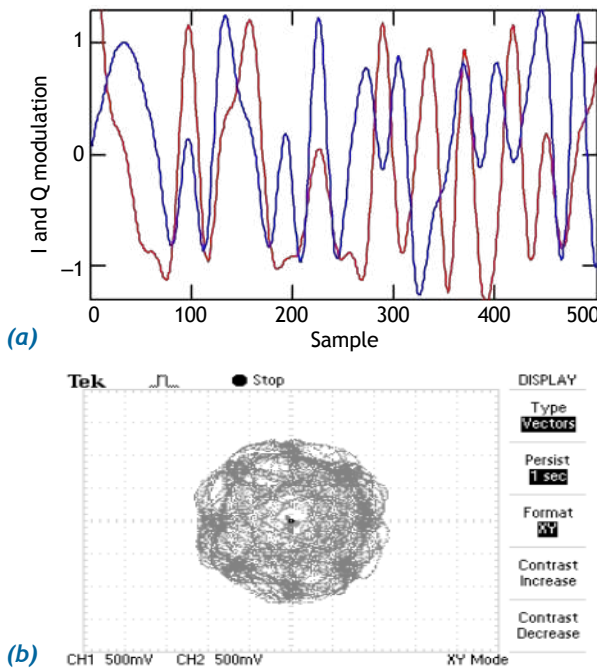


FIGURE A8 Modulating waveforms: (a) displayed graphically and (b) in the form of a phasor diagram

Blinding

The basic principle behind the blinding was the random allocation of the 256 possible switch positions between the possible device modes, such that each mode had approximately the same number of random settings. The experimenters would have no knowledge of this mapping function and only the principal investigator who planned the experimental campaign would have access. There was no indication on the handset of the mode selected for a given switch position. The only switch positions known to the experimenters were those that mapped the output of the device to the test port for the regular verification that the device continued to be operational by measurement of the sampled power.

In the different modes of operation the handsets would consume different amounts of power, which would result in different handset temperatures if not compensated. To ensure similar heating in all modes, resistors were included in the device to dissipate additional power in the higher efficiency modes and bring the total to the same. The value was based initially purely on DC power from the battery, and then optimised based on infrared thermometry of the handset case in the different modes, to ensure that heating would not provide a clue as to the exposure state.

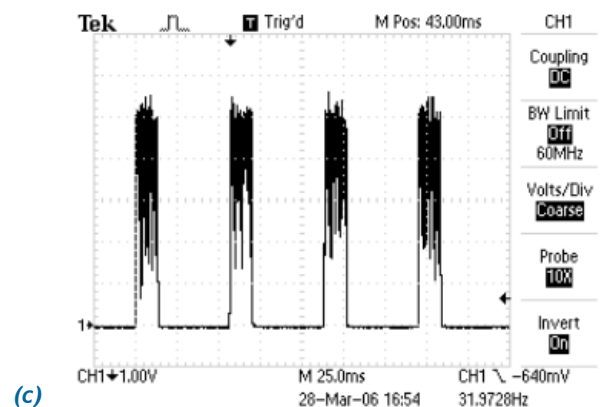
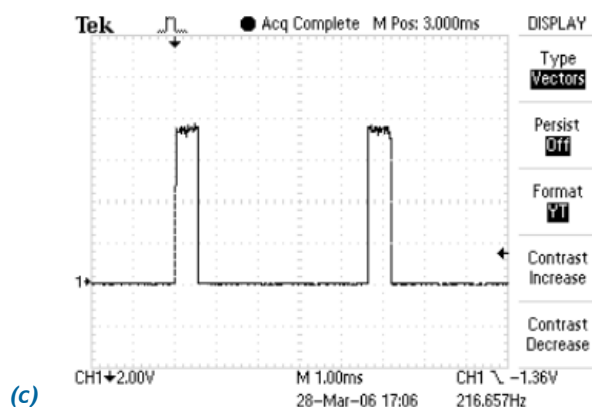
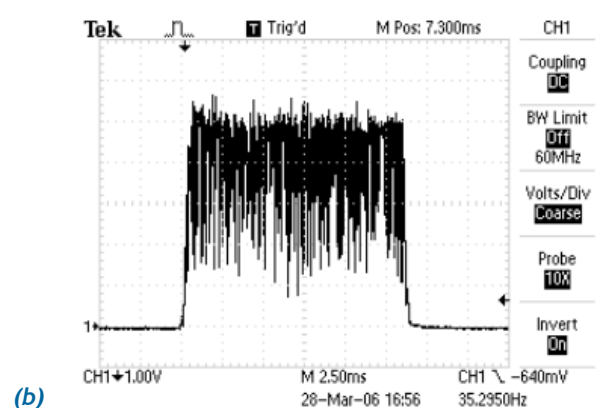
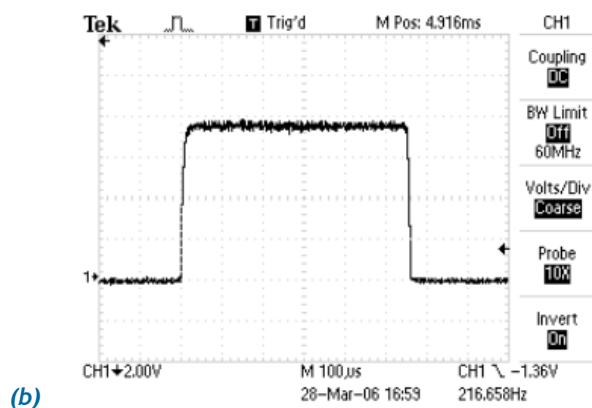
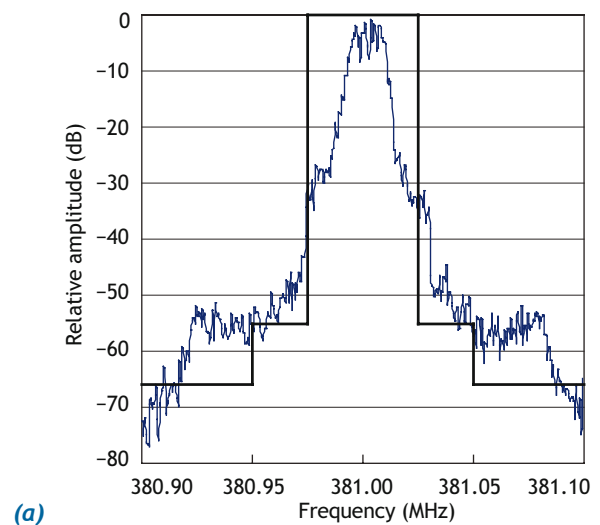
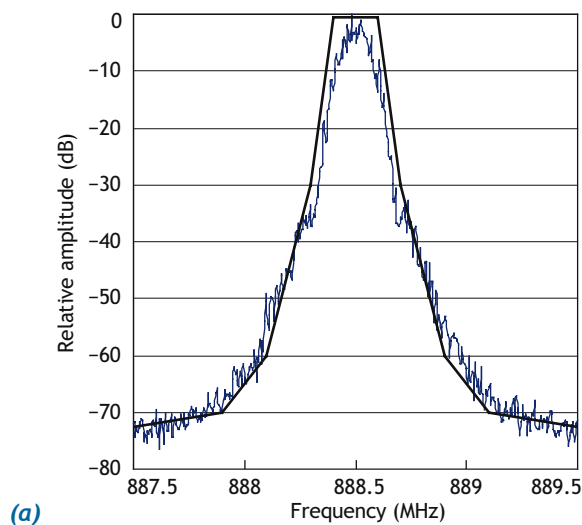


FIGURE A9 Measured outputs from GSM exposure system: (a) in the frequency domain; and (b) and (c) in the time domain, showing an individual timeslot and a complete frame, respectively

FIGURE A10 Measured outputs from TETRA exposure system: (a) in the frequency domain; and (b) and (c) in the time domain, showing an individual timeslot and a complete frame, respectively

Dosimetry and calibration

Dosimetric assessment and ongoing calibration of the exposure systems was carried out by Phil Chadwick at MCL.

Dosimetric assessment

Assessment of exposure from each handset was made using a robot-mounted, computer-controlled miniaturised probe to map the internal electric field strengths in a headshell phantom filled with tissue-simulating material. The tissue-simulating materials were formulated and tested to ensure that they were matched to tissue electrical conductivity and permittivity at the frequency of operation of the handset, as specified in CENELEC/IEEE standards.

The dosimetry system and procedures were consistent with CENELEC EN50360:1 specifications for the SAR testing of mobile phone handsets. The standardised exposure geometry used for mounting the units on each subject's head facilitated dosimetric assessment using

standard CENELEC protocols. SARs were assessed in a fully calibrated test facility with UKAS accreditation.

Assessments confirmed that the peak SAR occurred close to the antenna for both the GSM and TETRA variants (see Figure A11) and had a value of 1.3 ± 0.4 W/kg when averaged over 10 g of contiguous tissue. The spatial peak SAR when averaged over 1 g of contiguous tissue was typically 4–5 W/kg.

The peak SAR from the body of the unit was typically 0.3–0.4 W/kg when averaged over 10 g of contiguous tissue. The spatial peak SAR in sham mode was less than the sensitivity of the measurement system (0.001 W/kg).

Ongoing maintenance and calibration of experimental systems

When we commissioned the exposure systems we were aware that there would be an ongoing need for maintenance and calibration, which would necessitate the return of systems to MCL. To ensure that this process did not affect the progress of individual research studies, we procured spare copies of each variant of the exposure system. When units were due for maintenance and calibration, exchange units were provided to the research teams so that their work could continue unhindered.

As discussed in the technical description above, the units were designed with a test port that could be used to calibrate the output power of the system. Calibrations were performed using Hewlett Packard HP432A power meters equipped with 300 mW thermistor sensors. This meter/sensor combination measures the rms power of both pulsed and CW signals. The power meters were themselves calibrated annually by Ben Loader at the National Physical Laboratory, who had loaned them in the first place. Hence the calibration of the exposure systems was traceable to the national standards maintained by NPL.

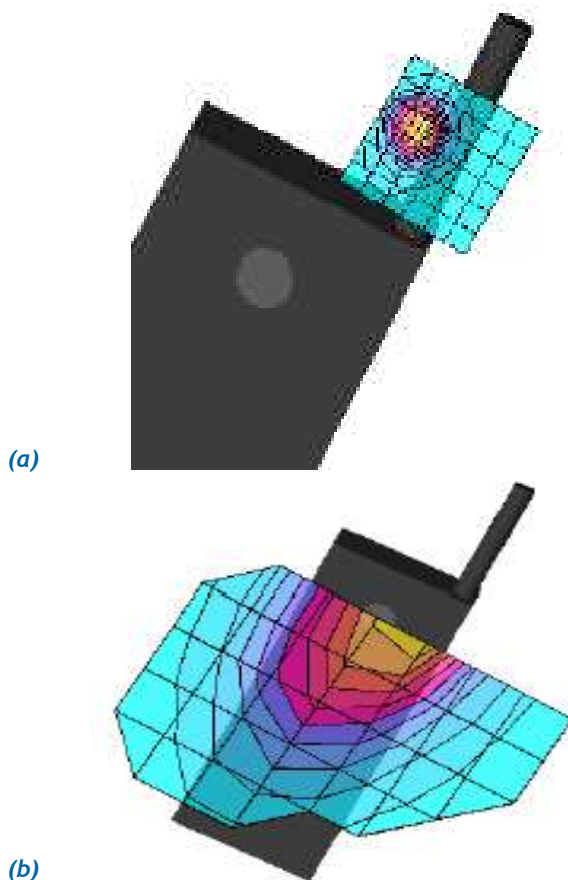


FIGURE A11 Spatial distributions of SAR close to: (a) antenna) and (b) unit body

Appendix B

MTHR Base Station Exposure System Specification

This appendix provides a technical description of the base station exposure system. As for the phone exposure system, we have explained in Section 5 of the report the considerations underlying our choice of exposure system design and exposure conditions. We again had a requirement to generate different types of signal (GSM/UMTS or TETRA). However, in this case the two studies that used the different signals followed each other. So, it was possible to have the supplier modify the system to convert it from a GSM/UMTS system to one generating a TETRA signal.

The system was designed by Bachir Belloul at Red-M Services Ltd and the technical description given below is taken from his technical reference manual. The description is given for the TETRA version of the system.

Technical description of the base station exposure system

This section describes the electromagnetic transmission system designed, implemented and installed by Red-M Services Ltd at the University of Essex. The system was developed as part of the MTHR Programme on the effects of electromagnetic exposure on hypersensitive individuals.

This system was designed to replicate real-world TETRA base station emissions as closely as practically possible, with repeatability of the transmit signal and control over the transmit parameters given high consideration for the purpose of the experiments for which the system was designed.

Transmit system description

Figure B1 shows the system set-up. As in the previous GSM/UMTS system, the current TETRA system's main component was the SMU200 digital signal generator from Rohde & Schwarz. The signal generator was

controlled by a dedicated PC via the Ethernet port. The PC also acted as a client station for the operating researcher to run the tests and daily checks.

System set-up

The RF output of the SMU200 was connected directly to a 10 W ETSA power amplifier optimised to operate at TETRA frequencies. The amplifier enabled the signal to be set to the correct levels to meet the requirements in terms of power density at the subject's area in the screened room.

The through-line microwave power meter (R&S NRP-Z11) fed the system's output power and return power back to the PC (via the serial port) for a continuous check of the transmitted power during the tests. The power meter reading was checked against a tolerance of 1 dB set by Red-M. Any deviation from the set power larger than 1 dB sent a warning signal back to the researcher via the user interface.

The digital signal generator, power amplifier and power meter were housed in a special rack.

The transmission system was linked to the transmit antenna by an LDF 4-50 coaxial cable. The cable was shielded and had a low loss characteristic.

Inside the screened room, the system radiated through a broadband (400 MHz to 3 GHz) log-periodic antenna (R&S HL040), mounted on a wooden tripod. The HL040 antenna had a 3 dB cutoff beamwidth of around 40° either side of the antenna's bore sight direction (Figure B2) and a high front-to-back ratio (>15 dB between 450 MHz and 3 GHz).

The subject's area was set at a distance of about 5 m from the antenna's centre of radiation and was 1 m across, giving an aperture of around 5.5° on either side, providing an almost constant gain (in free space) across the subject's area.

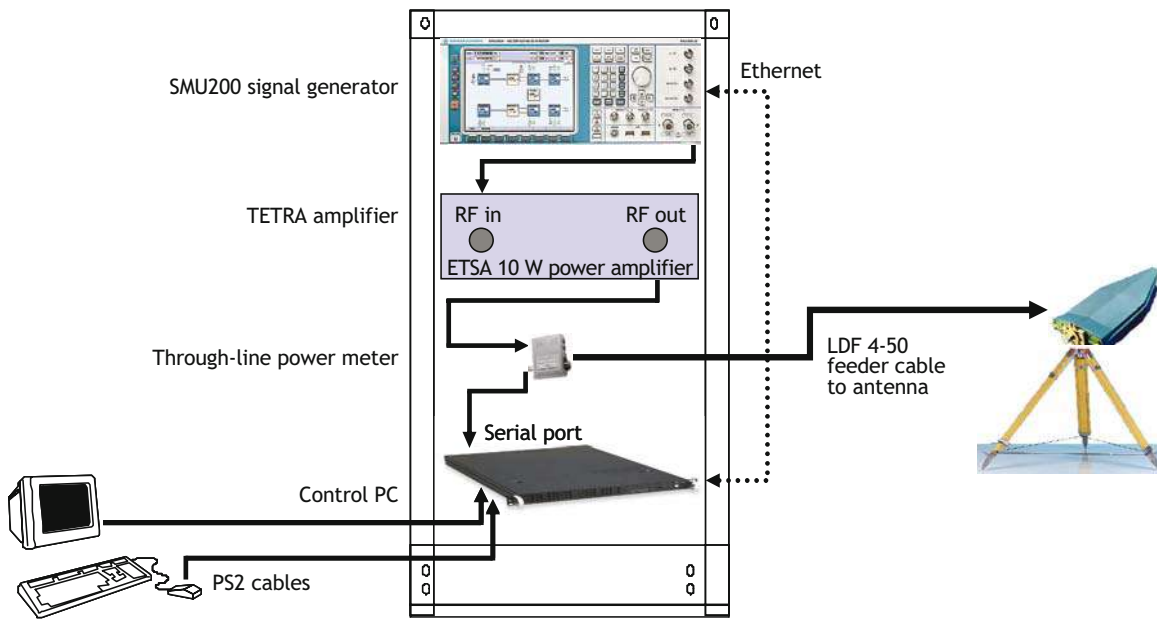


FIGURE B1 TETRA system setup

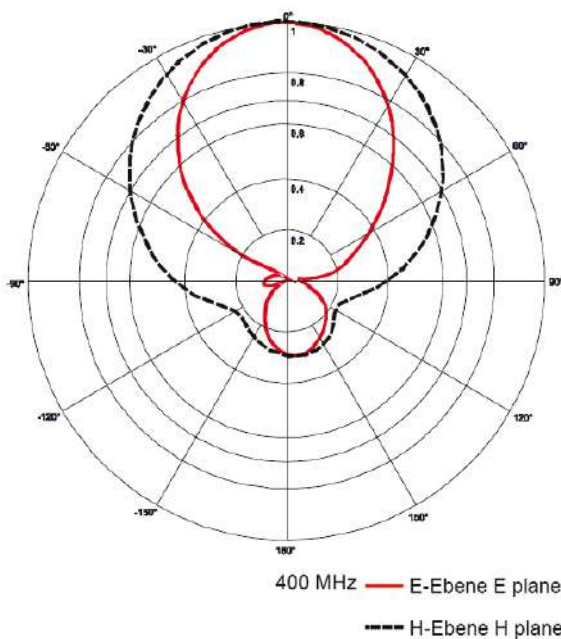


FIGURE B2 Radiation pattern of the HLO40 antenna at 400 MHz

Characteristics of the transmit signal

The characteristics of the transmit signal are summarised in Table B1.

TABLE B1 Transmit frequencies of the system

Parameter	Value
Frequency	420 MHz
Signal type	TETRA
Number of channels	1
Channel bandwidth	25kHz
Multiple access	TDMA
Modulation	$\pi/4$ DQPSK

Simulating the TETRA waveform

Although the TETRA standard (ETSI EN 300 392-2) is very clear with regard to the structure of the transmitted signal, there remains a large element of freedom in the way different manufacturers of base stations can set the various transmit parameters. For example, transmission modes (continuous or burst), the occurrence of the control channels or the type of modulation will be set according to a particular operator's requirements.

One other element of variability in the waveform consists of whether or not traffic is carried on the channel. This aspect was found to have a profound effect on the shape of the waveform.

To illustrate the impact of traffic on the waveform, Figure B3 shows what two successive TDMA frames will look like when captured on a spectrum analyser. The figure shows timeslots 1 to 4 of the two successive frames (ie timeslots 1,2,3,4,1,2,3,4). It should be noted that on timeslot 1 of each of the frames, there is no preamble (marked as FCCH, or frequency correction channel on timeslot 2 of frame 1 in the figure), while the remaining three slots in the frame do have an FCCH. The FCCH is used by the system to synchronise the transmit frequency.

In the TETRA standard, the FCCH is transmitted only if there is no traffic in the timeslot (incidentally, the FCCH is not a logical channel as such, but is defined as the frequency synchronisation block in the continuous downlink burst). In the example shown, none of slots 2, 3 or 4 of the two successive frames shown carries traffic. If any of slots 2, 3 or 4 were carrying traffic, then there would be no marked interval at the start of the slots, resulting in a continuous, 'uninterrupted' waveform being transmitted across the frame. Timeslot 1 does, however, carry traffic and so has no FCCH, as observed on the figure. Control channels also do not have an FCCH, but these do not occur on every frame and therefore have a lower repeat rate.

This situation had obvious implications for system implementation as the presence of traffic will have a direct repercussion on the presence or not of the various harmonics of the timeslots (the 17.6 Hz and the 70.5 Hz harmonics in particular).

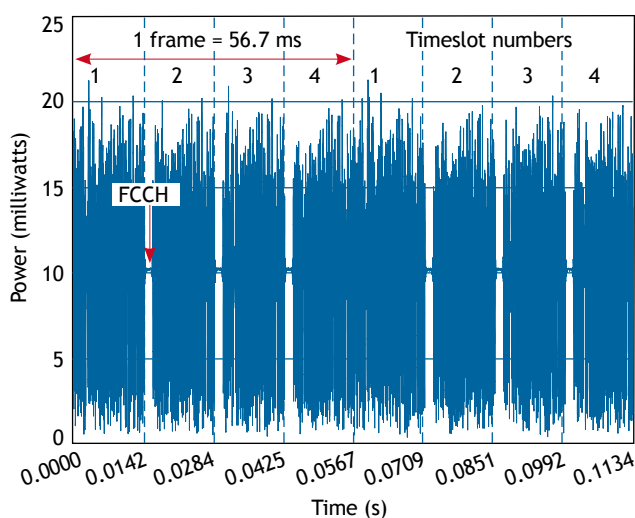


FIGURE B3 Laboratory-generated TETRA waveform showing two successive frames of four timeslots each

In agreement with the research team, Red-M implemented a signal containing balanced periods of traffic and non-traffic timeslots (over the period of the tests, 50% of the timeslots carried traffic and 50% did not). The traffic profile was generated according to a Markov process, similar to the one used for simulating the traffic in the GSM system.

System calibration

The first calibration (pre-commissioning) of the system was performed on 9 May 2007 following the guidelines set in the system installation guide. Subsequent calibrations were carried out at six-monthly intervals during the experimental period in order to confirm the stability of the system.

This section describes the calibration set-up and the results of the initial calibration.

Calibration set-up

Figure B4 illustrates the layout of the screened room. During the calibration process, the doors were closed and the probe positioned 4.95 m from the tip of the antenna and fixed to a plastic tripod that was moved laterally along the walkway, which is shown as a thick line.

Following each calibration measurement, the probe was re-positioned horizontally along the walkway by moving the tripod to the right (or to the left), as shown in Figure B5. Five measurement positions were used for each height of the probe, each separated by 25 cm. The central position was used as the reference position when reporting the results given below.

The tripod used for the calibration measurements was made of a non-conductive material. Once measurements at all five positions were completed at a given height, the tripod height was re-adjusted and the five lateral positions measured once more. The measurements were performed with the probe set at heights of 65 cm, 90 cm, 1.15 m and 1.4 m, as shown in Figure B5.

Measurements were made at a total of 20 positions, corresponding to a 'window' of size 1 m in width by 75 cm in height, representing approximately a cross-sectional area covering a subject's upper body, to include the upper legs, the abdomen, torso, shoulders and head when seated.

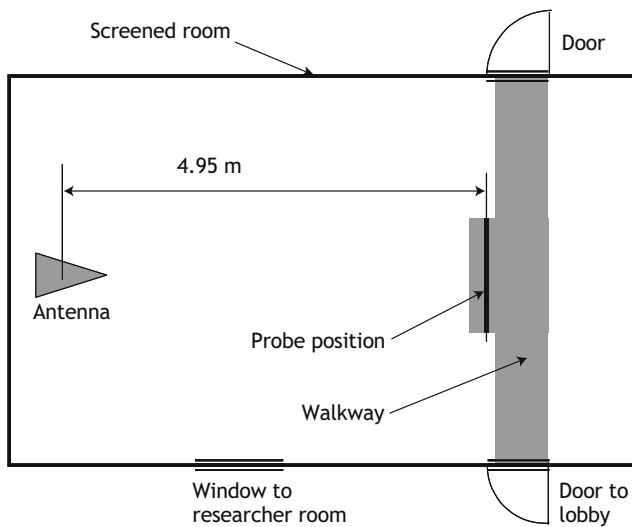


FIGURE B4 Layout of the screened room during calibration

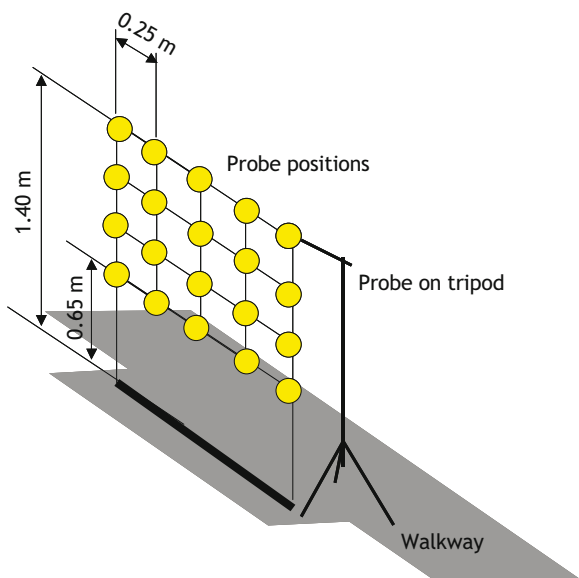


FIGURE B5 Positions of the probe during the measurements

Calibration results

For the calibration, the output power was initially set at the level required to provide a power density of 10 mW/m^2 at the centre of the subject's 'window'. Measurements of the power density at the positions described above were carried out and the average power across all the measurements estimated. An adjustment factor of the output power was then calculated and the power adjusted accordingly. A second set of measurements was carried out across the entire window and the following results are those of the second set of measurements.

The measurements were performed using an EMR300 probe, manufactured by Narda. The settings used on the EMR300 are given in Table B2. The measured values were then converted to mW/m^2 to be compared with the specifications set by the PMC.

TABLE B2 Settings on the EMR 300 power meter

Parameter	Value/comment
Calibration factor	1.0034
Power setting	Average
Averaging time	2 minutes
Measurement type	Power density
Probe barcode	4274
Meter barcode	628
Units	W/m^2

Power density levels measured at each of the probe positions are given in Table B3. The average power density value was calculated over the entire measurement area and found to be 11 mW/m^2 . The initial system requirements set the target power density level at the subject's area to 10 mW/m^2 , so this was approximately 0.4 dB out from the target level but well within the 3 dB variability tolerated by the requirements.

TABLE B3 Results of the measured power density at each probe position on 9 May 2007

Position	Measured power density (mW/m^2)				
	-50 cm	-25 cm	0 cm	+25 cm	+50 cm
1.40 m	3.50	22.50	38.40	7.20	0.90
1.15 m	3.10	22.40	37.50	6.30	3.60
0.90 m	1.70	13.60	23.20	5.20	1.50
0.65 m	3.90	9.60	11.00	4.00	1.80

However, the variability within the window remained large, with a range of values measured between 0.9 mW/m^2 (on the top right) and 38.4 mW/m^2 (top centre).

This variability was highlighted by Red-M and an action was put on the contractors who designed and installed the internal absorptive material. The subsequent addition of more absorber material reduced the variability, as can be seen in Table B4, which gives the results obtained on 11 January 2008. Following this modification, the average power density over

the measurement area dropped to around 8 mW/m² and remained within 1 dB of the target level for the remainder of the study.

Following the initial calibration of the system, Red-M performed a routine check of the system in order to establish the forward power and return loss recorded by the system's through-line power meter. The results of the check are given in Table B5.

TABLE B4 Results of the measured power density at each probe position on 11 January 2008

Position	Measured power density (mW/m ²)				
	-50 cm	-25 cm	0 cm	+25 cm	+50 cm
1.40 m	4.50	8.90	15.50	10.70	6.70
1.15 m	4.40	9.80	18.40	12.40	6.90
0.90 m	4.40	7.30	15.80	7.50	5.10
0.65 m	2.80	3.20	7.90	4.30	2.90

TABLE B5 Forward power and return power recorded during the calibration on 9 May 2007

Parameter	Measured power (dBm)
Forward power	24.14
Return power	16.89

Appendix C

Publications Arising from the MTHR Programme

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Appendix D

Membership of the MTHR Programme Management Committee

In order to ensure the independence of the MTHR Programme, an independent Programme Management Committee (PMC) was set up to decide on research priorities, select projects and manage the research. Sir William Stewart originally chaired the PMC, which included some members of the Independent Expert Group on Mobile Phones along with additional experts, who together provided 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, while in January 2008 Professor Challis was succeeded by Professor David Coggon.

New members have also been appointed from time to time to maintain the expertise needed for effective management of the programme.

Professor David Coggon OBE

Member 2008, Chairman 2008–2012



David Coggon studied mathematics and medicine at the universities of Cambridge and Oxford. He is currently Professor of Occupational and Environmental Medicine at Southampton University where he works in the Medical Research Council Lifecourse Epidemiology Unit. He has been engaged in epidemiological research for more than 30 years, focusing mainly on occupational and environmental causes of disease. Special interests include the relation of musculoskeletal disorders to physical activities in the workplace and psychosocial determinants, and the health effects of chemical pollutants. He is also a consultant occupational physician and holds an honorary contract with University Hospital Southampton NHS Foundation Trust. He is a Fellow of the Academy of Medical Sciences and Chairman of the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment. In the past, he chaired the Depleted Uranium Oversight Board and the Advisory Committee on Pesticides, and was a member of the Expert Panel on Air Quality Standards, the Industrial Injuries Advisory Council, the Independent Expert Group on Mobile Phones and the Advisory Group on Non-ionising Radiation. He was awarded the OBE in 2002.

Professor Lawrie Challis OBE

Vice-chairman 2001–2002, Chairman 2002–2008, Member 2008–2012



Lawrence 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. His research interests were on the properties of low dimensional semiconductors. In 1994 he 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. He was Vice-chairman of the Independent Expert Group on Mobile Phones and a member of the Advisory Group on Non-ionising Radiation and of the Health and Safety Management Committee of TETRA.

Professor Sir William Stewart FRS FRSE

Chairman 2001–2002



Sir William Stewart is a former Chief Scientific Adviser to the Prime Minister and to the Government and the first Head of the UK Government's Office of Science and Technology. He is a biologist by training and Emeritus Professor of Biology at the University of Dundee. He has served as President of the Royal Society of Edinburgh, as Vice-President of the Royal Society of London, Chairman of the Health Protection Agency, Tayside University Hospitals NHS Trust, the Microbiological Research Authority, the National Radiological Protection Board and Cyclacel plc, and as Chief Executive of the Agricultural and Food Research Council. He has served on various advisory committees including the Royal Commission on Environmental Pollution and the Natural Environment Research Council.

Professor Les Barclay OBE FREng

Member 2001–2002, Vice-chairman 2003–2012



Professor 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 Bradford, Lancaster and Surrey. He has been chairman of the study group on radiowave propagation within the International Telecommunication Union and chairman of the Scientific Committee on Telecommunications within the International Union of Radio Science. He is a Fellow of the Royal Academy of Engineering and is currently a member of the Electronics and Communications Divisional Board of the Institution of Electrical Engineers. He has been awarded the OBE and the Polar Medal.

Professor Colin Blakemore FRS

Member 2001–2003, Vice-chairman 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, where he was also Director of the Oxford Centre for Cognitive Neuroscience. 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 is a Fellow of the Royal Society and the Academy of Medical Sciences and is a member of several foreign academies, including the Chinese Academy of Engineering. He holds ten honorary doctorates and is an Honorary Fellow of the Royal College of Physicians, the Royal Society of Medicine and the Society of Biology. He has been President of the British Neuroscience Association, the Biosciences Federation (now the Society of Biology), the Physiological Society and the British Association for the Advancement of Science (now the British Science Association).

His research has been concerned with many aspects of vision and the early development of the brain. His awards include the international Alcon Prize for vision research, the Ralph Gerard Prize of the Society for Neuroscience, the Friendship Award from the People's Republic of China and both the Michael Faraday Award and the David Ferrier Award from the Royal Society. He is a former member of the Advisory Group on Non-ionising Radiation and was a member of the Independent Expert Group on Mobile Phones. Colin retired from the PMC in 2003, following his appointment as Chief Executive of the Medical Research Council. He is now Emeritus Professor of Neuroscience at Oxford and Professor of Neuroscience and Philosophy at the School of Advanced Study, University of London.

Professor Dame Glynis M Breakwell DBE DL

Member 2002–2007



Professor Dame 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. In 2012 she was made a DBE for her contribution to higher education. Her research on identity process theory and on the psychology of risk management has led to many awards and recognition from academic and professional bodies (including being made an Honorary Fellow of the British Psychological Society and an Academician of the Academy of Social Sciences). She has authored or co-authored more than 400 refereed journal articles and conference papers, authored or co-authored 13 books, and edited or co-edited a further 15.

Dame Glynis is a member of the Council of the Economic and Social Research Council (and chairs its Research Committee). She is a director of Universities UK, of the Student Loans Company and of the Universities Superannuation Scheme. She is a director of the West of England Local Economic Partnership and Deputy Lieutenant of Somerset. She is chair of the Daphne Jackson Trust and a member of the RCUK Panel on public engagement in research. She is a member of the World Cultural Council prize committee.

Professor Clair Chilvers BSc(Econ) MSc DSc FFPHM

Member 2002–2005



Professor 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 R&D 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.

Professor Paul Elliott MA MB BS MSc PhD FRCP FFPHM FMedSci

Member 2001–2008



Paul Elliott trained in mathematics and medical sciences at the University of Cambridge, and clinical medicine at University College Hospital Medical School, London. He worked as a medical epidemiologist at the London School of Hygiene and Tropical Medicine for 13 years and was Head of the Environmental Epidemiology Unit, from 1990 to 1995. He is currently Professor of Epidemiology and Public Health Medicine in the School of Public Health at Imperial College London and is Director of the MRC-PHE Centre for Environment and Health which incorporates the Small Area Health Statistics Unit (SAHSU). Professor Elliott is principal investigator of the AIRWAVE health monitoring study in UK police officers which is studying the possible long-term health effects from the use of the TETRA airwave communication system. He also leads the UK arm of the international COSMOS study on mobile phone use and health. He wrote the chapter on adult cancers for the WHO Environmental Health Criteria No. 238 on Extremely Low Frequency Fields (2007). He has been a member of a number of high-level scientific and government advisory boards including Defra's Science Advisory Council (2006–2009), representative for the Academy of Medical Sciences on the National Information and Governance Board (2011–2013) and the Government Chief Scientist's Blackett Review on Biodetection (2012–2013). He is a lead investigator for UK Biobank and a founding member of its Steering Committee. He chaired the Phenotype Enhancements Committee which made recommendations for biochemical, occupational and environmental enhancements to the UK Biobank resource.

Dr Tony Fletcher

Member 2008–2012



Dr Tony Fletcher is Senior Lecturer in Environmental Epidemiology at the London School of Hygiene and Tropical Medicine having been there since 1992, and Adjunct Research Professor in Environmental Health in the School of Public Health, Boston University, Massachusetts, USA, since 2007. He has previously been employed at the International Agency for Research on Cancer (IARC), the MRC Environmental Epidemiology Unit in Southampton, and Birmingham and Aston universities.

He has worked for over 30 years in occupational and environmental epidemiology and risk assessment, and has experience of studies of cancer, endocrine disruptors and gene-environment interaction. Major studies he has led include two multicountry environmental epidemiology projects funded by the European Union: 'ASHRAM' on cancer risks in relation to water contaminated by arsenic in Central Europe and 'PATY' on the respiratory effects of air pollution in 12 countries in Europe, North America and Russia. More recently he has been running a study on health effects of drinking water exposure to perfluorooctanoic acid (PFOA or C8), in West Virginia and Ohio, USA.

Dr Simon Gerrard

Member 2001–2003



During his PMC membership Dr Simon Gerrard was 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 adviser 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 was 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 focused on three main case study areas: waste disposal (including radioactive wastes), mobile phones and climate change. The key themes within these areas were 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 was involved in the UK element of the HERMES research project which is seeking to develop a European perspective on the management of base stations. Since 2003 Dr Gerrard has been working in low carbon innovation within the Adapt Group at the University of East Anglia.

Professor Ted Grant

Member 2001–2010



Professor Grant studied 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 joined MCL as Principal Scientific Consultant and Non-executive Director. He was a member of the Board of NRPB from 1989 to 1997 and was a member of the Advisory Group on Non-ionising Radiation for 11 years. Professor Grant was also Chairman of the BSI GEL 106 Committee concerned with the development of international standards to assess human exposure to electromagnetic fields. Professor Grant retired from the MTHR Programme Management Committee in January 2010.

Professor Patrick Haggard

Member 2003–2012



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

Member 2001–2012



Professor Kjell Hansson Mild worked at the Swedish National Institute for Working Life and at Örebro University, where he conducted research on the bioeffects of electromagnetic fields. He has worked on the bioeffects of electromagnetic fields since 1976. After the closure of NIWL he transferred to Umeå University, Department of Radiation Sciences, in 2007. He has a background in physics and theoretical physics, and he presented his thesis in 1974 on problems on cell membrane permeability and the state of water in the cytoplasm. In the last 15 years he has carried out research on mobile phone use and brain tumours. Presently he is also working on the effects of occupational exposure from the MRI machines.

Professor Hansson Mild has published over 300 articles and 200 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. He has also served as associate editor for the journal *Bioelectromagnetics* during the years 1988 to 1996.

Professor Niels Kuster

Member 2001–2012



Niels Kuster was born in Olten, Switzerland, in June 1957. He received a master's degree in electrical engineering and a doctoral degree in technical science from the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. In 1993, he was elected as Professor at the Department of Electrical Engineering of the Swiss Federal Institute of Technology (ETH) in Zurich. In 1999 he was appointed as Director of the Foundation and Laboratories for Research on Information Technologies in Society (IT'IS), Switzerland (www.itis.ethz.ch). 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. This includes:

- a** measurement technology
- b** computational electrodynamics for evaluation of close near fields in complex environments (eg handheld or body-mounted transceivers and living-work environments)
- c** exposure assessments
- d** development of exposure setups and quality control for bioexperiments evaluating interaction mechanisms and therapeutic effects as well as potential health risks
- e** wireless life support systems

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 bioexperiments. He is a member of several standardisation bodies and has acted as a consultant for several government agencies around the globe 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

Member 2001–2008



Alastair McKinlay was Head of the Physical Dosimetry Department in the Radiation Protection Division of the Health Protection Agency until his retirement in 2009.

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 former Chairman of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). He has been active in the International Commission on Illumination (CIE) for many years and is a past Chairman of the United Kingdom National Committee. He is a founder member and a past president of the European Society for Skin Cancer Prevention (EUROSKIN). He has served as a member of several WHO risk assessment groups dealing with non-ionising radiations and was formerly a member of the WHO International EMF and INTERSUN Programmes Advisory Committees.

Professor Jim Metcalfe

Member 2001–2012



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 powerline 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.

Dr Mike Repacholi

Member 2001–2007



Michael Repacholi is a graduate of the University of Western Australia (BSc, physics), London University (MSc, radiation biology) and Ottawa University (PhD, biology). He is co-author of over 220 scientific publications and is currently a visiting professor in the Department of Information Engineering, Electronics and Telecommunications (DIET), University of Rome 'La Sapienza'.

He initiated the International EMF Project at the World Health Organization, Geneva, in 1995 and was Coordinator of the WHO Radiation and Health Unit until retirement in June 2006. He has participated in 14 WHO task groups on various aspects of non-ionising radiation, was a founding member and chaired the International Non-Ionizing Radiation Committee of the International Radiation Protection Association (INIRC/IRPA) and was the first Chairman of the International Commission on Non-Ionizing Radiation Protection at its inception in 1992. In May 1996 he was elected Chairman Emeritus of ICNIRP.

He was awarded honorary doctorates in 2002 from the Minsk Medical University for his contribution to Belarus on the Chernobyl accident and from San Marco University in 2011 for his contribution to Peru on non-ionising radiation protection. Prior to this he was awarded the WG Morgan Lectureship for 'Outstanding international contributions to the radiation field' June 1993 by the Health Physics Society, honorary life membership in the Italian Radiation Protection Society in 1994, the Russian Academy of Medical Science's Speransky Gold Medal for 'Great contributions to protection against ionizing and non-ionizing radiation' and the NW Timofeef-Ressovsky Medal for 'Valuable contribution to research on the effects of non-ionizing and ionizing radiation on human health and the environment' in 2004.

Dr Repacholi is Fellow and Past President of the Australian Radiation Protection Society, and the Australian College of Physical Sciences and Engineering in Medicine.

Professor Michael Rugg FRSE

Member 2001–2003, Member 2005–2012



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

Member 2001–2012



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 National Radiological Protection Board (whose functions are now carried out by Public Health England) 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 member of the International Commission on Non-Ionizing Radiation Protection and a member of a number of other groups and committees concerned with the effects of non-ionising radiation.

Dr Emilie van Deventer

Member 2006–2012



Emilie van Deventer obtained her PhD from the University of Michigan, USA, in electrical engineering. She became a professor at the University of Toronto, Department of Electrical and Computer Engineering, in 1992 where she was awarded a Junior Chair in Electromagnetics. She joined the World Health Organization in 2000, where she has been the team leader of the Radiation Programme since 2006. Her activities focus on the development of scientific documents, policy frameworks and information brochures relating to public health protection from non-ionising radiation. She is a WHO designated observer on several groups and committees concerned with the effects of ionising radiation (ICRP Committee 4) and non-ionising radiation (Swedish Radiation Safety Authority).

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