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Dear Dr Stoate

Parliamentary Commission on Childhood Leukaemia and Electric and Magnetic Fields (EMF)

My apologies for the delay in returning to you the evidence you requested on the position taken by my organisation on the increased risk of childhood leukaemia that might be posed by living in close proximity to powerlines and how this view has evolved in response to scientific papers published in recent years. As my PA explained to you, I spent much of the month before Christmas in London helping to deal with the polonium-210 poisoning incident and so was unable to complete this report for you.

The main text explains how the views of the National Radiological Protection Board (NRPB) and its successor organisation the Radiation Protection Division (RPD) of the Health Protection Agency (HPA) have developed in response to scientific publications, with our most recent advice being given in 2004. I have also included two Annexes that summarise the work on dosimetry and experimental biology that we have undertaken in recent years and an indication of the funding that has gone into the work.

I hope this gives you the information you require but if you need further information, I would be pleased to help you.

Yours sincerely

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cc Dr R Cox
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INVESTOR IN PEOPLE



NRPB Radiation Protection Division, formerly
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HEALTH PROTECTION AGENCY

SUBMISSION OF EVIDENCE

PARLIAMENTARY COMMISSION ON CHILDHOOD LEUKAEMIA AND ELECTRIC AND MAGNETIC FIELDS

Introduction

The Parliamentary Commission on Childhood Leukaemia and Electromagnetic Fields (EMFs) has requested the Health Protection Agency (HPA) to provide information on the position statements that it has made in relation to health effects of exposure to electric and magnetic fields and the background thinking behind them. HPA was particularly asked to detail the view of the organisation on the increased risk of childhood leukaemia that might be posed by living in close proximity to power lines, and how this view has evolved in response to scientific papers published over recent years. The Commission also asked for information on how much investment has been made by HPA in this work.

The following notes summarise how the policy and advice of the National Radiological Protection Board (NRPB) and its successor organisation the Radiation Protection Division (RPD) of the HPA have developed in this area in recent years. The development of NRPB/RPD policy has been influenced by advice from the independent Advisory Group on Non-ionising Radiation (AGNIR). The developing views of AGNIR on exposure to EMFs and the risk of childhood cancer, and in particular leukaemia, are also described.

Whilst HPA staff have some involvement in the work of the Stakeholders Advisory Group on Extremely Low Frequency (ELF) Electromagnetic Fields (SAGE) this work is distinct from the development of HPA advice and is not addressed here.

Dosimetry studies carried out by NRPB/HPA in support of epidemiological studies set up to address the question of childhood leukaemia and exposure to power frequencies are covered in Annex A and experimental studies are summarised in Annex B.

This is a topic that remains an active research area. HPA staff have a watching brief to monitor scientific developments and are also conducting relevant research as described in the Annexes. Further advice will be issued if new evidence becomes available that alters the views expressed in this evidence.

Background

Modern industrial and technological development has resulted in people being increasingly exposed to a complex mix of electric and magnetic fields and radiations that cover a wide frequency range. Major sources of exposure to EMFs arise from electrical power generation, transmission and use in residential and occupational situations and from telecommunications and broadcasting. In addition, electronic devices for communications, security and process control have proliferated in industrial plants, in offices, homes, cars and in the environment.

The HPA (up to 1 April 2005 the NRPB) has a statutory responsibility to advise UK Government Departments and others on standards of protection for exposure to non-ionising radiation. This covers static and low frequency EMFs and radiofrequency radiations (including microwaves) as well as optical radiation (including ultraviolet radiation). The electromagnetic spectrum is shown in the Figure and the frequency range for different sources is summarised in the Table.

There has been increasing interest over the last 25 years in the possible health effects of exposure to magnetic fields from extremely low frequency (ELF) EMFs from powerlines and in particular whether they can influence the development of childhood leukaemia. Cancer in children was first associated epidemiologically with exposure to EMFs in 1979 when Wertheimer

and Leeper in the USA reported an excess of high current configuration powerlines near the homes of children who developed cancer, as compared to the homes of control children. The cause of the correlation was uncertain but possible effects of currents in water pipes or power frequency magnetic fields were suggested.

Many other studies were reported in the following 12 years that examined the risk of cancer and exposure to domestic sources of EMFs, to parental exposure, or to employment in occupations where exposures to such fields might be unusually high. Many of these studies were reviewed in a draft document issued by the United States Environmental Protection Agency (US EPA) on *An Evaluation of the Potential Carcinogenicity of Electromagnetic Fields*. This draft report, which became available in 1990 was not formally published but received considerable scientific and media attention. A substantial research programme was set up by the US Department of Energy in 1992 on the possible consequences of exposure to power frequencies EMFs. The Electric and Magnetic Fields Research and Public Information Dissemination (EMF RAPID) Programme co-ordinated the federal research programme on EMFs, evaluated the results, and provided information for the public.

Advisory Group on Non-ionising Radiation (AGNIR)

As a consequence of developing concerns about possible health effects of exposure to EMFs the Director of NRPB set up, in 1990, an independent Advisory Group on Non-ionising Radiation (AGNIR) under the chairmanship of Sir Richard Doll. The Group was given a remit:

To review work on the biological effects of non-ionising radiation relevant to human health and to advise on research priorities.

The first task of the Advisory Group was to consider epidemiological and experimental studies on carcinogenic effects of EMFs and to determine the extent to which the evidence suggested they should be treated as a potential carcinogen. The Group issued its first report in 1992 (AGNIR, 1992). The AGNIR was reconstituted in 1999 and now reports directly to the Centre Sub-Committee of the Board of HPA.

The membership and programme of work of AGNIR is considered by the Centre Sub-Committee annually and posted on the HPA web site (www.hpa.org.uk/radiation).

AGNIR 1992 Report

The 1992 report by AGNIR comprehensively reviewed experimental and epidemiological studies concerned with the effects of exposure to static and time varying EMFs. The experimental evidence reviewed strongly suggested that these fields do not harm genetic material and so would not normally be expected to initiate cancer. There was, however, a possibility that they might act as tumour promoters, that is, they might increase the growth of potentially malignant cells. The results of experimental studies, when taken together were, however, inconclusive. It could not be concluded that any effect of EMFs on cells and tissues could be regarded as potentially carcinogenic in humans.

The epidemiological studies that were examined related to both residential and occupational exposure. Most studies reviewed related to exposure to ELF EMFs. Although some studies had suggested that the incidence of leukaemia may be influenced by exposure to power frequency magnetic fields (50 Hz in the UK, 60 Hz in North America), a review of the totality of the evidence indicated that the excess reported could have resulted from selective publication and the inappropriate choice of controls. The only epidemiological finding that was at all notable was the consistency with which "the least weak evidence relates to a small risk of brain tumours". This had been reported both in some residential studies in children and in some occupational studies. As brain tumours in childhood and adult life are different in origin, arising from different types of cell, this evidence was considered to be less impressive than it might appear.

In the absence of any unambiguous experimental evidence to suggest that exposure to EMFs was likely to be carcinogenic, the AGNIR concluded that:

The epidemiological findings that have been reviewed provide no firm evidence of the existence of a carcinogenic hazard from exposure of paternal gonads, the fetus, children, or adults to the extremely low frequency electromagnetic fields that might be associated with residence near major sources of electricity supply, the use of electrical appliances, or work in the electrical, electronic, and telecommunications industries.

The Group also concluded that the findings could only be regarded as sufficient to justify formulating a hypothesis for testing by further investigation and made a number of recommendations for further work. It stressed that experimental studies would have a significant role to play in resolving uncertainties on the possible association between EMFs and carcinogenesis. It also supported the need for further epidemiological studies. The Group stated that there was a strong case for carrying out a large scale epidemiological study of cancer in children. It noted in a recommendation that:

Children's cancers have the advantage from the point of view of epidemiological investigation that past exposures of the children relevant to the causation of disease can have been only brief and, in most cases, it is possible to identify and make measurements in all the locations in which the children have lived.

The AGNIR considered that research along these lines should be carried out as soon as possible.

AGNIR 1994 Statement

Following publication of the first report of the AGNIR, several more epidemiological studies were reported relating to residential and occupational exposure to power frequency EMFs. The Group issued a Supplementary Report in April 1994 (AGNIR 1994) giving its views on these additional studies and on the results of more recent experimental investigations.

Three residential studies of childhood cancer, including leukaemia, conducted in Scandinavia (from Sweden, Denmark and Finland) were reviewed. The Group considered that these more recent studies on childhood leukaemia were well controlled and provided substantially more information than those that had previously reported associations with childhood cancer. The studies did not, however, establish that "exposure to electromagnetic fields is a cause of cancer but, taken together, they do provide some evidence to suggest that the possibility exists in the case of childhood leukaemia. The number of affected children in the studies is, however, very small"

Experimental studies were also considered by the AGNIR. It was concluded that to date they had failed to establish any biological mechanism whereby carcinogenic processes can be influenced by exposure to the low levels of EMFs to which the majority of the population are exposed.

The Group concluded in its 1994 Statement that:

there is no persuasive biological evidence that ELF electromagnetic fields can influence any of the accepted stages in carcinogenesis. There is no clear basis from which to derive a meaningful assessment of risk nor is there any indication of how any putative risk might vary with exposure.

Exposure Guidelines issued by NRPB in 1993

These reviews by AGNIR were taken into account by NRPB when it issued advice on restrictions on human exposure to static and time-varying EMFs and radiation in 1993 (NRPB, 1993). It was

concluded that the reviews from AGNIR and other bodies provided no clear evidence of adverse health effects at the levels of exposure to EMFs to which people are normally exposed.

NRPB's guidance was, therefore, based on available biological data describing thresholds for well-established direct and indirect effects of acute exposure. In the case of exposure to ELF electric and magnetic fields, the restrictions were intended to avoid the effects of induced electric currents on functions of the central nervous system such as the control of movement and posture, memory, reasoning and visual processing. Exposure to much higher magnetic fields had been reported to result in headaches and nerve and muscle stimulation. The 1993 guidelines were also set to avoid the possibility of indirect surface electric charge effects such as contact currents and microshocks.

AGNIR 2001 Report

The AGNIR was asked by the Board of NRPB to maintain a watching brief on epidemiological studies and experimental work related to an assessment of the health effects of exposure to ELF EMFs. In 2001 it published its second major report on *ELF Electromagnetic Fields and the Risk of Cancer* (AGNIR, 2001). In the 8 years since the first AGNIR report (AGNIR, 1992) much of the experimental work that was being carried out at that time had been completed. A number of substantial occupational and residential epidemiological studies had also been published, some of which had taken advantage of improved methods of exposure assessment and of experimental design. Additionally, a number of reviews on health effects related to exposure to EMFs have been issued. These included reviews by Oak Ridge Associated Universities (ORAU, 1998), the US National Research Council (NRC, 1997) and the National Institute of Environmental Health Sciences (NIEHS 1998).

The 2001 report by AGNIR was concerned specifically with the possible risk of cancer resulting from exposures to ELF EMFs. One limitation of the epidemiological studies published prior to the Group's 1992 report was the weakness of the information available on personal exposure. In residential studies, wire codes (proximity to power supply circuits) had been commonly used as a surrogate for individual exposure, despite the limitations in the approach and the possibility of confounding. In subsequent years considerable advances had been made that permitted substantial improvements in measurements of exposure at work and at home and exposure assessments had therefore been used extensively in human health studies (See Annex A).

In particular four studies published in Scandinavia and case control studies of childhood cancer carried out in the United Kingdom, in North America and in Canada had put emphasis on exposure assessments. In North America, the National Cancer Institute and the Children's Cancer Group studied children diagnosed with acute lymphatic leukaemia in 11 US States (Linnet et al, 1997). A Canadian case-control study of childhood leukaemia considered children diagnosed with the disease between 1990 and 1995 (McBride et al, 1999).

In the UK, the Childhood Cancer Study (UKCCS) had examined a number of possible causes of childhood cancer, including exposure to ionising radiation such as radon in homes, potentially hazardous chemicals and EMFs. The magnetic field study was carried out in two phases, the second of which included a 48-hour measurement in homes (UKCCS, 1999). In addition a further study examined the incidence of childhood cancer as a function of distance from the electrical supply distribution network (UKCCCR, 2000). The main conclusion of these studies was that there was no evidence that exposure to magnetic fields in the UK increases risks for childhood leukaemia or any other childhood cancer.

These residential studies were the subject of an influential pooling analysis conducted by Ahlbom et al (2000). The analysis suggested the possibility of a doubling of the risk of childhood leukaemia in homes where the time-average exposure is estimated to be 0.4 μ T (400 nT) or higher (see Annex A). In most UK homes time averaged magnetic field levels are between 10 nT

and 100 nT (UKCCS, 1999). The individual studies and the pooling study were analysed by AGNIR together with experimental studies published since the first report.

The conclusions in the 2001 AGNIR report were that laboratory experiments have not provided evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general.

In relation to exposure of children, however, the Group considered that:

There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children. In practice, however, such levels of exposure are seldom encountered by the general public in the UK. In the absence of clear evidence of a carcinogenic effect in adults, or of a plausible explanation from experiments on animals or isolated cells, the epidemiological evidence is currently not strong enough to justify a firm conclusion that such fields cause cancer in children.

The Group also said that unless further research indicates that the finding is due to chance or to some currently unrecognised artefact, the possibility remains that intense and prolonged exposure to magnetic fields can increase the risk of leukaemia in children. The Board of NRPB concurred with this analysis (see below)

Sir Richard Doll retired as chairman of AGNIR in March 2003 and Professor Tony Swerdlow (Institute of Cancer Research, London) was appointed by the Board of NRPB as the new Chairman.

International Agency for Research on Cancer. Report on Childhood Leukaemia and Residential Exposure to Magnetic Fields

In 2001 a Working Group (WG) of the World Health Organization's International Agency for Research on Cancer (IARC) reviewed health effects of static and ELF EMFs (IARC, 2002).

The IARC WG examined epidemiological and experimental studies relevant to an understanding of possible health effects of exposure to static and ELF electric and magnetic fields. They concluded that the pooled analysis of data from a number of well conducted studies (Ahlbom, 2000) had shown a fairly consistent statistical association between a doubling of the risk of childhood leukaemia and exposure to power frequency, (average) residential ELF *magnetic field* strengths above 400 nanotesla (nT) (equivalent to 0.4 μ T).

In contrast, no consistent evidence was found that childhood exposures to ELF electric or magnetic fields are associated with brain tumours or any other kinds of solid tumours. No consistent evidence was found that residential or occupational exposure of adults to ELF magnetic fields increase risk for any kind of cancer. Studies in experimental animals have not shown a consistent carcinogenic or co-carcinogenic effect of exposure to ELF magnetic fields and no scientific explanation has been established for the observed association of increased childhood leukaemia risk with average exposures above 400 nT.

Overall, extremely low frequency magnetic fields were evaluated as possibly carcinogenic to humans (Group 2B, see below), based on 'limited' epidemiological evidence of a statistical association of higher level residential ELF magnetic fields and increased risk of childhood leukaemia. ELF electric fields could not be classified as to carcinogenicity to humans (Group 3).

IARC Classification Scheme for Potential Carcinogens

<i>Group</i>	<i>Effect</i>
Group 1	exposure is carcinogenic to humans
Group 2A	exposure is probably carcinogenic to humans
Group 2B	exposure is possibly carcinogenic to humans
Group 3	exposure is not classifiable as to its carcinogenicity to humans
Group 4	exposure is probably not carcinogenic to humans

It should be noted that in the IARC procedure, the Group 2B classification means that a positive association has been observed for which a causal interpretation is considered credible, but that chance, bias or confounding could not be ruled out with reasonable confidence. The Group 3 classification indicates that either the available studies are of insufficient quality, consistency or statistical power to permit a conclusion, or that no data on cancer are available.

NRPB Board Statement on AGNIR 2001 Report

The Board of NRPB welcomed the 2001 AGNIR report and in a published Statement noted in particular, that the question of whether exposure to EMFs can influence the development of cancer cannot at present be completely resolved. It was estimated that there are around 500 cases of leukaemia and about 1000 cases of other cancers reported in children (under 15 years) in the UK each year. The report by AGNIR concludes that any risk relates to leukaemia in children and young persons and in particular to those exposed at relatively high levels of average domestic exposure to magnetic fields at or above 400 nT.

In the absence of any special effect of magnetic fields, and assuming that these cases occur at random in the population, two of the 500 cases of childhood leukaemia occurring annually in the UK would be expected to be associated with exposures of 400 nT or more. If there was an effect of magnetic fields at high levels of domestic exposure a further two cases might occur. As not all cases of childhood leukaemia are fatal, an effect of exposure to high levels of exposure to magnetic fields, if confirmed, might cause an additional death a year. As had been demonstrated in the UKCCS it has not been possible to detect this increase in the UK.

The Board also noted that there is no evidence that residential exposure to EMFs is involved in the development of cancer in adults, and in particular of leukaemia or brain cancer.

The Board considered that despite the small proportion of children in the UK likely to be exposed at levels above 400 nT there was a need to understand better the factors in the UK that might result in such levels of residential exposure to magnetic fields. It was known from the results of the UKCCS that this is not solely due to proximity to power lines. International work in this area may help to explain the observed association between high levels of exposure and an increase in the leukaemia risk in children. Work undertaken by NRPB/HPA in this area is described in Annex A.

The Board considered that the AGNIR report provided no additional scientific evidence to require a change in its recommended exposure guidelines. The Board did, however, support the need for a full review of the scientific basis of the exposure guidelines which was initiated in 2001.

Exposure Guidelines issued by NRPB in 2004

NRPB issued new advice on exposure guidelines for EMFs (NRPB, 2004b) following a review of the relevant scientific data (NRPB, 2004a) and an extensive consultation exercise. Advice was obtained from an ad hoc expert group that was set up by NRPB to consider the effects of weak electric fields in humans and from external scientists. The review of recent scientific information, the need to adopt a cautious approach to the interpretation of these data, and a recognition of

the benefits of international harmonisation, were combined in the Board's recommendation to adopt the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for occupational and public exposure to EMFs between 0 and 300 GHz (ICNIRP, 1998).

The main physical effect of high levels of exposure to EMFs of frequencies less than about 100 kHz, which include power frequencies, is the induction of electric fields and currents in body tissues. These can cause adverse health effects and provide the basis for the exposure guidelines recommended by ICNIRP. This is the same basis as had been adopted by NRPB in 1993.

The detailed scientific analysis supported the recommendation by ICNIRP that exposure guidelines for members of the public should be more restrictive than for workers. Generally occupational exposure concerns healthy adults working under controlled conditions. These conditions include the opportunity to apply engineering and administrative measures and, where necessary and practical, provide personal protection.

For members of the public, similar controls do not generally exist, and individuals of varying ages can have wider variability in health status and responses to exposures to EMFs. NRPB judged that, on the basis of recent evidence, the potential for such differences in response needs to be taken into account in recommending exposure guidelines for the public (NRPB, 2004a). The ICNIRP recommendation of a reduction factor of five in the basic restrictions for members of the public compared with workers was considered appropriate.

The Board of NRPB recognised the concerns that prolonged low level exposure to EMFs across the range 0-300 GHz may be implicated in the development of long-term health effects, in particular childhood cancer. The relevant epidemiological and biological studies related to exposures to both power frequencies and radiofrequencies had been reviewed in the reports by AGNIR (AGNIR, 2001, 2003) and it had been concluded that there is no firm evidence of such adverse health effects at the levels of EMFs to which people are normally exposed.

An association between prolonged exposure to intense power frequency magnetic fields and a small raised risk of childhood leukaemia had, however, been found. Such studies taken together with people's concerns provided the basis for the Board's advice, that in addition to the recommendation on the quantitative restrictions recommended by ICNIRP, "the need for further precautionary measures should be considered by government", (NRPB, 2004a). Melanie Johnson MP (Under Secretary of State for Public Health) welcomed the new advice from NRPB (DoH, 2004).

Following publication of the 2004 report the Government set up the Stakeholders Advisory Group on ELF Electromagnetic Fields (SAGE). The work of SAGE has been directed to understanding the sources of exposures to EMFs in the home and the extent to which practical measures could be taken to reduce them if considered necessary.

Childhood Cancer and Distance from High-Voltage Power Lines (Draper et al, 2005)

Subsequent to publication of the 2004 Guidelines by NRPB, a study by Draper *et al* (2005) considered the risk of developing childhood cancer in relation to proximity to the power lines rather than electric or magnetic field strengths. The study involved 29,081 cases of cancer in children aged 0-14 years who were diagnosed during 1962-95. For each case, a matched control was selected. For each case and control, the distance of residence at the time of birth to the nearest high-voltage overhead power line was calculated. The study concerned all 275 and 400 kV overhead lines in the UK and a small fraction of 132 kV lines.

Draper *et al* found that, compared with children born more than 600 m from a line, the risk of leukaemia was greater by a factor of 1.69 for those born within 200 m and by a factor of 1.23 for those born between 200 and 600 m; both these elevations were statistically significant. In

contrast to leukaemia, there was no tendency for the risk of other childhood malignancies to increase with increasing proximity to a power line.

Draper *et al*'s study covered cases over a much longer period than the UKCCS analysis. Also, since the UKCCS investigators approached parents to collect extra data, the UKCCS may be susceptible to bias because some potential study members did not participate. On the other hand, the UKCCS collected detailed data on the children's exposure to EMFs, together with data on possible confounding factors.

Draper *et al* estimated that, of the 400-420 cases of childhood leukaemia that occur annually in England and Wales, their results suggested that about five cases might be associated with living in proximity to high voltage power lines. This is more than twice the previous estimates of about two cases per year in the UK (AGNIR, 2001), based on the doubling of risk at exposures above about 0.4 μ T reported by Ahlbom *et al* (2000), although Draper *et al* stressed that their estimate is very imprecise. In particular, it is highly dependent on their findings more than 200 m from lines, whose interpretation is unclear.

The absence of field measurements in homes and the lack of information on potential confounders make it difficult to know whether the raised risks reported for leukaemia indicated a possible direct effect of electromagnetic field exposure. However, certain findings, such as a weaker evidence for a raised risk when an alternative set of controls is used and a raised risk reported more than 200 m from a line, where the magnetic fields from lines are at or below background levels, would suggest that at least some of the increased leukaemia risk may be associated with factors other than EMFs.

There are therefore some problems interpreting the results of the study and the authors did not regard their findings as establishing a definite causal association between childhood leukaemia and exposures to EMFs from power lines.

AGNIR 2004 Report on Corona Ions

In the late 1990s it was suggested that the strong electric fields that occur in the vicinity of power lines might increase the adverse effects of atmospheric pollutants on the health of the general public. Such pollutants include radon decay products, chemicals, spores, bacteria and other organisms. It had been suggested that deposition of pollutant particles present in the atmosphere on the skin and in the lungs may be increased if they are electrically charged. High voltage electricity transmission lines may cause corona discharge, which can increase the charge on pollutant particles.

The effect of charge on the deposition of pollutant particles has been examined in a report by AGNIR (AGNIR, 2004). Although the review suggested that some increase in lung deposition of pollutant particles was likely as a result of charging by corona ions, and there could be some increased deposition on exposed skin, the Group concluded that:

it seems unlikely that corona ions would have more than a small effect on the long-term health risks associated with particulate air pollutants, even in the individuals who are most affected. In public health terms, the proportionate impact will be even lower because only a small fraction of the general population live or work close to sources of corona ions.

In its recommendations the Group considered that there was not a strong case for an epidemiological study to be carried out. It did consider that there was some merit in undertaking further work to understand the factors that could influence exposure to aerosols upwind and downwind of powerlines and the effects of charge on deposition in the lungs.

AGNIR 2006 Report on Melatonin and Breast Cancer

Finding a plausible biophysical mechanism that would support weak field interactions with living tissues, and give an explanation for the epidemiological association is an important goal of EMF research. In this regard, the most recent AGNIR report has relevance because it considers a hypothesis first made almost 20 years ago, that chronic exposure to power frequency EMFs may increase the risk of breast cancer via a reduction in melatonin secretion from the pineal gland (AGNIR, 2006). Disruption in melatonin brought about by exposure to EMFs has also been suggested to account for the increased risk of childhood leukaemia observed in pooled analyses of epidemiological studies (Henshaw and Reiter, 2005), although no direct data exist.

AGNIR concluded that there was no consistent evidence from research using cells, animals and humans, that EMF exposure was a cause of breast cancer, nor has a mechanism for such an association been demonstrated. This assessment was important in that it did not alter the previous AGNIR conclusions with respect to ELF EMF and cancer (AGNIR, 2001).

Conclusion

The development of NRPB and HPA advice on the possible increased risk of cancer, and in particular childhood leukaemia, as a result of exposure to electromagnetic fields has reflected the results of epidemiological and biological studies published in peer reviewed journals. The most recent advice was published in 2004 in the Documents of NRPB (NRPB, 2004a). It was concluded in that report that there is no firm evidence from epidemiological studies of such adverse health effects at the levels of exposure to EMFs to which people are normally exposed. An association between prolonged, high levels of domestic exposure to power frequency magnetic fields and a small raised risk of childhood leukaemia had, however, been found. Such studies, taken together with people's concerns, provided the basis for advice from the Board of NRPB that, in addition to the recommendation to adopt in the UK the guidelines on exposure to EMFs recommended by ICNIRP, "the need for further precautionary measures should be considered by government".

This is a topic that continues to develop and remains an active area of research in the UK and in other countries around the world. HPA staff have a watching brief to monitor scientific developments and are also conducting relevant research. Further advice will be issued if new evidence becomes available that alters the views expressed in this evidence.

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Table Electromagnetic Fields and their Sources

Frequency	Wavelength	Description	Band	Sources
0 Hz		Static		Earth's field Magnetic, DC supplies
<hr/>				
		Sub-extremely low frequency	SELF	
30 Hz	10 000 km			Electric power lines and cables. Domestic and industrial appliances
50 Hz	6 000 km	Extremely low frequency	ELF	
300 Hz	1 000 km			
		Voice frequency*	VF	Induction heaters
3 kHz	100 km			
		Very low frequency	VLF	Television sets Visual display units
30 kHz	10 km			
		Low frequency	LF	AM radio
300 kHz	1 km			
		Medium frequency	MF	Induction heaters
3 MHz	100 m			
		High frequency	HF	RF heat sealers
30 MHz	10 m			
		Very high frequency	VHF	FM radio
300 MHz	1 m			
		Ultra high frequency	UHF	Cellular telephones Television broadcast Microwave ovens
3 GHz	10 cm			
		Super high frequency	SHF	Radar Satellite links Microwave communications
30 GHz	1 cm			
		Extra high frequency	EHF	Point-to-point links
300 GHz	1 mm			
		Infrared		

*Radiofrequencies equivalent to speech (sound) frequencies.

Note – 1000 Hz = 1 kHz; 1000 kHz = 1 MHz; 1000 MHz = 1 GHz.

ELECTROMAGNETIC SPECTRUM

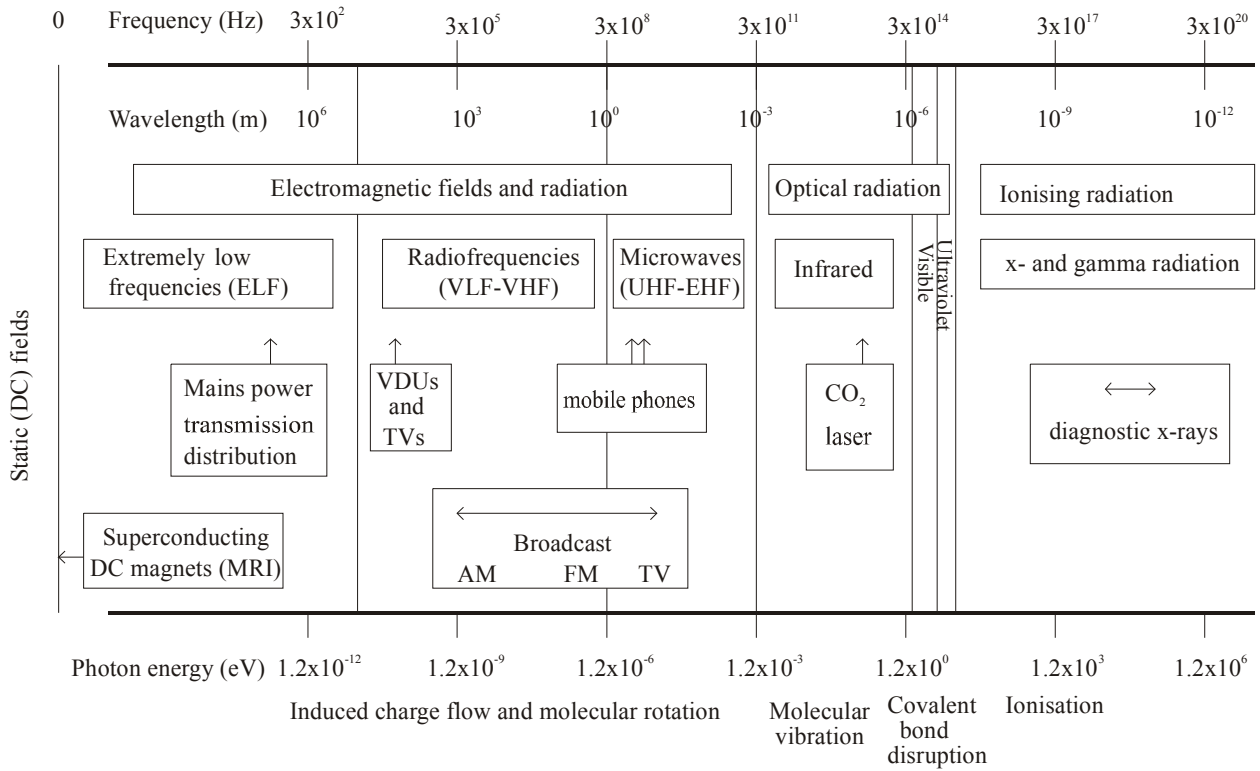


Figure The Electromagnetic Spectrum

ANNEX A

Dosimetry Research on ELF-EMF Relating to Childhood Leukaemia

The following notes summarise dosimetry related research conducted by NRPB/HPA in relation to electromagnetic fields (EMFs) and childhood leukaemia.

NRPB first became involved in this area of research in the early 1990s at a time when there was growing interest in the possible association between exposure to extremely low frequency (ELF) EMFs and childhood leukaemia, particularly in the USA. Since then, a programme of physical measurement-based research has been undertaken which has been aimed at developing knowledge about EMF exposure in the environment and supporting epidemiological and biological studies.

Research into the sources of exposure to EMFs has been made available to the Stakeholder Advisory Group on ELF EMF (SAGE).

It is estimated that NRPB/HPA has invested around £2,000,000 in these dosimetry studies over the period since 1990. The work has involved 1-2 person years per year. The research has been supplemented by funding from external bodies, notably from the UK Co-ordinating Committee on Cancer Research (UKCCCR).

The UK Childhood Cancer Study (UKCCS)

The bulk of the research has been in support of the UKCCS, at the time the largest and most comprehensive case-control epidemiological analysis of the possible causes of childhood cancer. Several distinct exposure-based hypotheses were assessed in the study, including childhood exposure to EMFs. Other factors considered have included exposure to radon, terrestrial gamma radiation and the use of various chemicals.

The key aspects of the NRPB/HPA dosimetry work included assistance in the design and development of appropriate exposure protocols; provision and development of instrumentation and instrument integrity check sources and the maintenance of calibration facilities; modelling and computation of exposure measures; and the training of study staff involved with data collection in 10 UK epidemiology regions in England, Wales and Scotland. Including preliminary work to investigate the feasibility of conducting exposure assessments in homes and schools and an investigation of the seasonal effects on exposure assessment, the work has involved research effort stemming from the early 1990s until the present.

Main Study on Magnetic Fields

UK Childhood Cancer Study Investigators (1999). Exposure to power frequency magnetic fields and the risk of childhood cancer. Lancet, 354(9194), 1925–31.

UK Childhood Cancer Study Investigators (2000). The United Kingdom Childhood Cancer Study: objectives, materials and methods. Br J Cancer, 82(5), 1073–1102.

The main UKCCS EMF study involved the assessment of the magnetic field exposure for more than 4,800 children on the basis of measurements in homes and schools and the key paper on magnetic fields was published in the Lancet in 1999. The study provides the largest body of information on childhood magnetic field exposure in the UK. The main conclusion was that there was no evidence that exposure in the UK increases risks for childhood leukaemia, cancers of the central nervous system, or any other childhood cancer. Some of the UK data were included in the international pooled analysis of Ahlbom *et al* which was published in 2000 and which forms the basis for the most recent AGNIR and IARC advice. The analysis suggested the possibility of a doubling of risk of childhood leukaemia in homes where the time-average exposure is estimated to be 0.4 μ T or higher.

Residential Proximity to Power Lines

UK Childhood Cancer Study Investigators (2000). Childhood cancer and residential proximity to power lines. Br J Cancer, 83(11), 1573–80.

The data obtained from the UKCCS study enabled the important public health issue of living near to power lines to be addressed. The study examined the circuit information provided by electricity companies for the homes of 3380 case and 2290 control children. The study was published in 2000, and the main conclusion was that there was no evidence that either residential proximity to power lines, or the magnetic field levels they produce, is associated with increased risk of childhood leukaemia or any other cancer.

Residential Electric Field Study

UK Childhood Cancer Study Investigators (2002). The United Kingdom Childhood Cancer Study: Exposure to power frequency electric fields and the risk of childhood cancer in the UK. Br J Cancer, 87, 1257–66.

This study, the largest study of residential electric fields in the UK, was carried out to examine the relationship between childhood cancer and exposure to residential electric fields. It required the development of instrumentation specifically for electric field strength measurements and was carried out as part of the second phase of the magnetic field study. The results were published in 2002, and the main conclusion was that there was no support for the hypothesis that residential exposure to extremely low frequency electric fields is associated with childhood cancer.

Residential Sources Study

Maslanyj MP, Mee TJ and Allen SG (2005). Investigation and identification of sources of residential magnetic field exposures in the UK Childhood Cancer Study. HPA-RPD-005.

Maslanyj MP, Mee T, Renew DC et al. Investigation of the sources of residential power frequency magnetic field exposure in the UK childhood cancer study. Radiation Protection Dosimetry (in press).

As a result of the identification of the higher exposures arising from the main study, a follow-up study was carried out to investigate the particular sources that contribute to elevated time-averaged exposure in UKCCS homes. The results provide a basis for considering possible options for exposure mitigation in the UK. The interesting finding was that most of the elevated exposures were found to be due to low voltage net currents in circuits inside and / or around the home. High voltage sources, including the HV overhead power lines, which have tended to be the focus of public concern, were found to account for less than one quarter of the exposures above 0.2 μ T, and less than half of those above 0.4 μ T.

Future Research Effort

The EMF Dosimetry Group is continuing its involvement in this area through representation on the UKCCS Research Committee¹.

Proposals for additional research work in the area of exposure to ELF fields have been made to further develop understanding and advice on the issue. The proposals include:

¹The UKCCS Management Committee is the body responsible for the appropriate scientific, ethical and lawful administration of the study data. Sir Richard Doll chaired the UKCCS Management Committee for over a decade and recently the Committee has been restructured to comprise two committees: an Oversight Committee chaired by Professor Sir Martin Bobrow and a Research Committee chaired by Professor Peter Smith of the London School of Hygiene and Tropical Medicine.

- a) A study to investigate the low voltage supply situations where the residual or “net” currents have been identified to be important sources of elevated residential exposure.
- b) A magnetic field characterisation study aimed at formulating an approach to identify the likely dominant source of elevated exposure.
- c) An exposure mitigation study the objective of which is to develop practical advice that might be offered to people as part of a precautionary EMF health policy aimed at reducing exposure to extremely low frequency magnetic fields.

These studies should lead to a more complete understanding of elevated ELF magnetic field exposure.

References

Ahlbom A et al (2000). A pooled analysis of magnetic fields and childhood leukaemia. *Br J Cancer*, **83**(5), 692–8.

NRPB (2001b). ELF electromagnetic fields and the risk of cancer. Report of an Advisory Group on Non-ionising Radiation. *Doc NRPB*, **12**(1), 1–179.

ANNEX B

Biological Research on ELF-EMF Relating to Childhood Leukaemia

In the late 1980s NRPB collaborated with MRC Harwell staff on a project examining the effects of ELF-EMF on mouse haematopoiesis (published in 1990). Since 1990 NRPB/HPA has undertaken its own programme of experimental work on the effects of ELF-MF. Initial studies focused on effects of 50Hz magnetic field exposure *in vitro* on cellular functions such as DNA synthesis, proliferation and transcription. Three publications came from these studies. Subsequent work has focused on the potential of ELF-MF to cause chromosome damage or modulate the chromosome damaging effects of ionising radiation in human lymphocytes cultured *in vitro*. None of these studies identified any effects of ELF-MF likely to contribute substantially to leukaemia in adults or children.

It is estimated that NRPB/HPA has invested some £320,000 in these studies, this has been supplemented by funding from external bodies, notably the EMF Biological Research Trust, of approximately £105,000. HPA-RPD currently hosts an EMF Trust funded ELF-MF exposure facility for cells in culture and also has exposure systems for rodents.

Recently pilot studies have been initiated in collaboration with a Japanese laboratory using advanced, state-of-the-art methods to assess the impact of ELF-EMF on gene transcription in bone marrow cells following *in vivo* exposure of juvenile and adult experimental mice.

A full list of HPA/NRPB publications and abstracts arising from studies completed to date is given below.

EMF publications relevant to childhood leukaemia

Lorimore SA, Kowalczyk CI, Saunders RD, Wright EG (1990). Lack of acute effects of 20 mT, 50 Hz magnetic fields on murine haemopoiesis. Int J Radiat Biol, 58(4), 713–23

Some epidemiological studies have drawn attention to a possible association between exposure to extremely low-frequency (ELF) EMFs and the development of acute myeloid leukaemia (AML) in adults. At present there is no experimental evidence for such an association. We have investigated the acute effects of power frequency magnetic fields on haemopoiesis in CBA/H mice known to be susceptible to the induction of AML after exposure to ionizing radiation. Up to 19 days after exposure to 50 Hz fields at 20 mT for 7 days no significant effects on peripheral blood characteristics were observed. Assays of the bone marrow stem cells and myelomonocytic progenitor cells also failed to reveal significant effects. These experiments cannot, however, rule out subtle effects on cell population dynamics, and further investigations, including long-term studies, would be required to establish the extent to which ELF magnetic fields might affect the haemopoietic system.

Cridland NA, Cragg TA, Haylock RG, Saunders RD (1996). Effects of 50 Hz magnetic field exposure on the rate of DNA synthesis by normal human fibroblasts. Int J Radiat Biol, 69(4), 503–11

Interest in the potential adverse biological effects of exposure to power-frequency magnetic fields has centred on the possibility that these fields may influence tumour promotion, possibly by increasing the rate of cell proliferation. In order to investigate whether exposure to magnetic fields can indeed affect the rate of cell proliferation, normal human fibroblasts were serum starved overnight and then exposed to 50 Hz magnetic fields in a purpose-built facility. The rate of DNA synthesis was taken as a measure of cell proliferation, and was determined by following the incorporation of [3H]-thymidine into macromolecular material. The rate of DNA synthesis in exposed cells was compared with that in control cultures maintained in a standard CO₂ incubator where they were exposed to background magnetic fields of < 200 nT. Positive controls were maintained in the same CO₂ incubator, but were treated with human recombinant fibroblast

growth factor to check that the cells were responsive to growth stimuli. Magnetic fields at 50 Hz and at a range of flux densities between 20 microT and 20 mT had no detectable effect on the rate of DNA synthesis by cells exposed for up to 30 h.

Cridland NA, Haylock RG, Saunders RD (1999). 50 Hz magnetic field exposure alters onset of S-phase in normal human fibroblasts. Bioelectromagnetics, 20(7), 446–52

This study was undertaken to investigate whether power frequency magnetic fields can affect the kinetics of cell cycle progression in exposed human cells. To achieve this, cultures of normal human fibroblasts were synchronised in the G(0) phase of the cell cycle and exposed to 50 Hz magnetic fields at a range of flux densities. Progression through the cycle was monitored by examining the timing of entry into S phase, as characterised by the onset of DNA synthesis. Simultaneous positive controls were exposed to human recombinant fibroblast growth factor to demonstrate that the system was responsive to external stimuli. Exposure to magnetic fields at 20 and 200 microT induced a small but significant increase in the length of the G(1) phase of the cell cycle. However, exposure at higher flux densities of 2 and 20 mT had no significant effect. These results are discussed in relation to weak magnetic field effects on free radical concentration.

Cridland NA, Sabour NR, Saunders RD (1999). Effects of 50 Hz magnetic field exposure on the rate of RNA synthesis by normal human fibroblasts. Int J Radiat Biol, 75(5), 647–54

To investigate whether exposure to magnetic fields can affect the rate of RNA synthesis, a broad measure of cellular activity. Normal human fibroblasts were exposed to 50 Hz magnetic fields at a range of flux densities between 2 microT and 20 mT. The rate of synthesis of total RNA was determined by following the incorporation of [3H]uridine into macromolecular material. In addition, polyadenylated RNA was isolated and used to estimate the rate of synthesis of mRNA. Incorporation of [3H]uridine into both total and messenger RNA increased progressively throughout the 5 h exposure period in all cells. However, magnetic field exposure had no detectable effect on the rate of synthesis of either total or messenger RNA when compared with controls. These findings indicate that under the conditions examined, gross transcription rates are not affected by exposure to power frequency magnetic fields. Taken together with previous data, this suggests that if magnetic fields do alter cellular activity, the effect is likely to be extremely subtle.

Hone P, Edwards A, Halls J, Cox R, Lloyd D (2003). Possible associations between ELF electromagnetic fields, DNA damage response processes and childhood leukaemia. Br J Cancer, 88(12), 1939–41

Epidemiology has shown an association between exposure to ELF EMFs and childhood leukaemia. The causal nature and biological basis of this association are however questionable. Studies with aneuploid cell lines raised the hypothesis that ELF EMFs may act as a coleukaemogen by compromising DNA damage response to genotoxic agents such as ionising radiation. We examined this hypothesis using gamma-ray-induced dicentric chromosome exchange in human lymphocytes. The results from 12 h post-gamma-ray exposure to fields of 0.23, 0.47 and 0.7 mT provide no support to the hypothesis. The power of the study was sufficient to exclude an ELF enhancement of chromosomal exchange of 10-15% (2SE).

Lloyd D, Hone P, Edwards A, Cox R, Halls J (2004). *The repair of gamma-ray-induced chromosomal damage in human lymphocytes after exposure to extremely low frequency electromagnetic fields. Cytogenet Genome Res, 104(1-4), 188–92*

G(0) human blood lymphocytes were irradiated with 2.0 Gy gamma-rays and cultured to metaphase whilst held in a 50-Hz power frequency magnetic field of 0.23, 0.47 or 0.7 mT. No differences were found in the frequencies of gamma-induced chromosome aberrations observed in cells held in the EM fields compared with replicates held in a sham coil. Similar field conditions have been reported to increase the frequency of gamma-induced HPRT mutations, leading to a suggestion that the EM fields alter the fidelity of repair of genomic lesions. This was not confirmed by the chromosome aberration assay described here.

Hone P, Lloyd D, Szluinska M, Edwards A (2006). *Chromatid damage in human lymphocytes is not affected by 50 Hz electromagnetic fields. Radiat Prot Dosim, 121, 321–4.*

Cultured human blood lymphocytes were exposed during the S/G2 phases of the cell cycle to continuous extremely low frequency (50 Hz) EMFs of 0.23, 0.47 or 0.7 mT either alone or immediately after an acute exposure to 1.0 Gy of gamma rays. The ionising radiation, as expected, induced chromosomal aberrations of the chromatid-type observed at the next metaphase. The field applied alone did not induce chromosomal damage nor did it modify the frequency of aberrations caused by the gamma rays.

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