Overhead Power Lines and Health

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It has been suggested that exposure to the electromagnetic fields in the vicinity of overhead power lines may increase the risk of contracting cancer. In addition to examining the scientific evidence for such a link, this paper also summarises the relevant exposure restrictions recommended by the National Radiological Protection Board. These are based on established health effects arising from exposure to electromagnetic fields and radiation.

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A. Electromagnetic fields and radiation

1. Electric and magnetic fields

At a fundamental level electricity and magnetism are different aspects of the same physical phenomenon. They play such an important role in twentieth century technology that it is often easy to forget that they occur in the natural world. Electrical processes in the earth's atmosphere are dramatically evident during a thunderstorm. But the earth also has a steady, or static, electric field which arises from electrically-charged atoms and molecules in the atmosphere. The strength of this electric field near the ground is about 120 volts per metre. This is a measure of the force which would be exerted on an electrically-charged particle placed in the region of space permeated by the field.

Moving electrical charges, i.e. electrical currents, below the earth's crust give rise to a magnetic field. The direction of this field can be determined by the force it exerts on a compass needle. A common measure of the strength of magnetic fields is the magnetic flux density, given in teslas. The earth's magnetic field varies from about 30 microteslas at the equator to about 70 microteslas at the north and south poles.[1] (One microtesla equals one millionth of a tesla). This is broadly comparable with a magnetic flux density of up to 40 microteslas at ground level directly underneath a 400 kilovolt power line.[2]

2. Time varying fields

A crucial feature of the magnetic field in the region of a power line is that its size and direction vary with time. Such an oscillating magnetic field produces an oscillating electric field which gives rise to electrical currents which circulate in conducting materials. Examples of such materials are copper wire and human tissue. As the human body is ordinarily a hive of electrical activity, it should not be too surprising that sufficiently large electrical currents induced by varying external magnetic fields could have health implications.

As has already been noted, the electric and magnetic fields which surround a power line vary with time; they do so in a regular fashion like a clock pendulum. In the UK these fields alternate with a frequency of 50 cycles per second. One cycle per second is usually referred to as one hertz. At the end of a complete cycle, the direction and size of the oscillating field are the same as they were at the beginning of the cycle. When a value of 40 microteslas is

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1 "Cancer and Power Lines" *Physics Today* April 1994 p.23

2 *Documents of the NRPB* volume 3 no 1 1992

quoted for the magnetic flux density directly under a power line, it is an effective average (called a root mean square) which is being taken. This is the value which most instruments would measure.

3. Electromagnetic radiation

Overhead power lines and other sources of alternating electrical current produce alternating magnetic fields which in turn give rise to alternating electric fields. The alternating electric fields can themselves produce alternating magnetic fields. One can imagine that when the fields are configured in a certain way that this process could continue indefinitely producing a wave or ripple of interacting electric and magnetic - electromagnetic - fields. This is electromagnetic radiation. Radio waves, visible light and X-rays are three familiar examples of electromagnetic radiation. They are distinguished by the frequency of the oscillating electromagnetic fields. X-rays have very high frequencies and can as a consequence deliver sufficiently large amounts of energy to ionise atoms and molecules. X-rays are thus one example of ionising radiation. Ionisation removes one or more of the particles called electrons which make up the outer part of an atom or molecule. Such a process can damage the genetic material, DNA, in human cells and initiate the development of cancer.

Visible light and radio waves have lower frequencies and are examples of non-ionising radiation. The 50 hertz radiation produced by power lines lies in the extremely low frequency band (30 - 300 hertz). Between the radio band and (higher frequency) infrared and visible light lies the microwave region. Domestic electrical appliances emit radiation over a wide range of frequencies in the ELF, radio and microwave regions. This cannot directly damage genetic material, but the associated electromagnetic fields can induce electrical currents in the body. Well-established biological effects can result from sufficiently high induced currents.

B. Restrictions and investigation levels

In 1993 the National Radiological Protection Board produced new recommendations for restrictions on human exposure to static and time varying electromagnetic fields and radiation. The recommendations for time varying fields covered extremely low frequency fields, radiofrequency and microwave radiation. In drawing up the revised recommendations, the NRPB used only the biological data describing established effects of acute exposure to these electromagnetic fields. The data come from a wide range of laboratory studies on animals and human volunteers as well as animal and human tissues and body cells. A large number of epidemiological studies of human populations have also been performed, with a view to

assessing the risk, if any, of cancer. These studies, to be discussed in more detail in the following section, provided "no clear evidence of adverse health effects at the levels of electromagnetic fields to which people are normally exposed".[3] Only when a cancer risk is reliably identified and reasonably well quantified would it become possible to incorporate this in exposure restrictions.

1. Basic restrictions

In order to avoid the adverse effects of exposure to electromagnetic fields and radiation, the NRPB has recommended compliance with "basic restrictions". How these are specified depends on the frequency with which the fields vibrate. For static, or constant, magnetic fields the magnetic flux density is the appropriate quantity. In the case of electric and magnetic fields which oscillate with frequencies up to 100 kilohertz (100 kilohertz is 100,000 cycles per second), the basic restriction is given in terms of the (electric) current density induced in the body. The current density provides a measure of the degree to which current electricity is concentrated in the body. At still higher frequencies, covering the rest of the radio range as well as microwaves, it is more appropriate to think in terms of electromagnetic radiation than separate electric and magnetic fields. The main biological effects of this radiation arise from the energy it delivers to the human body causing heating. Except in the case of the highest frequencies corresponding to microwaves it is not straightforward to measure directly the relevant quantity used to specify the basic restriction. For this reason the NRPB specifies "investigation levels" for the electric and magnetic fields using quantities which can be readily measured.

2. Investigation levels

In their statement on human exposure to electromagnetic fields,[4] the NRPB stress that "investigation levels are not limits on exposure". The investigation levels provide measures of the electric and magnetic field strengths set close to values based on the basic restrictions. Dosimetric calculations provide a link between the external electromagnetic field and the physical effects induced by it in the human body. Provided the electromagnetic field is below the investigation level, then the basic restrictions on the effects induced in the body will not be exceeded. This is because the calculations linking the field to the internal consequences are judged to err on the side of caution. Accordingly, the basic restrictions will not necessarily be exceeded even if the fields exceed the investigation levels. The NRPB state:[5]

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3 "Statement by the National Radiological Protection Board: Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation" *Documents of the NRPB* volume 4 No 5 1993

4 *Documents of the NRPB* volume 4 No 5 1993

5 *Documents of the NRPB* volume 4 no 5 1993

> "If the field to which a person is exposed exceeds the relevant investigation level then it is necessary to investigate compliance with the basic restriction. Factors that might be considered in such an assessment include, for example, the efficiency of the coupling of the person to the field, the spatial distribution of the field across the volume of space occupied by the person, and the duration of exposure."

The investigation levels for electric fields in the frequency range 0 to 12 megahertz are detailed in the table 1. Twelve megahertz (12,000,000 cycles per second) corresponds to the high frequency end of AM radio. The investigation levels for the electric field strength are expressed in terms of the root mean square value. As noted earlier this is an effective average of the time varying field strength; the maximum value of the field will be about 40% higher than the rms value. To obtain the investigation level for the power frequency fields of relevance to overhead electricity cables, one can use the information in table 1. The investigation level is 600 divided by the power frequency (50 hertz) expressed in kilohertz (i.e. 0.05).

> **For overhead power lines, the investigation level for the electric field strength is 12,000 volts per metre.**

This investigation level is designed primarily to avoid annoyance caused, for example, by the vibration of body hairs. Such an effect is the result of alternating electric charges on the body's surface induced by the external electric field. When an electric field interacts with the human body and a metallic object then indirect effects can occur for field values below the investigation level. An electric shock when opening a car door or interference with the operation of a heart pacemaker are two examples.

Table 1: Investigation levels (in volts per metre) for electric fields in the frequency range 0 to 12 megahertz.

Frequency range	Electric field strength (in volts per metre)
less than 24 hertz	25,000
24 hertz to 600 hertz	600 divided by the frequency in kilohertz
600 hertz to 600 kilohertz	1,000
600 kilohertz to 12 megahertz	600 divided by the frequency in megahertz

The maximum electric field strength at ground level directly underneath the highest voltage (400 kilovolts) power lines in the UK is about 11,000 volts per metre.[6] This is just below the 12,000 volts per metre investigation level. Buildings act as effective shields from electric fields, reducing their strength by factors of between 10 and 100.[7] This is not the case for magnetic fields, which are also the main source of concern from a health standpoint.

In the case of magnetic fields the investigation level can be expressed in terms of either the magnetic field strength or the magnetic flux density. These quantities are related by a property of the medium (e.g. air, human tissue etc.) called the magnetic permeability. Table 2 below gives the investigation levels in terms of the magnetic flux density.

Table 2: Investigation levels (in microteslas) for magnetic fields in the frequency range 0 to 12 megahertz.

frequency range	magnetic flux density (in microteslas)
less than 0.4 hertz	200,000
0.4 hertz to 1 kilohertz	80,000 divided by the frequency in hertz
1 kilohertz to 535 kilohertz	80
535 kilohertz to 12 megahertz	23 divided by the square of the frequency in megahertz

As with the electric fields, the magnetic field investigation levels are expressed as the root mean square (rms) values; these can be read from instruments called fluxmeters. To get the investigation level for power frequency (50 hertz) magnetic fields, one divides 80,000 by 50.

For overhead power lines, the investigation level for the magnetic flux density is 1,600 microteslas.

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6 "Electromagnetic Fields and the Risk of Cancer" *Documents of the NRPB* volume 3 no 1 1992 (p18)

7 *Documents of the NRPB* volume 3 no 1 1992 p.18

This is only a little less than the "reference level" of 2,000 microteslas specified in the NRPB's 1989 advice.[8] Such a change is probably no more than an indication of the precision of dosimetric calculations and the sensitivity of the results to small changes in the form the basic restrictions take. The investigation level of 1,600 microteslas is aimed at ensuring that the electrical current densities induced in the body by the magnetic field are not so high as to affect adversely central nervous system functions. Examples of these functions which could be affected by induced currents include the control of movement and posture, memory, reasoning and visual processing.[9]

It should be noted that table 2 focuses on the direct effects of exposure to magnetic fields. One example of an indirect effect would be interference with the operation of a heart pacemaker. This should be avoidable if the magnetic flux density is kept below 20 microteslas,[10] which is much lower than the 1,600 microtesla investigation level for direct effects.

3. Exposure to magnetic fields

The maximum magnetic flux density at ground level directly beneath (for the minimum clearance of 7.6 metres) a 400 kilovolt power line is 40 microteslas. This is forty times less than the investigation level. As one moves away from a power line, the magnetic flux density falls off rapidly: at a distance of 25 metres, the field is more than four times weaker. For comparison purposes, table 3 gives some examples of the magnetic flux densities from sources of power frequency fields in the home.[11]

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8 "Guidance as to Restrictions on Exposures to Time Varying Electromagnetic Fields and the 1988 Recommendations of the International Non-Ionizing Radiation Committee" *NRPB-GS11* May 1989

9 "Guidelines on limiting exposure to electromagnetic fields" *Radiological Protection Bulletin* December 1993 pp19-24

10 *Documents of the NRPB* volume 4 no 5 p.31

11 "Electromagnetic Fields and the Risk of Cancer" *Documents of the NRPB* volume 3 no 1 1992 (p20)

Table 3: Power frequency magnetic flux densities at various distances from various of household appliances

distance (in centimetres or metres) from the named **appliance**	the **magnetic flux density** (in microteslas) falls within the given range
3 cm from a HAIR DRYER	6 to 2,000
30 cm from a HAIR DRYER	0.01 (or less) to 7
30 cm from a REFRIGERATOR	0.01 to 0.25
1 metre from a REFRIGERATOR	less than 0.01
3 cm from a SHAVER	15 to 15,000
30 cm from a TELEVISION	0.04 to 2
1 metre from a TELEVISION	0.01 (or less) to 0.15
30 cm from a VACUUM CLEANER	2 to 20
1 metre from a VACUUM CLEANER	0.13 to 2
1 cm from an ELECTRIC OVER-BLANKET	2 to 3

For people who work in the electricity supply industry, something like 70% of total exposure to power frequency magnetic fields arises in the workplace.[12] Some of the highest magnetic fields arise in industries where use is made of arc-welding equipment and induction furnaces.[13] Some radiofrequency fields even below the appropriate investigation levels may also ignite flammable atmospheres. These examples are chosen to illustrate that specific conditions may arise in certain workplaces, and for this reason the NRPB plans to introduce additional guidance for exposure conditions in different workplaces.

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12 "Electromagnetic Fields and the Risk of Cancer" *Documents of the NRPB* volume 3 no 1 1992 (pp19-20)

13 *Review of Occupational Exposure to Optical Radiation and Electric and Magnetic Fields with Regard to the Proposed CEC Physical Agents Directive* NRPB-R265 January 1994

4. Health and safety

A proposed EC Directive on physical agents[14] defines an **action level** of 400 microteslas for power frequency magnetic fields. The meaning of the term "action level" is described in the amended[15] directive as "the value above which one or more of the measures [aimed at avoiding or reducing exposure] specified in the relevant Annexes must be undertaken." The 400 microtesla action level is four times lower than the NRPB's present investigation level. This may be attributable to subtleties in the definition of these terms. Alternatively it may be taken as indicative of the present level of precision attainable either by the dosimetric calculations or the medical studies they exploit.

The aim of the physical agents directive is to set minimum health and safety requirements regarding the exposure of workers to the risks arising not only from non-ionising radiation, but also from noise and vibration. The proposed directive was submitted to the Council of Ministers - in this case the Labour and Social Affairs Council - on 8 February 1993. An opinion by the Economic and Social Committee on 8 July 1993 approved the proposal by a majority vote.[16] The Health and Safety Executive issued requests to industry seeking opinions on the directive's potential effects. Most replies underlined the HSE's opposition.[17] In the context of the non-ionising radiation aspects of the directive, this opposition is due to a lack of reliable data underpinning the action levels.[18,19] The CBI has also been highly critical of the proposed directive on the grounds that it is not based on good risk assessment principles and is potentially "one of the most costly health and safety measures imposed on British business".[20] Support for the directive has been voiced by the TUC. The Government's view is that the amended proposal is unnecessary and unjustified on scientific grounds.[21]

At the moment there is no specific statutory protection against exposure from electromagnetic fields, though the general provisions of the *Health and Safety at Work etc. Act 1974* (cap 37) will apply. This situation contrasts to the case of X-rays, gamma-rays and particulate radiation like alpha and beta rays which are subject to the controls of the *Ionising Radiations Regulations* SI 1985/1333. The purpose of the NRPB's investigation levels, some of which are given in tables 1 and 2, is to provide a framework for any future system of restrictions

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14 OJC 77, 18 March 1993

15 EC Draft 8392/94 25 July 1994

16 *Eurosafety* Spring 1994

17 "New physical agents appeal" *Health, Safety and Environment Bulletin* March 1994

18 "Effect of proposed non-ionising electromagnetic radiation rules would be wide ranging, says HSE-funded report" HSE news release 10 February 1994

19 "Review of Occupational Exposure to Optical Radiation and Electric and Magnetic Fields with Regard to the Proposed CEC Physical Agents Directive" *NRPB-R265*

20 "CBI questions EC proposals" *Health, Safety and Environment Bulletin* October 1993

21 *European Parliament: Briefing for United Kingdom Members* Employment Department 26 September 1994

on the exposure of both workers and the public to electromagnetic fields. The recommendations do not apply where the exposure arises from a medical procedure as the balance between risk and benefit is altered in such cases.

5. Biological effects

More details on the NRPB advice appear in an article entitled "Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation",[22] the contents of which have been summarised in the *Radiological Protection Bulletin.*[23] The advice extends beyond the frequency range covered in tables 1 and 2 above. For frequencies in the range **100 kilohertz to 300 gigahertz** (1 gigahertz = 1,000,000,000 hertz), which cover much of the radio and microwave regions, the main concern is potential heating of body tissues. Acute exposure to intense electromagnetic fields could adversely affect mental performance and lead to headaches, nausea and dizziness. Changes could also occur in some immune responses and in the levels of stress hormones circulating in the blood stream. The developing embryo or fetus is also regarded as being vulnerable to any temperature rise accompanying exposure to radiofrequency and microwave radiation. At the higher microwave frequencies the heating effect is largely confined to the cornea of the eye and the skin. The guidance also takes into account effects arising from exposure to intense pulses of microwave or radiofrequency radiation; one example is "microwave hearing", the likely result of a sound wave in the head caused by a minute but very rapid expansion of brain tissue.

For zero frequency, i.e. **static**, electric fields the NRPB guidance is aimed at avoiding annoyance due to electric charges induced on the surface of the body. Additional care may be needed to avoid electric shocks arising from near contact with an object in an electric field. Static magnetic fields of less than 2 teslas will not give rise to acute responses such as vertigo and nausea. Furthermore, cardiac arrhythmia (abnormal heartbeat) or impairment of mental function will not occur at these very high levels. The fact that the relevant investigation level is ten times smaller (200,000 microteslas - see the first row of table 2) reflects uncertainty about the chronic effects of exposure to static magnetic fields. Static magnetic fields below the investigation level could affect implants such as pacemakers.

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22 "Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation" *Documents of the NRPB* volume 4 no 5 1993

23 "Guidelines on limiting exposure to electromagnetic fields" *Radiological Protection Bulletin* December 1993

This paper is mainly concerned with the health effects arising from exposure to time varying electromagnetic fields of **frequencies less than 100 kilohertz**, since this includes the 50 hertz fields in the space surrounding overhead power lines. Stress due to the perception and annoyance of surface charge effects, such as body hair movement, will generally be avoidable for electric field strengths below the root mean square values quoted in table 1. Health concerns focus on the magnetic fields which can induce circulating electrical currents in the body. Sufficiently large currents can interfere with central nervous system functions such as the control of movement and posture, memory, reasoning and vision. An example of the latter is provided by reports of faint, flickering, visual sensations induced in volunteers being exposed to power frequency magnetic fields above 15,000 microteslas. Exposure to intense electric and magnetic fields can induce electrical currents which could cause headaches as well as nerve and muscle stimulation.[24]

One source of concern has been rumours of an adverse effect on pregnancy outcome due to the low intensity electromagnetic fields surrounding VDUs. Taking all research into account, there is no indication that spontaneous abortions (miscarriages) are associated with VDU use, and similar reassurance with respect to congenital malformations has been provided by a smaller number of studies which have been performed on this.[25,26]

In recommending investigation levels for exposure to electric and magnetic fields below 100 kilohertz, the NRPB used the established medical data alluded to above. There is less clear evidence for other effects such as the suggestion that circadian rhythms (i.e. the biological body clock) may be affected by such exposures. However, the health implications are unclear. A variety of physiological, reproductive, genetic and cancer-related studies have also been performed, looking mainly at animals or cells. There is little clear evidence that power frequency (50 hertz in the UK) electromagnetic fields can effect a change in the genetic material (DNA). Accordingly "if electromagnetic fields have any role in carcinogenesis [cancer development], they are more likely to act as promoters than as initiators, enhancing the proliferation of genetically altered cells rather than causing the initial lesion".[27]

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24 "Statement by the National Radiological Protection Board: Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation" *Documents of the NRPB* volume 4 No 5 1993

25 "Visual display units" *Radiological Protection Bulletin* June 1994 p.6

26 "Electromagnetic fields" *Croner's Health and Safety Special Report* October 1994

27 "Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation" *Documents of the NRPB* volume 4 no 5 1993

C. Electromagnetic fields and cancer

1. Cancer

There are hundreds of different kinds of cancer,[28] but they share in common the unrestrained proliferation of damaged cells. The human body comprises up to 100 million million cells of different types with specialist functions.[29] One requirement for good health is that cells divide, replacing ones that die, at a rate which does not interfere with the proper functioning of their neighbours. The operation of individual cells, and their response to chemical signals from other parts of the body, proceeds via a vast number of chemical reactions which are in turn controlled by the operation of proteins. The instructions for the manufacture of these enzymes are stored in the genetic material, DNA, contained in the cell. Damage to the DNA can lead to the enzymes regulating cell division either being produced in inappropriate amounts (including not at all) or being defective thus failing to fulfil their function correctly.[30]

Deoxyribonucleic acid, or DNA, is a long molecule which is wrapped around structures, forming chromosomes, like thread around a bobbin. On closer inspection, DNA resembles a rope ladder, twisted along its length, with four different types of "rung". Each rung is labelled by two letters (AT, TA, CG or GC), representing the two molecules (called bases) which are linked together to form the rung. A typical gene comprises a stretch of DNA of between about 1,000 and 100,000 rungs in length.[31] When a gene is expressed ("switched on"), it leads to the production of a particular protein, the precise form of which depends on the detailed sequence of base pairs (rungs). If a gene responsible for regulating cell division and growth sustains damage, which the cell's repair mechanisms fail to remedy, then cancer can result. A problem with the cell's repair mechanisms, governed by other genes, can predispose a person to a wide range of cancers.[32] Genes which nudge severely damaged cells towards premature death, thus preventing further division, can be thought of as providing a somewhat gross protection mechanism.[33]

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28 "The enemy with a thousand faces" *The Economist* 5 August 1989 p.79
29 *Human Genetics* Parliamentary Office of Science and Technology Technical Report October 1994
30 "Cancer and Oncogenes" *New Scientist* 10 March 1990
31 *Gene Therapy* House of Commons Library Research Paper 93/66, 14 June 1993
32 "Proofreaders for the code of life" *New Scientist* 6 August 1994 p.23
33 "Making Friends with Death-Wish Genes" *New Scientist* 30 July 1994 p.31

Ordinarily a successive accumulation of harmful genetic mutations (changes) in a cell has to occur for cancer to develop.[34] The simplest kind of mutation involves the substitution of one DNA base by another.[35] Occasionally mutations are inherited from the sperm or egg cell of a parent and these will be present in cells throughout the resulting offspring. These may contribute to the chain of mutations necessary to initiate cancer in a single cell if the affected genes regulate cell growth and development. However, most cancers result from a combination of age and exposure to environmental factors such as tobacco smoke, diet, pollution, ionising radiation, and viruses.[36] Genes which promote abnormal growth and proliferation, when activated, are called oncogenes. Those which inhibit proliferation are called tumour suppressor genes. Taking one of the better understood cancers, chronic myeloid leukaemia, as an example, the *abl* oncogene is activated when the two chromosomes numbered 9 and 22 swap some of their genetic material (by a process called chromosome translocation).[37]

A major problem with the hypothesis that exposure to external electromagnetic fields can cause cancer is the absence of an acknowledged mechanism by which the necessary genetic damage could be induced. One suggested possibility could arise from the potentially carcinogenic action of highly reactive atoms and molecules called free radicals.[38] These occur naturally as necessary by-products of chemical processes in cells and can also be generated by the interaction of **ionising** radiation with atoms and molecules in a cell. If such free radicals are generated close to a DNA molecule in the cell then they can cause mutations.[39]

A possible role of non-ionising radiation, such as that associated with power-frequency electromagnetic fields, might be to prolong the length of time that existing free radicals could wander around the cell, before harmlessly recombining with other free radicals. The longer lifetime of free radicals could conceivably tilt the balance between DNA damage and repair decisively in favour of the former.[40] It is, however, far too early to say whether this particular mechanism could play a significant role in the development of cancer, though research is continuing.[41] Alternative mechanisms based on electrical currents induced by typical exposures to power lines are problematical since natural electrical activity in the body is usually at least 1,000 times greater. Such a statement derives from calculations of electric

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34 "Genetics of Malignant Disease" *British Medical Bulletin* volume 50 number 3 July 1994 p.517

35 For more information on mutations leading to genetic diseases (including cancer), see *Gene Therapy* (House of Commons Library Research Paper 93/66, 14 June 1993).

36 "Cancer Prevention in Primary Care: Current trends and some prospects for the future - II" *British Medical Journal* 20-27 August 1994 p.517

37 "Molecular genetics of cancer" *British Medical Journal* 9 May 1992 p.1234

38 "Oxy-radicals and cancer" *The Lancet* 24 September 1994 p.862

39 "Free radicals, antioxidants, and human disease: curiosity, cause, or consequence?" *The Lancet* 10 September 1994 p.721

40 "Are power lines bad for you?" *New Scientist* 11 April 1992 p.22

41 "Are environmental magnetic fields dangerous?" *Physics World* January 1992 p.41

fields in the body.[42] More subtle "window effects" arising from specific combinations of static (e.g the earth's magnetic field) and time-varying fields would be difficult to investigate experimentally as their action would depend on the animal species under study.[43]

2. Experimental evidence

The absence of an accepted mechanism by which electromagnetic fields could cause, or even promote, cancer leads to difficulties in designing suitable biological experiments. This point has been made rather clearly by the Oxford chemist, Keith McLauchlan, whose research includes studies of the influence of magnetic fields on chemical reactions involving free radicals:[44]

> "Magnetic fields do affect certain classes of chemical reactions, and field effects are well established at the molecular level. This knowledge has not been applied in the medical, health and general biological areas. Worldwide, large amounts of research funding have been put into epidemiological and direct biological studies, despite the absence of any suggested mechanisms for field effects that can be tested, and with the experiments often poorly designed as a result.
>
> It is not apparent that this is the best way of establishing whether fields might affect humans. Ultimately, all action originates in the chemistry of the body, and we cannot be happy to accept that there are negligible health hazards, whilst we know that there are ways in which fields can, and do, affect reactions. No stronger statement than this can be made, for it is not established yet how relevant radical reactions are in the human biological situation."

Notwithstanding the general reservations expressed above, it is useful to summarise briefly the results obtained from biological experiments which have been performed to look for a link between electromagnetic field exposure and cancer. Much of the experimental data, as well as epidemiological studies to be discussed in the next subsection, have been reviewed by the Advisory Group on Non-Ionising Radiation, chaired by Sir Richard Doll. The Advisory Group was established by the Director of the NRPB in November 1990 "to review work on the biological effects of non-ionising radiation relevant to human health and to advise on research priorities".[45] Their first report was published in March 1992.[46]

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42 "Cancer and power lines" *Physics Today* April 1994 p.23

43 "Biological and human health effects of EM fields" *Radiological Protection Bulletin* August 1994

44 "Are environmental magnetic fields dangerous?" *Physics World* January 1992 p.41

45 "Visual display units" *Radiological Protection Bulletin* June 1994

46 "Electromagnetic Fields and the Risk of Cancer" *Documents of the NRPB* volume 3 no 1 1992

Much of the experimental work reviewed was performed on rodents or other animals belonging to the same biological class (mammals) as humans. In addition, an increasing number of studies have been performed on tissue preparations and cell cultures. Time-varying fields at a variety of intensities and frequencies (as well as static fields) have been applied to look for a range of biological effects, including those associated with cancer. This paper shall focus on the power frequency (50 hertz as in the UK, or 60 hertz as in the USA) fields relevant to overhead power lines and underground cables. As noted in a recent report,[47] "Inconsistent and contradictory effects have been reported, and few attempts made to replicate important or controversial studies. Needless to say, this has generated debate and dispute among scientists, and misunderstanding and confusion among members of the public."

There does not appear to be any convincing evidence that electromagnetic fields cause genetic damage and they are therefore extremely unlikely to **initiate** cancer. Experimental work has focused on seeing whether exposure to electromagnetic fields could **promote** cancer, a reference to the multiplication and accumulation of already damaged cells. In one experiment leukaemic cells were injected into mice which were then exposed to 60 hertz magnetic fields of up to 500 microteslas; no significant effect was observed in comparison with mice not exposed following injection. Preliminary studies on the effects of magnetic fields of varying frequencies, and up to 6,000 microteslas in flux density, on mice with mammary tumours showed that the exposed group actually lived longer than the unexposed controls.[48] A more recent German study looked at the effect of chronic exposure of rats to 50 hertz magnetic fields of 100 microteslas. The chemical carcinogen DMBA was administered to the rats, and those which were also exposed to the magnetic fields had a significantly higher incidence of mammary tumours than the control (i.e. no magnetic field exposure) group. A number of other animal studies are under way. These include work to study the effect of 60 hertz magnetic fields on the promotion, in rats, of brain tumours induced by the chemical ENU.[49]

Similarly equivocal results have emerged from studies on both human and rodent cell cultures. One potential effect which has been looked for is increased proliferation of groups of cells arising from the influence of electromagnetic fields on the chemical reactions responsible for passing messages from one part of a cell to another. It has been hypothesised that these "signalling pathways" may be affected in such a way as to stimulate a cell to divide. There have been reports that electromagnetic fields can increase the transcription (i.e. "reading") of genes, but the results have been difficult to reproduce and their clinical significance is

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47 "Electromagnetic Fields" *Croner's Health and Safety Special Report* issue 13, October 1994

48 *Biological Effects of Exposure to Non-ionising Electromagnetic Fields and Radiation. II. Extremely Low Frequency Electric and Magnetic Fields* NRPB-R239 July 1991

49 "Biological and human health effects of EM fields" *Radiological Protection Bulletin* August 1994

uncertain.[50,51] A supplementary report by the Advisory Group on Non-Ionising Radiation, of 12 April 1994, concluded that " ... **at present, there is no persuasive biological evidence that ELF electromagnetic fields can influence any of the accepted stages in carcinogenesis**".[52]

In November 1992, the Institution of Electrical Engineers established a working party to assess peer-reviewed scientific studies on the biological effects of electromagnetic fields. The working party's terms of reference restricted their deliberations to magnetic flux densities up to 50,000 microteslas and electric fields of up to 20,000 volts per metre. Both figures are well above the NRPB's investigation levels. A survey of 245 relevant papers published during 1993 failed to persuade the working party of the existence of "firm evidence of biological effects of low-level, low-frequency electromagnetic fields". They added:[53]

> "The quest for such effects has been primarily driven by epidemiological studies that suggest a link between exposure and leukaemia and other cancers."

The following two subsections consider the status and implications of the epidemiological data.

3. Epidemiology and childhood cancers

Epidemiology is the study of disease in a population with the aim of establishing the factors responsible. For causality to be established beyond reasonable doubt it is first necessary to find a convincing association between the disease and the factors under investigation. Second, and most importantly, one has to eliminate as far as possible alternative explanations such as chance, bias and **confounding**. A possible example of the latter is the reported small increase in leukaemia and brain cancer among some workers in the electrical and electronics industries; this could be due to exposure to certain carcinogenic chemicals rather than electromagnetic fields. A more familiar example of confounding may be in the apparent relationship between coffee drinking and coronary heart disease. This could simply be a consequence of the combined facts that cigarette smokers tend to drink more coffee and that cigarette smoking is a cause of coronary heart disease. In this example, smoking is a confounding factor.[54]

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50 "Electromagnetic Fields" *Croner's Health and Safety Special Report* October 1994

51 "Biological and human health effects of EM fields" *Radiological Protection Bulletin* August 1994

52 "Electromagnetic fields and the risk of cancer" *Radiological Protection Bulletin* June 1994

53 *The Possible Biological Effects of Low-frequency Electromagnetic Fields. Supplement to the Public Affairs Board Report No 10* The Institution of Electrical Engineers, June 1994

54 *Basic Epidemiology* World Health Organisation 1993

Basic Epidemiology, published by the World Health Organisation (1993), details further criteria which a study should match in order to establish the cause of a disease. These include plausibility based, for example, on supporting biological studies and a dose-response relationship. The latter means that a higher risk of disease should accompany greater exposure to the causative factor, though the importance of this requirement has been questioned in the context of electromagnetic fields.[55] One of the most important guidelines for causation is consistency, i.e. the degree to which the results of a study are reproduced by others. By pooling the results of a number of studies, one can attempt to eliminate chance findings resulting, for example, from flawed scientific methodology.

One of the main issues addressed in the 1992 report[56] of the NRPB Advisory Group on Non-ionising Radiation was the possibility that residential exposure to electromagnetic fields might increase the risk of cancer in children. The first evidence for such an effect came from a 1979 study carried out in Colorado, USA. This study, together with the seven subsequent investigations also considered by the Advisory Group, was of the **case-control** type. In this kind of epidemiological work a group of persons with the specified disease (the cases) are compared to persons who are unaffected (the controls) to see if there are any differences in exposure to putative risk factors such as electromagnetic fields. The selection of a control population which is genuinely comparable with the cases who have the disease is the most difficult task of a case-control study; a task which provides ample scope for the introduction of misleading correlations between the disease and the proposed risk factor.

In a case-control study the association of a disease (e.g. leukaemia) with an exposure (e.g. to electromagnetic fields) is measured in terms of the **odds ratio**. This is the ratio of the odds (chance) of exposure among the cases to the odds of exposure among the controls. As an illustration, consider a hypothetical study involving 1,000 people who contract a disease within the study period, 200 of whom are known to have been exposed to a putative risk factor (such as ionising radiation, a foodstuff or electromagnetic fields); the odds of exposure among the cases are accordingly 200 in 1,000 (or 0.2). Now consider the control group of 1,000 other people who are free of the disease, 100 of whom are known to have been exposed to the possible risk factor; here the exposure odds are 100 in 1,000 (or 0.1). The odds ratio is therefore 2 (i.e. 0.2 divided by 0.1), an indication that exposure doubles the **relative risk** of disease. Mathematical methods may then be used to assess the **statistical significance** of an association between exposure and disease, which is usually expressed in terms of a 95% confidence interval. This is the range of values between which the true odds ratio may be said to lie with 95% certainty. If the lower limit of the 95% confidence interval is greater than 1, then we have a statistically significant association between the disease and exposure to the proposed risk factor.

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55 "Are power lines bad for you?" *New Scientist* 11 April 1992 p.22

56 "Electromagnetic Fields and the Risk of Cancer. Report of an Advisory Group on Non-ionising Radiation" *Documents of the NRPB* volume 3 no 1 1992

The eight studies analysed by the NRPB Advisory Group assessed exposure to magnetic fields (which penetrate buildings) using three different criteria: direct measurement of magnetic flux density, distance from the power line or other source (transformer substation or cables), and wire configurations. An estimate of exposure based on typical wire configurations involves noting the type and distribution (height, size, distance) of power cables outside a house,[57] and is ".. the least clearly defined way of assessing exposure".[58] Table 4 details the odds ratios obtained for different cancer types and exposure assessment methods. The values quoted are the result of pooling a number (given in square brackets) of different studies. Statistically significant odds ratios are highlighted in bold type. The table attempts to summarise the results of the first seven studies which followed the initial findings of Wertheimer and Leeper from Colorado.[59] Detailed references and further information are given in the Advisory Group's report.[60]

Table 4: Odds ratios for different types of childhood cancer. The results of seven different studies employing one or more exposure assessment methods have been pooled

cancer type	odds ratio [number of studies pooled]	exposure assessment
all cancers	**1.82** [2] 1.11 [3] **1.52** [1]	direct measurement distance from source wire configurations
leukaemia	1.16 [3] 1.35 [3] **1.39** [3]	direct measurement distance from source wire configurations
brain tumours	1.85 [2] **3.96** [1] **2.04** [1]	direct measurement distance from source wire configurations
all cancers other than leukaemia and brain tumours	**2.96** [2] 0.99 [1] 1.37 [1]	direct measurement distance from source wire configurations

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57 source: National Grid Company spokesman

58 *Documents of the NRPB* volume 3 no 1 1992 p.55

59 "Electrical wiring configurations and childhood cancer" *American Journal of Epidemiology* volume 109, 1979, p.273

60 *Documents of the NRPB* volume 3 no 1 1992 pp55-80

The odds ratio of 3.96 for brain tumours is of **borderline significance**, the lower limit of the 95% confidence interval being 1.00. Furthermore, the single study contributing to this finding has been criticised by the NRPB Advisory Group partly on account of the method used to measure the distance from the residence to the source of magnetic fields and because of the method of selecting the control group. A second study which also used distance from the magnetic field source to estimate exposure, but which could not be pooled with the quoted risk estimate, showed no association between electromagnetic fields and brain tumours.

Problems with the selection of controls and failure to specify the types of cancer in some cases have led the Advisory Group to question the other studies producing statistically significant odds ratios. Confounding factors such as higher traffic density (and a consequently greater exposure to carcinogens from exhaust fumes) in the vicinity of power lines were also inadequately accounted for in some studies, if at all. Finally, it may be noted that many of the statistically significant odds ratios, highlighted in bold type, arise from those studies which used wire configurations to assess exposure. The reliability of this method has been called into question.[61] Overall, the Advisory Group concluded:

> "While there is suggestive evidence of an association between childhood cancer and residential electromagnetic field exposure, the methodological shortcomings of the studies are such that the evidence is insufficient to allow conclusions to be drawn."

The uncertainty surrounding the possible link between electromagnetic fields and childhood cancer was later echoed by a report in the American journal *Science* (29 October 1993, p.649) entitled "EMF - cancer links: yes, no, and maybe". This article focused on two studies, one from Denmark[62] the other from Finland,[63] which were both published, and reviewed by the Director of Oxford's Childhood Cancer Research Group (Gerald Draper), in the 9 October 1993 issue of the *British Medical Journal*. Though the scientific methodology of both was criticised by Alasdair Philips of Scientists for Global Responsibility,[64] it is still better[65] than many of the earlier studies discussed above. For this reason, these two studies will now be considered individually in turn.

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61 *The Possible Biological Effects of Low-frequency Electromagnetic Fields. Supplement to the Public Affairs Board Report No 10*, Institution of Electrical Engineers, June 1994

62 "Residence near high voltage facilities and risk of cancer in children" *BMJ* 9 October 1993 p.891

63 "Risk of cancer in Finnish children living close to power lines" *BMJ* 9 October 1993 p.895

64 "Risk of cancer and exposure to power lines" *BMJ* 30 April 1994 p.1162

65 "Electromagnetic fields and the risk of cancer" *Radiological Protection Bulletin* June 1994 p.10

The Danish study (Olsen and co-workers)

In this work, Olsen and co-workers used the case-control approach to assess the risk of cancer arising from residence near high voltage installations, comprising mainly overhead lines but also transformer substations and underground cables. The cases comprised 1,707 children, under 15 years old, newly diagnosed as having leukaemia, tumour of the central nervous system, or malignant lymphoma. The period covered was from 1968 to 1986. Particular care went into the selection of 4,788 children as controls. Magnetic field strengths were computed from historical information about surrounding electricity sources and cumulative exposure was also studied.

By comparing the exposure rates of the various cases with those of the controls, odds ratios were obtained for the three categories of cancer studied, as well as all cancers combined. When the three cancer types are considered together in this way, six cases had been exposed to magnetic fields of at least 0.40 microteslas, and a statistically significant **odds ratio of 5.6** was obtained. Three children with malignant lymphoma, who had been exposed to an average magnetic field of at least 0.1 microteslas, accounted for a statistically significant **odds ratio of 5**. However, the authors acknowledged that these relative risk estimates were highly unstable on account of the small numbers of affected children. No elevated risk was found for brain tumours or leukaemia considered separately. The authors added that "Data indicate that the proportion of childhood cancers caused by electromagnetic fields must be small".

The Finnish study (Verkasalo and co-workers)

The second of the two studies published in the 9 October 1993 issue of *BMJ* is interesting because it is a **cohort** study covering the whole of Finland. In this approach to epidemiology, one begins with a group of people (a cohort) who are free of the disease under study. Their progress is followed over the years to see how the subsequent development of the disease is correlated with exposure to the putative risk factor. One then compares the number of resulting cases with the number expected from a knowledge of the incidence of the disease to obtain a measure of the relative risk called the **standardised incidence ratio**. The Finnish study was actually of the historical cohort design in that it used information gathered from national records spanning two decades. The progress was followed of a cohort of 134,800 children aged between 0 and 19 years living within 500 metres of overhead power lines. That cohort developed 140 cases of cancer which should be compared with the 145 cases one would expect from such a population. Like the Danish study discussed above, the magnetic flux density in residences was calculated from the known characteristics of the surrounding power lines; a procedure which should provide a reliable estimate of exposure. The key results of this study were summarised as follows:

> "In conclusion, our study shows no significant increase in the incidence of leukaemia, lymphoma, or cancers overall in children exposed to residential magnetic fields from power transmission lines in Finland. The significant increase in the incidence of nervous system tumours among boys is likely to be a chance finding. The results suggest that the risk of childhood cancer in the vicinity of these power lines is not a major public health concern. The relation between a risk of childhood cancer and exceptionally high levels of residential exposure to magnetic fields should not, however, be inferred from this study."

Two points from the above quotation may be enlarged upon. First, even assuming that the increased incidence of nervous system tumours in boys was not due to chance, then the observed **standardised incidence ratio of 4.2** implies one extra case every two years in the whole of Finland. Second, this study in common with others has been able to say very little about the relative risk of contracting cancer arising in the few cases of very high residential exposure. A credible biological explanation and a clear dose-response relationship for cancer and magnetic field exposure would help to establish any such link.

Pooling the Nordic results

Taking the two studies discussed above, and pooling them with a case-control study from Sweden published in 1993,[66] results in a statistically-significant **relative risk of leukaemia of 2.1**, largely the impact of the Swedish contribution.[67] As the risk of developing leukaemia between birth and the age of 15 is about 1 in 1,900 then a relative risk of 2.1 would lead to a substantially higher risk (1 in 900) for children exposed to higher (above 0.2 microteslas) magnetic field levels.[68] The pooled results for nervous system tumours, lymphoma or all cancers combined do not show statistically significant relative risks arising from exposure to magnetic fields. Referring to these three newer studies, the NRPB Advisory Group stated in the June 1994 issue of *Radiological Protection Bulletin*:

> "**The Group has concluded that all these studies were well controlled and substantially better than those that previously reported associations with childhood cancer. The studies do not 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.**"

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66 "Magnetic fields and cancer in children residing near Swedish high-voltage power lines" *American Journal of Epidemiology* volume 138 p.467

67 "Electromagnetic fields and childhood cancer" *The Lancet* 20 November 1993 p.1295

68 "Little light on high voltage" *The Independent* 18 October 1994 p.26

In April 1992, the UK Coordinating Committee for Cancer Research set up a national cancer study looking into five different possible causes (one of which is magnetic fields) of childhood cancers.[69] The results of this study are not expected until 1995 or 1996.[70] A parallel case-control study of childhood leukaemia is being undertaken by the US National Cancer Institute in conjunction with the Children's Cancer Group, and other research is also under way. In addition, the US Environmental Protection Agency is expected to publish next year a report on the potential carcinogenicity of electromagnetic fields; a draft issued in October 1990 was never formally published following criticisms as to the quality of the science.[71,72]

4. Other epidemiological studies

The 1992 report by the NRPB Advisory Group also considered several other epidemiological studies concerned with the risk of cancer from electromagnetic fields. On the subject of **residential exposure in adults**, the Advisory Group concluded:

> "Information on adult cancers does not suggest that residential electromagnetic field exposure is a risk factor, but data are too sparse to permit firm conclusions."

Although the focus of this paper is on exposure to magnetic fields from overhead power lines, it is pertinent to summarise briefly epidemiological cancer studies involving other sources of exposure. More than 50 studies have now been carried out on **workers in electrical trades**, many of which were reviewed in the 1992 Advisory Group report. A general lack of evidence for a convincing dose-response relationship in these occupational studies was noted. However, a weak association between leukaemia and electromagnetic field exposure seems to be a "fairly consistent tendency" among the results, according to a review in *Radiological Protection Bulletin* (August 1994). Welders, who receive the highest exposures, are not observed to have an increased risk of leukaemia; this adds weight to the suggestion that exposure to chemicals may provide the correct explanation for the leukaemia risk observed in other workers.[73] The Advisory Group also noted an increased risk of brain cancer which ".. may indicate an occupational hazard from some types of electronic work but the nature of the hazard (if it exists) is unclear".

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69 "£6m study begins into child cancer" *The Independent* 13 March 1992 p.1

70 *Environmental Health* March 1994 pp56-7

71 "Guessing Game. The EPA tries to decide if there's harm from ELF" *Scientific American* March 1991

72 "Responsibilities and research on electromagnetic fields in the USA" *Radiological Protection Bulletin* December 1993

73 "Electromagnetic Fields" *Croner's Health and Safety Special Report* October 1994

A more recent study of the cancer risks associated with exposure to magnetic fields has been performed in which the subjects comprised some 220,000 male electrical utility workers in France and the Canadian provinces of Ontario and Quebec. Over a period of two decades 4,151 new cases of cancer had occurred in this group. After assessing the cumulative exposure to magnetic fields (measured in microtesla-years), it was concluded that those with above average (actually the median or "middle value") exposure had a higher risk of leukaemia, though there were inconsistencies in this result. Still higher exposures were associated with an increased risk of brain cancer, though this lacked statistical significance. That this "comprehensive and well-conducted"[74] study has not given a clear result underlines the uncertainty surrounding this field.

A number of studies reviewed by the NRPB Advisory Group have concerned the relationships between childhood cancer and **paternal occupational exposure**, with a view to assessing any risk arising from damage to sperm cells. Given the low quality of the available data, no definite conclusions could be drawn for or against the existence of a hazard.

The final area reviewed by the NRPB Advisory Group covered exposure from **electrical appliances** and cancer in both children and adults. "No association with electrical appliance use was found in studies of adult cancer".[75] Two studies of childhood cancer provided some suggestion of an association with electric over-blanket use, the stronger indication linking brain tumours with *in utero* exposure. However, this result was based on small numbers of cases, and substantial flaws in both studies were identified by the Advisory Group.

With the exception of the possible link between residential exposure and childhood leukaemia, discussed in the preceding subsection, there seems little need to modify the general conclusions reached by the Advisory Group in 1992:[76]

> "**In summary, 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**

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74 *Radiological Protection Bulletin* August 1994 p.19

75 *Documents of the NRPB* volume 3 no 1 1992 pp112-29

76 "Electromagnetic Fields and the Risk of Cancer. Report of an Advisory Group on Non-ionising Radiation" *Documents of the NRPB* volume 3 no 1 1992, p.132

industries..."

D. Policy implications

There is a great deal of public concern worldwide about the possible cancer risks associated with power lines, which the inconclusive nature of present scientific knowledge has done little to allay. In the USA, various campaigning groups of citizens have been set up and the number of electromagnetic field related court cases is steadily increasing. These observations lay behind an article in *APS News* (June 1994), published by the American Physical Society, where a number of possible policy responses were elucidated:

> "There are essentially four options for policy response: (1) conclude there is no basis for concern and do nothing; (2) provide information to allow individuals to make private decisions; (3) take prudent steps to minimize exposure to EMF's when it can be done at little cost or inconvenience; or (4) undertake more expansive field exposure management."

The last suggestion would include expensive retrofits of electrical cables or outright bans on power lines in certain locales. It has been estimated that, in the USA, the annual cost due to concerns over power line safety amounts to $1,000 million. The factors contributing include the effects on property prices, project delays and cancellations, siting restrictions, redesign and retrofits of equipment, and insurance costs to cover possible litigation.[77]

Public concern in Britain has been addressed in a number of articles including one entitled "Power lines. The leukaemia link" which appeared this year in the publication *What Doctors Don't Tell You* (volume 5, no 3). This article even provides four suggestions as to how one might set about protecting oneself from any such risk: (1) increase consumption of green vegetables and fruit which are good sources of antioxidants; (2) measure the magnetic fields in the home, particularly bedrooms; (3) re-position furniture to minimise exposure; (4) consider moving house, as a last resort, if concerned about magnetic fields

The first suggestion (eating fruit and vegetables) is sound dietary advice regardless of the motive underlying it. There is, for example, an indication that dietary antioxidants could reduce mortality from cancer of the lung and colon,[78] possibly by "mopping up" any excess free radicals which could damage DNA. This underlines the likelihood that diet is an important contributing risk factor for cancer. Assistance with magnetic field measurements

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77 "Biological and human health effects of EM fields" *Radiological Protection Bulletin* August 1994 p.19

78 "Oxy-radicals and cancer" *The Lancet* 24 September 1994 p.862

can be provided either by the utility companies or by pressure groups such as Powerwatch. Such measurements would also provide information on the areas of the home most likely to receive exposure and guide any repositioning of beds. The final suggestion about moving house seems rather drastic in view of the lack of firm evidence for a link between power lines and ill-health. It does appear that a number of property values have been depressed, with little justification, because of the proximity of power lines.[79]

A number of campaigns against power lines and underground cables have been established, including "Stop The Overhead Power lines" (STOP),[80] and "Children Against Cables".[81] STOP is arguing against Scottish Power's plans to erect pylons, as part of a link to Northern Ireland, in the villages of Coylton and Ballantrae.[82] An application for judicial review has also been brought on behalf of three children from north-east London where the National Grid Company is presently laying a high voltage underground cable. This application was dismissed since, in the opinion of the Queen's Bench Divisional Court, the President of the Board of Trade had not acted unlawfully in declining to take measures to limit the level of electromagnetic fields from the cables.[83] His role in the related issue of the siting of pylons was referred to in a written answer earlier this year (HC Deb 17 March 1994 c.835W):

> "**Mr. Alex Carlile:** To ask the Secretary of State for Health what assessment she has made of the policy which allows electricity pylons to be sited near homes; and if she will make a statement.
>
> **Mr. Sackville:** Advice to Government, including both this Department and the Department of Trade and Industry, about radiation matters is provided by the National Radiological Protection Board. New electric lines above ground, with the exception of connections to individual customers and certain very minor developments, require the consent of my right hon. Friend the President of the Board of Trade who may also grant deemed planning permission.
>
> I refer the hon. Member to the reply I gave him on 21 February at columns *40-41* concerning the question of any health risk."

The earlier written answer focused on the "prudent avoidance" policy option which is finding favour in Nordic countries and the USA.[84] In addition, the lack of widely accepted scientific evidence for a link between power lines and cancer was emphasised (HC Deb 21 February

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79 "Cause for concern or media hysteria?" *Environmental Health* July 1994 p.170
80 "National campaign over pylons" *Scotsman* 21 March 1994
81 "Hidden powers" *The Guardian* 8 April 1994
82 "Scots to fight on in spite of power line verdict" *Scotsman* 4 October 1994
83 "Minister need not act on possibility of health risk" *The Guardian* 11 October 1994 p.8
84 "Sparks fly over power line health hazards" *The Sunday Telegraph* 6 November 1994 p.24

1994 cc40-1W):

> "**Mr. Alex Carlile:** To ask the Secretary of State for Health if she will make it her policy to encourage the enactment of a prudent avoidance policy with regard to electrical powerline work, which ensures that all future powerlines will be sited away from schools and houses until the possible link between electromagnetic fields and cancer is disproved; and if she will make a statement.
>
> **Mr. Sackville:** The National Radiological Protection Board and Committee on Medical Aspects of Radiation in the Environment have considered this question and concluded that the available information does not establish that electromagnetic fields cause cancer. The significance of an epidemiological study depends, among other things, on the strength of the association, the presence of a dose-response relationship, supporting experimental evidence and a credible biological explanation. These tests for causality are not satisfied for the link between electromagnetic fields and cancer. On the basis of present evidence, the two bodies have not recommended the adoption of a policy of prudent avoidance. The position is being kept under review."

The government position set out in the above replies was affirmed recently (HC Deb 3 November 1994 cc1272-3W).

At least eight sets of parents are seeking compensation from electricity companies on account of leukaemia and brain tumours developed by their children.[85,86] By the time these test cases come to court, there will hopefully be more scientific evidence about the nature of a link, if any, between electromagnetic field exposure and cancer. It will be particularly important to assess the nature of any cancer risk arising from unusually high exposures. Although it is clearly of no comfort to those affected, the evidence points to very few individuals being at significant risk and most scientists would agree that power lines do not appear to present a major public health problem. The consequences of this not being the case were outlined by a concerned West Midlands GP, Dr Mark Payne, who was reported in *General Practitioner* as stating ".. If you say there is a problem, you then have to change the safety limits - and that would mean virtually rewiring Britain. It would cost millions - there are about 60,000 people living close to power lines".[87] Such an alarming prospect doubtless drives the large programme of ongoing research, some of it supported by the National Grid Company,[88] aimed at settling this issue. In an article fittingly entitled "Fields of contention", the Director of the

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85 "Little light on high voltage" *The Independent* 18 October 1994 p.26
86 "The down side of electricity" *Environmental Health* March 1994 p.56
87 "Jury is still out on power lines risk" *General Practitioner* 17 April 1992 p.34
88 "Grid to the Fore in worldwide study" *Electricity UK* April 1992

NRPB (Dr Roger Clarke) alluded to section 1 of the *Radiological Protection Act 1970* (cap 46) when he wrote:[89]

> "Should a causal relationship be scientifically established between exposure to electromagnetic fields and cancer induction, NRPB would not hesitate to offer advice to government on further protection of the community or of persons who are particularly at risk. Indeed, it is required by statute to do so."

At the moment it is only possible to observe that higher than normal exposure to electromagnetic fields might increase the, albeit very small, risk of childhood leukaemia. Other cancers have been implicated by some epidemiological studies of varying quality. All sides of this debate will await with interest the outcome of the research being performed worldwide into the origins of cancer, and the relative roles played by a variety of risk factors.

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89 "Fields of contention" *Radiological Protection Bulletin* April 1994 p.3

E. Glossary

abl	the name of a specific oncogene
antioxidants	chemical substances which inhibit the action of free radicals
atom	the basic building block of chemical elements, the simplest everyday substances. 10 million atoms placed end to end would measure about a millimetre in length.
cell	the basic unit of an organism. Cells vary enormously in size: typically 20 or more placed end to end would measure a millimetre.
confidence interval	the range of values which a quantity may be said to have with a specified level (usually 95%) of confidence.
culture	cells or tissues growing in nutrient medium in the laboratory.
DMBA	dimethylbenz(a)anthracene. A chemical with carcinogenic properties.
DNA	deoxyribonucleic acid. The name given to very large molecules, found in cells, which contain the genetic information.
dosimetry	the measurement or calculation of the physical effects (electrical currents, energy absorption) induced in the body by external electromagnetic fields or other sources of radiation.
electric field	A region in which an electric charge, either stationary or moving, experiences a force. An analogy may be drawn with the everyday situation of apples falling from trees; the result of the force exerted on them by the earth's gravitational field.
electromagnetic fields	generic term for electric and magnetic fields
ELF	extremely low frequency. Between 30 and 300 cycles per second (hertz). Power frequencies (50 hertz) fall within this band.
ENU	ethylnitrosourea. A chemical with carcinogenic properties.

free radical	an atom or molecule, the internal structure of which has been changed in a certain way. The result is often an atom or molecule which is highly reactive (i.e. undergoes chemical reactions readily)
gene	a segment of the DNA molecule serving as a template for a specific protein with a specific function.
hertz	the unit of frequency. One hertz is one cycle per second
magnetic field	a region in which a moving electric charge experiences a force, not due to an electric field.
microtesla	a millionth of a tesla, the unit of magnetic flux density.
molecule	an assemblage of chemically-bound atoms, the basic building blocks of everyday matter. Examples include the water molecule with three atoms, and a human DNA molecule with several billion atoms.
odds ratio	a measure of the relative risk of a disease arising from exposure to an hypothesised causative agent, derived from case-control epidemiological studies.
protein	large molecules of many different kinds with a range of functions, including the control of chemical reactions and the formation of bodily structures.
reaction	the interaction of two or more chemical substances to form different products.
rms	root mean square. A kind of average. In the case of oscillating electromagnetic fields from power lines, the maximum value of the field strength is about 1.4 times the rms value.
standardised incidence ratio	a measure of the relative risk, from cohort epidemiological studies.
tesla	the unit of magnetic flux density, a quantity related to the strength of the magnetic field.
tissue	an aggregate of cells. Combinations of tissues make up the organs of the body.
VDU	visual display unit

wire configurations	alternatively, wire codes. An approximate way of estimating the magnetic field inside a house from the type and configuration (height, distance) of electrical cables outside.

F. Further reading

1. "Electromagnetic Fields and the Risk of Cancer. Report of an Advisory Group on Non-ionising Radiation" *Documents of the NRPB* volume 3 no 1 1992

2. "Electromagnetic Fields and the Risk of Cancer. Summary of the Views of the Advisory Group on Non-ionising Radiation on Epidemiological Studies Published Since Its 1992 Report" *Documents of the NRPB* volume 4 no 5 1993 pp65-8

3. "Electromagnetic fields and the risk of cancer. Supplementary Report by the Advisory Group on Non-ionising Radiation, of 12 April 1994." *Radiological Protection Bulletin* June 1994 p.10

4. "Statement by the National Radiological Protection Board. Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation." *Documents of the NRPB* volume 4 no 5 1993 pp1-5

5. "Restrictions on human exposure to static and time varying electromagnetic fields and radiation. Scientific Basis and Recommendations for the Implementation of the Board's Statement." *Documents of the NRPB* volume 4 no 5 1993 pp7-63

6. "Electromagnetic Fields" *Croner's Health and Safety Special Report* October 1994

7. "EMF - cancer links: yes, no, and maybe" *Science* 29 October 1993

8. "The down side of electricity" *Environmental Health* March 1994 p.56

9. "Little light on high voltage" *The Independent* 18 October 1994 p.26

10. "Electro-magnetic fields" *Which? Way to Health* December 1992 p.200

11. "Power lines. The leukaemia link" *What Doctors Don't Tell You* volume 5 no 3 pp1-3