Environmental issue report | No 29

Children's health and environment: A review of evidence

A joint report from the European Environment Agency
and the WHO Regional Office for Europe

Experts' corner

Edited by:
Giorgio Tamburlini
Ondine S. von Ehrenstein
Roberto Bertollini

WHO Regional Office for Europe

World Health Organization
Regional Office for Europe

European Environment Agency

Layout: Brandenborg a/s

Note
The contents of this publication do not necessarily reflect the official opinions of the European Commission or other European Communities institutions. Neither the European Environment Agency nor any person or company acting on the behalf of the Agency is responsible for the use that may be made of the information contained in this report.

The views expressed in this publication are those of the author(s)/contributors and do not necessarily represent the decisions or the stated policy of the World Health Organization or the European Environment Agency.

While WHO endorses the technical and policy content of this report, it is not responsible for its production and therefore the terminology used may not necessarily follow the United Nations guidelines.

The designations employed and the presentation of the material, including any maps, in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Health Organization or of the European Environment Agency concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines in maps represent approximate border lines for which there may not be full agreement.

For further information and for providing comments on this publication please contact the WHO Operational Division in Rome at the address below.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server (http://europa.eu.int).

Luxembourg: Office for Official Publications of the European Communities, 2002

ISBN 92-9167-412-5

European Environment Agency
Kongens Nytorv 6
DK-1050 Copenhagen K
Tel.: (45) 33 36 71 00
Fax: (45) 33 36 71 99
E-mail: eea@eea.eu.int
Internet: http://www.eea.eu.int

World Health Organization
European Centre for Environment and Health
Rome Operational Division
Via Francesco Crispi, 10
I-00187 Rome
Tel: (39) 06 48 77 51
Fax: (39) 06 48 77 599
E-mail: ecehr@who.it
Internet: http://www.euro.who.int/ecehrome

Foreword

Children's health and environment needs to be high on the political agenda. It is not possible to talk about health and quality of life without taking into consideration, and paying special attention to the needs of children. We must never forget that a healthy environment is not a privilege but a basic human right — not least for our children.

'Environment and health' is one of four priority areas outlined in the 6th Environmental Action Programme, which defines the Community's environmental policy for the next ten years. The fundamental objective is to promote a quality environment where levels of man-made pollutants, including different types of radiation, do not have a significant impact on or pose a risk to human health. In this regard, the action programme calls for special attention to the more vulnerable groups in society, including children.

Children are, for a variety of reasons, particularly vulnerable to the impact of environmental pollution. They are often the first to pay the price for unsustainable development. Children and young people also have limited opportunity to influence the present or the future. They do not participate in the planning and decision-making process. We adults bear, therefore, a great burden of responsibility — a responsibility that we must take much more seriously in the future.

The first thing that we must achieve if we want to promote a 'child friendly' environment is to gain a better understanding of children's situation today and of the relationship between their health and the environment. We need much more information and research data. This is largely lacking at the moment. This publication, *Children's health and environment: A review of evidence* is therefore a very useful tool for gaining a clearer understanding of the major threats, challenges and opportunities that exist in the field of children's health and the environment.

Promoting a healthy environment for our children is a major task that will require all our energy and application. But we cannot achieve it on our own. If we are to succeed, all the parties involved must co-operate closely with each other. The World Health Organization and the European Environment Agency have given us a good example of how successful close co-operation can be. It's up to us to follow that example.

I hope that our joint efforts will succeed in promoting a more 'child friendly' environment and help us take another step along the road to sustainable development. What is good for our children is good for society as a whole. We need to give children a voice.

Margot Wallström
European Commissioner for the Environment

Foreword

Children's health and the environment lie at the centre of sustainable development. Failing to focus on this concept will amplify not only the health burden of today's children but also of future generations. There is no doubt that protecting children from environmental hazards *now* will be of benefit to the well-being of the population as a whole in the long term. We should not forget that the developing organism of a child is likely to be the most 'sensitive indicator' for the environmental health of populations. Can we afford to continue involving our children in this 'environmental experiment'?

The need to prioritize children's particular vulnerability was addressed by World Health Organization (WHO) Member States at the Third Ministerial Conference on Environment and Health in London, 1999. The European Member States recognized that 'exposure prevention is the most effective means of protecting children from environmental threats to health' and they committed to develop prevention-oriented policies and actions. At the same time, it became increasingly clear that scientific evidence on the specific needs and vulnerabilities of children, as well as scientific uncertainties have to be translated into environmental health policies, including cautionary policies when there is the risk of severe and irreversible damage. This joint publication of the WHO Regional Office for Europe and the European Environment Agency, which is based on the background documentation of the Third Ministerial Conference on Environment and Health, is a first step in this direction. The process leading to this publication has increased the collaboration between WHO, the European Environment Agency and other agencies and institutions in the field of children's health and environment. Moreover, it has strengthened WHO's technical support to governments that have committed to increase their efforts to protect children's health in a number of declarations and policy statements. The forthcoming Fourth Ministerial Conference on Environment and Health, which will be held in Budapest in 2004, will focus on the health of children and future generations in the broader context of sustainable development. This gives further emphasis to the importance of the need to implement the protection of children's health in environmental policies.

Improving the science basis for priority-setting and decision-making and increasing the effectiveness of the use of limited resources in the protection of children against environmental hazards is an important challenge for the future. This publication contributes to the capacity of European institutions and the governments of the WHO European Region to provide appropriate answers to the challenge of protecting children's health against environmental threats.

Marc Danzon
Regional Director,
WHO Regional Office for Europe

Contents

Preface

This publication was prepared by the WHO European Centre for Environment and Health, Rome Operational Division, with support from the European Environment Agency, building on a collection of background papers prepared for the Third Ministerial Conference on Environment and Health in London in 1999. It provides an overview of the available evidence of the relationship between the physical environment and children's health, identifying both research needs and policy priorities to protect children's health from environmental hazards. The report aims to assist policy-makers and public health officials as they develop plans and strategies to address the most serious environmental health threats to children. It is also intended to promote a better understanding of children's environmental health issues within the scientific and professional communities involved in both child health and environmental protection.

The environment in which children live and play is an important determinant of their health and well being even if the extent of its importance is difficult to assess. Damage to children's health is also an important driver for the improvements to those parts of the environment that are associated with such ill health. It is therefore vital that there is close cooperation between environmental and health organisations, not least so as to minimise duplication of efforts.

Many publications on environmental health adopt a toxicant-centred approach, which is appropriate in view of the need to summarise the epidemiology, toxicology, risk assessment and risk-reduction interventions for each specific substance. This publication, which focuses on children rather than on toxicants, is aimed also at providing readers with different, yet equally important, perspectives on children's environmental health issues:

- the developmental perspective, which considers the risks in the different developmental stages, from preconception to adolescence;
- the environmental setting perspective, which considers the various risks that children may face in their different environments;
- the disease perspective, which considers the various health effects and the role played by various environmental hazards.

We hope that these complementary perspectives may help provide a comprehensive overview of risks and exposures as well as a basis for integrated prevention policies.

The chapters in this publication are grouped in four parts:

Part 1 provides an overall view of children's environmental health from a developmental and environmental setting perspective. It describes the biological and psychosocial factors that cause the particular vulnerability of children to environmental threats, from preconception to adolescence, and provides an overview of the environmental hazards in various settings where children live and grow.

Part 2 deals with the specific health effects of environmental contamination, such as asthma and atopic disorders, neurodevelopmental toxicity, cancer, birth defects, waterborne and foodborne gastrointestinal disorders, and injuries.

Part 3 addresses multiple health effects of environmental exposures such as tobacco smoke, pesticides, electromagnetic fields, and ultraviolet radiation. For each chapter current knowledge is summarised, data gaps are identified and actions needed to ensure adequate health protection for children are highlighted.

Part 4 is intended to offer the basis for the assessment and development of child-focused environment health policies. This part includes a discussion of the relevance of environmental justice issues. The methodological challenges relating to the risk assessment process are described, and approaches to decision-making, in the presence of scientific uncertainties, ignorance and multicausality, are proposed. Finally, the rationale and some guiding principles for developing and implementing environmental and health policies, specifically focusing on children, are provided.

This publication is intended to represent a starting point of a collaborative effort, involving experts as well as policy makers, aimed at improving the scientific basis of child-focused environment and health policies. Knowledge in this field is rapidly progressing: new information is continuously made available on old issues; new data are produced; innovative methodological and policy approaches are proposed; and new environmental threats emerge. A focus on emerging environmental threats to children may be particularly useful because children might be the 'canaries in the coalmines', the first ones to suffer from adverse health effects — with possible life long implications for both adults and children. The widespread distribution of endocrine disrupting chemicals in the environment might be such an emerging threat that not only impacts on children today but also on future generations. However, the risks to public health from exposure to endocrine disrupting substances are yet to be fully understood, particularly with regard to the timing of the dose. Due to the importance of this issue, the EEA and WHO will be providing a separate publication on endocrine disrupting chemicals and their importance for children's health later this year.

A cross-cutting issue is the question of how to assess and monitor children's health effects and how to identify and describe a possible association with environmental impacts, ultimately leading to the implementation of protective policies. Several international agencies, including the WHO and EEA, as well as expert groups from different countries, have already started to work in this field. Necessary steps in the establishment of such a monitoring and reporting system in the European Region include: identification of the most significant and sensitive check points in the system, taking into account possible critical pathways, multi-causal effects, synergies and additional factors such as changing diets, behavioural and lifestyle patterns; development of indicators on health outcomes in childhood and linked to relevant environmental exposures; the standardisation of a reporting system based on key indicators that are relevant for all countries in the region; performance of original research to improve the monitoring system and the timely identification of early warnings; and close collaboration between governments, international agencies and experts. The impact of environmental policies on children's health may be evaluated on the bases of key indicators, and the improvement of children's health should be one of the main measures of effective policies.

The evaluation of scientific evidence about the environmental causes of ill health is difficult, and, beyond the cancer and climate change fields, there have been few attempts to produce criteria for classifying evidence based on a 'strength of evidence' approach. A simple 'typology of causation' has been used in the chapter on birth defects (Chapter 6), where the evidence has been roughly sorted into 'very likely', 'likely' and 'possible' causes. This approach needs further development for application in this and other fields of environmental health.

Overall, there are many areas of uncertainty in children's health related to the environment, and consensus among experts may still be lacking on many issues. For all these reasons, we think that the best way to serve the cause of scientific evidence on children's environmental health would be to consider this publication as work in progress, to periodically update it, and to invite scientists involved in this area to contribute to this providing their comments and suggestions. We plan a specific web-site for this purpose.

This monograph is published as an Expert Corner in the EEA's environmental issues series of publications continuing the joint activities of EEA and WHO on children and environmental health that began in 1999. Such reports are designed to stimulate debate on issues that may contribute to the identification, framing and evaluation of environmental policy measures. This emerging and very cross-disciplinary issue poses considerable challenges to WHO and EEA, and hence the need for such an integrated approach and stock taking of expert knowledge. We trust that this will a be useful starting point from which improved reporting and policy support can develop.

Finally, it remains for us to thank all the authors, editors and other contributors who have made this report possible. The chapters in this monograph have been reviewed within the WHO network and we would therefore also like to express our thanks to all those experts involved.

Domingo Jiménez-Beltrán, Executive Director, EEA
Roberto Bertollini, Director, Division of Technical Support, WHO Regional Office for Europe

13. Electromagnetic fields

Kristie L. Ebi

Contributing authors: Ondine S. von Ehrenstein, Katja Radon

Summary of existing knowledge
- The classification of power-frequency electromagnetic fields (EMF) as a possible human carcinogen is partially based on studies of childhood leukaemia.
- Available evidence suggests that exposure to power-frequency EMF is not associated with childhood brain tumours.
- The possible adverse health effects in children associated with radiofrequency fields have not been fully investigated.

Main challenges
- To improve understanding of the effect of EMF on children's health, particularly in early development.
- To determine the biological mechanism of action.
- To determine relevant exposure and improve knowledge of all sources of exposure.

Action points
- As any population-level effect is likely to be small, prudent avoidance is one approach to dealing with the uncertainty.

13.1. Introduction

Public concern continues about the possible negative health consequences of exposure to power-frequency and radiofrequency electromagnetic fields (EMF). Modern industrial development has resulted in everyone being exposed to a complex mix of electric and magnetic fields and radiation, with exposure beginning before birth. The possible health outcomes associated with power-frequency EMF were recently reviewed by national and international agencies, including the International Agency for Research on Cancer (IARC), the National Radiological Protection Board (NRPB), the US National Institute of Environmental Health Sciences (NIEHS) and others (NRPB, 2001; WHO, 2001; Tenforde, 2000; Portier and Wolfe, 1998). One priority issue was the association between power-frequency fields and childhood leukaemia. All reviews noted that more than 20 years of research have not resolved scientific questions about the possible adverse health effects of EMF exposure and that evaluations of exposure assessment and epidemiological studies were made more difficult because of the lack of knowledge of what, if any, is the biologically relevant exposure and the lack of a biological mechanism. The following chapter gives an overview of EMF, and then summarises research on the association between EMF and adverse health effects in children.

13.2. Physical characterisation

Electromagnetic radiation is the transportation of energy through space. The electromagnetic spectrum spans a very large range of frequencies — more than 15 orders of magnitude. It ranges from below power-frequency fields to ionising radiation. This spectrum can be divided into three broad bands based on their frequency or wavelength: electromagnetic fields and radiation (0 hertz (Hz) to 300 gigahertz (GHz), where 1 000 Hz = 1 kilohertz (kHz), 1 000 kHz = 1 megahertz (MHz) and 1 000 MHz = 1 GHz); infrared and optical radiation; and ionising radiation (Figure 13.1.). Electromagnetic fields and radiation are further broken down (Table 13.1.) into: extremely-low-frequency (ELF) EMF (between 30 and 3 000 Hz); radio frequencies, which range from the very low frequencies of television sets and visual display units (about 30 kHz) to the high frequencies of FM radio (about 300 MHz); and microwaves, which are at the high end of this spectrum (up to 300 GHz). Power-frequency EMF falls into the ELF range of the spectrum; the frequency depends on the power source. Power systems operate at frequencies of either 50 or 60 cycles per second (50 or 60 Hz).

Table 13.1. Electromagnetic fields and their sources

Source: NRPB, 2001

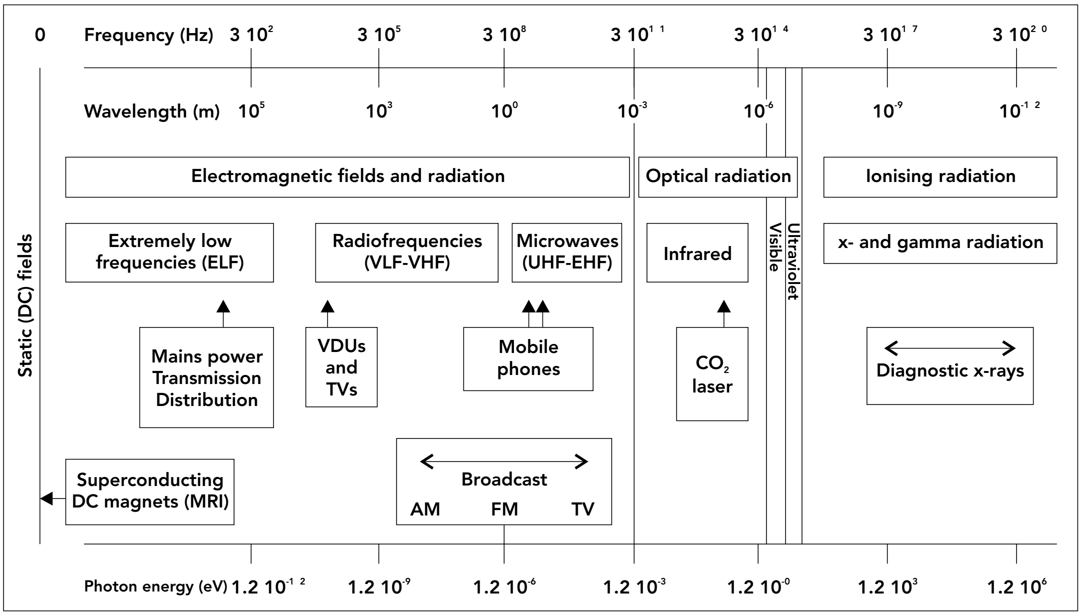
Frequency	Wavelength	Description	Band	Sources
0 Hz		Static		Earth's field Magnets, DC supplies
		Sub-extremely low frequency	SELF	
30 Hz 50 Hz	10 000 km 6 000 km	Extremely low frequency	ELF	Electric power lines and cables Domestic and industrial appliances
300 Hz	1 000 km	Voice frequency*	VF	Induction 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	Mobile phones 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.

Figure 13.1. Electromagnetic spectrum

Source: NRPB, 2001



13.3. Extremely-low-frequency electromagnetic fields (ELF-EMF)

An electromagnetic field is composed of two components, the electric and the magnetic fields. The electric field is created by the presence of an electric charge and is determined by the voltage. Whenever electricity is generated, transmitted or used, magnetic fields are created from the presence and motion of electric charges. The current determines the magnitude of a magnetic field. Magnetic fields are three-dimensional (described by the directional components x, y, z) and time-varying vector quantities that can be described by a number of parameters, including their frequency, phase, direction and magnitude. Electric and magnetic fields have different properties that are of importance when considering possible biological effects. Essentially all materials, including clothing, easily shield power-frequency electric fields. In contrast, the properties of magnetic fields are such that they pass through nearly all materials, including living tissues, building structures and the earth. The primary determinants of magnetic field exposure are source geometry and distance from the source to the measurement location. One consequence is that the magnitude of a magnetic field decreases fairly rapidly with distance from an isolated source. In general, magnetic fields from transmission and distribution lines decrease with the inverse square of the distance, while the fields from appliances decrease with the inverse square to the inverse cube of the distance. The strength of a magnetic field is usually designated by its magnetic flux density or B field measured in tesla (T). Magnetic field exposures from power frequency fields are in the range of µT (1×10^{-6} T).

Sources and magnitude of exposure

Major sources of EMF exposure include electrical power generation, transmission and use in residential and occupational settings, and telecommunications and broadcasting. Most devices that have electrical wires are potential sources of power-frequency EMF. Although the predominant exposure is to alternating current waveforms, humans are also exposed to a mixture of frequencies, including switching events that generate abrupt spikes of high-frequency transients that can extend into radio frequencies. Residential exposures include power-frequency exposures, radio frequencies and microwave sources.

Magnetic field exposures from power lines are dependent on the current carried on the line, the geometry of the system, the number of consumers, the distance to the nearest electrical equipment (often substation or transformer), the grounding practices, and the season (Johnsson and Mild, 2000). Typical magnetic field exposures directly under transmission lines are: 40 µT under a 400-kilovolt (kV) line, 22 µT under a 275-kV line and 7 µT under a 132-kV line (NRPB, 2001). Exposures 25 metres away from these same lines typically are 8, 4 and 0.5 µT, respectively.

Table 13.2. summarises children's personal magnetic field exposures in six studies (Foliart *et al.*, 2001). Some of these studies were of childhood leukaemia and others were surveys. The 24-hour mean time-weighted average measurements ranged from 0.10 to 0.14 µT, with 10–14 % of children having exposures above 0.2 µT. Typically, high-voltage transmission lines account for a minority of high exposures. For example, in Germany, only 29 % of all higher magnetic field exposures were attributable to high-voltage transmission lines (Schütz *et al.*, 2000).

The high visibility of overhead power lines has resulted in most concern about EMF exposure being associated with them. A frequently proposed solution is undergrounding of transmission and distribution lines. However, exposures from underground cables may be higher due to the properties of magnetic fields and the constraints in building an electrical supply system. Electricity is carried in three separate phases (seen as the three conductor bundles carried on transmission lines). The spatial arrangement of these phases will cancel some amount of the magnetic field (compared with a single conductor). The amount of cancellation is determined by the configuration of and distance between these phases. Transmission and distribution lines require a minimum ground clearance to prevent flashover hazards; this clearance is often more than 7 metres. Undergrounding cables are individually insulated and placed much closer together than overhead conductors. This close physical spacing results in more field cancellation than occurs with overhead lines. However, underground wires are often buried at a depth of 1 metre, placing the magnetic field source closer to an individual than an overhead source (Figure 13.2.).

Besides overhead power lines, residential EMF exposures arise from current flowing in conducting pipework and the ground, and from appliance use. Away from power lines, background magnetic field levels arise because the load current a particular house draws is rarely exactly balanced by the current returning via the neutral conductor. In the United Kingdom, residential exposures away from power lines are mostly in the range of 0.01 to 0.2 µT, with very few exposures exceeding 0.3 µT (Swanson and Kaune, 1999). Different operating characteristics and wiring practices result in higher exposures in the United States. For most people, their highest magnetic field

Children's personal magnetic field exposures by study[1)] Table 13.2.

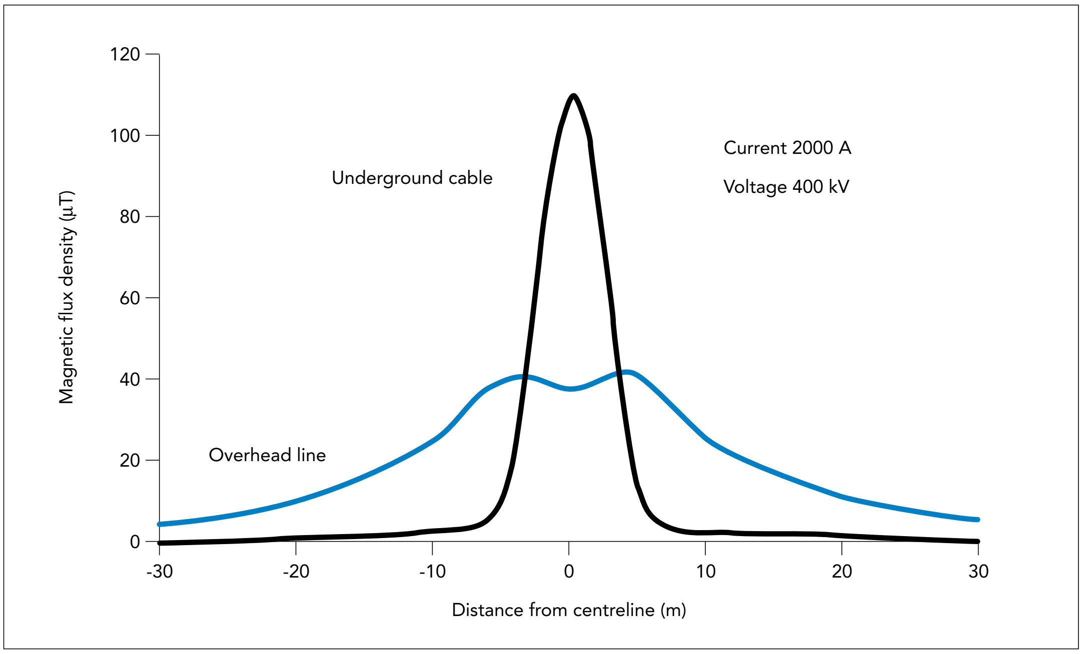
Source: Foliart *et al.*, 2001

Study (age range)	N	24-hour time-weighted average mean (µT)	24-hour time-weighted average ≥ 0.2 µT	Geometric mean (µT)	Geometric standard deviation	Median (µT)
Childhood leukaemia survival (case study: 0–15 years)	356	0.115 (0.104)[2)]	10.1 %	0.075	2.30	0.073 µT
EMF-RAPID 1 000 person (0–18 years) (Zaffanella and Kalton, 1998)[3)]	138	0.106	12.3	0.077	2.19	0.069
NCI – Washington, DC pilot (0–8 years) (Kaune *et al.*, 1994)	29	0.13	14.3[4)]	0.105	1.89	n/a
EPRI – Enertech study (0–18 years) (Kaune and Zaffanella, 1994)	31	0.14	13	0.097[5)]	2.46	n/a
NCI – cases (<15 years) (Linet *et al.*, 1997)	615	0.104	11.4	0.077	2.09	0.072
BCCA study – controls (0–14 years) (McBride *et al.*, 1999)	329		12.8[6)]			

1) Includes studies reporting exposures among children.
2) Excludes outlier associated with night-time use of portable fan.
3) Includes 138 children up to the age of 17: the 24-hour time-weighted average exposures were 0.11 µT for children less than 5 years and 0.10 µT for children 5–17 years of age.
4) Per cent ≥ 0.25 µT.
5) At-home average for combination of two days.
6) Lifetime predicted exposure; contemporaneous measurements yield 15.3 %.

Magnetic fields from overhead lines and underground cables Figure 13.2.

Source: NRPB, 2001



exposures arise from the use of domestic appliances that incorporate motors, transformers or heaters (NRPB, 2001). For example, at 3 centimetres (cm) distance, the magnetic field exposures from hair dryers and can openers may be several hundred microtesla.

Exposure assessment

One goal of exposure assessment is to choose a summary measure that is both physically meaningful and biologically relevant. Challenges include the facts that residential (and most occupational) exposure is not perceptible by humans; the sources of EMF are ubiquitous in modern urban life making it difficult to predict circumstances that might lead to particularly high exposures; EMF are highly variable in time and space, which means that measurements can be subject to large random variations; and there is no generally accepted biophysical mechanism and no established biomarker of exposure or response (Portier and Wolfe, 1998). Various approaches have been used to summarise EMF exposure over time within groups of individuals. There is no scientific consensus on which exposure metrics (if any) are related to biological responses.

One commonly used exposure surrogate in studies of childhood cancers is the time-weighted average. Another surrogate is called a wire or wiring code, which combines information on the identifying characteristics of the distribution and transmission lines visible from outside a home and the distance from the home to the wires. Wire codes were primarily used in studies conducted in the United States.

Biological interactions

As the issues of concern for children are leukaemia (specifically acute lymphocytic leukaemia) and brain cancer, the following discussion will focus on the association between exposure to ELF-EMF and cancer development and progression. The full range of possible biological effects associated with power-frequency fields has been extensively reviewed by NRPB, NIEHS and others (NRPB, 2001; Tenforde, 2000; Portier and Wolfe, 1998).

Experimental studies relevant to carcinogenesis

A large number of papers have been published describing cellular and animal studies designed to determine whether or not electric or magnetic fields are capable of carcinogenesis. The focus of recent studies has been cancer promotion or progression as earlier studies demonstrated that ELF-EMF fields do not contain enough energy to directly cause DNA damage and, therefore, are not genotoxic (Murphy *et al.*, 1993; McCann *et al.*, 1993). A comprehensive review of fields below 1 μT also concluded that these fields are not mutagenic (Lacy-Hulbert *et al.*, 1998).

The 2001 NRPB review concluded that: 'At the cellular level, there is no clear evidence that exposure to weak ELF electromagnetic fields (of less than 1 μT) can affect biological processes. Studies are often contradictory and there is lack of confirmation of positive results from different laboratories using the same experimental conditions.' The review also concluded that there were three areas with suggestive evidence where further investigation is needed: possible enhancement of genetic change caused by known genotoxic agents; effects on intracellular signalling, particularly calcium flux; and effects on specific gene expression. The results that claim to demonstrate positive effects tend to show small changes with uncertain biological consequences; also, these positive effects are generally at field levels much higher than those found in residences.

In addition to NRPB and NIEHS, Boorman *et al.* (2000) and McCann *et al.* (2000) extensively reviewed the animal carcinogenic studies. The studies investigated the possible effects of exposure to mostly power-frequency fields on spontaneous and chemically induced tumour incidence, and on the growth of transplanted tumour cells. Most of the recent large-scale studies found no evidence of carcinogenicity. Specifically, four large-scale studies of the effects of lifetime exposures on spontaneous tumour incidence in rats and mice were mostly negative (Mandeville *et al.*, 1997; Yasui *et al.*, 1997; Boorman *et al.*, 1999; McCormick *et al.*, 1999). Several studies investigated the possible effects on brain cancer or on leukaemia, the childhood cancers of concern. The reviews concluded that most studies reported a lack of effect of power-frequency magnetic fields on leukaemia or lymphoma in rodents (mostly mice). Two of the studies used transgenic mice that develop a disease with some similarities to childhood acute lymphocytic leukaemia (Harris *et al.*, 1998; McCormick *et al.*, 1998). Other studies found no effect of EMF on the progression of transplanted leukaemia cells in mice or rats.

The most marked effect reported in only one study was an increase in lymphoid hyperplasia and lymphoma in mice exposed over three generations (Fam and Mikhail, 1996); however, NRPB concluded that there were a number of deficiencies that made it difficult to place a high degree of confidence in the result (NRPB, 2001). Although there is no natural animal model of spontaneous brain tumour, a recent large-scale study in female rats found no effect of EMF exposure on chemically induced nervous system tumours (Mandeville *et al.*, 2000). Other large-scale rat studies reported a low incidence of brain cancers (Mandeville *et al.*, 1997; Yasui *et al.*, 1997).

Epidemiological studies of childhood cancers

IARC, NRPB and US NIEHS reviewed the scientific literature regarding possible evidence for an association between exposure to ELF-EMF and cancer development (NRPB, 2001; WHO, 2001; Portier and Wolfe, 1998). All used a similar process of expert judgment for evaluation of the scientific evidence and IARC and US NIEHS summarised their findings according to the strength of the overall evidence using the IARC categories. IARC and US NIEHS concluded that the scientific evidence, in particular the evidence as it relates to childhood leukaemia, suggests that power-frequency EMF is possibly carcinogenic to humans (category 2B). The decisions were based on the evaluations that there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals. NIEHS concluded that there was inadequate evidence of carcinogenicity with respect to childhood nervous system tumours.

There is a considerable body of epidemiological research on the association between power-frequency EMF and childhood leukaemia dating from 1979 (Wertheimer and Leeper, 1979). NIEHS, NRPB and others have extensively reviewed the epidemiology studies of ELF-EMF and childhood leukaemia (NRPB, 2001; Portier and Wolfe, 1998). The strengths of the reported associations between residential exposure to power-frequency magnetic fields and childhood leukaemia vary in the studies from no association to about a two-fold increased risk of childhood leukaemia among children with higher exposure. A number of methodological issues make interpretation of these studies difficult; these include exposure assessment, confounding and selection bias. The exposure assessment issue revolves around the question of the appropriate metric to be used as a surrogate for exposure. As noted above, unknowns include the possible mechanism of action of power-frequency magnetic fields, the aspect of the fields that is of biological relevance and the etiologically relevant time period. An additional difficulty arises from the problem of estimating exposures prior to disease diagnosis. The variety of metrics used to estimate exposure are not able to capture the hourly, daily, weekly, seasonal and long-term fluctuations in magnetic-field strength.

In addition, as little is known about the etiology of childhood cancers, studies have searched for factors that could confound the reported associations between EMF and childhood leukaemia. Recent reviews, including NIEHS and NRPB, conclude that confounding is unlikely to be an explanation for the reported results (NRPB, 2001; Portier and Wolfe, 1998). Langholz used the mathematics of confounding to explore factors that could explain the reported associations between wire codes and childhood leukaemia in three major case-control studies conducted in the United States (Langholz, 2001). Very few potential explanatory factors were identified (age and type of home, and magnetic fields). The question of selection bias arises because some of the studies conducted in the United States used methods to choose controls that may have resulted in controls not being representative of the population from which the cases arose. However, other studies, particularly those conducted in Scandinavian countries, were unlikely to suffer from selection bias because individual-level morbidity and mortality data are available across the population.

The NIEHS and NRPB reviews concluded that there is limited evidence that residential exposure to ELF magnetic fields is carcinogenic in children (NRPB, 2001; Portier and Wolfe, 1998). The NIEHS stated that 'although the exposure metrics used as surrogates for exposure to magnetic fields are of varying precision, it is difficult to find an explanation other than exposure to magnetic fields for the consistency of the reported excess risks for childhood leukaemia in studies conducted in different countries under different conditions, with different study designs' (Portier and Wolfe, 1998).

Two recent studies conducted pooled analyses of magnetic fields and childhood leukaemia (Ahlbom *et al.*, 2000; Greenland *et al.*, 2000). Original data were used in both analyses. Ahlbom *et al.* (2000) based their re-analysis on nine studies with comparable cases and controls that used direct measurements of exposure. Exposure assessment in these studies was based either on magnetic field measurements of 24 to 48 hours (studies in Canada, Germany, New Zealand, the United Kingdom and the United States), or on calculated field exposures (studies in Denmark, Finland, Norway and Sweden). There were 3 203 cases, of whom 83 % had acute lymphocytic leukaemia, and 10 388 controls. Exposure categories were defined *a priori* as < 0.1 μT (baseline for comparison); 0.1 to < 0.2 μT; 0.2 to < 0.4 μT; and ≥ 0.4 μT. There were 44 cases and 62 controls in the highest exposure category of ≥ 0.4 μT. In the measurement studies, the summary relative risk (RR) for all types of leukaemia in the highest exposure category was 1.83 (95 % CI 1.08–3.11; p = 0.01). In the calculated field studies, the relative risk in the highest exposure category was 2.13 (95 % CI = 0.93–4.88; p = 0.04). The summary relative risk in all studies combined was 2.00 (95 % CI = 1.28–3.13; p = 0.002). Relative risks in the intermediate exposure categories were close to unity for both measured and calculated fields. Continuous analysis estimated the relative risk at 1.15 (95 % CI 1.04–1.27) per 0.2 μT (p = 0.004). Adjustment for potential confounding variables did not appreciably change the results. The percentage of children in the highest exposure category varied by country. The results for acute lymphocytic leukaemia were essentially the same. The authors pointed out that the results mean that the 99.2 % of children residing in homes with exposure levels < 0.4 μT had estimates compatible with no increased risk, while the 0.8 % of children with exposures ≥ 0.4 μT had a relative risk estimate of about two. This increased risk is unlikely to be due to random variability.

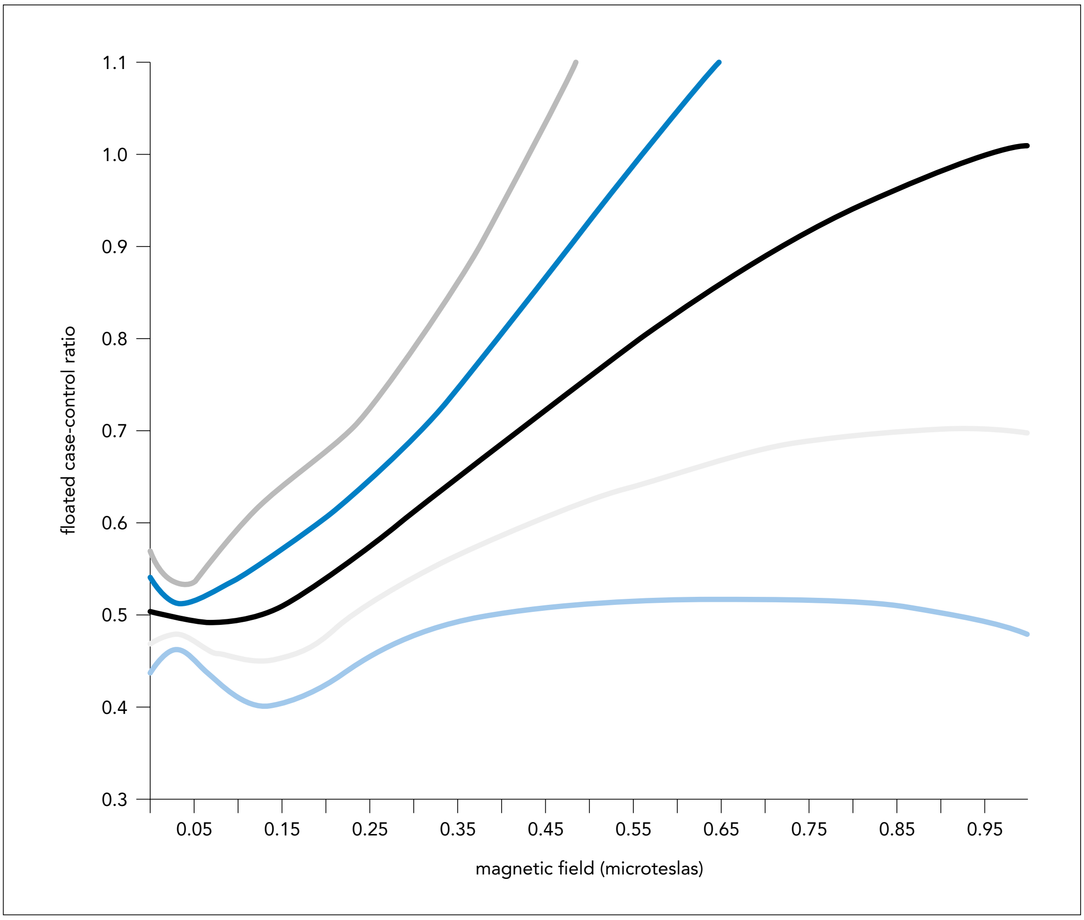
Greenland *et al.* (2000) re-analysed the data from 12 studies of childhood leukaemia. Eight of the studies were included in the Ahlbom *et al.* (2000) re-analysis. As much as possible, calculated historical fields or averages of multiple measurements were used. The target metric was each child's time-weighted average exposure up to three months prior to diagnosis. The cut-off for the highest exposure category was ≥ 0.3 μT. The results were similar to those reported by Ahlbom *et al.* (2000); the summary odds ratio (OR) for those in the highest exposure category was 1.7 (95 % CI 1.2–2.3) compared with exposure to 0 to 0.1 μT. There also was evidence of increasing risk with increasing exposure to magnetic fields above 0.15 μT (Figure 13.3.). Controlling for various potentially confounding variables made little difference in the risk estimates. The authors calculated that for the population of the United States, the population-attributable fraction of childhood leukaemia associated with residential exposure might have been 3 % (95 % CI –2 % to +8 %). The authors concluded 'both our categorical and trend analyses indicate that there is some association comparing fields above 0.3 μT to lower exposures'. However, they caution that 'the inconclusiveness of our results seems inescapable'.

The NRPB review supports the possible small effect of magnetic field exposures on the incidence of childhood leukaemia (NRPB, 2001). Among children up to 14 years of age, about 430 cases of leukaemia (all types) are registered each year in England and Wales. The UK Childhood Cancer Study found that 0.4 % of children are exposed to ≥ 0.4 μT. Assuming a doubling of risk at this exposure level, then annually about two cases of leukaemia would occur anyway and a further two cases might be attributable to EMF exposure. If regression dilution were concealing a relative risk of 1.5 for children exposed to between 0.2 and 0.4 μT, then the annual number of attributable cases might be six or seven.

These reviews are supported by a recent population-based case-control study in West Germany that included 24-hour measurements of magnetic field exposures for 514 cases of acute lymphocytic leukaemia and 1 301 controls (Schütz *et al.*, 2001). The analysis compared exposures above and below 0.2 μT. Only 1.5 % of the study population had exposures above 0.2 μT. The strongest association was found for night-time exposures (OR = 3.21, 95 % CI 1.33–7.80). A dose-response relationship was observed after combining the data of all German studies on childhood leukaemia and magnetic field exposures (OR rising to 4.28 (95 % CI 1.25–14.7) in the highest exposure category of ≥ 0.4 μT). The authors note that even if the observed association were confirmed, the impact would be small in Germany.

Floated case-control ratios from 3-degree-of-freedom quadratic-logistic spline model fit to pooled magnetic field data, with adjustment for study, age, and sex. Inner dotted lines are pointwise 80 % confidence limits; outer dotted lines are pointwise 99 % confidence limits

Figure 13.3.



Source: Greenland *et al.*, 2000

However, further analyses of the United Kingdom Childhood Cancer Study, a population-based case-control study covering the whole of England, Scotland and Wales, found no association between any childhood cancers, including acute lymphocytic leukaemia, and residential proximity to electricity supply equipment, distances to high-voltage lines, underground cables, substations and distribution circuits (UK Childhood Cancer Study Investigators, 2000). Magnetic field exposures were calculated from this equipment using distance, load and other circuit information for 3 380 cases and 3 390 controls. There was no evidence that either proximity to electrical installations or the magnetic field levels they produce were associated with increased risk of childhood leukaemia or any other cancer.

A review of the epidemiological evidence of an association between exposure to ELF-EMF and childhood brain tumours concluded that there is no support for an overall association (Kheifets *et al.*, 1999).

The NIEHS concluded that the limited data on maternal exposure to ELF-EMF during pregnancy or paternal exposure before contraception do not suggest an exposure-related increased risk of spontaneous abortion or adverse outcomes of pregnancy (Shaw, 2001). However, two new studies suggest an association (Lee *et al.*, 2002; Li *et al.*, 2002). Lee *et al.* (2002) conducted a nested case-control study of residential and personal magnetic field exposures and spontaneous abortion. The study included 177 cases and 550 controls. A variety of exposure metrics were assessed at 30 weeks of gestation (or the equivalent point relative to the onset of pregnancy for women who had a spontaneous abortion), including rate of change, maximum value and time-weighted average. Women in the second through fourth quartiles were generally associated with a more than 50 % increased risk of spontaneous abortion. Spontaneous abortions were not associated with either spot measurements or with time-weighted average exposures over 0.2 µT. Li *et al.* (2002) conducted a population-based prospective cohort study of personal magnetic field exposures during pregnancy. The study included 969 women with a positive pregnancy test at less than 10 weeks of gestation. Personal magnetic field exposure data were collected over a 24-hour period. No association was observed between spontaneous abortion and average magnetic field exposure. Magnetic field exposures over 1.6 μT were statistically significantly associated with spontaneous abortion (RR = 1.8, 95 % CI 1.2–2.7) when compared with exposures less than 1.6 μT. The association was stronger for spontaneous abortions that occurred at less than 10 weeks (RR = 2.2, 95 % CI 1.2–4.0) and for women with multiple prior fetal losses or with subfertility (RR = 3.1, 95 % CI 1.3–7.7). In a commentary published with the papers, Savitz concluded that: 'These two new studies provide fairly strong evidence against an association with time-weighted average magnetic fields and moderately strong evidence for an association with other indices; both of these findings may be due to an artifact resulting from a laudable effort to integrate behavior and environment' (Savitz, 2002). Savitz suggested that behavioural differences between the study groups could introduce differential misclassification of exposure. Further research is needed on the question of whether there is an association between magnetic field exposure and spontaneous abortion.

Protection against ELF

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) publishes EMF guidelines for general public exposure to time-varying electric, magnetic and electromagnetic fields up to 300 GHz (ICNIRP, 1998). These guidelines are based on shock hazards, not cancer or other health effects. The current recommendations for 50/60-Hz electric fields are 2 milliamperes per square metre (mA/m^2) current density to prevent effects on nervous system function; for 50-Hz power-frequency fields, this translates to 5 000 volts per metre (V/m) for electric fields and 100 μT for magnetic fields. Some countries have legally implemented these guidelines (SVDB, 1996). Several governmental authorities have issued statements proposing action to reduce exposure to EMF, e.g. the Swedish Board for Safety recommended avoiding the placement of schools and day-care centres in environments where the magnetic fields exceed 0.2–0.3 μT (Johnsson *et al.*, 2000).

Faced with the uncertainties regarding a potential causal association between exposure to ELF-EMF fields and adverse health outcomes, some have suggested that 'prudent avoidance' of EMF exposure may be justified (Johnsson *et al.*, 2000; WHO, 1998; Kheifets *et al.*, 2001). The NIEHS report concluded that: 'In summary, the NIEHS believes that there is weak evidence for possible health effects from ELF/EMF exposure, and until stronger evidence changes this opinion, inexpensive and safe reductions in exposure should be encouraged' (Portier and Wolfe, 1998). These are 'no regrets' options that are inexpensive, safe and easy to implement. Further research is needed to clarify these issues.

13.4. Radiofrequency fields

The term radiofrequency (RF) is not strictly defined, but often indicates the part of the electromagnetic spectrum ranging from 100 kHz to 300 GHz; this is the part of the spectrum below the frequencies of visible light and above ELF fields. RF fields have higher frequency (shorter wavelength) than ELF-EMF. An RF wave used for radio communication is referred to as a carrier wave. The information it carries (speech, computer data, etc.) has to be added to the carrier wave in some way, a process known as modulation. The information can be transmitted in either analogue or digital form. The RF spectrum includes, in approximate order by increasing frequency: amplitude modulation (AM) radio, frequency modulation (FM) radio, very-high-frequency (VHF) radio and television, ultra-high frequency (UHF) television and cellular telephone transmissions, and microwave ovens, radar and satellite communications. Natural exposure to RF fields is negligible.

RF is usually expressed as a power density measured in watts per square metre (W/m^2) (or milliwatts per square centimetre (mW/cm^2)) and for dosimetry as specific absorption rates (SARs). SARs are the basis for virtually all RF exposure guidelines. The SAR is defined in watts per kilogram (W/kg) and is the rate of absorption of RF energy in a unit mass of tissue. As such, the SAR represents the energy actually absorbed. The SAR cannot be readily measured in routine exposure assessment, but requires special techniques to determine it. SAR levels are specified for whole body and for partial body or localised exposure. A variety of physical, biological and environmental factors can affect the SAR. These include the frequency, polarisation, modulation, power density, tissue properties, size (of person or animal), orientation relative to fields, temperature, humidity and other factors (Polk and Postow, 1996). Unlike ELF electric fields, most common household materials do not block RF fields.

Sources and magnitude of exposure

RF field sources in the home include microwave ovens, mobile telephones, burglar alarms, video display units and television sets. Most RF fields in the environment originate from radio and television broadcasting and telecommunication facilities. Studies of RF conducted at frequencies exceeding 1 MHz are of exposures that do not relate to everyday life exposures. When considering mobile telephones, one has to distinguish between continuous exposure from base stations and voluntary exposure to the telephones themselves. The maximum field intensity at 2.2 cm from the antenna of a telephone (the distance at which calculations are made) is about 200 W/m^2; actual exposures depend on telephone characteristics (Polk and Postow, 1996). This is about one-quarter of the intensity of the sun's radiation on a clear summer day, although the frequency of the emissions from a telephone is a million or so times smaller (IEGMP, 2000). This field intensity compares with a maximum intensity of 0.01 W/m^2 typically found around base stations (IEGMP, 2000).

Exposure assessment

RF exposure assessment is limited as measurements are rarely available. Exposure has been based on work site, distance from transmitters and other facilities, number of minutes of cellular telephone use, etc. Unlike ELF-EMF, RF measurement instrumentation is not available to conduct personal monitoring. For most studies, there is limited information on other factors that may relate to the health outcome.

Biological interactions

The depth of penetration of the RF field into the tissue depends on the field frequency and is greater for lower frequencies (WHO, 1998). The interactions of RF fields and biological systems are complex. One categorisation of these interactions is as thermal and non-thermal. Thermal effects result from the heating of biological materials due to energy deposition and absorption. Non-thermal effects are defined as alterations in biological/biochemical functions at RF energy levels not sufficient to heat biological systems. There is a growing body of scientific evidence that exposure to RF fields at intensities far less than levels required to produce measurable heating can cause effects in cells and tissues (RSCHC, 1999). These effects are often at the cellular membrane and enzyme activity level, coupled with other exposure conditions (presence of other chemicals, modulation of RF fields, etc.)

The rate of tissue temperature rise at any body location depends on the rate of energy absorption at that location. RF fields below 1 MHz do not produce significant heating, but they may induce electric fields in tissues. RF fields between 1 MHz and 10 GHz penetrate tissues and may cause tissue heating (increases in tissue or body temperature by ≥ 1 °C) (IEGMP, 2000). RF fields above 10 GHz are absorbed at the skin surface with very little energy penetrating into underlying tissues. Adverse health effects such as eye cataracts and skin burns occur from RF fields above 10 GHz; these are generated by power densities above 1 000 W/m^2 and are not found in everyday life.

The research on RF interactions with biological systems is extensive. Numerous biological systems or health end-points have been studied, including: chromosome-genetic, membrane or cell function, carcinogenesis, reproduction, nervous system, cardiovascular system, immune system and ocular effects. An Expert Panel Report prepared at the request of the Royal Society of Canada for Health Canada concluded: 'Scientific studies performed to date suggest that exposure to low intensity non-thermal RF fields do not impair the health of humans or animals. However, the existing scientific evidence is incomplete, and inadequate to rule out the possibility that these non-thermal biological effects could lead to adverse health effects' (RSCHC, 1999).

Experimental studies relevant to carcinogenesis

A review of the literature suggests that RF fields are unlikely to be mutagenic based on many negative results from *in vitro* studies on DNA damage, mutation frequency and chromosome aberration frequency (Michaelson and Lin, 1987). An ICNIRP review of animal studies concluded that exposure to RF fields is unlikely to initiate carcinogenesis (ICNIRP, 1998). There are various experimental results that are consistent with biological effects, some of which may be related to carcinogenic mechanisms at RF field strengths below those that produce thermal effects. For example, a number of studies reported some evidence of an effect of RF on intracellular levels of ornithine decarboxylase (ODC), an enzyme implicated in tumour promotion (tumour promoters increase ODC synthesis) (Michaelson and Lin, 1987). However, the results are inconsistent and no clear mechanism has been shown.

In 1997, an animal study of genetically susceptible mice exposed to pulsed RF fields of 900 MHz observed a more than two-fold increase in lymphoma compared with control mice (RR = 2.4, 95 % CI 1.3–4.5) (Repacholi *et al.*, 1997). This experiment was designed to assess exposures that would be encountered with the use of digital cellular telephones. The exposures were in the range 2.6–13.0 W/m^2 (0.26–1.3 mW/cm^2), yielding a range of SARs of 0.13–1.4 W/kg. These SARs are near the maximum levels of existing standards. The authors encouraged caution in the interpretation of their study: 'While the increase in the incidence of lymphoma found here was highly statistically significant, and the exposure conditions were designed to mimic the fields generated by a digital mobile telephone, the implications of the study for the risk of carcinogenesis in humans are unclear. It is difficult to extrapolate directly from mice to humans due to differences in their absorption of energy from RF fields.'

Epidemiological studies

Elwood recently reviewed the epidemiologic studies of RF field exposures and human cancers (Elwood, 1999). He categorised the studies into: studies of cancer clusters; studies of general populations exposed to television, radio and similar emissions; studies of occupational groups with exposure to such fields; and case-control studies. Several studies looked at associations with childhood cancers. Although there are suggestions of an association between RF exposures and childhood leukaemia (Figure 13.4.), Elwood concludes: 'The studies individually are weak and, as a consequence, the results cannot be easily interpreted in terms of cause and effect. The major impression from these studies is their inconsistency. There is no type of cancer that has been consistently associated with RF exposure.'

As noted in the Canadian review, certain subgroups such as children are more susceptible than healthy, young adults to various environmental health hazards (RSCHC, 1999). They note that susceptible subgroups has received very little study with respect to RF exposure, and the studies that have been conducted have not been particularly rigorous in their design and have studied group rather than individual-level data. Consequently, these studies are not particularly informative about potential RF health risks.

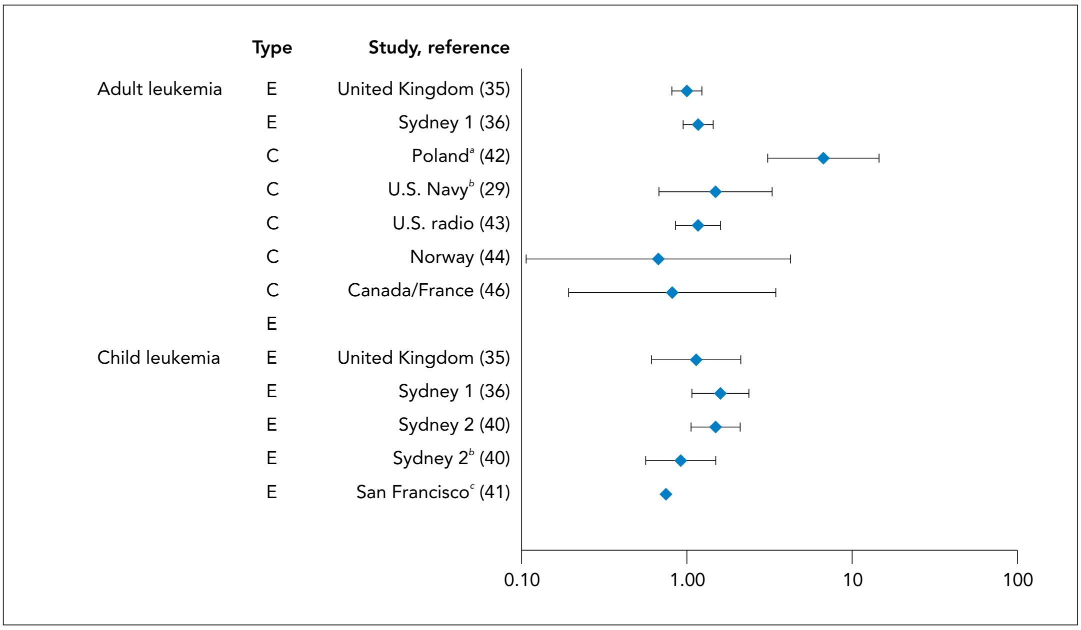
Results were recently published from two case-control studies and one cohort study of cellular telephone use and cancer (Muscat *et al.*, 2000; Inskip *et al.*, 2001; Johansen *et al.*, 2001). None found evidence of a link between cellular telephone use and increased brain cancer risk. The cohort study found no excess risk for cancers of the salivary glands, leukaemia or other site-specific cancers (Johansen *et al.*, 2001). Although the length of follow-up on these studies was relatively short, if RF exposure is assumed to act by promoting the growth of underlying cancers, then the recent intense use of cellular telephones (as considered in these studies) may be of more importance than latency or long-term use considerations. Additional studies are under way that may further clarify the relation between the use of mobile telephones and cancer.

The level of energy absorption in children while using mobile telephones is comparable to the levels found for adults; however, due to the larger number of ions contained in the tissue of children, the specific tissue absorption rate is considered to be higher (Schonborn *et al.*, 1998). Given their growing tissues, the fetus and the child may be more susceptible than adults to any adverse effects of RF.

The advisory Scientific Committee on156, Ecotoxicity and the Environment (SCTEE) to the European Commission recently updated its opinion on the possible health effects of mobile telephone use (SCTEE, 2001). The committee was asked specifically to consider the long-term exposure to low non-thermal levels. It was also asked to review whether or not the European safety limits for exposure to mobile telephone emissions, as set by ICNIRP, are still valid considering the latest scientific knowledge. The SCTEE concluded: 'The additional information which has become available on carcinogenic and other non-thermal effects of radiofrequency and microwave radiation frequencies in the last years does not justify a revision of exposure limits set by the Commission on the basis of the conclusions of the 1998 opinion of the Steering Scientific Committee.'

Relative risks and 95 % confidence limits for studies of leukemia in adults and in children. Type of study: C, occupational cohort; E, ecological

Figure 13.4.



Source: Elwood, 1999

[a]All lymphatic and hematopoietic-total leukemia not given.
[b]Excluding Lane Cove area. [c]No confidence limits given; nonsignificant.

The Independent Expert Group on Mobile Phones (IEGMP, 2000) concluded:

'First, the balance of the evidence available does not suggest that RF radiation from mobile telephones or base stations causes cancer or other disease. However, there is now evidence that effects on biological functions, including those of the brain, may be induced by RF radiation at levels comparable to those associated with the use of mobile telephones. There is, as yet, no evidence that these biological effects constitute a health hazard but at present only limited data are available. This is one reason why we recommend a precautionary approach.'

'Second, concerns have been expressed that the pulsed nature of the signals from mobile telephones and masts may have an impact on brain function. This is an intriguing possibility, which deserves further research, particularly if pulsed signals continue to be used in the third generation of telephones and related technologies. Research should concentrate on signal modulations representative of present and future telephone technology.'

In addition to direct effects, there can be indirect effects of RF. For example, an association between mobile telephone use while driving and an increased risk of traffic accidents has been shown in experimental as well as epidemiological studies (Redelmeier and Tibshirani, 1997).

Protection against RF

The guidelines for protection against adverse health effects in the optical and radiofrequency region are largely directed at limiting living tissue temperature rise due to absorption of thermal energy. Safety standards were developed following a review of RF-associated thermal and non-thermal effects by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1988). The safety limits recommended are well above the RF exposures found in the daily environment. The basic restriction for whole body exposure is an SAR of 0.4 W/kg for occupational exposure and 0.08 W/kg for general population exposure. The ICNIRP review shows that the threshold for irreversible effects in the most sensitive tissues is more than 4 W/kg under normal environmental conditions (ICNIRP, 1988). Higher limits were set for exposure of smaller body parts. The standards do not take into account the effects of RF exposures on the fetus and the developing child.

The SCTEE concluded: 'Thus current knowledge is insufficient for the implementation of measures aimed at the identification and protection of a highly sensitive sub-group of the population.' (SCTEE, 2001). The Independent Working Group on Mobile Phones recently stated that: 'If there are currently unrecognised adverse health effects from the use of mobile phones, children may be more vulnerable because of their developing nervous system, the greater absorption of energy in the tissues of the head, and a longer lifetime of exposure.' (IEGMP, 2000) The group believes 'that the widespread use of mobile telephones by children for non-essential calls should be discouraged'.

Protection against RF and ELF

Because there are suggestions that RF exposure may be more hazardous for the fetus and child due to their greater susceptibility, prudent avoidance is one approach to keeping children's exposure as low as possible.

Summary

Extremely low frequency (ELF) electromagnetic fields (EMF) are classified as a 'possible carcinogen' (IARC category 2B) primarily based on epidemiological studies of childhood leukaemia. High exposure to ELF-EMF is relatively rare in the general population (a few per cent of the population). Summary studies suggest that there is about a two-fold increased risk of childhood leukaemia among highly exposed children. There is no or little evidence for other health effects of ELF-EMF exposure in children. Adverse health effects following exposure to radio frequencies have not been consistently identified. Prudent avoidance is one approach to dealing with uncertainty concerning exposure in this portion of the electromagnetic spectrum. Recent reviews encourage the reduction of exposure through 'no regrets' options that are inexpensive, safe and easy to implement. Further research is needed to clarify the potential risks of ELF-EMF and radiofrequency fields for children's health.

References

Ahlbom, A., Day, N., Feychting, M. *et al.*, 2000. A pooled analysis of magnetic fields and childhood leukaemia, *Br J Cancer*, Vol 83, pp. 692–8.

Boorman, G.A., McCormick, D.L., Findlay, J.C. *et al.*, 1999. Chronic toxicity/ oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats, *Toxicol Pathol*, Vol 27, pp. 267–78.

Boorman, G.A., Rafferty, C.N., Ward, J.M. *et al.*, 2000. Leukaemia and lymphoma incidence in rodents exposed to low-frequency magnetic fields, *Radiation Res*, Vol 153, pp. 627–36.

Elwood, J.M., 1999. A critical review of epidemiologic studies of radiofrequency exposure and human cancers, *Environmental Health Perspectives*, Vol 107(suppl 1), pp. 155–68.

Fam, W.Z. and Mikhail, E.L., 1996. Lymphoma induced in mice chronically exposed to very strong low-frequency electromagnetic field, *Cancer Lett*, Vol 105, pp. 257–69.

Foliart, D.E., Iriye, R.I., Tarr, K.J. *et al.*, 2001. Alternative magnetic field exposure metrics: Relationship to TWA, appliance use, and demographic characteristics of children in a leukemia survival study, *Bioelectromagnetics*, Vol 22, pp. 574–80.

Greenland, S., Sheppard, A.R., Kaune, W.T. *et al.*, 2000. A pooled analysis of magnetic fields wire codes, and childhood leukemia, *Epidemiology*, Vol 11, pp. 624–34.

Harris, A.W., Basten, A., Gebski, V. *et al.*, 1998. A test of lymphoma induction by long-term exposure of E-PIM1 transgenic mice to 50 Hz magnetic fields, *Radiation Res*, Vol 149, pp. 300–7.

ICNIRP, 1998. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz), International Commission on Non-Ionizing Radiation Protection, *Health Physics*, Vol 74, pp. 494–522.

IEGMP, 2000. *Mobile phones and health*, Independent Expert Group on Mobile Phones. http://www.iegmp.org.uk (in 2001)

Inskip, P.D., Tarone, R.E., Hatch, E.E. *et al.*, 2001. Cellular-telephone use and brain tumors, *N Engl J Med*, Vol 344, pp. 79–86.

Johansen, C., Boice, J.D. Jr., McLaughlin, J.K. *et al.*, 2001. Cellular telephones and cancer — a nationwide cohort study in Denmark, *J Natl Cancer Inst*, Vol 93, pp. 203–7.

Johnsson, A. and Mild, K.H., 2000. Electromagnetic fields — a threat to children's health? in *Children and radiation. Selected topics raised at an international conference* (edited by T. Christensen and S. Stephens), Norwegian Centre for Child Research, Trondheim, Norway, pp. 53–86.

Kaune, W.T. and Zaffanella, L.E., 1994. Assessing historical exposures of children to power-frequency magnetic fields. *J Expo Anal Environ Epidemiol* Vol 4, pp. 149–70.

Kaune, W.T., Darby, S.D., Gardner, S.N. *et al.*, 1994. Development of a protocol for assessing time-weighted-average exposures of young children to power-frequency magnetic fields, *Bioelectromagnetics*, Vol 15, pp. 33–51.

Kheifets, L.I., Sussman, S.S. and Preston-Martin, S., 1999. Childhood brain tumors and residential electromagnetic fields (EMF), *Rev Environ Contam Toxicol*, Vol 159, pp. 111–29.

Kheifets, L.I., Hester, G.L. and Banerjee, G.L., 2001. The precautionary principle and EMF: Implementation and evaluation, *J Risk Research*, Vol 4, pp. 113–25.

Lacy-Hulbert, A., Metcalfe, J.C. and Hesketh, R., 1998. Biological responses to electromagnetic fields, *FASEB Journal*, Vol 12, pp. 395–420.

Langholz, B., 2001. Factors that explain the power line configuration wiring code-childhood leukemia association: What would they look like? *Bioelectromagnetics* (suppl 5), pp. S19–31.

Lee, G.M., Neutra, R.R., Hristova, L. *et al.*, 2002. A nested case-control study of residential and personal magnetic field measures and miscarriages, *Epidemiology*, Vol 13, pp. 21–31.

Li, D.K., Odouli, R., Wi, S. *et al.*, 2002. A population-based prospective cohort study of personal exposure to magnetic fields during pregnancy and the risk of miscarriage, *Epidemiology*, Vol 13, pp. 1–3.

Linet, M.S., Hatch, E.E., Kleinerman, R.A. *et al.*, 1997. Residential exposure to magnetic fields and acute lymphoblastic leukemia in children, *N Engl J Med*, Vol 337, pp. 1–7.

Mandeville, R., Franco, E., Sidrac-Ghali, S. *et al.*, 1997. Evaluation of the potential carcinogenicity of 60 Hz linear sinusoidal continuous-wave magnetic fields in Fischer F344 rats, *FASEB Journal*, Vol 11, pp. 1127–36.

Mandeville, R., Franco, E., Sidrac-Ghali, S. *et al.*, 2000. Evaluation of the potential promoting effect of 60 Hz magnetic fields on N-ethyl-N-nitrosourea induced neurogenic tumours in female F344 rats, *Bioelectromagnetics*, Vol 21, pp. 84–93.

McBride, M.L., Gallagher, R.P., Theriault, G. *et al.*, 1999. Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada, *Am J Epidemiol*, Vol 149, pp. 831–42.

McCann, J., Dietrich, F., Rafferty, C. *et al.*, 1993. A critical review of the genotoxic potential of electric and magnetic fields, *Mutation Res*, Vol 297, pp. 61–95.

McCann, J., Kavet, R. and Rafferty, C.N., 2000. Assessing the potential carcinogenic activity of magnetic fields using animal models, *Environmental Health Perspectives*, Vol 108, pp. 79–100.

McCormick, D.L., Ryan, B.M., Findlay, J.C. *et al.*, 1998. Exposure to 60 Hz magnetic fields and risk of lymphoma in PIM transgenic and TSG-p53 (p5s knockout) mice, *Carcinogenesis*, Vol 19, pp. 1649–53.

McCormick, D.L., Boorman, G.A., Findlay, J.C. *et al.*, 1999. Chronic toxicity/ oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice, *Toxicol Pathol*, Vol 27, pp. 279–85.

Michaelson, S.M. and Lin, J.C., 1987. *Biological effects and health implications of radiofrequency radiation*, Plenum Press, New York.

Murphy, J.C., Kadan, D.A., Warren, J. *et al.*, 1993. Power frequency electric and magnetic fields: A review of genetic toxicology, *Mutation Res*, Vol 296, pp. 221–40.

Muscat, J.E., Malkin, M.G., Thompson, S. *et al.*, 2000. Handheld cellular telephone use and risk of brain cancer, *JAMA*, Vol 284, pp. 3001–7.

NRPB, 2001. *ELF electromagnetic fields and the risk of cancer,* Report of an Advisory Group on Non-Ionising Radiation, Vol 12, No 1. National Radiological Protection Board, Chilton, UK.

Polk, C. and Postow, E., 1996. *Biological effects of electromagnetic fields,* CRC Press, Boca Raton, FL.

Portier, C.J. and Wolfe, M.S., eds, 1998. *Assessment of health effects of exposure to power-line frequency electric and magnetic fields,* National Institutes of Health working group report, NIEHS.

Redelmeier, D.A. and Tibshirani, R.J., 1997. Association between cellular-telephone calls and motor vehicle collisions, *N Engl J Med,* Vol 336, pp. 453–8.

Repacholi, M., Basten, A., Gebski, V. *et al.*, 1997. Lymphomas in Eμ-*Pim1* transgenic mice exposed to pulsed 900 MHz electromagnetic fields, *Radiation Res,* Vol 147, pp. 631–40.

RSCHC, 1999. *A review of the potential health risks of radiofrequency fields from wireless telecommunication devices,* An expert panel report prepared at the request of the Royal Society of Canada for Health Canada, Ottawa, RSC EPR 99–1.

Savitz, D.A., 2002. Commentary: Magnetic fields and miscarriage, *Epidemiology,* Vol 13, pp. 9–20.

Schonborn, F., Burkhardt, M. and Kuster, N., 1998. Differences in energy absorption between heads of adults and children in the near field of sources, *Health Physics,* Vol 74, pp. 160–8.

Schütz, J., Grigat, J-P., Strmer, B. *et al.*, 2000. Extremely low frequency magnetic fields in residences in Germany. Distribution of measurement, comparison of two methods for assessing exposure, and predictors for the occurrence of magnetic fields above background level, *Radiat Environ Biophys,* Vol 39, pp. 233–40.

Schütz, J., Grigat, J-P., Brinkmann, K. *et al.*, 2001. Residential magnetic fields as a risk factor for childhood acute leukaemia: Results from a German population-based case-control study, *Int J Cancer,* Vol 91, pp. 728–35.

SCTEE, 2001. *Opinion of possible effects of electromagnetic fields (EMF), radio frequency fields (RF) and microwave radiation on human health,* Scientific Committee on Toxicity, Ecotoxicity and the Environment, adopted 30 October 2001. http://europa.eu.int/comm/health/ph/programmes/pollution/ph_fields_index.html

Shaw, G.M., 2001. Adverse human reproductive outcomes and electromagnetic fields: A brief summary of the epidemiologic literature, *Bioelectromagnetics* (suppl 5), pp. S5–18.

SVDB (Sechsundzwanzigste Verordnung zur Durchfürhung des Bundes-Immissionsschutzgesetzes), 1996. *Verordnung über elektromagnetische Felder,* 16. December, Germany.

Swanson, J. and Kaune, W.T., 1999. Comparison of residential power-frequency magnetic fields away from appliances in different countries, *Bioelectromagnetics,* Vol 20, pp. 244–54.

Tenforde, T.S., 2000. Biological interactions and potential health effects of static and ELF fields, in *ICNIRP. Non-ionizing radiation. Executive summary of the 4th International Non-ionizing Radiation Workshop Kyoto, Japan, May 22–25, 2000* (edited by R. Matthes, J.H. Bernhardt and M. Taki), pp. 29–32.

UK Childhood Cancer Study Investigators, 2000. Childhood cancer and residential proximity to power lines, *Br J Cancer,* Vol 83, pp. 1573–80.

Wertheimer, N. and Leeper, E., 1979. Electrical wiring configurations and childhood cancer, *Am J Epidemiol,* Vol 109, pp. 273–84.

WHO, 1998. *International EMF project,* World Health Organization. http://www.who.int/peh-emf/index.htm (in 2001)

WHO, 2001. Fact Sheet 263: *Electromagnetic Fields and Public Health: Extremely Low Frequency Fields and Cancer.* http://www.who.int/inf-fs/en/fact263.html.

Yasui, M., Kikuchi, T., Ogawa, M. *et al.*, 1997. Carcinogenicity test of 50 Hz magnetic fields in rats, *Bioelectromagnetics,* Vol 18, pp. 531–40.

Zaffanella, L.E. and Kalton, G.W., 1998. Survey of personal magnetic field exposure: 1000-person survey, *EMF RAPID Engineering Project No 6. Final report*, Enertech Consultants.

European Environment Agency

Children's health and environment: A review of evidence
A joint report from the European Environment Agency and the WHO Regional Office for Europe

Environmental issue report No 29

Luxembourg: Office for Official Publications of the European Communities

2002 – 223 pp. – 21 x 29.7 cm

ISBN 92-9167-412-5