
ARTICLE

Is the Risk Comparison Made by the Public Between EMF and Smoking or Asbestos a Valid One?

KEN K. KARIPIDIS

Australian Radiation Protection and Nuclear Safety Agency, Victoria, Australia

ABSTRACT The possibility of adverse health effects from exposure to extremely low frequency (ELF) electric and magnetic fields (EMF) has caused considerable controversy in the scientific community and has received great attention in the media and among the general public with many comparing ELF EMF with tobacco smoking and asbestos. Although both smoking and asbestos are now classified by the International Agency for Research on Cancer (IARC) as Group 1 or “established” carcinogens, this was not always the case. In this paper the evidence for the carcinogenicity of ELF EMF is compared with that for smoking and asbestos using the Bradford Hill model for establishing causality between exposure and disease. Application of the model shows that present data are insufficient to demonstrate that exposure to ELF EMF poses a definite human health hazard. However, while the bulk of the evidence is weak, there are several epidemiological studies which have reported an association between prolonged exposure to magnetic fields at levels above what is normally encountered and an increased risk in childhood leukaemia. On this basis IARC has classified ELF magnetic fields as a Group 2B or “possible” carcinogen.

KEY WORDS: Electric and magnetic fields, smoking, asbestos, Bradford Hill criteria, cancer

Introduction

The use of electricity has continued to grow throughout the developed world since the first public power station began operation over a century ago. In

Correspondence Address: Ken Karipidis, Electromagnetic Radiation Section, Non-Ionizing Radiation Branch, Australian Radiation Protection and Nuclear Safety Agency, 619 Lower Plenty Road, Yallambie, Victoria 3085, Australia. Tel.: +61 3 9433 2282; Fax: +61 3 9432 1835; Email: ken.karipidis@arpana.gov.au

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the present day, developing nations look to electricity as a primary means of improving the quality of life and creating jobs (Kheifets *et al.*, 2001). While the countless benefits of electricity are undeniable, concern has been raised about the possibility of adverse health effects, and especially cancer, from exposure to extremely low frequency (ELF) electric and magnetic fields (EMF) (WHO, 2001).

Many among the general public have labelled exposure to ELF EMF as the new smoking or asbestos. Although the causal link between these latter two agents and cancer now seems obvious, the connection was not established till the second half of the twentieth century. This long time delay between earliest use of these agents and the eventual proof of harmful effects has fuelled concern that ELF EMF could be a similarly harmful yet largely unrecognised agent. The aim of this paper is to give a brief overview of the scientific evidence surrounding these agents and apply the Bradford Hill model for establishing causality between exposure and disease to determine whether the comparison between ELF EMF and smoking/asbestos is valid.

Smoking and Asbestos – Established Carcinogens

Smoking

Tobacco was introduced into Europe at the end of the fifteenth century from America where it was mainly used for medicinal purposes. It was during the sixteenth century that the practice of tobacco smoking through pipes spread in Europe and throughout the world. Pipe smoking was eventually replaced by nasal snuff, followed by cigars and eventually cigarettes (Doll, 1998). Cigarette smoking became the dominant form of tobacco use in the developed world in the early twentieth century after the introduction of cheap, mass produced, cigarettes. Although the prevalence of smoking is decreasing in developed countries, smoking is increasing in developing countries with an estimated 1.2 billion smokers worldwide (Edwards, 2004).

Evidence that smoking tobacco causes adverse health effects has been accumulating for over 200 years, originally in relation to lip and mouth cancer, and then in relation to vascular disease and lung cancer (Doll, 1998, 1999). The evidence was largely ignored until 1950, when Doll and Hill (1950), in England, and Wynder and Graham (1950), in the United States, published case-control studies that implicated smoking with the development of lung cancer. A controversy developed over the credibility of this finding and was increased in 1954 when two independent large cohort studies by Doll and Hill (1954), and Hammond and Horn (1988), supported the association with lung cancer. By the end of the 1950s, convincing evidence linking smoking with lung cancer and other cancers had been obtained from several case-control and cohort studies and animal studies had also shown that components of cigarette tar were carcinogenic (Vineis *et al.*, 2004). In 1986 and more recently in 2002 expert Working Groups of

the International Agency for Research on Cancer (IARC) concluded that tobacco smoke is a multi-potent carcinogenic mixture that can cause cancer in many different organs and classified the agent as a Group 1 carcinogen to humans (IARC, 1986, 2002a).

Smoking is currently the single biggest avoidable cause of death and disease in developed countries (Edwards, 2004). The agent is currently responsible for an estimated 30% of all cancer deaths in developed countries, and according to current smoking trends, a cancer epidemic attributable to smoking is expected to occur in developing countries. In addition to cancer, smoking causes even more deaths from vascular, respiratory, and other diseases, so overall, smoking is estimated to account for approximately 4–5 million deaths a year, worldwide. This number is projected to increase to more than 10 million a year by 2030, by which time 70% will be in developing countries (Edwards, 2004; Vineis *et al.*, 2004). Moreover, smokers are also at greater risk of many other non-fatal diseases, including osteoporosis, periodontal disease, impotence, male infertility, and cataracts. Smoking during pregnancy is associated with increased rates of foetal and perinatal death and reduced birth weight for gestational age. Although the evidence is weaker than for active smoking, involuntary, or passive, smoking is associated with cot death during infancy, respiratory disease in childhood and lung cancer, heart disease, and stroke later in life (Edwards, 2004).

Asbestos

Asbestos is a term used for a number of naturally occurring fibrous silicate minerals, which can be divided into two groups. Most common is the serpentine group, which is comprised of what is known as chrysotile fibres. A second asbestos group, known as the amphiboles, has a series of subvarieties including crocidolite, anthophyllite, actinolite, amosite and tremolite fibres (Niklinski *et al.*, 2004). The fibres have high tensile strength, and chemical, electrical and heat resistance – properties that have made asbestos extremely useful in commercial applications, especially in acoustical and thermal insulation. Inhalation of asbestos fibres can lead to serious diseases such as lung cancer, mesothelioma (a cancer of the lining of the lungs or lower digestive tract) and asbestosis (chronic fibrosis of the lungs). Asbestos has become the leading cause of occupationally related cancer mortality and is second only to tobacco smoking as the most lethal manufactured carcinogen (Tweedale, 2002). Studies also show a multiplicative interaction between asbestos and smoking in the causation of lung cancer i.e., the risk of lung cancer for a smoker exposed to asbestos is greater than the sum of the individual effects (Boffetta, 2004).

The potential hazards to human health from asbestos were noted as early as 1899 but it was not until the 1920s that medical experts first described the ill effects of inhaling asbestos fibres and named the condition asbestosis (Tweedale, 2002). The first cases of lung cancer among asbestos workers were reported in the 1930s and the link with mesothelioma was first noted in

the early 1940s (Wood and Gloyne, 1934; Lynch and Smith, 1935). Since then numerous studies have described the carcinogenic effects of asbestos and at least two major multidisciplinary review panels have concluded that all forms of asbestos fibres are associated with lung cancer and mesothelioma (Tossavainen, 1997; International Program on Chemical Safety, 1998). In 1977 IARC classified asbestos as a Group 1 carcinogen to humans (IARC, 1977).

Throughout the twentieth century, and especially since 1940, millions of people have been occupationally and environmentally exposed to asbestos (Tweedale, 2002). Many cases of these diseases occurring now are a result of exposure in industries which used asbestos extensively in the past. However, the fact that asbestos was also installed in many buildings means that a wider range of people still have the potential to be exposed – particularly building and maintenance workers. It is expected that deaths caused by asbestos worldwide will rise to at least a million over the next 30 years, mainly due to cancer (Tweedale, 2002).

Scientific Uncertainty About EMF

ELF EMF occupies the lower part of the electromagnetic spectrum in the frequency range 0-3000 Hz. Exposure to ELF EMF arises mainly from the generation, transmission and use of electricity at the power frequencies of 50 Hz or 60 Hz and common sources include power lines, electrical wiring and appliances, and industrial devices. The widespread use of electricity means that people are exposed to ELF EMF in the home, in the environment and in the workplace (WHO, 2001).

In theory, the characteristics of ELF EMF make it an unlikely cause of adverse health effects. In particular as ELF EMF is non-ionising, it has insufficient quantum energy to damage biological tissue through single photon interactions, and therefore, should not be capable of initiating cancer by the usual, DNA damaging, genotoxic mechanisms, involving ionisation (Ahlbom *et al.*, 2001). However, in 1979 an epidemiological study in Denver, Colorado by Wertheimer and Leeper (1979) reported an excess risk of leukaemia in children residing near so-called “high-current configurations”, i.e. power lines, transformers and devices characterised by a high current. Since then, a large number of epidemiological and laboratory studies have been conducted into a variety of diseases and exposure conditions to further investigate this unexpected result. The largest body of evidence for an effect comes from several epidemiological studies which have reported an association between prolonged exposure to high-level power frequency magnetic fields (fields greater than 0.4 μ T) and an increased risk in childhood leukaemia (Ahlbom *et al.*, 2001). Other scientific evidence, including in vivo and in vitro studies, has not supported these findings, and many of the epidemiological studies themselves suffer from a number of methodological problems including inadequate exposure assessment (WHO, 2000).

Determining Causality

The results of individual studies alone can only indicate an association and cannot in general prove causality. Statistically significant associations could possibly be attributed to chance, study design, features of the data collecting process, or the effects of confounding factors which are closely related to the exposure (Preece *et al.*, 2000; Linet *et al.*, 2003).

A framework for investigating the cause and effect relationship was proposed by Sir Austin Bradford Hill in 1965 (Hill, 1965). Hill outlined a systematic approach in the use of scientific judgement to infer causation from epidemiological and related scientific data (Phillips & Goodman 2004). Hill proposed nine criteria to be considered when judging whether observed associations indicate a causal relationship. They are: strength of association, consistency, specificity, temporality, biological gradient, plausibility, coherence, experimental evidence and analogy (Hill, 1965). These are often termed the “Bradford Hill criteria” for causality however none of these considerations alone, as Hill himself noted, can be determinative in establishing a cause and effect relationship. Conversely, it is not necessary for all nine criteria to be met in order that evidence of causality be convincing. Hill emphasized that a causal judgment can only be made in the context of all the available data and the nine criteria that he lists can assist in that process (Hill, 1965). Hill’s nine causality criteria will be considered in the context of the smoking/lung cancer and asbestos/mesothelioma relationships and compared with the issue of whether ELF EMF causes adverse health effects and in particular cancer.

Strength of Association

The strength of an effect in a particular epidemiological study is usually specified by the statistical measurement of the excess risk observed. A strong association between exposure and disease is more likely to be causal than is a weak association, which could be influenced by extraneous factors such as bias or confounding (Beaglehole *et al.*, 1993). Smoking, for example, shows a strong association, with the risk of lung cancer in smokers being 10–30 times that of non-smokers (IARC, 1986).

In the case of asbestos and mesothelioma the rarity of the disease, the lack of mortality rates in the populations used as reference, and problems in diagnosis and reporting, make the assessment of the actual risk difficult (Lemen, 2004). In many studies, therefore, risks have not been calculated, and cruder measures have been used, such as absolute numbers of cases and deaths and ratios of mesothelioma over lung cancer or total deaths. Proportions of deaths attributable to mesothelioma in cohort studies in the various mining and production sectors have been shown to be up to 10% (Hillerdal, 1999).

The majority of the ELF EMF studies showing a positive association have reported relative risks of two or less although some have reported

relative risks greater than two (although rare, relative risks close to 5 have been reported but these results were based on a small number of subjects) (IARC, 2002b). For childhood leukaemia, a pooled analysis of nine studies by Ahlbom *et al.* (2000), found a twofold excess risk for exposure to ELF magnetic fields greater than $0.4 \mu\text{T}$ (95% confidence interval: 1.3–3.1). Another pooled analysis of 15 studies by Greenland *et al.* (2000), found a relative risk of 1.7 for exposure above $0.3 \mu\text{T}$ (95% confidence interval: 1.2–2.3). Although these risks are smaller than those found for smoking and asbestos, Hill pointed out that weak associations cannot be precluded from being causal (Hill, 1965). However in such situations it is more difficult to exclude alternative explanations.

Consistency

Consistency requires that a proposed effect is replicated under different circumstances. Hence, for a relationship to be causal, it is important to show similar findings in several studies using diverse methods and performed in different populations (Gerstman, 1998). Hundreds of epidemiological studies since 1950, which have employed different methods such as prospective and retrospective study designs, have shown an association between smoking and lung cancer (IARC, 1986). The three large cohort studies (totalling over a million subjects) by Doll and Hill (1954), on British physicians, Hammond and Horn (1959), on US male volunteers and Dorn (1959) on US veterans, showed similar mortality rates from lung cancer and cigarette consumption per day. Consistency has also been amply demonstrated with regard to asbestos exposure and mesothelioma. The relationship between asbestos and mesothelioma has been shown in various studies of miners in South Africa (Wagner *et al.*, 1960), in workers manufacturing asbestos cement in the US (Hughes *et al.*, 1986), and in mechanics who installed asbestos brake linings in Australia (Leigh and Driscoll, 2003).

Since the report by Wertheimer and Leeper in 1979 which found an association between residential ELF EMF and childhood leukaemia, dozens of increasingly sophisticated studies worldwide have examined this association as well as a possible connection with other diseases (IARC, 2002b). Among all the health outcomes, the findings in several studies of a positive association of childhood leukaemia in relation to exposures above $0.4 \mu\text{T}$ have been the only consistent evidence implicating ELF EMF as a health hazard. These associations were unlikely to be due to chance, but may have been affected by selection bias particularly in the case-control studies which relied on residential measurements because of the low response rate. Studies which relied on historical calculated EMF fields were not subject to selection bias, but suffered from very low numbers of exposed subjects. The existence of unknown confounding factors could be a possibility but is unlikely to explain the entire observed effect. It is possible that a combination of selection bias, some degree of confounding and chance could explain the observed consistent associations (IARC, 2002b).

Studies of childhood brain tumours or cancers at other sites have not shown a consistent relationship, although these have generally suffered from small sample sizes and lower methodological quality. For adults, a consistent association between residential exposure to ELF EMF and leukaemia, brain cancer and other cancers has not been established, although research has been quite limited. Early studies of occupational exposure conducted in the 1980s and early 1990s pointed to a possible increased risk of leukaemia, brain tumours and male breast cancer in jobs with presumed exposure to elevated ELF EMF levels, however, these studies suffered from methodological limitations such as poor exposure assessment. Later occupational studies with improved exposure assessment reported inconsistent findings (Ahlbom *et al.*, 2001; IARC, 2002b).

Specificity

Specificity is established when a single putative cause produces a specific effect so that a particular risk factor, for example, causes a very specific disease as opposed to a range of diseases (Schlesselman, 1982). Several authors have found specificity to be quite misleading (e.g., Rothman, 1988; Rothman and Greenland, 1998) and even Hill himself noted that the importance of this characteristic should not be over-emphasized as specificity of an association supports causality but lack of specificity does not negate it (Hill, 1965). Both smoking and asbestos are associated with a number of diseases so causality cannot be ruled out based on the inability to establish specificity (Gerstman, 1998). In the past, arguments against smoking as a cause of lung cancer were partly based on the absence of specificity (Schlesselman, 1982). It may be possible that ELF EMF is associated with a number of different diseases. Although the criterion of specificity is met to some degree since the only reasonably convincing evidence for an effect comes from the childhood leukaemia studies.

Temporality

Temporality requires that the cause must precede the effect, taking into account a suitable latent period. A temporal sequence, according to Hill, is essential to establishing causality but is not always self-evident (Hill, 1965). Proving temporality may occasionally be difficult in studies where measurements of the cause and effect are made simultaneously (e.g., case-control and cross-sectional studies) (Schlesselman, 1982). For example, some studies have shown higher lung cancer mortality rates among former cigarette smokers during the first year after cessation than among those who continue to smoke. Although this would seem to indicate that continuing to smoke decreases the risk of lung cancer it seems more likely that many of those that stop smoking do so because of early symptoms of the already existing but as yet undiagnosed respiratory illness (Hennekens, 1987). Cohort studies of workers examining the carcinogenic potential of asbestos

have shown that exposure to the agent preceded the development of mesothelioma by up to some decades (Lemen, 2004). Similarly EMF studies that have shown a positive association with adverse health effects have established a temporal relationship (IARC, 2002b).

Biological Gradient

Biological gradient refers to the existence of a dose-response relationship i.e. increases in the dose of exposure to an agent is accompanied by progressive increases in the observed risk (Gerstman, 1998). The demonstration of a clear dose-response relationship in unbiased studies provides strong evidence for causality although its absence does not rule out a causal relationship (Beaglehole *et al.*, 1993). For example, it has been shown in numerous studies that the mortality rate due to lung cancer rises linearly with the number of cigarettes smoked daily (IARC, 2002a). A dose-response relationship has also been shown between asbestos and mesothelioma e.g., Rogers *et al.* (1991) found a significant trend in the rise of mesothelioma with increasing fibre concentrations in lung tissue. In such studies, exposure assessment has usually been of high quality, which suggests greater confidence in identified dose-response relationships.

Exposure assessment is particularly difficult in EMF epidemiology because the exposure is ubiquitous, has multiple sources, and it can vary greatly over time and short distances. The majority of ELF EMF studies have not shown a dose-response relationship between measured fields or surrogate measures and cancer rates (Ahlbom *et al.*, 2001). However, not all relationships between dose and risk can be described by simple linear dose-response curves where risk is strictly proportional to dose. A threshold may exist above which a relationship may develop. In the pooled analyses by Greenland *et al.* (2000) and Ahlbom *et al.* (2000), childhood leukaemia risks did not increase until estimated time-weighted-average magnetic field exposures reached levels greater than 0.3 and 0.4 μT , respectively – although a dose-response was not shown above these levels.

Plausibility

Plausibility refers to biological plausibility of the observed association i.e. there should be some biologically acceptable or relevant mechanism for the cause to produce a certain effect (Beaglehole *et al.* 1993). While the mechanisms of cancer causation are not as yet completely known, the biologic facts known about the various chemicals in tobacco smoke and how they cause disease are consistent with the finding that smoking is strongly associated with the development of lung cancer (IARC, 1986). Similarly, laboratory studies have identified the pathologic processes by which asbestos can produce mesothelioma (Lemen, 2004). For example, Malorni *et al.* (1980) showed that asbestos fibers penetrate the cell, enter the nucleus, and induce abnormal chromosome formations in dividing cells.

ELF EMF at levels normally found in the environment interacts with living tissue by inducing electric fields and currents whose magnitude is less than the currents occurring naturally in the body. Although several theories have been proposed (radical pair mechanisms, ion charge-to-mass resonance mechanisms, stochastic resonance, etc), no plausible mechanism has been established to explain how low level EMF can interact with humans to produce adverse health effects (IARC, 2002). However, biological plausibility is a reflection of currently available knowledge which may change with time. For example, the carcinogenic or cancer promoting effects of the constituents of tobacco smoke were not identified till 1959, nine years after Doll and Hill first showed the association with lung cancer (Hennekens and Buring, 1987).

Coherence

Coherence implies that a causal association should not conflict with current knowledge about the natural history and biology of the disease (Hill, 1965). Therefore all available data from experimental, clinical and epidemiological studies should form cohesive evidence for a causal inference. For example, in considering smoking and lung cancer, the rise of smoking in developed countries during the early and mid-20th century saw a corresponding increase in the rates of lung cancer mortality as shown by our current epidemiologic knowledge. Furthermore the histopathological evidence of cytotoxicity from the bronchial epithelium of smokers and the isolation of carcinogenic factors from tobacco smoke in animal experiments contribute to a coherent whole in supporting the causal argument for smoking and lung cancer (Gerstman, 1998). Similarly, epidemiological evidence and animal data are coherent in establishing the causal link between asbestos and mesothelioma (Lemen, 2004).

Although there is some epidemiological evidence suggesting a possible link between ELF EMF and childhood leukaemia, experimental studies have not supported an association with cancer or other health effects. Laboratory research has provided no consistent evidence that ELF EMF at levels found in the environment can affect biological processes or affect the risk of cancer in animals (IARC, 2002b; Advisory Group on Non-Ionising Radiation, 2001).

Experimental Evidence

According to Hill, the strongest support for the causation hypothesis may be revealed by experimental evidence where the removal of an agent can lead to a change in the effect (Hill, 1965). For example, the cessation of tobacco smoking is associated with a reduction in the risk of lung cancer compared to that in people who continue to smoke (Edwards, 2004). Similarly, a reduction in the use of asbestos is expected to lead to a decrease in the incidence of mesothelioma, however, although restrictions, or total bans, on

the use of asbestos occurred around 1985, a decrease in the incidence of mesothelioma is not expected until after 2020 (Niklinski *et al.*, 2004). In the case of ELF EMF, based on current scientific knowledge it is unlikely that the exposure will be removed and the impact of exposure minimisation has not been scientifically evaluated, so it is difficult to test this criterion.

Analogy

Analogy implies that an agent analogous to the agent being considered may cause similar effects and thus provide further evidence for a causal inference (Lemen, 2004). It is difficult to provide an analogy for tobacco smoking and lung cancer and although several etiological factors for lung cancer have been identified (e.g., cooking oil vapour, coal burning, radon, asbestos, etc), none are lifestyle factors (Lam *et al.*, 2004). The use of the illicit drug marijuana has been linked with lung cancer however the evidence is inconclusive (Mao and Oh, 1998). Similarly to smoking and lung cancer, it is difficult to find an analogy for asbestos, which is almost exclusively the cause of mesothelioma (IARC, 1977). However, the mineral erionite has been shown to cause mesothelioma in various studies conducted in central Turkey (IARC, 1987).

The natural choice for an analogy to ELF EMF would be another form of EMF such as radiofrequency (RF) electromagnetic radiation (EMR), which is mainly used for telecommunications purposes such as mobile telephony. It must be stressed that although ELF and RF are both non-ionising radiation they interact with the human body differently thus producing different biological effects. Exposure to sufficiently high levels of RF EMR can heat biological tissue and potentially cause tissue damage. At low levels of exposure to RF EMR which are routinely encountered by the general public (i.e., field intensities lower than those that would produce measurable heating) the evidence for production of harmful biological effects is ambiguous and unproven. Similarly to ELF EMF, expert review panels that have assessed RF EMR agree that although there have been studies reporting a range of biological effects at low levels, there has been no indication that such effects might constitute a human health hazard (Royal Society of Canada, 1999; Independent Expert Group on Mobile Phones, 2000; Zmirou Report, 2001; Health Council of the Netherlands, 2002).

Discussion

A summary of the comparison between ELF EMF and smoking/asbestos is shown in Table 1. In applying the Hill model for causation in the associations between smoking and lung cancer and asbestos and mesothelioma, the evidence for a causal relationship between these two agents and cancer is overwhelming. The same cannot be said, however, for exposure to ELF EMF and adverse health effects. Human studies have largely been inconsistent apart from the childhood leukaemia findings which, although

Table 1. Application of the Bradford Hill model for ELF EMF/cancer, smoking/lung cancer and asbestos/mesothelioma

	Smoking and lung cancer	Asbestos and mesothelioma	ELF EMF and cancer
Strength of association	Relative risks in different studies range from 10–30	Assessment of risk difficult. Proportions of deaths attributable to mesothelioma in cohort studies in the various mining and production sectors have been shown to be up to 10%.	Most positive studies show relative risks of two or less. Childhood leukaemia studies show relative risks of two for magnetic fields >0.4 μ T
Consistency	Hundreds of studies employing different methods worldwide have shown an association between smoking and lung cancer	Cases of mesothelioma have been observed in miners in South Africa, in workers manufacturing asbestos cement in the US, in mechanics who installed asbestos brake linings in Australia, etc	Most studies have been inconsistent apart from the childhood leukaemia studies.
Specificity	This consideration not met. Smoking is associated with over 40 different diseases	This consideration not met. Asbestos is also associated with lung cancer and asbestosis	It may be possible that ELF EMF is associated with a number of different cancer types.
Temporality	Smoking preceded lung cancer	Asbestos preceded mesothelioma	Temporality not established at present
Biological gradient	Dose-response established in various studies	Dose-response established in various studies	Majority of studies have not shown a dose-response. Childhood leukaemia studies have shown a statistical threshold of around 0.3–0.4 μ T

Table 1. (*Continued.*)

	Smoking and lung cancer	Asbestos and mesothelioma	ELF EMF and cancer
Plausibility	The constituents of tobacco smoke are known carcinogens	Asbestos fibres affect mitotic processes in the mesothelia lining	No plausible mechanism has been established to account for carcinogenesis
Coherence	Cohesive evidence from epidemiological, cell and animal data for a causal association	Cohesive evidence from epidemiological, cell and animal data for a causal association	Epidemiological evidence for childhood leukaemia not cohesive with cell and animal data.
Experimental evidence	The cessation of smoking is associated with a reduction in the risk of lung cancer	Reduction in the use of asbestos is expected to lead to a decrease in the incidence of mesothelioma however due to long latency this is not expected till after 2020	Based on current scientific knowledge it is unlikely that ELF EMF exposure will be removed thus it is difficult to test this consideration.
Analogy	The illicit drug marijuana has been linked with lung cancer however the evidence is inconclusive	The mineral erionite has been shown to cause mesothelioma in various studies conducted in central Turkey	Although there have been studies reporting a range of biological effects from exposure to radiofrequency radiation at low levels, indication that such effects might constitute a human health hazard is ambiguous and unproven.
IARC classification	Group 1 carcinogen to humans	Group 1 carcinogen to humans	Group 2B or “possible” carcinogen to humans

they raise some concern, have to be viewed with caution. The small observed increased risk in childhood leukaemia has not demonstrated a convincing dose response relationship and although unlikely to be due purely to chance, could be attributed to selection bias or possibly some unknown confounding factor. In addition, experimental studies have not supported the biological plausibility of the association between ELF EMF and adverse health effects or cancer, in particular. There is no consistent evidence that exposure to ELF EMF has led to the initiation or promotion of cancer in animal studies or shown to be mutagenic *in vitro* (IARC, 2002b).

It may be argued that all the compelling evidence we have for the causal relationship between smoking/asbestos and cancer was not known many years ago, for example, the clear link between smoking and lung cancer was not established till the late 1950s. It is true that current scientific knowledge may change with time and that criticism of the past scientific evaluations of smoking and asbestos are largely made in retrospect. Much of the knowledge that is used to assess physical agents today such as epidemiology and DNA research was not available prior to 1950. In fact only since the 1980s has epidemiology improved methodologically. Even cancer registries which could potentially have been introduced 100 years ago are a relatively recent public health measure. Furthermore, exposure to smoking and asbestos showed clear signs of shorter-term ill-affect i.e. smokers experienced excessive coughing and asbestos workers showed physical signs of asbestosis such as restricted breathing. Exposure to environmental levels of ELF EMF does not indicate such physical signs of an ailment and although people have reported a range of symptoms from being exposed to EMF fields, the symptoms experienced are generally without well-defined measurable end-points and so the relationship with exposure to ELF EMF is difficult to make.

In scientific research, causality must always remain a matter of judgment based on all the available evidence in accordance with a structured framework such as the Bradford Hill criteria described above. Application of the considerations in the criteria do not establish a cause and effect relationship for ELF EMF and adverse health effects, such as that found between smoking and lung cancer, and asbestos and mesothelioma. Expert committees that have reviewed the scientific evidence on the subject have consistently concluded that present data are insufficient to show that exposure to ELF EMF poses a human health hazard (National Institute of Environmental Health Sciences, 1998; Advisory Group on Non-Ionising Radiation, 2001; IARC, 2002; International Commission on Non-Ionizing Radiation Protection, 2003). But clearly there is considerable scientific uncertainty as well as a high level of public apprehension about the issue. So while the bulk of the evidence is weak, the epidemiological findings of childhood leukaemia are too consistent to be ignored and require further research. On this basis IARC has classified power frequency magnetic fields as a Group 2B or “possible” carcinogen (IARC, 2002).

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