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STATUS REPORT ON INVESTIGATIONS OF POTENTIAL HUMAN HEALTH EFFECTS ASSOCIATED WITH POWER FREQUENCY ELECTRIC AND MAGNETIC FIELDS

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STATUS REPORT ON INVESTIGATIONS OF POTENTIAL HUMAN HEALTH EFFECTS ASSOCIATED WITH POWER FREQUENCY ELECTRIC AND MAGNETIC FIELDS (EMF)

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Prepared by:

Sandra S. Patty
Transmission Program Manager
Power Plant Research Program

Doreen Hill, Ph.D.
Hill Consulting

Prepared for:

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FOREWORD

This report, "Status Report on Investigations of Potential Human Health Effects Associated with Power Frequency Electric and Magnetic Fields," is the most recent of a continuing series, produced by the Power Plant Research Program, reviewing recently published research on health effects associated with exposure to power frequency electric and magnetic fields (EMF). The purpose of these reports is to provide the Maryland Public Service Commission with the latest information regarding the human health effects of exposure to EMF as part of its ongoing assessment of the need for regulations to ensure the safety of Maryland citizens. Unlike most past reports that focused on original research, this report focuses more on hazard evaluations and risk assessments, and programmatic and policy developments because the direction and momentum of EMF research has similarly changed. The results and developments summarized herein are the most recent of the eight status report summaries published since 1990.

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EXECUTIVE SUMMARY

The potential health effects of exposure to electric and magnetic fields (EMF) have been the subject of intense scientific and public scrutiny. This report reviews developments and the results of various research and other reports addressing the issues of health effects and EMF, published between September 1998 and June 2001. The hallmark of this period is less direct basic and applied research and more analysis, evaluation, and assessment of published reports. This shift reflects completion of many major studies, especially epidemiological investigations; conclusion of large research programs; and reductions in research funding.

In 1989, the Maryland Public Service Commission (PSC) issued an order requesting that reports of scientific evidence concerning the possible adverse health effects from exposure to the electric and/or magnetic fields produced by electric power lines be monitored, and periodic reports be submitted to the Commission on any significant evidence for this issue. This report is the eighth in the series. The last report was published in December 1998 (1). An overview of relevant journal articles, reports, and reviews published in the scientific literature is presented.

Three significant reviews have been issued in this period that evaluated the literature on potential human health effects, especially cancer risk, from exposure to extremely low frequency electric and magnetic fields (ELF EMF). The scientific organizations that conducted these assessments are the National Institute of Environmental Health Sciences (NIEHS), the Advisory Committee on Non-Ionizing Radiation for the National Radiological Protection Board (NRPB) of the United Kingdom (U.K.), and the EMF Working Group formed by the International Agency for Research on Cancer (IARC) (2-4). These expert reviewing bodies, while pointing out continuing uncertainties, flaws, and negatives in the available evidence, could not fully eliminate EMF exposures as a potential public health risk. The assessments have drawn stronger conclusions about health effects from exposure to electric and magnetic fields, especially for childhood cancer. To varying degrees, all concluded EMFs are a possible cause of cancer in children. Adverse health effects from EMF exposures have, however, neither been rigorously affirmed nor discounted. This continued lack of resolution relates to remaining uncertainties in scientific knowledge such as poor supporting evidence in laboratory animals and cellular test systems and limitations in dose/exposure assessment.

In addition, all reviews, assessments, and governmental summaries have identified the need for further research, especially on dose/exposure assessment and biological mechanisms. However, EMF research in the U.S. is now very minimal. Most major funding agencies have ended or severely curtailed their support, and the Federal EMF Research and Public Information Dissemination (RAPID) Program drew to its mandated conclusion.

Subject Terms

Electric and Magnetic Fields (EMF); Extremely Low Frequency (ELF); Power Line Frequency; Transmission Lines; Power Substations; Appliances, Electrical; Cancer Risk, Cancer Etiology; Health Effects; Biological Effects, Animal; Biological Effects, Human; Epidemiologic Studies; Experimental Studies; Cellular Studies; Exposure Mitigation; Prudent Avoidance; State Regulations, Exposure Guidelines; and Literature Review.

I. INTRODUCTION

Electric and magnetic fields, also called electromagnetic fields (EMF), occur both naturally and because of the generation, transmission, and use of electricity. In our society, where the use of electricity is extensive, exposure to EMF from the vast array of electrical appliances and equipment, building wiring, distribution lines, and transmission lines is common.

Electromagnetic fields are fields of force created by electric voltage and current. They occur whenever power lines are energized. **Electric fields** are due to voltage, the electric force that causes a current in a conductor. They emanate from electrical appliances and cords whenever an appliance is plugged into an outlet (even if the appliance is turned off). The strength of electric fields is typically measured in volts per meter (V/m) or in thousand of volts per meter (kilovolts per meter, kV/m). Electric fields can be shielded by objects like trees, buildings, and vehicles. Burying power lines can also reduce human exposure to electric fields.

Magnetic fields result from the motion of the electric charge called current, such as when current flows through a power line or when an appliance is plugged in and turned on. Appliances plugged in, but not turned on, normally do not produce magnetic fields. Magnetic fields are measured in tesla (T) or in gauss (G) or milligauss (mg). One tesla equals 10,000 gauss and 1 gauss equals 1,000 milligauss. Magnetic fields cannot be shielded in the same fashion as electrical fields; however, conductors carrying current can be arranged so that the magnetic fields produced tend to cancel. Burying transmission lines reduces magnetic fields because the conductors are closer to each other, rather than through shielding by the earth. However, the peak magnetic field at ground level can sometimes be higher with buried transmission lines due to the closer proximity of the conductors to the ground surface. The common way to reduce exposure to magnetic fields is to increase distance from the source.

The Earth's natural electric field is essentially static (non-alternating or DC, direct current) and averages less than a few hundred V/m. The Earth's magnetic field is also essentially static and ranges from about 0.3 to 0.6 G (300 to 600 mG). In the United States, the electric power system uses alternating current (AC) which is not static, switches direction 60 times each second, and is called 60-Hertz (60-Hz; cycles per second) power. In Europe and many other parts of the world, the frequency of electric power is 50-Hz.

Generating electrical power and moving this power from the source to the end user are complex processes. First, electricity is generated at an electrical generating station at voltages usually around 20,000 volts [20 kilovolts (kV)]. The power then passes through a transformer, which increases the voltage with an associated decrease in current, allowing the power to be transported with minimum loss. Transmission voltages in Maryland range from 69 kV to 500 kV. Transmission lines connect to substations where the voltage is reduced, and power is transferred to lower-voltage lines usually referred to as primary distribution lines. These lines still operate at thousands of volts. Finally, additional distribution lines (secondary lines) and transformers deliver power locally to individual users at voltages of 120 V.

The amount of **power** that a line actually transmits is related to the product of the line's voltage and current. Transmission lines are designed to hold voltages relatively constant while currents increase and decrease depending on the power demand of the load. Consequently, for a given voltage, the electric field remains relatively constant over time, but the magnetic field increases or decreases

depending upon the power that particular electric line is delivering at any given time.

Even though both electric and magnetic fields are present around appliances and power lines, most recent interest is focused on magnetic fields. This is because epidemiological studies have found associations between increased health risks and power line configurations, which are thought to be surrogates for magnetic fields. Although extensive studies on the safety aspects of electric fields have been conducted, no health effects have been associated with electric fields of the magnitude associated with electrical power usage.

Given these general understandings, **exposure** to magnetic fields can be separated into two broad categories. The first is a chronic low-level exposure such as what one would experience living in proximity to an active distribution or transmission line. This could result in long-term or chronic exposure to magnetic field levels generally in the milligauss range. A second category is transient high-level exposure that one might experience when operating small household appliances, such as a toaster or hair dryer, for a short period. For such exposures, magnetic field levels could well exceed hundreds of milligauss. These very different modes of exposure not only make it difficult to design consistent research efforts but have very different implications for potential mitigation actions.

The possibility that exposure to EMF causes cancer, including childhood malignancies, is an issue of continuing public concern and scientific debate. Many scientific communities follow this issue and have prepared summaries or investigations of the issue. Some of these major reports are described in this summary.

II. KEY DEVELOPMENTS

The hallmark of the recent period of scientific investigation of the potential health effects of electric and magnetic fields is less direct basic and applied research and more analysis, evaluation, and assessment of published reports. This shift reflects completion of many major studies, especially epidemiological investigations, conclusion of large research programs, and reductions in research funding.

U.S. EMF RAPID Program

One of the most important U.S. developments since the publication of the last report relate to the ending of the Congressionally-mandated Federal EMF research program, the Research and Public Information Dissemination (RAPID) Program. This program was established with a limited period of operation and as it approached its end-date, hazard evaluation, risk assessment, and documentation activities began. A step-wise process to review the research results was instituted, as described below.

Research and Program Reviews

Three scientific symposia were held in 1997 and 1998 on mechanistic and cellular research, human population studies, and laboratory and clinical research. Participants included scientists, the public, and other stakeholders who were asked to review the literature, identify key research findings, and comment on the quality of research. Reports documenting the symposia were published (5,6,7).

Next, in June 1998, an expert Working Group was convened to formally and comprehensively review EMF research literature and assess the evidence for human and biological effects (8). Using the criteria developed by the International Agency for Research on Cancer (IARC), the Working Group characterized the strength of the evidence for causality between EMF exposure

and disease and determined that EMFs are possibly carcinogenic to humans:

> **A majority of the Working Group concluded that classification of ELF EMF as possibly carcinogenic (Group 2B) is a conservative, public-health decision based on limited evidence of an increased risk for childhood leukemia with residential exposure and an increased occurrence of CCL[1] associated with occupational exposure.** For these particular cancers, the results of *in vivo, in vitro*, and mechanistic evidence do not confirm or refute the findings of the epidemiological studies.

IARC criteria are described later in the context of a recent IARC review. The discussions and conclusions of the Working Group were published (8) and made available on CD-ROM and online at the NIEHS web site, http://www.niehs.nih.gov/emfrapid/home. The Working Group report was also discussed in the last PPRP report to the PSC (1).

A series of public hearings were held next to solicit public comment on the reports from the symposia and the Working Group. These hearings were in Tucson, Arizona, September 1998; Washington, DC, September 1998; San Francisco, California, October 1998; and Chicago, Illinois, October 1998. Comments were also provided on other topics of concern to the public, researchers, regulatory agencies, and industry. The meetings were recorded and transcripts were prepared.

Building upon the above discussed series of reviews, the National Institute of Environmental Health Sciences (NIEHS) in 1999 published a report on its assessment of the EMF literature, including results from the RAPID program, and the potential health risks of EMFs (2).

While noting the conclusions of the Working Group it had convened, the Agency did not wholly adopt the conclusions nor the carcinogenicity classification recommended by the Working Group. The NIEHS noted:

> The NIEHS agrees that the associations reported for childhood leukemia and adult chronic lymphocytic leukemia cannot be dismissed easily as random or negative findings. The lack of positive findings in animals or in mechanistic studies weakens the belief that this association is actually due to ELF-EMF[2], but cannot completely discount the findings . . . the probability that ELF-EMF exposure is truly a health hazard is currently small. The weak epidemiological associations and lack of any laboratory support for these associations provide only marginal, scientific support that exposure to this agent is causing any **degree of harm. The NIEHS concludes that ELF-EMF exposure cannot be recognized as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard . . .** this finding is insufficient to warrant aggressive regulatory concern. However, because virtually everyone in the US uses electricity and therefore is routinely exposed to ELF-EMF, passive regulatory action is warranted such as a continued emphasis on educating both the public and the regulated community on means aimed at reducing exposures . . .

The NIEHS report was required by the Energy Policy Act of 1992 (PL 102-486, Section 211B) for submission to the U.S. Congress.

National EMF Advisory Committee

The National Electric and Magnetic Fields Advisory Committee (NEMFAC) was established under the Energy Policy Act of 1992 to perform oversight and provide advice to the

[1]CLL is chronic lymphocytic leukemia.

[2]ELF means extremely low frequency.

managers and researchers of the RAPID Program. The NEMFAC participated in various planning and implementation activities of the RAPID Program, held at least two public meetings per year starting in 1992, and attended various scientific conferences.

As NEMFAC's activities drew to a close in late 1998, they issued three letters of advice to Federal officials (9, 10, 11). Two main themes were present in the NEMFAC advice, namely: (1) targeted research needs to be continued and (2) the public needs a reliable flow of up-to-date information. Throughout its lifetime and in its formal advisories, the committee also commented on diverse technical matters, including endorsing the NIEHS Working Group recommendations and expressing opposition to cessation of DOE's basic research programs at the National Laboratories and other facilities.

Federal Interagency Committee

A concluding and policy oriented report was required under the Energy Policy Act from the Federal EMF Interagency Committee (IAC) (12). The IAC report is due to be formally released in 2001. The brief report describes the IAC's work and provides comments and recommendations in several areas, namely, health effects, exposure, personal risk reduction, regulation, information distribution, research, and coordination. The IAC agreed with the findings of the final NIEHS report. The Committee did not recommend developing quantitative exposure limits for the public or lowering the existing workplace guidelines given the lack of convincing dose-response information which the Committee believed is needed to form the basis of regulatory limits.

UK National Radiological Protection Board

The National Radiological Protection Board (NRPB) in the United Kingdom (UK) established an independent expert Advisory Group on Non-ionizing Radiation which has periodically reviewed and evaluated the scientific literature on power frequency electromagnetic fields and the risk of cancer. Reviews or supplementary reports were published in 1992, 1993, and 1994. On March 6, 2001, the NRPB's Advisory Group released another scientific review that evaluated experimental and epidemiological studies published since its 1992 report (3). Their overall conclusion was:

> Laboratory experiments have provided no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels[3] of power frequency magnetic fields is associated with a small risk of leukemia in children ....In the absence of clear evidence of a carcinogenic effect in adults, of a plausible explanation from experiments on animals or isolated cells, the epidemiological evidence is currently not strong enough to justify a firm conclusion that such fields cause leukemia in children. **Unless, however, further research indicates that the finding is due to chance or some currently unrecognized artifact, the possibility remains that intense and prolonged exposures to magnetic fields can increase the risk of leukemia in children.**

The Advisory Group noted that levels of exposure associated with potential health risk are very rare in the UK, that is, average domestic exposure of 0.4 μT (4 mG) or more. Noting that such exposure related to about 0.5% of the UK population, the Board of the NRPB estimated a doubling of the annual risk of leukemia from 1 in 20,000 to 1 in 10,000 children in general and from 1 in 1400 to 1 in 700 for the 0.5% of children possible exposed to magnetic

[3] Not stated directly in this specific citation, but presumably greater than 0.4 μT (4 mG).

fields averaging 0.4 □T (4 mG) or more (13). This was viewed as a low level of risk for which any increase may still be explained by biases in data collection.

Similar estimates are available for the U.S. The NIEHS estimated the lifetime risk of childhood leukemia attributable to ELF-EMF (conditional on assuming the risk is real) between 2.5 to 7.5 per 100,000 people and, on a yearly basis, 2 to 6 additional cases per million children per year (2). The NIEHS report also cited the risk of getting leukemia before age 15 in the U.S. as about 0.05% or 5 per 10,000 people (2).

International Agency for Research on Cancer

Part of the World Health Organization, the International Agency for Research on Cancer (IARC) is producing a new health monograph on static and ELF-EMF. The IARC Monographs series publishes authoritative independent assessments by international experts of the carcinogenic risks posed to humans by a variety of agents, mixtures and exposures. Working Groups are established to review the literature and draft the evaluations.

The IARC EMF Working Group met in France to write their report, and their conclusions were publicly released at the end of June (4). This group of 21 experts from 10 countries found limited evidence that residential magnetic fields increase the risk of childhood leukemia. Their specific conclusions were:

- Pooled analyses of data from a number of well-conducted studies show a fairly consistent statistical association between childhood leukemia and power-frequency residential magnetic field strengths above 0.4 □T (4 mG), with an approximately two-fold increase in risk. This is unlikely to be due to chance, but may be affected by selection bias. Therefore, this association between childhood leukemia and high residential magnetic field strengths was judged *limited evidence* for excess cancer risk in exposed humans.

- There is no evidence that electric fields are associated with childhood leukemia, and there is no consistent relationship between childhood brain tumors and residential ELF electric and magnetic fields.

- There is no consistent evidence that residential or occupational exposures of adults are related to excess risks of cancer at any site . . .

- Evidence for excess cancer risks of all other kinds, in children and adults, as a result of exposure to ELF electric and magnetic fields was considered *inadequate.*

- Overall, evidence for carcinogenicity of ELF magnetic fields in experimental animals was judged *inadequate*. No data on carcinogenicity to animals of static magnetic fields, or of static of ELF electric fields, were available to the working group.

- Static magnetic fields and static and ELF electric fields *could not be classified as to carcinogenicity to humans (Group 3).*

- **Overall, ELF magnetic fields were evaluated as possibly carcinogenic to humans (Group 2B), based on the statistical association of higher level residential ELF magnetic fields and increased risk for childhood leukemia.**

The IARC evaluates evidence for carcinogenicity from human and experimental data using criteria for each of the categories given below (14). The categories refer to the strength of the evidence and not to the extent of carcinogenic activity (potency) nor to the involved mechanisms of action.

- Sufficient evidence of carcinogenicity
- Limited evidence of carcinogenicity
- Inadequate evidence of carcinogenicity
- Evidence suggesting lack of carcinogenicity

For EMF, the reviewers classified the epidemiological data from studies of children to be "limited," meaning:

> . . . A positive association has been observed between exposure . . . and cancer for which a causal interpretation is considered by the Working Group to be credible, but chance, bias or confounding could not be ruled out with reasonable confidence.

The IARC then also considers other relevant information such as pathology, results from cellular studies, and mechanistic data. The strongest evidence for carcinogenicity in humans is human evidence. For an overall evaluation, IARC considers the body of evidence in entirety, including the categorization listed above, and describes the agent, mixture, or exposure under review according to the following categories:

- Group 1: The agent is carcinogenic to humans. The exposure circumstance entails exposures that are carcinogenic to humans.
- Group 2:
  - Group 2A: The agent is probably carcinogenic to humans. The exposure circumstance entails exposures that are probably carcinogenic to humans.
  - Group 2B: The agent is possibly carcinogenic to humans. The exposure circumstance entails exposures that are possibly carcinogenic to humans.
- Group 3: The agent is not classifiable as to its carcinogenicity to humans.
- Group 4: The agent is probably not carcinogenic to humans.

For the recent EMF review, the Working Group classified ELF magnetic field exposure in Group 2B likely meaning that there is limited evidence of carcinogenicity in humans but less than sufficient evidence of carcinogenicity in experimental animals.

The final EMF monograph should be available in 2002. The IARC sets a goal of producing a final monograph within six months of a Working Group meeting.

Prospects for Research

The creation and cessation of the U.S. Federal EMF RAPID program had important impacts on the conduct of research by non-Federal organizations. With the increase in Federal activity, most states cutback their own programs or did not implement proposed initiatives. State programs have not been restored upon the ending of Federal RAPID Program. In some areas, industry research increased in parallel with Federal efforts but there was an eventual leveling off largely because the RAPID program was cost-shared with Federal funds and industry contributions. Now industry has sharply curtailed its own research programs, too.

At present, the most active research programs are in other countries. The U.S. program has been severely cutback, as described. The NIH/NIEHS may still fund grant research through their routine grant administration

procedures. There is, therefore, no guarantee that grants will be awarded without the presence of a focused applied research program.

The State of California has had the largest state research program, and it is close to conclusion. The California EMF program is soliciting reviews of its research and program products, including reports on exposure assessment, risk evaluation, and policy decision-making.

All of the hazard evaluations, research assessments, and governmental summaries have identified specific areas worthy of further scientific investigation, especially to develop better data for dose/exposure assessment and on biological mechanisms.

In the 1999 Report to Congress, NIEHS Director Dr. Kenneth Olden noted:

> The interaction of humans with ELF-EMF is complicated and will undoubtedly continue to be an area of public concern . . . . While some questions were answered, others remain. Building upon the knowledge base developed under the EMF-RAPID Program, meritorious research on ELF-EMF through carefully designed, hypothesis-driven studies should continue . . . (2)

It is apparent that scientific and policy uncertainties remain unresolved. Yet sources for sponsoring and supporting the development of research results and information have dwindled. Identified research leads will probably not be pursued.

III. OVERVIEW OF LITERATURE ON HEALTH EFFECTS OF ELECTRIC AND MAGNETIC FIELDS

Highlights from some of the research studies published during the period covered by this report are described below.

Epidemiological Studies

Residential Studies

Several more epidemiological studies of childhood cancer have been published, with mixed results. One study from Canada was largely negative, and one was positive (15, 16). A study from Great Britain was negative, but has been criticized because EMF exposure at homes and in the study population is practically nil (17). A small case-control leukemia study by Michaelis et al. in Germany reported elevated but not significant odds ratios for children with exposures over 0.2 □T (2 mG) (18). Another major study of children is underway in Japan.

Two studies on reproductive effects, supported by the California Department of Health Services were recently released and are described below. Expected to be published in scientific journals later this year, these two studies are important new additions to the literature with advancements in exposure assessment over past studies of reproductive effects.

Li et al. (19) conducted a population-based prospective cohort study on the risk of spontaneous abortion among almost 1,000 pregnant women in a health maintenance organization (HMO) in the San Francisco area. Study participants were interviewed, kept activity diaries, and wore magnetic field measurement meters for 24-hours. Pregnancy outcomes were determined from medical charts, HMO data bases, and telephone follow-up. Excess risk of spontaneous abortion was found among women with increasing maximum

magnetic field exposure with an apparent threshold around 16 mG (1.6 □T) where the risk estimate was 1.8 (95% confidence interval [CI][4] 1.2-2.7). The association was larger for early spontaneous abortions (before 10 weeks of gestation (2.2 [95% CI 1.2-4.0]) and among women who had past difficulties in pregnancy (3.1 [95% CI 1.3-7.7]). The estimates went higher when analyses eliminated women who said their activity patterns when wearing measurement equipment was atypical.

Lee et al. (20) conducted a nested case-control study of clinical miscarriages and residential magnetic field exposure. Magnetic field exposure was determined by power line wire coding, spot measurements, and three types of personal exposure measurements (rate of change, maximum, and time-weighted average). No associations were found for spot measurements or wire coding. Excess risk of miscarriage with increasing exposure was found for all methods of evaluating personal exposure. The highest risk was estimated for the rate of change metric which represents average differences between consecutive exposure levels; the odds ratio for the highest group was 3.08 (95% CI 1.59-5.95). These results may indicate that high brief exposures are important in determining risk of miscarriage, and such exposures are more typical of exposures from appliance use than from nearby power lines. Results of a prospective substudy were consistent with the case-control results.

Occupational Studies

Wijngaarden et al. published the results of a study on suicide among electric utility workers (21). It was a nested case-control study (536 cases, 5,348 controls) drawn from a cohort of 138,905 male workers. This data set has also been examined for other endpoints by Savitz, Loomis, and other colleagues at the University of North Carolina. Suicide mortality was found to be increased among workers in jobs with high exposure (electricians, linemen) and increased with increasing magnetic field exposure, determined through measurement surveys. Risks, given as odds ratios, also were highest among the youngest employees, those under 50 years of age. The authors believed their data supported an association between occupational exposure to electromagnetic fields and they suggested that the conduct of laboratory studies on melatonin and depression would be fruitful lines of future investigation to discover mechanisms.

Meta-Analyses

As major large epidemiological studies have been completed, the need to assess the emerging data has increased. Projects have been conducted that pool data from multiple studies and perform meta-analyses. Meta-analysis is an approach with methods to synthesize and analyze data from multiple, often small, single studies with different methodologies. The reports continue to observe a small and statistically significant increased risk of childhood cancer, when multiple studies are pooled and analyzed in combination, using various types of analytical methods. There may be stronger support that the increase in risk may

[4]In general, risk estimates, given as relative risks or odds ratios, mean a comparison of the level of disease in an exposed population (subjects or cases) versus the level of disease in an unexposed population (controls). Since there are many factors that could influence these estimates, a confidence interval (CI) gives a measure of the precision of the estimates, namely, based on the statistical assumptions, data, and study methods, the risk estimate is believed to fall within the range of the confidence interval. The range probably contains the true value. Although determining statistical significance concerns mathematical methods for evaluating data and testing hypotheses, it is often common to consider confidence intervals that are less than or include 1.0 as not statistically significant or indicative of no effect or not different from baseline.

be more tied to actual field exposure (rather than simply surrogates of exposure such as wiring configuration codes) than previously thought.

Ahlbom et al. performed a pooled analysis of magnetic fields and childhood leukemia, evaluating individual records from nine international studies (22). The authors reported twice as much leukemia among exposed children. The estimated summary relative risk was 2.00 for exposure over 0.4 μT (4 mG) with a 95% CI of 1.27-3.13. For North American children, the summary risk estimate was more modestly elevated and not statistically significant [RR=1.24 (95% C1 0.82-1.87)].

Greenland et al. evaluated original individual data from 15 studies of childhood leukemia that provided magnetic field or wire code information (23). Of these, 12 studies had magnetic field data and from these the authors calculated a summary odds ratio of 1.7 (95% CI 1.2-2.3) for exposures greater than 0.3 μT (3 mG) compared to 0.1 μT (1 mG) as the baseline exposure. Different analytical methods produced similar results. Odds ratios for wire coding methods of exposure assessment varied widely across studies. Because the authors found an association between leukemia and measured magnetic fields when considering all studies together, they concluded that the view that childhood leukemia is only weakly or inconsistently associated with magnetic fields when actually measured in individual studies, as opposed to indirect estimations of exposure with surrogate techniques such as wire codes, was not borne out by their meta-analysis. The investigators also concluded that (1) magnetic field effects, if any, may be concentrated among groups with high and uncommon exposures, and (2) studies of highly exposed populations are needed.

Kheifets, Sussman, and Preston-Martin examined nine studies of childhood brain tumors and residential exposure to EMF, based on five exposure metrics, and six studies concerning appliance use (24). Each metric of residential exposure had been associated with brain cancer in single studies, but there was no consistent association across studies. The authors did not believe the evidence supported an overall association between EMF exposure and brain cancer in children.

An occupational meta-analyses of three major international studies of electrical workers by the Electric Power Research Institute found a small increased risk in workers (25).

Over time, studies on EMF exposure and breast cancer risk in both men and women have been conducted for occupational and residential settings and appliance use. While not a meta-analysis per se, Caplan et al. reviewed this literature (26). Of 11 occupational studies of women, three found elevated levels of breast cancer with high exposures or in certain jobs, two found effects in subsets of groups, and six found no significant effects. Results from six studies of residential exposure and four of electric blanket use were more inconsistent and usually without significant associations. It was proposed that methodological issues and problems in non-occupational exposure assessment may explain the inconsistent results. The authors stated that the suggestions of possible adverse effects and biological plausibility warrant further research on EMF and breast cancer. In an earlier review, Kheifets and Matkin concluded that is it was not possible to rule out a relationship between EMF and breast cancer, citing possible methodological problems in the literature (27).

Biological Studies

Although the risk evaluations did not find any confirmed or clearly causal effects from laboratory studies, using both *in vitro* and *in vivo* methods, certain lines of recent investigation have produced interesting and

potential important results, pending further research. For *in vitro* (cellular) studies, effects have been seen on polyamines involved in the intracellular cascade leading to ornithine decarboxylase (ODC, an enzyme activated during carcinogenesis), on neutrophil (immune system cells) movement with electric field exposure, enhanced expression of stress genes, and bone growth and wound healing. Walleczek et al. examined magnetic field effects on mutation rates following ionizing radiation exposure (28). The results indicate that the magnetic field may be affecting DNA repair, and the effect is dose dependent. A Japanese research group independently reported similar effects in a series of papers, which reported effects at very high magnetic field levels and at lower exposures closer to the levels Walleczek used (29). This work may ultimately be important and prove to be a real effect because of the agreement between independent groups.

For *in vivo* (animal) studies, some investigators have seen increased breast cancer in rodents with exposure while others have not found such effects. Löscher et al. in Germany had reported increased development and growth of mammary tumors in rats exposed to 50-Hz magnetic fields (30). These results were not replicated in a U.S. study by Anderson et al. which used a similar experimental protocol, and, in a September 2000 paper, the two experimental teams reported on a mutual evaluation of their studies and differing experimental results (31). They concluded that the discrepancies might be explained by use of different substrains of rats, different sources for diet and 7,12-dimethylbenz[a]anthracene (DMBA) in the experimental model, differences in environmental conditions, and differences in magnetic field exposure metrics.

In a report published in March 2000, McCann, Kavet, and Rafferty reviewed animal studies of magnetic fields and carcinogenesis (32). This was an update of a 1997 publication and included 29 new reports (for a total of 41) covering six different types of *in vivo* animal models using rats or mice. Applying defined criteria for data quality and reproducibility, the authors concluded: (1) long-term exposure to continuous 50- or 60 Hz magnetic fields in the range of 0.002 - 5mT is unlikely to result in a carcinogenesis in rats or mice, and (2) a weak promoting effect of magnetic fields cannot be ruled out although results of most cancer promotion or progression studies are negative. Carcinogenicity studies by the National Toxicology Program were negative (2).

Results have also been mixed for studies on EMF effects on melatonin levels in rodents (2). Clinical studies of humans have also reported altered melatonin levels and alterations in heart rate variability; these results have not been robust (2).

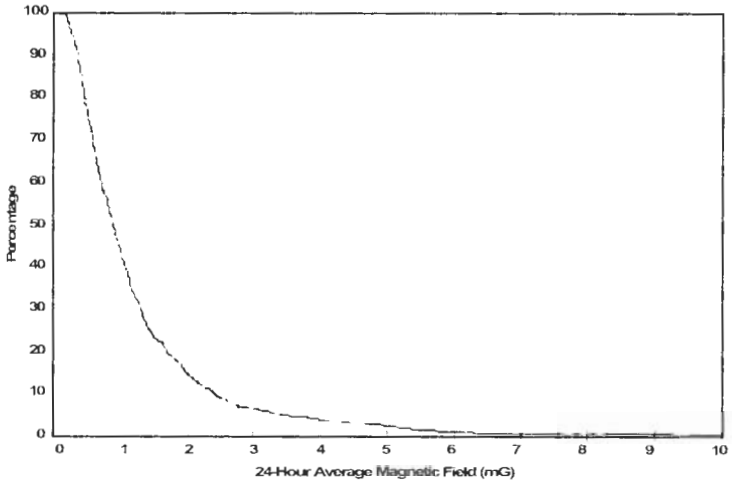
Exposure and Engineering Studies

Source characterization, exposure assessment, field mitigation, and related engineering research have been primarily supported by industry sponsors, chiefly the Electric Power Research Institute (EPRI), as well as by the RAPID Program, under the management of the Department of Energy.

Some of the most important results come from a two-part study by Zaffanella et al. (33i, 33j). This project has produced the best estimates to date of the extent and level of EMF exposure in the general population, based on a random sample of 1000 persons who wore/used meters to monitor their personal exposures. As seen in the following table and figure, most Americans experience exposures below 0.5 mG (0.05 □T) which is considered ambient or background exposure. The major contributors to high level exposures are transmission lines and occupational sources.

Percentage of U.S. Population with 24-Hour Average Field Exceeding Given Values

Average 24 Hour Field	Estimated Percentage
> 0.5 mG	76.3
> 1 mG	43.6
> 2 mG	14.3
> 3 mG	6.3
> 4 mG	3.4
> 5 mG	2.4
> 10 mG	0.4
> 15 mG	0.1



The NRPB reported estimates of average domestic exposure of 0.4 □T (4 mG) or more related to about 0.5% of the UK population (3,13). The data from Zaffanella et al. found about 3.4% of the U.S. population experiences exposures at similar levels, accounting for total exposure at home, at work, and in transit (33j). The EPRI 1000-home study (area, not personal measurements of people) found about 3% of residences with exposures of 0.4 □T (4 mG) or above (34,35,36). U.S. population exposures are thus higher than exposures in the U.K. Any derived cancer risk estimates would likely differ, too.

There have not been any new or major developments in exposure or engineering assessment since the end of the RAPID program. The National Institute of Occupational Safety and Health and EPRI are going to conduct a joint project on occupational exposure assessment. They will be testing the feasibility of combining measurements and new exposure metrics with existing epidemiological data; the goal is to produce more valid assessments of EMF health risks.

IV. STATE ACTIVITIES

Maryland is one of the few states to retain an EMF program. The Power Plant Research Program (PPRP) continues to serve as a source for information for Maryland citizens, answering inquiries about EMF health effects and exposures. The PPRP advises other state agencies on EMF matters, especially the PSC on siting and licensing issues. The PPRP is also supporting research to develop field estimates and calculations for transmission lines to map exposure profiles throughout the state for integration with related state GIS (geographic information systems) and mapping activities. Program activities are reviewed by an Advisory Committee, composed of relevant stakeholders, which can also recommend research and program initiatives.

The California Public Utilities Commission (CPUC) created the California Electric and Magnetic Fields Program in 1993. The program has played a prominent role in EMF research and development and is guided by a Stakeholders Advisory Committee. The program has supported research in the areas of policy analysis, exposure assessment, epidemiology, and electrical engineering and EMF mitigation. It also operates an Education and Technical Assistance Unit to provide information about EMFs to the public and various organizations. The final phase of the EMF program, termed "program synthesis," is to review and use research results as the basis for preparing reports and products. There are four elements to program synthesis:

- An evaluation of evidence of risk based on results of this program as well as other research.
- A policy integration document to help decision-makers use the results from policy analyses.
- A process for releasing the data collected in and results of the research projects.
- Opportunities for potential end-users of the research effort to familiarize themselves with complex technical documents.

The CPUC extended the program through December 31, 2001.

Reports from the California EMF program, in various stages of review, have been posted on their web site (37) and include:

- Draft reports on an EMF Risk Evaluation and on EMF Policy Options (38). The Risk Evaluation is similar to the IARC review but cites health end points other than childhood leukemia as possible risks, too, and applies an additional and different approach (degree of confidence) to health risk assessment.
- Reports on school analyses (37).
- Two epidemiological studies on miscarriages and spontaneous abortions have been accepted for publication by the journal *Epidemiology*. Both may be published in the same issue, probably in late 2001. These studies, discussed earlier, are appended to the draft Risk Evaluation report (38).
- Report on Power Grid/Land Use Policy Analysis (39).

V. INFORMATION RESOURCES

As EMF programs have been scaled back, the more traditional sources of public information have also decreased – people or places to call or write, published brochures, and information agencies. The number of industry, government, or independent groups that have tracked EMF development has declined. Trade associations and utilities still provide information to consumers and others but outreach activities are not as intense as before. Copies of public information documents from the RAPID program are still available from NIEHS and NIOSH. These are *Questions and Answers About Electric and Magnetic Fields Associated with the Use of Electric Power* (40) and *EMF in the Workplace* (41). The *Questions and Answers* brochure is being updated and may be finished in late 2001.

Internet resources have increased. The Federal EMF RAPID Program still maintains two web sites but new postings have not been made. Some major internet links for EMF information include:

http://www.bioelectromagnetics.com

http://www.cdc.gov/niosh/emfpg.html

http://www.emf-data.org

http://www.ebea.org

http://www.epri.com

http://www.dnai.com/~emf

http://www.iarc.fr

http://www.icnirp.de

http://www.ieee.org

http://www.infoventures.com/emf

http://www.microwavenews.com

http://www.microwavenews.com/www.html

http://www.niehs.nih.gov/emfrapid/home.htm

http://www.nrpb.org.uk

http://www.who.int/peh-emf

VI. OTHER DEVELOPMENTS

The World Health Organization (WHO) established its international EMF Project in 1996 to assess health environmental effects of exposure to static and time varying electric and magnetic fields in the frequency range 0-300 GHz. The project objectives are:

- Provide a coordinated international response to concerns about possible health effects of exposure to EMF,
- Assess the scientific literature and make status reports on health effects,
- Identify gaps in knowledge needing further research to make better risk assessments,
- Encourage focused, high quality research programs,
- Incorporate research results into WHO's Environmental Health Criteria monographs where formal health risk assessments will be made of EMF exposure,
- Facilitate the development of internationally acceptable standards for EMF exposure,
- Provide information on the management of EMF protection programs for national and other authorities, including monographs on EMF risk perception, communication and management, and
- Provide advice to national authorities and others on EMF health and environmental effects and any protective measures or actions needed.

Collaborating organizations include eight international agencies, over 40 national authorities, and eight WHO collaborating centers. The program is planned to end in 2005.

The International Commission on Non-ionizing Radiation Protection published guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz) in 1998 (42). The guidelines consider field levels that can produce immediate health effects such as stimulation of peripheral nerves, shocks, and elevated tissue temperatures. The guidelines do **not** consider potential health effects that might occur from long-term exposures to field levels typically encountered in residences or at ground level near power lines.

The International Committee on Electromagnetic Safety, formerly the IEEE Standards Coordinating Committee 28, develops voluntary standards on human exposure safety to nonionizing radiation, using a subcommittee structure. Subcommittee 4 (SC4) is assessing health effects of ELF/EMF. SC3 is working on draft standards for maximum levels for human exposure to EMF at frequencies of 0-3 kHz.

VII. CONCLUSIONS

Major U.S. and international health risk assessments have been performed. They are from the U.S. NIEHS, the NRPB in the U.K., and the IARC, a multi-national organization affiliated with WHO. These assessments have drawn stronger conclusions about possible health effects from exposure to electric and magnetic fields, especially for childhood cancer, than most reviews in the past.

They concluded that the available scientific evidence pointed to a small increased risk of childhood leukemia with EMF exposure. IARC's EMF Working Group classified ELF magnetic fields as Group 2B carcinogens, meaning they are possibly carcinogenic to humans based on limited evidence for excess cancer risk in exposed humans. This is similar to the conclusion put forth by an EMF Working Group commissioned by NIEHS to evaluate the scientific evidence in 1998. The Advisory Committee for the NRPB concluded that it is a possibility that prolonged exposure to magnetic fields increases the risk of leukemia in children. The NIEHS con concluded that EMF could not be ruled as entirely safe, and measures to reduce exposure and to provide public information, despite the uncertainty, might be pursued.

None of the assessments determined EMF to be a confirmed cause of human cancer, instead calling EMF a possible human carcinogen, based on the epidemiological evidence. The lack of complementary confirmatory evidence from animal and other laboratory studies bears on the distinction between a known vs. probable vs. possible carcinogen classification. All assessments commented on the uncertainties in determining causality, particularly because causative exposure and dose characteristics had not yet been clearly identified from the research. In summary, EMF exposures remain suspect but remaining unknowns are the reason for continued lack of firm clear affirmation of health risks from EMF exposures.

Research funding support has declined dramatically, especially in the U.S. The prospects of resolving EMF health questions and issues with certainty in the near future remains dim.

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