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

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FOREWORD

This report, “Status Report on Investigations of Potential Human Health Effects Associated with Power Frequency Electric and Magnetic Fields,” produced by the Power Plant Research Program, is the most recent of a continuing series of reports that reviews recently published research and related developments about 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. This is the ninth status report published since 1990. The information summarized herein highlights major developments during the reporting period. The report focuses chiefly on continuing hazard evaluations and risk assessments as well as programmatic and policy developments.

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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 for almost 30 years. This report presents developments and the results of various research reports and other documents addressing issues about health effects and EMF, published between July 2001 and February 2006.

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 PSC. This report is the ninth in the series. The last report was published in October 2001 (1). An overview of key journal articles, reports, and reviews published in the scientific literature is presented.

What has been selected to highlight includes new epidemiological studies on childhood cancer in additional populations, epidemiological studies of adults or workers that focus on different endpoints or interactions with other agents, biological studies aimed at trying to untangle the uncertainties and discrepancies in the laboratory-based evidence, and studies aimed at improving information about relevant exposures. Also included is an update on reviews and assessments conducted by (or, in progress) scientific advisory groups or consensus-building organizations.

Included in this report are new developments by some states on policy and regulatory initiatives to require more stringent documentation of the potential health and environmental impacts of electric and magnetic fields in applications for electric utility facilities.

There were three significant major national and international reviews in the last reporting period that concluded there was a consistent association reported between magnetic field exposure and leukemia in children in epidemiological studies; however, uncertainties in the data and little confirmatory evidence in laboratory studies led to a conclusion that it could not be stated with certitude that magnetic fields cause cancer. Little has changed since then. Reviews and evaluations have continued. As Feychting, Ahlbom, and Kheifets stated (44) in their review:

> Research on ELF fields has been performed for more than two decades, and the methodology and quality of studies have improved over time. Studies have consistently shown increased risk for childhood leukemia associated with ELF magnetic fields, whereas ELF fields most likely are not a risk factor for breast cancer and cardiovascular disease. There are still inadequate data for other outcomes.

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; Precautionary Principle; Precautionary Policies; State Regulations, Exposure Guidelines; and Literature Review.

I. BACKGROUND

Electric and magnetic fields, also called electromagnetic fields (EMF), occur both naturally and as a result 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 occur when an electric charge is present and results from the force electric charges exert on each other. Electric fields 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 thousands of volts per meter (kilovolts per meter, kV/m). Electric fields can be shielded by objects such as trees, buildings, and vehicles. Burying power lines can also reduce human exposure to electric fields.

Magnetic fields are produced by the movement of the electric charge (i.e., by the flow of the electric current). 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 direct current (DC)) 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 research has focused on magnetic fields. Early epidemiological studies 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.

- Long-term (i.e., chronic) low-level exposure such as what one would experience by living in proximity to an active distribution or transmission line. Such exposure to magnetic field levels is generally in the mG range.
- 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 mG.

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 and especially childhood malignancies, as well as other health effects is subject to continued review by expert scientific organizations and regulatory or policy-setting organizations, as described herein.

II. KEY DEVELOPMENTS

The U.S. government no longer conducts EMF research in unified programs since the ending of the Research and Public Information Dissemination (RAPID) Program. This Congressionally-mandated EMF research program was established in 1992 with a limited period of operation ending in 1998. Final reports are maintained on the website of the National Institute of Environmental Health Sciences (NIEHS) at http://www.niehs.nih.gov/emfrapid. The current sponsor of EMF research in the U.S. is the Electric Power Research Institute (EPRI), a research organization funded by the electric utility industry. The NIH/NIEHS or other agencies may still fund grant research through their routine grant administration procedures. EPRI is involved with the current scientific assessment at the World Health Organization (WHO). Research and scientific assessments are being conducted in other countries.

Health and biological research has continued in various countries, however results have not substantially altered or changed assessments made by expert advisory, consensus groups or regulatory bodies. Highlights from some of the research studies published during the period covered by this report are described below.

Research Update (2001 – 2006)

EPIDEMIOLOGY

General Population Studies

Japan's Childhood Leukemia Study

During this reporting period, a long-awaited study of childhood cancer in Japan was completed by Kabuto et al. (2, 3). This population-based case control study evaluated children (15 years of age and younger) with newly-diagnosed acute leukemia in 1999-2001[1].

[1] Leukemia is the name for cancers that show excess proliferation of white blood cells (WBC) and may also impair other types of blood cells or blood components. Leukemias are classified by the type of WBC proliferating abnormality. Two major classifications are acute and chronic. Acute

Of the 1606 patients in Japan, 792 resided in the selected study area, 18 prefectures accounting for 53% of the Japanese population. 391 cases agreed to participate (49.4%), and 312 cases remained for analysis after specific exclusions. Setting a starting criteria of 10 controls per case, random selection of controls, with matching on age, sex, and municipality, produced 3833 possible subjects, and 1097 (28.6%) agreed to participate. These participation rates are low. After exclusions (for reasons such as moving or relocating), 603 controls remained. Interviews of subjects were conducted, and information about various relevant factors, including appliance use, was elicited. Magnetic field measurements were made and consisted of week-long continuous measurement in the child's bedroom and multiple in-home spot measurements. The main exposure metric was weekly arithmetic mean bedroom levels. The referent or "no exposure" category was magnetic field level <0.1 µT (1 mG). The other exposure categories were 0.1-0.2 µT (1-2mG), 0.2-0.4 µT (2-4 mG), and > 0.4 µT (4 mG).

The study by Kabuto et al. showed a modest increase in acute leukemia for children exposed to the highest magnetic field levels, but there are limitations in the study with respect to exposure and participation, as discussed below.

For all acute leukemias combined, there was an increased risk in the highest exposure category, but the odds ratio (2.6) was not statistically significant[2]. When limited to acute lymphoblastic leukemia cases, the odds ratio was 4.73 (95% CI[3] 1.4-19.7). It must be noted that there were very few children whose exposure was above 0.4 µT (4 mG), namely, 11 children diagnosed with acute leukemias and 9 diagnosed with acute lymphoblastic leukemia. The authors commented that Japan did not have a high percentage of residents exposed to high field levels as was initially speculated, yet the few children in the high category had exposures far above 0.4 µT (4mG).

As previously noted, there was low participation in the study by the eligible population. The degree of participation is important to consider, because it could reflect an undefined bias or a lack of representativeness of the studied or sampled group as compared to the larger population from which the study group was drawn possibly resulting in spurious results. The authors reported that distance to high voltage power lines (the marker for exposure) for participating versus nonparticipating controls was similar which implies no difference. Case families seemed to be more willing to participate if their physician asked them to do so. The implications of physician involvement in the study are unclear.

<u>United Kingdom Childhood Study</u>

In 2005, Draper, Kroll, and Swanson reported the results of a very large case-control study on childhood cancer and the distance from high voltage power lines in England, Wales, and Scotland (4). Records of 29,081 children with cancer, born in 1962-95 and aged 0-14 years, were evaluated. Matched controls were selected from birth registries. Of the records reviewed

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leukemias generally have rapid onset, usually involve immature cells, and are most common in children, especially a type called acute lymphoblastic leukemia.

[2] In general, risk estimates, given as relative risks (RR) or odds ratios (OR), 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.

[3] CI=95% Confidence Interval

9,700 leukemia cases were reported. Power lines nearest to the birth address were determined from National Grid records, and distance between the lines and the homes was calculated. No magnetic field measurements were made. There was no contact with cases or controls (such as to solicit participation), thus, eliminating the possibility of selection bias. Homes located at a distance above 600 meters (m) (1,968 ft) were taken as the reference or "no exposure" group. Children who lived within 200 m (656 ft) of a high voltage power line had a relative risk of leukemia of 1.69 (95% CI 1.13-253) and those whose birth home was between 200 and 600 m had a relative risk of 1.23 (95% CI 1.02-1.49). Thus, children living close to power lines were at an increased risk of developing leukemia than children living farther away from the lines. There was also a statistically significant trend in relation to the reciprocal of distance from the line. No elevations in risk were seen for other cancers.

These results are consistent with those of other residential studies of childhood cancer, but with the major exception that the distances and, presumably the magnetic field levels, are much greater and lower, respectively. For example, the meta-analysis by Ahlbom et al. (5) identified a 2-fold increased risk from pooled studies in relation to magnetic fields of 4 mG. The meta-analysis by Greenland et al. (6) was similar with a statistically significant increase in relative risk at 3 mG. The UK authors calculated estimated magnetic field levels to be about 4 mG at 60 m (196.8 ft) and about 1 mG at 200 m. Therefore, it is unclear why the presumptive exposures are much lower in the Greenland et al. study. Because the lower exposures resulted in elevated leukemia risk, this study has generated a great deal of discussion in the scientific literature.

<u>The Long Island Breast Cancer Study Project</u>

This was a multidisciplinary, multi-study, multi-institutional research program designed to investigate environmental factors and breast cancer and was initiated by Congressional directive (7). The largest project was a case-control study of Long Island women potentially exposed to selected organochlorine pesticides and polycyclic aromatic hydrocarbons. An EMF case-control study was included in the research effort for a subset of the participants (7). The main selection criteria for the EMF component were residence in current homes for at least 15 years to best reflect long-term residential exposures. After determining eligibility and refusals, 576 cases and 585 controls were included. Interviews were conducted, and EMF residential measurements were made including spot measurements, 24-hour measurements, and ground-current magnetic field measurements. Wire coding, or mapping, was also done. There were no differences between cases and controls with respect to mean and median values for all magnetic field measurements. All odds ratios for breast cancer centered around 1.0 for both the various measurements and for wire coding, and none were statistically significant.

This was a well-conducted detailed study. There is, however, some question about refusals to participate, especially among controls, in the primary study (86% for cases, 69% for controls) and with a further reduction in the secondary EMF add-on study for eligible subjects (87% for cases and 83% for controls). It is not really possible to determine if nonparticipants would have been eligible for the EMF study or if exposures were different. To evaluate exposure differences, the authors looked at regional wire coding for nonparticipants and found no differences for regional or Wertheimer-Leeper wire coding (8); however, according to wire coding under the Kaune-Savitz scheme (9), more participants had low exposure and more nonparticipants had medium exposure. The percentage of participants with a residence classified as having a high wire code was similar to the percentage of nonparticipants with a residence with a high wire code. Also, participants were younger, had higher income and more education, and were more likely to be white. For control of potentially confounding factors, the authors believed their quality control and analytical procedures were sufficient so that the lack of an EMF association is unlikely to be due to errors. They concluded that their study provided no evidence that residential EMF exposures are related to breast cancer risk.

Occupational Studies

Prostate Cancer

A large multi-utility database has been developed and used for several studies on mortality among utility workers and various environmental and work factors, especially EMF. A recent study using this database examined prostate cancer mortality in relation to separate and combined exposure to EMFs and polychlorinated biphenyls (PCBs)(10). The interest in prostate cancer stems from data that these agents may decrease the body's melatonin levels, and melatonin may provide protection by reducing hormone levels that stimulate cells growth. But the authors also indicated that some PCBs (dioxin-like) may decrease melatonin yet others may reduce growth of prostate tumor cells, and the literature shows little evidence for a role of PCBs in cancer.

The development of work-exposure histories and other relevant factors was very extensive, and detailed multivariate analyses were applied. There were 387 prostate cancer cases (deaths) and 1,935 age-matched controls, drawn from the utility cohort. Adjustment was made for race. When evaluated separately, the highest level of cumulative EMF exposure was positively associated with the risk of death from prostate cancer, but PCB exposure was not (a modest but nonstatistically significant elevation in mortality risk was obtained). When considering the joint effects of EMFs and PCBs, there was no excess risk of prostate cancer mortality when exposures to both EMFs and PCBs were at the highest levels. While these findings are unclear, the authors suggest the combined high exposures do seem to be acting together in some way to reduce the risk estimates. For EMFs at the highest levels and PCB exposure at its lowest estimated level, statistically significant elevated odds ratios were obtained (2.0, 95% CI 1.34-3.04). In the reverse scenario (low EMFs, high PCBs), the risk ratios were elevated but were not statistically significant. The interaction analyses were based on smaller numbers of cases and controls and may, thus, be imprecise. Race (being non-white) presented the greatest risk of prostate cancer mortality which, based on the literature, probably reflects time of diagnosis and socioeconomic status. Non-whites were a small proportion of the workforce. In conclusion, this study found an association between prostate cancer mortality and high exposure to EMFs in the electric utility workplace and only limited evidence of an association with PCB exposure.

Brain Cancer

Extensive research on occupational EMF exposure and brain cancer has shown a small elevation in risk, but there are uncertainties in the evidence. The effect, if real, might be small or may depend on understanding interactions with other risk factors. A report by Navas-Acién et al. examines the potential for interaction between chemicals and EMF occupational exposures on glioma and meningioma risk among a cohort of Swedish male workers (11). In a previous study, the authors found an increased risk of glioma in men associated with occupational exposures to arsenic, mercury, and petroleum products and an increased risk of meningioma with lead exposure (12). Study data came from the Swedish cancer environment registry which includes extensive background information (including occupation, the 1970 census with occupational, industrial, and residential information, a developed EMF job-exposure-matrix data base with exposure estimates based on measurements, and a chemical job-exposure-matrix that classified chemical exposure for combinations of occupations and industries). The authors believe that use of job-exposure-matrices is superior to use of job titles.

The reference low EMF exposure was an average mean below 0.13 µT (1.3 mG). For EMFs alone and over all occupations, there was a significant yet very modest increase in risk of glioma for 0.13-0.2 µT (1.3-2 mG; RR 1.12, 95% CI 1.02-1.25) and for 0.2-0.3 µT (2-3 mG, RR 1.12, 95 CI 1.01-1.25), but not in the highest exposure category of >0.3 µT (3 mG). There was no increased risk of glioma with increasing exposure for office-type workers, but there was an increased risk among transport, communication, production, and service workers. There was no association between EMFs and meningioma risk. Analysis of interaction was done on a subcohort for whom both EMF and chemical exposure information was available. Almost across the board, there was a modest elevation of glioma risk for combined chemical and EMF exposure, with the following combinations producing statistically significant results: petroleum products and low EMF exposure, pesticides/herbicides and arsenic with medium EMF exposure, and solvents with high EMF exposures. The only interaction for meningiomas was with lead; however, the number of subjects was very small, suggesting inconclusive results.

There were inconsistent results for EMF exposure alone, but there was some increase in risk of glioma in combination with occupational exposure to certain chemicals, (i.e., in the presence of some known or suspected carcinogens). In commenting on this report, Costa stated that cellular research in his laboratory is relevant to this epidemiological study and may add further evidence to the supposition that EMFs may act as a cancer promoter (13); Wei et al. found EMFs to increase proliferation of human astrocytoma (the commonest glioma) cells *in vitro* (14). The authors suggested that exploring such potential interactions for other tumors in epidemiological studies that can better evaluate individual exposures or in laboratory studies may be a fruitful new direction for EMF research.

LABORATORY STUDIES

Risk evaluations state that there are no confirmed or clearly causal effects from laboratory studies. Research has continued to investigate this problem. Using both *in vitro* and *in vivo* methods, certain lines of recent investigation have produced interesting and potential important results, pending further research.

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. had reported increased development and growth of mammary tumors in rats exposed to 50-Hz magnetic fields (15). These results were not replicated by Anderson et al., using a similar experimental protocol. The two experimental teams reported on a mutual evaluation of their studies and differing experimental results (16). 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) used in the experimental model, differences in environmental conditions, and differences in magnetic field exposure metrics.

Subsequently, Löscher's laboratory team has further investigated potential substrain differences (17). They tested two substrains of Sprague-Dawley rats. One, the type used in their previous studies, exhibited increased mammary tumor development and growth with magnetic field exposure in the DMBA model. The second substrain showed no enhanced cell proliferation. The authors suggested that these data may indicate the importance of genetics in magnetic field effects, and different animal strains or substrains can be used to evaluate genetic factors. The research may help elucidate some of the inconsistencies seen in studies of effects of EMF exposure in animal models.

In a further examination, Fedrowitz and Löscher compared effects of magnetic field exposure at 100 µT (1000 mG) over 2 weeks on mammary gland cell proliferation in eight strains and substrains of outbred and inbred rats (18). Only the one previously tested Sprague-Dawley substrain and Fischer 344 rats showed significantly increased bromodeoxyuridine (BrdU) labeling which indicates cell proliferation. They also reported that tissue examination revealed an increased number of terminal end buds, the site of origin of mammary carcinomas. The authors believe Fischer 344 rats may be a useful model for investigating genetic factors underlying any co-carcinogenicity or tumor-promotion effects.

One of the longstanding discussions on the potential carcinogenicity and other effects of magnetic fields has been that fields throughout the nonionizing portion of the electromagnetic spectrum are not energetic enough to cause direct effects on DNA. As Navas-Acién stated in his paper, the inability of nonionizing radiation to break DNA indicates that ELF magnetic fields could not be mutagenic and would require the presence of an initiator to start the process of cancer development (11). This has led to theories and research on whether magnetic fields may be cancer promoters or interact with biological systems in other ways that could possibly lead to cancer or other adverse effects.

Cellular Studies

A recent study by Lai and Singh provided data about possible mechanisms of EMF interaction (19). Several cellular studies have reported DNA strand breaks while others have not reported such effects in their tests. In previous work, Lai and Singh reported that melatonin and a "spin trap compound" could block 60-Hz magnetic field effects on DNA (20). In another study, they reported that exposure could induce formation of DNA protein and DNA-DNA cross links (21). According to the authors, these results suggest involvement of free radicals[4] and free-radical damage involving iron cations. In 1990 and 1993, Stevens had proposed the possibility of free radical increases and oxidative stress due to EMF-induced loss of iron (22, 23, 24). In the current study by Lai and Singh, Sprague-Dawley rats were exposed to magnetic fields alone and magnetic fields in combination with drugs. At the study conclusion, brain tissues were examined for DNA strand breaks (19). The regimens were magnetic field exposure alone at 0.01 mT for 24 and 48 hours and exposure for 2 hours at 0.5 mT magnetic fields with a vitamin E analog Trolox, the nitric oxide synthase inhibitor 7-nitroindazole, and the iron chelator deferiprone. For EMF alone, they found more DNA strand breaks in rat brain cells for the longer exposure, a possible duration or cumulative effect. For the drug-treated animals, DNA damage was not seen, suggesting that the drugs were protective.

Based on the results, Lai and Singh proposed a two-stage model where first iron homeostasis is disrupted, leading to the generation of damaging hydroxy radicals. For cell membranes, this can result in damage that produces calcium leakage which in turn increases synthesis of the free radical nitric oxide, the second stage. They also examined incidence of apoptosis[5] and necrosis in brain cells for acute magnetic field exposures and found significant increases following magnetic field exposure. The failure of oxidative processes can cause cells to undergo necrosis or apoptosis while an outcome depends on a variety of factors including exposure parameters, and iron-rich tissues such as in the brain may be susceptible to EMF-induced damage (25).

[4] Free radicals are atoms or electrically neutral molecules that have one or more unpaired electrons in the outer orbit. Free radicals are unstable and react quickly with other atoms and molecules and, thus, can cause damage to living tissues.

[5] Apoptosis is the most common form of physiological (not pathological) cell death; requires metabolic activity by the dying cell; often characterized by cell shrinkage and cleavage of DNA into fragments; cells dying by apoptosis do not usually elicit inflammatory responses associated with necrosis; may also be called programmed cell death signaled by the nuclei in normally functioning cells when age or state of cell health and condition dictates.

EXPOSURE ASSESSMENT

One of the difficulties in interpreting the potential health risks of EMF has been the lack of understanding how fields can interact with biological systems to produce adverse effects (i.e., what are the mechanisms of action). Despite research over time, this question remains unanswered. Added to this is the quandary that human studies are generally positive yet animal studies are generally negative. There are uncertainties about what is the appropriate exposure metric or "dose." At a workshop on Children's Health, Brain et al. proposed "contact currents' or "contact voltages" as an exposure metric that might help explain some of the uncertainties and inconsistencies in EMF data. This discussion was published in a 2004 paper (26).

While contact currents or voltages might be most relevant in occupational settings, the authors believe that they may also be a factor in residential environments if (1) there is an association between contact current exposures and magnetic field levels, (2) levels of contact currents in homes are sufficient to deliver an adequate dose to bone marrow, and (3) a target population (children) encounters contact currents. It was suggested that these criteria are met based on modeling and theoretical considerations. Yet the authors also suggested that further research in *in vitro* and animal laboratory studies and, ultimately, epidemiological studies is needed in order to confirm if contact currents or voltages are an appropriate exposure metric that could explain scientific results to date.

In related work, Bowman et al. evaluated a new contact current meter (CCM) in a pilot study at Southern California Edison among utility employees working in low voltage or de-energized environments (27). The volunteers wore the meters during their work activities. Measurements were below maximum permissible exposures for contact currents set by the Institute of Electrical and Electronic Engineers (IEEE). Internal electric fields were estimated. These were found to be below applicable IEEE standards but above levels (1 mV/m) where some laboratory studies have reported biological effects. Time-weighted-average calculations showed that internal electric fields from contact currents and magnetic fields were comparable. The authors suggested that this may mean contact currents could have been an effect modifier in EMF occupational epidemiological studies of neurodegenerative diseases, leukemia, and cardiovascular diseases which have been inconsistent in result. The authors also reported that "this pilot study identified other improvements to the CCM that would make it better able to measure exposures in future health studies."

In 2002, McDevitt et al. compared magnetic field personal exposure meters, the MultiWave System III and EMDEX Lite (often used in epidemiological studies), which have different operating specifications and capabilities (28). While the ultimate research goal of this project is to determine if capturing diverse exposure metrics may better relate to biologically active metrics, this particular paper focused on how the different instruments compare with respect to commonly taken values as maximum and time-weighted-average root-mean-square magnitudes. It was found that the two instruments are comparable with respect to time-time-weighted-averages in various occupational settings and magnetic field conditions; however, the EMDEX Lite underestimated maximum exposure in comparison to the MultiWave III. Further work has continued, and a new paper is in development (29). The continued development and evaluation of measurement meter technology should help improve exposure assessment.

Reviews and Assessments

The National Radiological Protection Board (NRPB) in the United Kingdom (UK) established an independent expert Advisory Group on Non-Ionizing Radiation (AGNIR) that 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, 1994, and 2001. The 2001 report (30) concluded:

> Laboratory experiments have provided no good evidence that extremely low frequency electro-magnetic 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[6] 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.

In March 2004 (amended April 2004), the NRPB released another scientific review that evaluated recent evidence on electromagnetic fields in the range of 0-300 GHz (31). This review was requested by the Department of Health, conducted by NRPB staff, and reviewed by AGNIR, among others. It was recommended that quantitative restrictions on exposures to EMF in the UK be based on guidelines by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). In an additional complementary document, NRPB provided advice on limiting exposure to electromagnetic fields (0-300 GHz (32). This report reiterated the recommendation to adopt the ICNIRP 1998 exposure guidelines, provided further rationale, and stated:

> An association between prolonged exposure to intense power frequency magnetic fields and a small raised risk of childhood leukaemia has, however, been found, the scientific reasons for which are presently uncertain. In the light of these findings and the requirement for additional research, the need for further precautionary measures should be considered by government.

Part of the World Health Organization, the International Agency for Research on Cancer (IARC) produced a health monograph on static fields and ELF[7] 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 evaluations.

The conclusions of the IARC EMF Working Group were publicly released June 2001, and the final monograph was published in 2002 (33,34). This group of 21 experts from 10 countries classified the epidemiological data from studies of children and residential magnetic fields as limited with respect to increased risk of childhood leukemia. The term “limited” means:

> . . . 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.

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

[7] ELF = extremely low frequency

Upon consideration of all other relevant information, the Working Group classified ELF magnetic field exposure in the possibly carcinogenic to humans category, Group 2B, meaning that there is limited evidence of carcinogenicity in humans but less than sufficient evidence of carcinogenicity in experimental animals.

As previously reported, 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. They launched a series of initiatives on research, risk assessment, standards, communications, and other issues. Program details and lists of publications are provided on the web site at http://www.who.int/peh-emf/. A monograph on static fields has been published (35) while the ELF monograph is not scheduled for publication until 2007. However, there seems to be some controversy surrounding the WHO program (36). The issues include too heavy an industry/utility presence, involvement, and funding; reevaluating and downplaying the literature in the face of existing expert review within WHO and elsewhere and perhaps not adopting IARC's review; indecision on whether to apply precautionary principles or not; and endorsing the ICNIRP guideline. The ICNIRP guideline is described below.

ICNIRP Guidelines for EMF Exposure

Exposure (60 Hz)	Electric field	Magnetic field
Occupational	8.3 kV/m	4.2 G (4,200 mG)
General Public	4.2 kV/m	0.833 G (833 mG)

Guidelines

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published voluntary guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz) in 1998 (37). The guidelines consider field levels that can produce immediate health effects such as stimulation of peripheral nerves, shocks, and elevated tissue temperatures. These effects occur at high magnitudes, much higher (more than 1,000 times higher) than EMF levels found typically in occupational and residential environments. The guidelines, thus, do not consider potential health effects that might occur from the long-term exposures to field levels encountered in residences or at ground level near power lines that have been investigated in epidemiological studies. It is the epidemiological and laboratory studies about power line and related fields that have undergone intense research scrutiny and risk assessment. Whether the ICNIRP guidelines will be acceptable in all quarters, such as by the public, is questionable (see discussion later on Connecticut's Attorney General referencing "so called standards"). Despite this, many countries, groups, and experts are advocating adoption of the ICNIRP guidelines; some advocate application of "precautionary principles" to undertake some additional measures, probably not formal regulatory actions but more likely advice for voluntary actions to account for the unknowns in the evidence and the existence of the possibility of the lower level effects. The European Union and the WHO are advocating "harmonization" of standards, that is, one common standard for all.

The ICNIRP has also published its own scientific review and the members of their Standing Committee on Epidemiology published a review of the epidemiological literature (38, 39).

Under the auspices of the Institute for Electrical and Electronic Engineers (IEEE), the International Committee on Electromagnetic Safety (ICES), 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. In 2002, SC3 published its recommended standards for maximum levels for human exposure to EMF at frequencies of 0-3 kHz (40):

ICES/IEEE Standard

Frequency	Population	Electric Fields	Magnetic Fields
50/60 Hz	Public	5 kV/m	9.04 G
	"Controlled Environment"	20 kV/m	27.1 G
	Exposure of arms and legs can exceed 631 G.		

III. STATE ACTIVITIES

Maryland

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 Maryland state agencies on EMF matters, especially the PSC on siting and licensing issues. During recent transmission line licensing cases, PPRP has been recommending that utilities present calculated field strengths in the application and follow up with actual field measurements following construction of the new facility. The PPRP also supported some research on biological effects and exposure assessment. Program activities are periodically reviewed by an Advisory Committee, composed of relevant stakeholders, which can also recommend research and program initiatives. The PPRP website is found at www.dnr.state.md.us/Bay/pprp/.

California

The California Public Utilities Commission (CPUC) created the California Electric and Magnetic Fields Program in 1993. The program played a prominent role in EMF research and development and was guided by a Stakeholders Advisory Committee. The program supported research in the areas of policy analysis, exposure assessment, epidemiology, electrical engineering, and EMF mitigation. It also operated an Education and Technical Assistance Unit to provide information about EMFs to the public and various organizations. The CPUC extended the program through December 31, 2001, but it has now ended.

Prior reports from the California EMF program were discussed in earlier summaries. The final reports are posted on their web site (41) which has been maintained. These include:

- Reports on an EMF Risk Evaluation and on EMF Policy Options.
- 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.
- Two epidemiological studies on miscarriages and spontaneous abortions, appended to the draft Risk Evaluation report.
- Report on Power Grid/Land Use Policy Analysis.
- Final letter report from their Science Advisory Panel.
- General public information.

The California website address is currently http://www.dhs.ca.gov/ehib/emf/. The program can be accessed through the website for the California PUC at http://www.cpuc.ca.gov by searching on the keyword EMF.

The CPUC launched a review of its 1993 decisions in 2004. The purpose was to determine if improvements should be made to rules and regulations concerning EMFs associated with transmission lines or other electric utility facilities. The review was to examine:

- Results of its "low cost/no-cost" mitigation policy and the need for modifications.
- Any need for any improvement in the implementation of that policy.
- Any need for new or revised mitigation policies as new data emerges.

In January 2006, the Commission reaffirmed its decisions concerning "low-cost/no-cost" policies to mitigate EMF exposures for new transmission and substation projects and to retain a benchmark of four percent of project costs for mitigation. They also:

- Adopted rules and policies to improve utility design guidelines.
- Directed a workshop to be held to implement policies and standardize design guidelines.
- Adopted policies and rules to address underground transmission lines, application of the 4% benchmarks, mitigation modeling techniques, and locations for measuring EMF mitigation.
- Directed utilities to standardized field reduction techniques and document reduction measures taken or rejected.
- Directed its Energy Division to monitor, review, and report on EMF research.

Connecticut

Several contentious issues have emerged in the State of Connecticut, centering on proposals to construct new transmission lines and upgrade other allied facilities. The primary state agency involved with EMF issues is the Connecticut Siting Council (CSC). The CSC is responsible for siting power facilities and transmission lines, hazardous waste facilities, and various other forms of infrastructure including telecommunications sites.

Application was made to the CSC by Connecticut Light and Power and The United Illuminating Company for a Certificate of Environmental Compatibility and Need for the Construction of a new 345-kV electric transmission line and associated facilities (including substations and switching stations) between Middletown and Norwalk. Also, portions of existing 115-kV and 345-kV lines would require reconstruction, modifications would be made to a switching station and substation, and certain interconnections would be reconfigured.

There was opposition from various quarters, such as citizen groups, towns, members of the legislature, and the State's Attorney General, on several grounds including EMF effects. There is an extensive docket set up online at http://www.ct.gov/csc. While the Attorney General did not strictly oppose the line, citing the need for upgrades, he wanted more time and close and careful consideration of environmental, public health, and safety issues; development of a plan to address conservation and load management programs and distributed generation; a 300-foot buffer where feasible; application of mitigation measures that do not violate legislative directives in the State rather than adopting what he called "so-called 'standards"; and other matters. The Attorney General wanted the Siting Council to exercise procedures to extend their decision deadline, but they did not do so and issued a decision on April 7, 2005.

The decision was to approve the application, finding that various effects (environment, ecologic, scenic, historic, recreational, health, safety) associated with the construction "are not disproportionate either alone or cumulatively with other effects compared to need, are not in conflict with the policies of the State concerning such effects, and are not sufficient reason to deny the application." There were, however, conditions on construction, operation, and maintenance. Some of those that relate to EMFs are:

- Modifications to location of undergrounding the 345-kV circuit (underground lines in application) and designation of cable type and redirection of river crossing.
- Conform to Siting Council's Best Management Practices for Electric and Magnetic Fields.
- Develop low magnetic field designs per the Council's Findings of Fact as part of the Development and Management (D&M) Plan and file Plan with each municipality for comment.
- If EMF levels are higher from underground transmission lines than overhead lines and in the vicinity of facilities listed in Conn. Gen. State § 16-50p(i), take measures to ensure public health and safety is protected no less than in the vicinity of statutory facilities near overhead lines.
- Comply with all future electric and magnetic field standards promulgated by State or Federal regulatory agencies. Upon establishment of any new standards, facilities shall be brought into compliance with such standards.
- Construction shall not begin until the Siting Council approves a D&M Plan consistent with State regulations. This Plan must contain a post-construction electric and magnetic fields monitoring plan.
- An environmental consultant, approved by the Council, must be hired to monitor and report on the installation of the overhead and underground transmission system.

The Siting Council had changed their policy document on Best Management Practices for EMF in December 2004, but, in March 2005, rescinded that and re-adopted their original 1993 policy while undergoing a process to consider revisions to the policy. The CSC commissioned a review document to serve as background information for their decision-making process (42). In January 2006, the CSC issued draft EMF Best Management Practices for the construction of new electric transmission lines (43). Public hearings were held in April 2006.

The CSC still has the policy goal of mitigating ROW magnetic field levels with low-cost and practical engineering approaches without compromising system reliability. The following elements are contained in the draft proposed revisions to Connecticut's EMF Best Management Practices (43). CSC will periodically review updates in research results and from consensus-group assessments and will seek advice and guidance from the Connecticut Department of Health. CSC will require applicants to describe design options and provide pre- and post-construction magnetic field calculations for different designs under peak load and project seasonal maximum 24-hour-average current load within the first five operational years. It is stipulated that the calculations be made perpendicular to the corridor for the proposed lines, from the ROW centerline out to 300 feet every 25 feet and, typically, at the location of maximum sag. Land uses within 300 feet must also be provided. The CSC also expects utility applicants to address engineering controls that determine magnetic field levels in publicly accessible areas: distance, height of towers, conductor separation, vertical configuration (arrangement of conductors), optimum phasing, and undergrounding.

The most notable difference in this proposed new policy from the 1993 Best Management Practices policy is the application of biological data to develop criteria to trigger in depth review of proposed new facilities. The CSC used concepts applied in lifetime animal carcinogenicity studies conducted by the National Toxicology Program (NTP, in NIEHS) to establish the highest "no-effect" level (NOEL) (about 10,000 mG), then applied an appropriate safety factor (the product of a factor of 10 to account for animal to human extrapolation, and a factor of 10 to account for variation in human susceptibility (or sensitivity)) to derive a NOEL). This approach yields a value of 100 mG that will be used as a "screening level" at the edge of a right of way (ROW). Epidemiological evidence in this formulation was not considered. As a screening tool, 100 mG is proposed as the level above which more attention will be placed on mitigation strategies. A comparison of other states' limits or trigger values is helpful. New York's 1991 policy was 200 mG for new high voltage transmission lines (which generally was for 345 kV lines). Florida's 1989 maximum magnetic field limit for transmission lines and substations was 150-250 mG, depending on line voltage. Massachusetts has used 85 mG as a benchmark for project design analyses and to elicit review of environmental impacts.

<u>Ohio</u>

The Ohio Public Utilities Commission has rules on electric and magnetic fields with the latest adoption date of 12/15/2003.

There is a notification rule for projects that includes required description of the production of electric and magnetic fields:

> (1) For electric power transmission lines, the production of electric and magnetic fields during the operation of the proposed electric transmission line. The discussion shall include:
>
> (a) Calculated electric and magnetic field strength levels at one meter above ground under the lowest conductors and at the edge of the right-of-way for:
>
> (i) Normal maximum loading.
>
> (ii) Emergency line loading.
>
> (iii) Winter normal conductor rating.
>
> (b) A discussion of the company's consideration of design alternatives with respect to electric and magnetic fields and their strength levels, including alternate conductor configuration and phasing, tower height, corridor location, and right-of-way width.

Another rule for projects addresses socioeconomic and land use impact analyses:

> 2) For electric power transmission facilities, the applicant shall discuss the production of electric and magnetic fields during operation of the preferred and alternate site/route. If more than one conductor configuration is to be used on the proposed facility, information shall be provided for each configuration that constitutes more than ten per cent of the total line length, or more than one mile of the total line length being certificated. Where an alternate structure design is submitted, information shall also be provided on the alternate structure. The discussion shall include:
>
> (a) Calculated electric and magnetic field strength levels at one meter above ground, under the conductors and at the edge of the right-of-way for:
>
> (i) Winter normal conductor rating.
>
> (ii) Emergency line loading.
>
> (iii) Normal maximum loading.
>
> Provide corresponding current flows, conductor ground clearance for normal maximum loading and distance from the centerline to the edge of the right-of-way. Estimates shall be made for minimum conductor height. The applicant shall also provide typical cross-section profiles of the calculated electric and magnetic field strength levels at the normal maximum loading conditions.
>
> (b) References to the current state of knowledge concerning possible health effects of exposure to electric and magnetic field strength levels.
>
> (c) Description of the company's consideration of electric and magnetic field strength levels, both as a general company policy and specifically in the design and siting of the transmission line project including alternate conductor configurations and phasing,

tower height, corridor location, and right-of-way width.
(d) Description of the company's current procedures for addressing public inquiries regarding electric and magnetic field strength levels, including copies of informational materials and company procedures for customer electric and magnetic field strength level readings.

IV. INFORMATION RESOURCES

Without vital U.S. EMF research programs, especially by government agencies, few person-to-person contact points for public information or active outreach programs remain. Also, the number of industry, government, or independent groups that have tracked EMF development has declined. Yet some information is still available on the internet. Some major internet links[8] for EMF information include:

http://www.bioelectromagnetics.com

http://www.cdc.gov/niosh/topics/emf

http://www.emf-data.org

http://www.ebea.org

http://www.epri.com

http://www.dhs.ca.gov/ehib/emf/

http://www.hpa.org.ur/radiation

http://www.iarc.fr

http://www.icnirp.de

http://www.ieee.org

http://www.microwavenews.com

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

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

V. CONCLUSIONS

Research on EMFs has continued around the world. Epidemiological studies of children have produced results and questions similar to those seen before. But, the Draper, Kroll, and Swanson study found increases in acute leukemia risk at lower levels than previous reports (4). A major US study found no breast cancer risk from environmental levels of EMFs, but they may represent stronger genetic and familial factors responsible for breast cancer, in general, and low response rates in the EMF study may be methodological problems. Occupational research is moving forward to examine interactions between EMF exposures and other potentially harmful agents in the workplace. In the laboratory and with modeling analyses, researchers are exploring ways to identify more precise exposure metrics and examining issues that could help explain inter-study differences and inconsistencies. There seems to be an explosion of continued review and interpretation of the literature. Besides formal governmental or industry organizations (discussed herein), reviews come from scientists (often allied to more formal reviews) who are reexamining the literature, especially with respect to methodological issues. An example is a review by Feychting, Ahlbom, and Kheifets that provides a helpful conclusion. The authors stated (44):

> Research on ELF fields has been performed for more than two decades, and the methodology and quality of studies have improved over time. Studies have consistently shown increased risk for childhood leukemia associated with ELF magnetic fields, whereas ELF fields most likely are not a risk factor for breast cancer and cardiovascular disease. There are still inadequate data for other outcomes.

[8]Note that web addresses are subject to change but can usually be reidentified through global searches.

There is momentum, especially in Europe for global adoption of the ICNIRP guidelines, largely to promote "harmonization of standards." While the ICNIRP guidelines are scientifically well-grounded and accepted with respect to high-level effects, the general public may not find them unacceptable because they do not address the possible, albeit unproven, low-level effects. Some have, thus, advocated application of additional precautionary measures. Reviews, assessments, and other summaries have largely continued to identify the need for further research, especially on dose/exposure assessment and biological mechanisms. Lastly, several states have instituted new policy directives for addressing EMFs for construction of new transmission and other electric utility facilities. Connecticut's Siting Council has taken the most proactive stance, by issuing a policy document, *Best Management Practices for the construction of Electric Transmission facilities in Connecticut,* These practices include discussions of advances in transmission facility siting and design that affect public exposure to EMF.

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