REPORT

EMF REPORT

A Review of the Current Scientific Literature on Health Effects of Electric and Magnetic Fields

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EXECUTIVE SUMMARY

Electricity and its resulting electric and magnetic fields (EMF) surround us on a daily basis. While the fact that humans are chronically exposed to varying intensities of EMF from a variety of natural and man-made sources is uniformly accepted, the potential response of these exposures by human and animal cells and physiology – and the possibility of resulting negative health effects or disease – is highly contested. Some researchers question whether the life-enhancing benefits of electricity are worth the possible health risks of EMF exposure. Others are unable to acknowledge any risk based on the equivocal scientific evidence to date. This report summarizes current scientific literature and international regulatory activities regarding the extremely low frequency EMF associated with electricity transmission and use.

Scientists have demonstrated both beneficial and harmful effects of EMF exposure on human, animal, and plant physiology. Beneficial effects include stimulation of bone growth and treatment of inflammation and inflammatory diseases. Other proposed beneficial effects (based on limited studies) in human health include improved cognitive and neuromuscular control in patients with multiple sclerosis, and as a treatment for certain cancers, either alone or in combination with anti-cancer drugs. Research into the health effects of EMF exposure to animals demonstrates no observable negative impacts on growth, hormone levels, or reproductive success. EMF exposure has been proposed as a treatment for a common parasitic infection in broiler chickens. In plant studies, EMF exposure appears to have no prolonged negative effects on plant growth or crop success (rather, research to date indicates a positive effect on these parameters).

Research into harmful effects associated with EMF exposure has been in the form of both epidemiological studies (investigating the incidence of disease in a population, compared with incidence of environmental exposures, such as EMF), and laboratory studies involving animals or cells. Some epidemiological reports suggest EMF exposure is associated with several health issues, including certain cancers, neurological diseases, heart disease, and miscarriage. However, other epidemiological studies are unable to demonstrate an association between EMF exposure and these conditions. At the time of this report, no clear biochemical or biomagnetic mechanism leading to a negative health effect has been universally proposed or supported, although many specific proposed rationales exist. Laboratory research investigating EMF is almost universally unable to demonstrate a link between extremely low frequency EMF exposure and negative human or animal health effects. It is the view of many researchers and reviewing bodies that the lack of supporting laboratory data weakens the plausibility of a causal link between environmental EMF exposure and health effects.

In the early 1990s, the US Congress and the European Union authorized independent reviews of the science concerning EMF, and the reviewers concluded that regulatory recommendations regarding environmental EMF exposure limits were unwarranted. In 2003, the Electric Power Research Institute and the Harvard School of Public Health sponsored a workshop on childhood leukemia and EMF exposure. Participants in the workshop summarized the general inability to observe laboratory effects from EMF exposure as possibly due to the electromagnetic and chemical "noise" of biological systems overwhelming environmental EMF exposure. The workshop participants further concluded that the scientific community may fail to detect EMF effects in bioassay systems because EMF is not the causal exposure in epidemiologic associations of childhood leukemia.

More recently, in 2009 the International Council on Non-ionizing Radiation Protection (ICNIRP) reviewed the most current scientific literature to date, and again concluded that research on proposed health effects is not sufficiently reliable to provide a basis for low-intensity human EMF exposure limits. The ICNIRP has developed acute exposure limits designed to protect against nerve or muscle stimulation that occurs with extremely high-intensity EMF exposure. Although the World Health Organization encourages member states to adopt the ICNIRP guidelines, it has also established guidelines for developing EMF standards for those policy makers seeking more precautionary measures, emphasizing that such policies be adopted only when scientifically-derived risk assessments and exposure limits are not undermined by arbitrary cautionary approaches.

The Oregon Energy Facility Siting Council (EFSC, or the Council) established an Electric and Magnetic Field Committee in 1991 that performed its own review of the science concerning EMF, and concluded that while low-cost prudent avoidance of EMF exposure by the general public was encouraged, it was premature to set health-based limits to EMF from 60 Hz power lines based on the available science at that time. The Committee did recommend continuing to review the science surrounding EMF and potential health issues, and the information in this report has been compiled upon request from the Council and the Oregon Department of Energy (ODOE), to allow these bodies to review the current state of the science on EMF. A discussion of US state and federal level regulatory activities regarding EMF from transmission lines is included in this report, along with a discussion of the factors that confound experiments and epidemiological EMF studies, complicating their interpretation.

Although there has been considerable research on the potential negative health effects of extremely low frequency EMF exposure in the last two decades, the conclusions drawn by US and international reviewing bodies are not significantly different from those drawn by the Council's Electric and Magnetic Field Committee in 1993. Those conclusions are (1) there is a need to continue to monitor the science on EMF, (2) low-cost prudent avoidance measures of public EMF exposure is appropriate, and (3) health-based exposure limits are not appropriate with the scientific data available to date.

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1.0 INTRODUCTION TO ELECTRIC AND MAGNETIC FIELDS

Electric power in Oregon, as in the rest of the United States, is predominantly transmitted in the form of a 60-Hertz (Hz) alternating current carried through electric circuits (Europe generally transmits in a 50-Hz current). The electric charges move back and forth 60 times per second. As the electrons move, they generate two types of distinct fields: electric and magnetic fields. Electric fields reflect the energy in the electrons and in the surrounding area; magnetic fields are generated as a result of the movement of those charges. Electric and magnetic fields are distinct forces at 60 Hz, but because of their mutual occurrence, are often referred to as electromagnetic fields (EMF). The frequency associated with electricity transmission and use generates what are considered extremely low frequency fields (ELF-EMF), compared with the much higher frequencies associated with radio and television waves, ionizing radiation (ultraviolet and X-rays), and cellular telephone signals. The ELF-EMF from electricity are also lower than EMF generated from normal cellular activity within the human body.

Magnetic fields emanate from the Earth itself, generated by electric currents within the planet's core and high above its surface. These forces facilitated the development of modern navigation systems, and are studied today to better understand the geomagnetic activity of the Earth. Geomagnetic Observatories operated by the US Geological Survey – such as the station in Newport, Oregon – monitor and collect data pertaining to naturally-occurring fluctuations in magnetic fields in North America (USGS; see Figure 1).

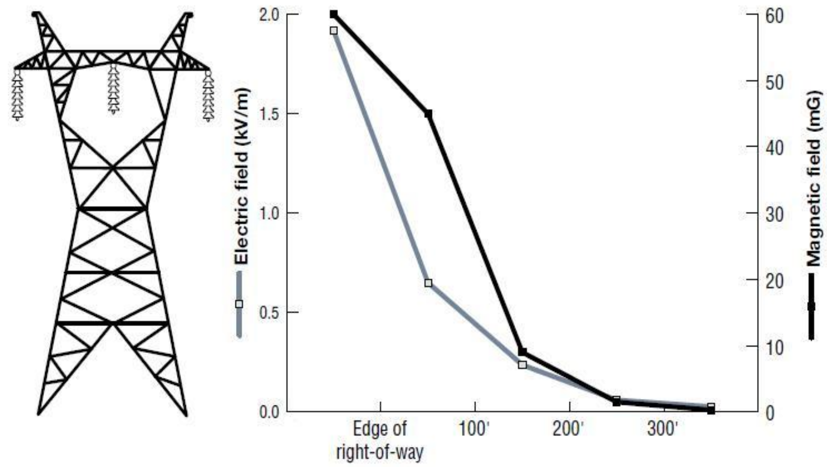
Figure 1. Fluctuating EMF patterns over North America: Schematic diagram of the EMF current pattern above the Earth's surface, driven by daytime atmospheric winds cause by heating from the sun (USGS).

The typical strength of electric fields from energy transmission or use is measured in kiloVolts (kV), while magnetic fields are typically measured in milliGauss (mG) in the United States, or microTesla (µT), which is the preferred unit in Europe (1.0 µT is equal to 10.0 mG). Magnetic field strength (in Tesla, or T) may also be converted to/from electric fields represented by voltage (V), time in seconds (s), and distance in square meters (m^2), as in the following equation:

$$T = \frac{V \cdot s}{m^2}$$

The physics governing EMF dictate their potential for effects on biological systems. Both electric and magnetic fields attenuate as the distance from the source increases (Figure 2). In other words, strength or intensity of EMF is inversely related to distance. However, electric fields are easily deflected by solid objects, whereas magnetic fields may move through such objects. Therefore, potential health effects in humans and animals are more a factor of magnetic field proximity and strength, as opposed to electric fields which are blocked by walls, plants, fur or clothing, and even skin. This report will continue to use the term EMF to maintain consistency with the scientific literature, but note that most studies referenced in this report discussing potential health effects describe the strength of EMF in terms of mG or µT.

Figure 2. Typical attenuation of EMF from a 230-kV transmission line (Western Area Power Administration).



Electricity and EMF literally surround us on a daily basis. Any appliance that uses electricity generates EMF; the amount of energy consumed to power the device and the proximity of the appliance to the user dictates the amount of EMF to which a person is exposed (Table 1). By comparison, the EMF generated by high-voltage (230-500 kV) transmission lines is around 60-90 mG (6-9 µT) directly beneath the power line, 20-30 mG at the edge of the utility's right of way, and within 200 feet drops to less than 4 mG (NIEHS 2002).

Table 1. Typical EMF from home appliances (Lacy-Hulbert et al 1998; NIEHS 2002)

Source	**EMF at 0.5 feet**		**EMF at 2.0 feet**	
	mG	µT	mG	µT
Vacuum Cleaner	300	30	10	1
Hairdryer	300	30	-	-
Microwave Oven	200	20	10	1
Personal Computer	14-100	10	2	-
Copy Machine	90	≤14	7	-
Digital Alarm Clock	4	0.4	-	-

The discussion of potential health effects from EMF exposure was initiated in the 1960s by a report of health issues in Russian electrical utility workers, and ignited in 1979 by an epidemiological report by Wertheimer and Leeper linking EMF and childhood leukemia (Hester 1992). Epidemiology is the study of the rate, or incidence, of a disease in a population, compared with the incidence of an exposure (for example, EMF exposure). Epidemiologists do not conclude causation from their findings, but rather report positive or negative associations between disease rates and exposure rates. Early epidemiological studies raised the question as to whether the theoretical risks of health effects from electricity could be supported by scientific evidence. In the ensuing decades, scientists have reported hundreds of epidemiological and laboratory studies and commentaries seeking to answer that question; the debate continues today.

It has been suggested that because magnetic fields are not perceived by the general public – EMF cannot be felt, seen, or physically sensed – that makes EMF mysterious and potentially threatening. When the scientific term radiation is associated with such exposures, and the exposures have been implicated in cancer, in many eyes that threat becomes fact, producing a culture of fear (Campion 1997). On the reverse side of the argument are those who argue that certain epidemiological evidence cannot be ignored, and that physiological effects from EMF exposures may have as-yet uncharacterized but significant and lasting impacts on the exposed. The causes for many cancers, including childhood leukemia, remain largely unknown to date, fueling the speculative fire of environmental factors and causality.

This report summarizes the current literature regarding EMF and discusses the regulatory implications of the state of the science. The National Institute of Environmental Health Sciences (NIEHS) issued an extensive report in 1999 detailing the state of the science on EMF and their conclusions and recommendations; therefore the focus of this current report will be primarily on studies and guidelines published since that date. This review is of readily available scientific literature, and while not completely comprehensive, attempts to represent the breadth of scope of studies related to EMF exposures and health effects.

2.0 RESEARCH SUMMARY – HUMAN HEALTH

2.1 Studies Suggesting a Link between EMF and Health Effects

The focus of this section is a review of the scientific literature regarding observations or studies of deleterious human health effects following EMF exposure. However, the concept that EMF may have an effect on the human body's tissues has been adapted for medical applications to treat several diseases. Therefore, before addressing reported negative outcomes of EMF exposure, this section will also discuss the reported beneficial effects.

2.1.1 Beneficial Effects

Beneficial effects have been reported in a number of consenting patients intentionally exposed to EMF in a clinical setting. In a report reviewing beneficial effects, Bassett (1993) discusses prevention of bone loss and stimulation of bone growth, to the extent of salvaging limbs scheduled for amputation in over 300,000 patients with chronically ununited broken bones. Other integument-related clinical conditions amenable to pulsed EMF treatment include failed joint fusions, spine fusions, and congenital pseudoarthritis (all FDA-approved), and osteonecrosis of the hip, osteochondritis dissecans (cell death in the knee joint following lost blood supply), osteoporosis, osteogenesis imperfecta, chronic tendinitis, and chronic skin ulcers (not FDA-approved). The success rates associated with the above conditions ranged from 70% to 100% after varying treatment durations (generally 3-12 months). The suggested mechanism of action related to the above conditions include increased mineralization and collagen production, increased osteoblast (bone-producing cell) activity and decreased osteoclast (bone-destroying cell) activity, and angiogenesis (stimulation of vascular development). EMFs of 1.3-3.2 G (0.13-0.32 mT) stimulate cultured osteoclast activity at the lower intensity, and inhibit osteoclast activity at the higher intensity (Chang et al 2003).

EMF has also been proposed as beneficial in the treatment of inflammatory diseases. In one study, a 50-Hz (1.0 mT) field exposure for 24 hours inhibited inflammatory chemokine production in human immune system cells (Di Luzio et al 2001). Angiogenesis, vasodilation, and anti-inflammatory properties of pulsed EMF have been suggested as a mechanism for successful treatment of post-surgical pain, swelling, and edema (Strauch et al 2009). Less clear is the mechanism behind improvements in cognitive function, mood, short term memory, concentration, strength and control of limbs, and bladder control in three multiple sclerosis patients exposed to EMF picoTesla intensities (Sandyk 1994). In that study, selective neurotransmitter synthesis and release were the proposed mechanism of action.

Last, one of the primary points of concern regarding EMF exposure is the potential link to cancer. Ironically, pulsed EMF has been efficacious in destroying human cancer cells selectively over human lymphocytes in culture (Radeva and Berg 2004). Pulsed EMF has also been demonstrated as effective when combined with anticancer drugs. Mouse and human leukemic drug-resistant cells had improved responsiveness to two anti-cancer drugs similar to that of twice the dose of drug alone; mice transplanted with cancer cells and treated with a combination of anti-cancer drugs and pulsed EMF exposure had an increased life span compared to control mice (Pasquinelli et al 1993). These researchers express optimism that EMF will have a significant role in certain cancer treatments as research into a cure for this disease progresses.

In his summary in 1993, Bassett acknowledged that "bioelectromagnetics still lacks concrete explanations for weak [EMF] field effects," but that as different field intensities produce functional "signatures," there are likely windows and thresholds for bio-effects that do not follow classic dose-response patterns when field patterns and "biotargets" are properly matched. The concept that reported laboratory effects following EMF exposure do not follow a traditional clinical dose-response has been perceived by some researchers as negating a causal link between EMF and health effects proposed in certain epidemiological reports (McCann et al 1998, Crasson 2003). However, similar to Bassett's theory regarding windows of exposure and non-traditional dose-response, the concept of "bi-phasic" or "non-monotonic" (resulting in a window of effects dually bordered by doses with low to no effects) dose-response has recently gained recognition in the field of environmental toxicology (Welshons et al 2003).

2.1.2 Deleterious Effects

Research into harmful effects associated with EMF exposure has been in the form of both epidemiological studies and laboratory studies involving animals or cells. As discussed above, epidemiological reports from the 1970s suggested EMF exposure was associated with several health issues, including certain cancers. As also stated above, no clear biochemical or biomagnetic mechanism has been universally proposed or supported, although many specific proposed rationales exist and are discussed below.

2.1.2.1 General Health Concerns

As with any chemical or physical parameter that influences human physiology, it is the degree and duration of exposure that to some extent dictates the body's response. The toxicologist's credo is "the dose makes the poison," a concept promulgated by Paracelsus in the 16th century. But often equal to the nature of the exposure in development of disease is individual response to the exposure. What may cause a disruption in normal cell, tissue, organism, race, or species function may not in another, in part due to the heterogeneity of biological life itself.

Researchers who report anecdotal observations of dermatological or general (any combination of neurological, respiratory, gastrointestinal, eye/vision problems, and heart palpitations) syndrome in some individuals propose a sensitivity or hypersensitivity to ELF-EMF emanating from computer monitors, although the paucity of experimental evidence in this area prohibits a definitive or even suggestive statement of causality (Levallois 2002). Blackman (2006) hypothesized that sensitivity to EMF in chemically-sensitive people may stem from an imprint of ambient EMF exposure in developing organisms, triggering a response later in life.

Limited reports of an association between certain neurodegenerative diseases such as Alzheimer's disease and amyotrophic lateral sclerosis (ALS, or Lou Gehrig's disease) and EMF suggest a weak, but possible, increased risk of Alzheimer's disease from EMF exposure, and an increased risk of ALS from occupational EMF exposures. However, the epidemiological studies from which these risks are calculated are often based on confounding assumptions, and have not been verified by laboratory studies. Likewise, the literature on depression and suicide from EMF exposure is difficult to interpret because the findings in epidemiological studies are not consistent (Ahlbom et al 2001). However, as noted above, EMF may be used as a treatment for neurological disorders that increases a patient's quality of life (Sandyk 1994).

There have also been epidemiological reports suggesting an increased risk for miscarriage associated with EMF, although the conclusions of these studies have been debated within the scientific community. Lee et al (2002) conducted a nested case-control study (a comparative assessment after an exposure has occurred) to assess the relation between retrospective magnetic field measures and miscarriage among over 700 pregnant women in California, and concluded that exposures to higher frequencies (≥23.4 mG, or 2.3 µT) and greater fluctuations in EMF exposure during a 24-hour period was associated with an approximately two times higher risk of miscarriage. However, the time-weighted average of EMF exposure in the women in that study was ≤1.3 mG (0.1 µT), and less statistically linked with miscarriage risk.

A follow-up study by Li et al (2002) examined a population-based prospective cohort study (following two or more groups through time to assess exposure outcomes) among almost 1000 pregnant women, measuring exposure over a 24-hour period at less than ten weeks gestation and then tracking pregnancy outcomes. The researchers in that study concluded that exposure to magnetic fields ≥16 mG (1.6 µT) increased miscarriage risk, and the association was stronger for early miscarriage (less than ten weeks gestation) and women with multiple prior miscarriages or subfertility. However, Li et al (2002) did not observe an association between time-weighted average magnetic field exposure and miscarriage risk, and several of the women with miscarriages were recruited into the study after their miscarriage, resulting in EMF exposure measurements that did not represent levels prior to or at the time of miscarriage.

Possible factors in miscarriage may be maternal response to EMF exposure, or – as postulated by Li et al (2002) – effects on the fetus during a sensitive developmental stage. Lahijani et al (2007) reported higher incidence of neuronal, brain, and eye abnormalities and early death in chick embryos exposed to 1.3-7.3 mT (13-73 G), although these levels are much higher than human exposure from close contact with electrical appliances or power lines. However, the researchers observed deformities in a small percentage of EMF-exposed embryos, irrespective of exposure level. The authors proposed that genetic susceptibility may play an important role in morphological response to EMF. More discussion of confounding variables and magnetic field measurements may be found in section 5.3.

Most recently in a review of EMF exposure and cardiovascular effects, McNamee et al (2009) suggested the heart is an unlikely site for direct electrical stimulation of cardiac muscle tissue due to the orders of magnitude difference between endogenous electrical activity and exogenous EMF. However, the authors suggest small rhythmic disturbances may occur though interaction with the cardiac pacemaker, resulting in measureable effects. For example, in one study of 59 substation workers, those exposed to approximately 1 µT EMF experienced a shorter Q-T interval (alteration in heart rhythm) than workers exposed to smaller (<0.1 µT) or greater (5 µT) magnetic fields; however, the workers in that study and in another study of railway drivers occupationally exposed to EMF did not experience reduced heart rate variability (HRV) – normal variation in the timing of beat to beat contractions, which at reduced levels are indicative of coronary heart disease – or risk of arrhythmia. The McNamee et al (2009) review focuses on the sparse, conflicting, and often irreproducible epidemiological and laboratory studies in the literature regarding heart rate, HRV, blood pressure, or cardiovascular disease.

2.1.2.2 Cancer

The “melatonin hypothesis” to link EMF and cancer was developed in the 1980s. Melatonin is a hormone whose synthesis is inhibited during daylight hours, but stimulated at night (in the dark). Melatonin is an antioxidant that has beneficial effects in tissues throughout the body as it scavenges free radicals. Melatonin has also been reported to inhibit tumor angiogenesis (development of tumor-supplying blood vessels), tumor proliferation, and metastasis (spread of cancer growth to other tissues in the body). These tumor-inhibiting effects have been incorporated in some cancer treatment regimens. The melatonin hypothesis proposes that EMF exposure during nighttime hours inhibits nocturnal melatonin synthesis, thereby reducing the protective capacity of this chemical messenger and increasing the risk for cancer.

Night-time plasma melatonin levels have been reported lower in women with women with malignant breast cancer than women with benign tumors or healthy breast tissue. Experimental evidence suggests that exposure to EMF may lower melatonin levels in some animals under certain exposure conditions, although it is unclear if this effect exists in humans (Stevens and Davis 1996). The authors of that review propose “light at night” in industrialized areas is a more plausible causative factor for certain breast cancers.

A more recent review of the effects of EMF on melatonin levels suggests these effects may stem from neural input changes, the perception of EMF as light by photoreceptors in the eye, and generation of free radicals in tissues by EMF (suggesting competition for melatonin's scavenging utility, rather than interference with its synthesis), although the authors stress the paucity of definitive direct evidence linking cancer and EMF exposure (Ravindra et al 2006).

Pursuant to discovering other mechanisms by which EMF might induce human cancer, researchers have investigated the initiation (the development of cancer-like behavior in cells, usually due to altered genetic activity) and promotion (facilitating growth or proliferation of initiated cells) characteristics of EMF. Environmental factors may induce initiation through genotoxicity – by direct gene damage (mutation), suppressed mutation repair, or stimulated cell growth and/or differentiation (maturation) gene expression. Lai and Singh (2004) reported DNA single and double strand breaks and apoptosis or necrosis (two types of cell death) in the brains of juvenile rats exposed to magnetic fields (60 Hz, 0.01-0.5 mT) for 2, 24, or 48 hours; pretreatment with antioxidants (including melatonin) blocked these effects, suggesting EMF-related free-radical formation. Similar experiments on humans are not possible for a wealth of reasons, but cultured human cells have demonstrated DNA single and double strand breaks with time-dependent and intensity-dependent intermittent (but not continuous) EMF exposure (up to 15 hours at 35 µT to 2 mT; Crumpton and Collins 2004).

Other research suggests EMF may have a role in tumor promotion. Chen et al (2000) reported 10-40 mG (1-4 µT) EMF partially blocked the differentiation of cultured erythroleukemic (undifferentiated, abnormal) cells in a "dose"-dependent manner similar to that of known chemical tumor promoters, resulting in a larger proportion of cultured cells in the undifferentiated, proliferative state. Such cells in the body are characteristic of bone marrow cancers; undifferentiated blood cells are immature, and therefore those responsible for immunity are ineffective against infection. As discussed in a review by Levin (2003), application of EMF has been demonstrated to both increase growth and selectively cause death of tumor tissue, and both induce and inhibit cell differentiation. Such variable responses of normal and cancerous tissue cloud the role EMF may play in promoting tumors.

Environmental factors may also influence carcinogenesis (development of cancer) through mechanisms that are not directly genotoxic, but rather induce stress and associated cellular responses. As discussed above, free radical formation or inhibition of antioxidant activity in the body may be associated with cancer. Binhi (2008) hypothesized that magnetic nanoparticles (produced naturally in some tissues) expose adjacent tissues to magnetic fields – which may be exacerbated by external EMF – and in turn may promote formation of free radicals. The presence of magnetic nanoparticles (intracellular ferritin or exogenous iron oxide) in hematopoietic (blood generation) stem cells, the author further postulates, could constitute a cancer risk factor.

Heat shock proteins play a role in normal cell functions such as proliferation, differentiation, and apoptosis, and increase in amount and activity when the cell is under stress (thermal stress is one example). In one study, human myeloid leukemia (undifferentiated, abnormal) cells responded to 50-Hz EMF (10-140 µT) exposure by producing certain heat shock proteins in a non-monotonic dose-response pattern (low and high intensities produced less effect than middle intensities); the heat shock protein response at 100 µT was similar to heat stress alone, and the combined stressors were additive for some proteins, while failing to produce a response in others (Tokalov and Gutzeit 2004).

Circulating natural killer cells are important non-specific host defense immune system cells, and play a role in inhibiting tumor growth. Gobba et al (2009) reported occupational exposure to EMF in electric utility workers was ten times greater than environmental (all non-work hours) exposures as measured by personal dosimeters. The authors of that study also found a significant negative correlation between natural killer cell activity and 0.2-1.0 µT time-weighted average EMF exposure.

As evidenced by the studies above, a useful tool for examining the effects of EMF on cancer or pre-cancerous cells is a comparison to known chemical carcinogens. These experiments are limited to the animal or cellular model, however, and may be confounded by the milieu of endogenous and exogenous factors that influence carcinogenesis in the human body. Susceptibility to carcinogens may be epidemiologically studied, however, in populations with genetic susceptibility to leukemia. Children with Down syndrome have a 20-fold greater risk for developing acute leukemia, and one group of researchers investigated the link between EMF exposure and leukemia in 166 children with Down syndrome. Spot measurements of EMF (5 minutes at the front door of the child's residence) were recorded with dosimeters and compared with incidence of acute leukemia. In this case-control study, the risk of acute leukemia in Down syndrome children elevated with exposure to ≥6 mG (0.6 µT) EMF, but was not different (or less than) in children exposed to <6 mG (Mejia-Arangure et al 2007).

Kheifets et al (2006a) estimated the attributable fraction of cases of childhood leukemia around the globe based on EMF exposure distributions in various countries, worldwide population levels, and the results of two pooled meta-analyses, and concluded that approximately 1% to 4% of cases might be attributable to EMF exposure (depending on one's view of the strength of the epidemiological evidence). A more detailed discussion of childhood leukemia rates follows in Section 5.2.

2.2 Studies Negating the Link

The studies in the previous section contained evidence or observations for increased risk of health effects often in conjunction with a discussion of supporting, conflicting, or irreproducible data, and universally called for further studies to elucidate the role of EMF – if any – in human disease. In a meta-analysis review of pooled epidemiological studies, Thériault and Chung-Yi Li (1997) found an association between leukemia and magnetic fields originating from high power transmission lines (although the results in the different studies were widely varied and not statistically significant), but cautioned that their assessment may be subject to a publication bias. "Papers reporting negative (no) results may have been rejected or not published, which may have entailed a bias towards finding an association that actually does not exist."

However, studies negating the link between EMF exposure and health effects do exist in the literature. Sahl et al (1993) found no increased incidence of leukemia, lymphoma, or brain cancer in electric utility workers over those in a reference group. A large United Kingdom Childhood Cancer Study (over 4,000 children) published in 1999 studying mean childhood exposures of up to 0.2 µT reported an odds ratio of less than 1.0 (no associated risk) for any childhood cancer (UK Childhood Cancer Study Investigators, 1999). Söderburg et al (2002) studied the incidence rate of childhood leukemia among children who spent time in an incubator following birth versus those who did not, and found no association between magnetic field exposure from infant incubators and childhood leukemia. In another review, the weight of evidence among studies of breast cancer and EMF exposure did not support an increased risk of breast cancer from occupational or residential magnetic field exposure (Feychting and Forssén, 2006).

Laboratory studies have also been reported that weaken the plausibility of a causal link between EMF and health effects. Nafziger et al (1997) examined the response of human hematopoietic (blood precursor) cells in culture after 5 days exposure to 50-Hz EMF with magnetic fields strengths of 10 µT (representing incidental or occupational exposure) and 1 mT (the maximum level of EMF residential exposure recommended at that time). Their investigation failed to produce leukemogenic cell response: proliferation, mitotic (cell division) activity, and cellular components were not different in EMF-exposed cells versus controls.

To investigate the role of EMF in cancer promotion, Shen et al (1997) injected newborn mice with a known chemical carcinogen and subsequently exposed a subgroup of them to high-intensity (50-Hz, 1 mT) EMF. They reported no association between EMF exposure and the incidence of lymphoma (cancer in the lymph system) or leukemia in the mice. Because one criticism of this study was that exposure duration in that study was short (3 hours/day, 6 days/week for 16 weeks), Negishi et al (2008) reproduced the experiment, injecting newborn mice with the chemical carcinogen and exposing them to 50-Hz EMF with increasing levels of intensity (0-350 µT) for 22 hours/day, 7 days/week for 30 weeks. Negishi et al observed no significant differences in malignant lymphoma or leukemia between control and EMF-exposed mice, and concluded that 50 HZ EMF up to 350 µT do not promote these cancers initiated by chemical insult.

Touitou et al (2006) reviewed human epidemiological and animal experimental data to examine the postulated link between EMF exposure and melatonin disruption, and concluded that between the contradictory laboratory results with animal models and the lack of strong evidence from even long-lasting exposures in humans to support the “melatonin hypothesis” (discussed in Section 2.1.2.2 above), “it is unlikely that malignancies or mood disorders reported by people exposed to 50/60-Hz EMF could be related to the disruption of the melatonin levels.”

As mentioned above, McNamee et al (2009) reviewed epidemiological and laboratory studies of EMF and cardiovascular effects, and concluded that the weight of scientific evidence was largely inconclusive, urging the need for further research to clarify the equivocal results reported in the literature to date. With respect to other health effects such as miscarriage, the body of scientific data and observations is also largely ambiguous. Such evidence to date is largely based upon epidemiological observations of association, and these studies report conflicting results with confounding variables that cast doubt on the investigators’ conclusions (see Section 5.3 below). Komakazi and Takano (2007) reported accelerated gastrulation early in frog embryo development with EMF exposure, but when those embryos were observed through the larval (tadpole) stage, no malformations were observed.

The reports discussed thus far have focused on experiments or studies targeting one outcome or physiologically similar outcomes following EMF exposure. General conclusions of experts in the field and reviews of the body of literature in broad context are further discussed in Section 5.1.

3.0 RESEARCH SUMMARY – ANIMALS AND VEGETATION

3.1 Reports Concerning Wildlife and Livestock

Written public comments on a proposed 500-kV transmission line route in eastern Oregon in 2008 revealed a risk perception of the health impacts from EMF not only to humans, but to wildlife and livestock as well. One commenter was concerned that power lines would disrupt livestock productivity, disrupt wildlife that inhabit agricultural lands, and affect bee flight (Price and Price 2008); another was concerned that EMF would have adverse impacts on their animals' health (Voile 2008). While some comments included only a brief reference to potential EMF effects among a plethora of other concerns, others elaborated on their concern. Per one comment, "our first concern is for the health of our grandsons who live near the proposed sight [sic]. You have not proved beyond a doubt [the transmission line] will not affect them in years to come… We are concerned for both the wild and domestic animals that are abundant in this region. They feel and respond to electricity in the air long before humans do. We have personally witnessed many times the animals' sensitivity to electricity in the air and electrical surges. We feel this line would drive the wild animals from their natural habitat" (Rau and Rau 2008).

3.1.1 Wildlife

Many bird species utilize electric power lines or towers for perching, hunting, and nesting, and for this reason are of concern to biologists examining potential behavioral or health effects from EMF. Fernie and Bird (2001) reported an immune response and oxidative stress (measured from alterations in blood biochemistry) in captive kestrels exposed to a 60-Hz current resulting in a 10-kV/m electric field and a 30-µT magnetic field, particularly in the early part of the breeding season. The authors did not observe any externally visible health problems (no changes in food intake or body mass), but postulated that EMF-exposed kestrels with a stressed immune system might be more susceptible to infectious disease, bacteria, viruses, and parasites.

Researchers have also investigated behavioral effects of breeding kestrels exposed to EMF and resulting hatch success or fledgling success. Wild and captive male and female kestrels nesting under high voltage transmission lines or in simulated experimental settings have been reported as more active and alert than control birds during courtship and/or egg incubation (Fernie et al 2000). However, the authors concluded the observed behavioral changes were unlikely to be associated with the observed better fledgling success, nestling growth, or poorer hatching success of the EMF-exposed birds.

In an extensive review of the effects of EMF on avian reproductive biology and physiology, Fernie and Reynolds (2005) discussed the highly variable species-specific and metric-specific (nesting success, behavior, etc.) results of bird EMF exposures. The authors acknowledged that changes in courtship behavior as a result of EMF exposure did not disrupt egg laying or reduce clutch size in scientific reports, but suggest that elevations in activity prior to egg laying may deplete energy reserves at a time when nutrient and energetic demands are high. More active females may have a seriously compromised egg-laying performance in some species. Other reports on reproductive success of ravens, eagles, hawks, eastern bluebirds, and house wrens showed no significant effects of EMF exposure on nesting success, while one study showed tree swallows nesting immediately below power lines experienced declines in fledgling success and fewer fledglings compared with swallows exposed to lower EMF.

There is some evidence that EMF may deter growth, but stimulate other physiological growth and development parameters, resulting in increased fledgling success. Other data suggests birds may perceive EMF as light, resulting in melatonin suppression and subsequent reproductive, metabolic, and immunity effects, in addition to altered migration, circadian rhythm, plumage characteristics, and mating success. These responses are only postulated as potential effects, based on the broad-sweeping role of melatonin in avian biology. The authors of the review discussed the great deal of uncertainty surrounding the findings on the effects of EMF exposure on birds, and noted that birds, like other vertebrates, appear to be diverse in their sensitivities to EMF exposure (Fernie and Reynolds 2005).

As discussed in Section 2.2, the amphibian model has been used to examine potential effects of EMF on early vertebrate development. Komakazi and Takano (2007) reported accelerated gastrulation early in frog embryo development with EMF exposure, but when those embryos were observed through the larval (tadpole) stage, no abnormalities in morphology or behavior were observed.

Based on data suggesting that hearing systems (particularly hair cells in the cochlea, the organ responsible for transforming sound vibrations into nerve impulses) are sensitive to exogenous agents including EMF, Budak et al (2009) examined the effects on the auditory systems of laboratory rabbits to 50-Hz, 5-10 kV/m-electric fields, and 2-4 pT (a relatively strong electric field but very small magnetic field compared with transmission line frequencies). The results of that study revealed no significant effects of ELF-EMF on the hearing sensation of rabbits, as measured by an electrophysiological analysis of otoacoustic emission (nerve signals of perceived sound) recordings.

Last, despite the conjecture on the internet that ELF-EMF disrupts bee physiology (in a range of effects from behavior changes to colony collapse), no studies supporting these hypotheses could be discovered in the scientific literature at the time of this report.

3.1.2 Livestock

Animals are often a significant source of agricultural revenue for farmers. In 2008, Oregon farmers maintained 1.2 million head of cattle and calves, over 220,000 sheep and lambs, over 100,000 horses, 38,000 goats, and 20,000 hogs, representing commodities valued at over $460 million (ODA 2009).

For this reason, animal scientists have investigated the potential effects of EMF exposure to livestock at the same time that epidemiologists and researchers have explored EMF’s role in human health. Mammals share highly conserved biochemical signaling mechanisms and physiologies, and similar endpoints of EMF exposures examined in humans have been discussed in animal science literature.

Lee et al (1993) penned female lambs in enclosures at the edge of a transmission corridor containing several 500-kV and 230-kV, 60-Hz transmission lines, where EMF measured 6-kV/m electric field and 40-mG, or 4-µT, magnetic field. The nearest line was a 500-kV line over the pen. The researchers also penned a control group of lambs over 200 meters away, where “ambient” EMF measured <10 V/m and <0.3 mG. The researchers sampled the lambs’ blood at various intervals over several weeks for melatonin and progesterone levels, and detected no significant differences in day-time or night-time melatonin levels in “line” lambs versus control lambs. Both groups also had the same shift in melatonin production levels as a result of a seasonal change that occurred during the course of the experiment (a normal circadian rhythm response). Growth of both groups of lambs was normal, and progesterone levels indicated no significant difference in age of maturation or number of estrous cycles between groups. Lee et al (1993) concluded “there was no evidence in the current study that chronic exposure to EMF from a 500-kV transmission line affected melatonin secretion or timing of puberty in female lambs.”

Similar experiments were conducted that suggested cortisol levels, weight gain, and wool growth in lambs was not affected by chronic exposure to EMF from a nearby transmission line (Thompson et al 1995). Another group reported that although in previous experiments interleukin-1 (IL-1, an immune system cytokine or chemical messenger) was reduced in lambs penned under a transmission line for 10 months, longer-term (27-month) experiments showed no significant difference in either IL-1 or IL-2 activity in young "line" versus control sheep (Hefeneider et al 2001).

Burchard et al (2006) enclosed pregnant cows in individual pens and exposed them to intermittent 10-kV/m, 30-µT EMF, tracking their blood thyroxine levels (a critical metabolic hormone). The levels were chosen to simulate continuous exposure to EMF from an overhead 735-kV transmission line (the voltage associated with many Hydro-Québec transmission lines). An approximately three-month intermittent EMF exposure did not induce a significant change in thyroxine levels. An approximately one-month (during the course of one bovine estrous cycle) experiment showed an initial 4% increase in thyroxine levels, although levels for both exposed and control cows were not different beginning mid-cycle. The authors concluded that because the variation in thyroxine levels due to EMF was considerably small, and resulted under a "worst-case" exposure scenario, these variations would not represent a health hazard for dairy cows under "normal commercial conditions."

The researchers conducted a similar experiment with another group of pregnant cows exposed to a 30-µT magnetic field, and despite some differences in physical (increased weight gain in exposed cows) and biochemical (decreased prolactin and insulin-like growth factor-1) factors, they concluded that the absence of abnormal clinical signs and the relatively small differences in blood serum levels "make it plausible to preclude any major health hazard" (Burchard et al 2007).

Perhaps the most fascinating of studies reporting effects of EMF on cattle concerns a recent paper that postulates the ELF-EMF from high-voltage power lines disrupts the ability of cattle and deer to align themselves in a normal north-south orientation. Burda et al (2009) reference an observation that resting or grazing cattle and deer tend to align their body axes in the geomagnetic north-south direction. However, they contend that satellite and aerial images show cattle and deer herds grazing near power lines do not predominantly align along the north-south axis, and the "disturbing effect of the ELF-EMFs on body alignment diminished with the distance from conductors." Despite the unknown mechanisms underlying this observation, the authors suggest "these findings constitute evidence for magnetic sensation in large mammals as well as evidence of an overt behavioral reaction to weak ELF-EMFs in vertebrates. The demonstrated reaction to weak ELF-EMFs implies effects at the cellular and molecular levels."

The studies above suggest a range of effects of EMF exposure in livestock from non-existent to relatively small to positive. Another study suggests a beneficial application for ELF-EMF in broiler chicken to fight a common parasitic infection. Coccidiosis in poultry is caused by a protozoan parasite infecting the gastrointestinal system, resulting in intestinal lesions and poor growth performance. Elmusharaf et al (2007) exposed a group of broiler chicks to a 5 to 10-µT magnetic field for 30 minutes per day for 21 days; a control group was raised without EMF exposure during the same period. At day 15, the researchers dosed half of each group of EMF-exposed and non-exposed chicks with the parasite, then monitored weight gain and oocyste shedding in excreta. At the end of the experiment period, a subset of each experiment group was euthanized and examined for intestinal lesions. While uninfected EMF-exposed birds exhibited lower feed intake and weight gain than non-exposed uninfected birds, the EMF-exposed infected birds fared significantly better than non-exposed infected birds. The authors concluded "exposure of the broiler chickens to the EMF antagonized the effects of infection. In the EMF-treated birds, the infection caused no effect on weight gain and feed intake, whereas severity of the intestinal lesions mediated by [the parasites] was less than in the infected controls." The authors recommend that ELF-EMF could serve as an alternative to the anti-coccidial drugs used in poultry production.

3.2 Reports Concerning Agricultural Plants

The paucity of reports concerning EMF on plant physiology prohibits a lengthy or detailed discussion. However, the few reports that are readily available in the scientific literature concerning EMF effects on Oregon agricultural crops suggest that EMF may have beneficial actions on plant development. It must be noted, however, that these experiments were conducted using magnetic fields that are over three orders of magnitude higher than the magnetic field generated by a typical transmission line.

Aksyonov et al (2001) reported data suggesting EMF (50-Hz, 30 mT) either stimulated or inhibited wheat seed sprout timing and growth, depending on the stage of development during which seeds were exposed, by affecting pH and intracellular proteins. The authors conclude that despite these ambivalent responses, on the whole the cell division changes may lead to "suppression, rather than stimulation, of wheat seed germination." EMF (5 mT) also has a stimulatory effect on sugar beet germination, chlorophyll (a plant product necessary for photosynthesis) content, growth of root mass, and sugar content, resulting in crops with higher yields and quality (Rochalska et al 2008). Likewise, the germination rate of tomato seeds is faster in 125 to 250-mT EMF-exposed tomato seeds, and early growth of tomato plants is increased with magnetic field exposure versus non-exposed plants (Martínez et al 2009).

4.0 REGULATORY ENVIRONMENT

4.1 US Federal Government and European Union Activities

In 1994, the European Parliament charged the International Commission on Non-Ionizing Radiation Protection, or ICNIRP (whose members currently include scientists from the United States, Europe, Australia, Japan, and China) with proposing legislative science-based measures limiting public and utility worker exposures to EMF for general health and safety protection. The ICNRP conducted their review and determined that evidence for chronic effects was not strong enough to use as a basis for exposure limits, though the group did suggest exposure limits based on protecting against acute effects (muscular or nervous system perturbations) of high-intensity EMF exposure. Based on these recommendations the Council of the European Union in 1999 recommended restriction of exposure based on a liberal safety factor and reference values of 250/f for electric fields and 5/f for magnetic fields, where f = the frequency of the magnetic field (in kHz). For the typical 50-Hz European high-voltage transmission line, the resulting reference levels were therefore 5,000 V/m and 100 µT (EU Council 1999). The Institute of Electrical and Electronic Engineers (IEEE) established its own acute exposure guidelines of 904 µT for a 60-Hz line, approximately ten times higher than that proposed by the ICNIRP (Kheifets et al 2005).

During this period, the United States initiated its own investigation of the science on EMF and the possible need for protective legislation. In 1992, the US Congress authorized the Electric and Magnetic Fields Research and Public Information Dissemination (EMF-RAPID) Program in the Energy Policy Act, requiring the National Institute of Environmental Health Sciences (NIEHS) and US Department of Energy to characterize EMF sources and potential health effects. In 1999, NIEHS released the summary report, encompassing an extensive scientific and public review process. The findings of the EMF-RAPID Program were that scientific evidence suggesting ELF-EMF exposures posed any health risk were weak at best. Experimental mechanistic and animal toxicology studies failed to demonstrate any consistent pattern of exposure effects, and although there was some epidemiological evidence for a “small, increased risk with increasing [EMF] exposure” for chronic lymphocytic leukemia and childhood leukemia, the authors point out that given the weak magnitude of these increased risks, “some other factor or common source of error could explain these findings” (NIEHS 1999).

In light of the equivocal nature of the epidemiological reports on EMF, the NIEHS EMF-RAPID Program Working Group recommended that ELF-EMF be classified as a “possible human carcinogen,” but did not recommend that ELF-EMF be included in the National Toxicology Program’s periodic Report of Carcinogens. The NIEHS EMF-RAPID Report likewise did not make recommendations for “aggressive regulatory concern” engendering regulatory standards on electrical appliance EMF emissions or numerical exposure limits, but advised that “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 Working Group also recommended that the power industry continue its current practice of siting power lines to reduce exposures, continue to explore ways to reduce the creation of magnetic fields around transmission and distribution lines, and encouraged the development of technologies that would lower the general public’s exposure to EMF.

Since the late 1990s, the federal government of the United States has not taken any further legislative steps toward regulatory standards of EMF emissions or exposure. The National Toxicology Program’s most recent 11th Report on Carcinogens included for the first time non-ionizing radiation sources (X-rays, gamma rays, and neutron radiation) as known human carcinogens, but did not include EMF in either this category or as a reasonably anticipated human carcinogen (NTP 2005). The list of candidate substances for the 12th Report on Carcinogens (under review at the time of this report) does not include EMF.

Over the last decade, several countries (Israel, Italy, Switzerland, The Netherlands) and US States or municipalities have developed precaution-based policy approaches that are on the order of 10 to 100 times lower than those recommended by ICNIRP, although this action has been viewed as arbitrary and inappropriate by one member of the ICNIRP (Kheifets et al 2005, see also Section 4.3). Although the World Health Organization encourages member states to adopt the ICNIRP guidelines, it has also established a Framework for Developing Health-based EMF Standards for those policy makers seeking more precautionary measures, emphasizing that such policies be adopted only when scientifically-derived risk assessments and exposure limits are not undermined by arbitrary cautionary approaches (WHO 2006).

The ICNIRP proposed new draft guidelines (under review at the time of this report) in 2009 for limiting acute exposure to time-varying ELF-EMF. Based on its review of the most current scientific literature to date, the ICNIRP did not find that research on neurobehavioral effects (cognition, sleep, hypersensitivity, or mood), neuroendocrine system effects, or cardiovascular effects was sufficiently reliable to provide a basis for human ELF-EMF exposure limits. The ICNIRP concluded that the evidence for association between ELF-EMF exposure and Alzheimer's disease and ALS was weak, evidence for an association with miscarriage or developmental effects was poor to very weak, and that the evidence for an association with childhood leukemia cannot be supported by the "almost universally negative" animal cancer data (including large-scale lifetime studies) or cell data. For this reason, "it is the view of ICNIRP that the currently existing scientific evidence that ELF magnetic fields is causally associated with childhood leukemia is too weak to form the basis for exposure guidelines" (ICNIRP 2009).

However, in light of acute physiological effects of high-intensity EMF exposure, and taking into account the inherent uncertainty of the available research and imposing safety factors, the ICNIRP proposed the updated reference levels listed in Table 2. The reference level derivation factors have not changed for 50-60 Hz frequencies from the 1999 levels. It should be noted that the draft reference values for general public magnetic field exposure is approximately ten times higher than the EMF generated by high voltage transmission lines.

Table 2. ICNIRP Draft ELF-EMF Reference Exposure Levels (ICNIRP 2009)

	Occupational Exposure			
Power Line Frequency (f)	Electric Field Factor	Reference Level (V/m)	Magnetic Field Factor	Reference Level (µT)
0.05 KHz (EU)	500/f	10,000	25/f	500
0.06 KHz (US)	500/f	8,333	25/f	416.7

	General Public Exposure			
Power Line Frequency (f)	Electric Field Factor	Reference Level (V/m)	Magnetic Field Factor	Reference Level (µT)
0.05 KHz (EU)	250/f	5,000	5/f	100
0.06 KHz (US)	250/f	4,166.70	5/f	83.3

4.2 US State-Level Activities

The State of Oregon includes in its Oregon Administrative Rules (OAR) on Siting Standards for Transmission Lines a limit to the alternating current electric fields generated by transmission lines: 9 kV/m at one meter above the ground surface in areas accessible to the public (OAR 345-024-0090). Magnetic fields generated from transmission lines are not addressed. The State of Florida regulates electric and magnetic fields emanating from high-voltage transmission lines, although the levels are not health-based, but rather based on those from existing lines at the time of the promulgated rule (FAC 62-814).

In 2002, the Minnesota State Interagency Working Group on EMF Issues published a White Paper on EMF Policy and Mitigation Options, based on its review of the literature. The Minnesota Department of Health concluded "that the current body of evidence is insufficient to establish a cause and effect relationship between EMF and adverse health effects. However, as with many other environmental health issues, the possibility of a health risk from EMF cannot be dismissed." As a result, the Working Group recommended a "prudent avoidance approach to mitigating EMF exposures." Measures to that end include applying low-cost engineering methods to new or upgraded lines to reduce EMF, encouraging conservation to promote a reduction in energy consumption (and the need for new generation and distribution facilities), promoting distributed generation facilities to reduce the need for new or upgraded transmission lines, and encouraging utilities to work with consumers to identify EMF sources in the home that may be attenuated. Last, the Working Group recommended continued monitoring of the science on EMF and health effects, and developing public education efforts on ways to reduce individual EMF exposure levels (MSIWG 2002).

The Working Group referenced the Minnesota Environmental Quality Board's restriction of maximum electric fields from transmission lines to 8 kV/m at one meter above ground level. The Working Group also identified several states that imposed numerical standards (establishing magnetic field limits, where restricted, based on those from existing lines at the time of the promulgated rule). Those numerical standards are listed in Table 3.

Table 3. US State EMF Standards (Minnesota State Interagency Working Group on EMF Issues, 2002)

State	Electric Field on ROW	Electric Field, Edge of ROW	Magnetic Field, Edge of ROW	
	kV/m		mG	µT
Florida	8[a] 10[b]	2	150[a] 200-250[b]	15 20-25
Minnesota	8			
Montana	7[c]	1		
New Jersey		3		
New York	11.8 11[b] 7[c]	1.6	200	20
Oregon	9			

[a]For 69 to 230-kV lines

[b]For 500-kV lines

[c]Maximum on roadway crossings

The California EMF Program also performed a risk analysis and reported resulting policy options from power frequency EMF in 2002. Their conclusions from a review of the literature are similar to those from other reviewing bodies, though perhaps slightly more conservative in terms of childhood leukemia risk potential from EMF exposure. The policy options delivered to the Governor's office reviewed sources of

EMF in residences and schools, the costs of moderate to expensive mitigation actions, and the number of deaths at which economists would view measures to be cost beneficial (California EMF Program 2002).

4.3 Regulatory-Based Reviews

Despite the fact that international guideline-setting committees have considered the epidemiologic evidence as not sufficiently strong for guideline development, it is this evidence – along with public pressure, scientific uncertainty, and widespread, chronic, public exposure to EMF – that has driven the development of precautionary-based policy. One review of the "inconsistent patchwork of policies at the national, state, and local levels" asserts that the numbers chosen are arbitrary, "largely the result of misinterpretation of the epidemiologic evidence," and "cannot be justified from the available science" (Kheifets et al 2005).

In a commentary on the perspective of Kheifets et al (2005), Kundi (2006) counters that the ICNIRP guidelines are based on acute biological effects, and do not account for the possibility of chronic effects associated with EMF exposure (as reported in epidemiological studies); therefore the precautionary approach is justified. In Kundi's view, "for many other environmental agents, there is no or only an incomplete mechanistic understanding of the interaction process, but this does not confer upon us a permission to ignore the knowledge we already have."

Compounding the ambiguity of the experimental data and epidemiological reports on EMF is the classical physicist view that thermal noise (activity from increased heat) overshadows any bioelectromagnetic response to ELF-EMF (Bassett 1993), as evidenced by different approaches to EMF standards proposed by the ICNIRP and the IEEE (Roy and Martin 2007).

The precautionary principal is an approach governing bodies may take when scientific data on a public health concern is weak or ambiguous. This approach recommends that actions should be taken to prevent potential harm to the public or a sensitive population, despite the lack of scientific consensus on likelihood, cause, or magnitude of that harm. However, in two experimental studies of the precautionary principle applied to EMF, Wiedemann and Schütz (2005) present results suggesting precautionary measures may have negative effects on public risk perception. When presented with information about "electrosmog," (the milieu of electric and magnetic fields from multiple sources that surround us on a daily basis), participants in one study felt increasingly threatened when policy approaches involved exposure minimization, special protection measures for sensitive areas, or setting precautionary exposure limits, as compared to no precautionary language. Participants in another study felt less confident in public health protection when precautionary measures were discussed in the information provided, as opposed to when precautionary measure language was not included. The authors contend that by considering precautionary measures, political decision makers hope to contend with public fears about EMF, but may ultimately "trigger concerns, amplify EMF-related risk perceptions, and lower trust in public health protection."

Analogous to the balancing act between information and alarm in public health policy regarding EMF is the situation regarding the H1N1 (or swine flu) epidemic faced by health officials at the time of this report. In a story in *The Oregonian* newspaper, the problem with the precautionary approach discussed above is summarized succinctly. "Oversell the danger, and health officials run the risk of causing public freakout – as well as accusations of crying "wolf!" Undersell the danger, and [health officials] run the risk of being blamed for recklessness, complacency and a policy botch" (Colburn 2009).

5.0 DISCUSSION

5.1 Summary Reviews

While the fact that humans are chronically exposed to varying intensities of magnetic fields from a variety of natural and anthropogenic sources is uniformly accepted, the potential responses of these exposures by human cells and physiology – and the possibility of resulting health effects or disease – is highly contested. The latter subject has been visited repeatedly in the science and the literature, resulting in numerous reviews of the state of the science on EMF. A few extensive reviews are discussed here.

In a review of biological responses to EMF at the time the European Union and United States were developing their policy options, Lacy-Hulbert et al (1998) concluded that the epidemiological studies reviewed at the time did not provide a clear answer to whether EMF exposure could be associated with cancer, primarily due to the inconsistencies in EMF exposure parameter analyses and poor or biased sample numbers. Furthermore, "the complexity of genetic and epigenetic factors that promote cancers… mitigates against clear epidemiological correlations," and data available at the time did not provide any consistent evidence that ELF-EMF affected cellular systems via free radical mechanisms. The authors noted that until a single, unequivocal ELF-EMF-induced response could be consistently reproducible in independent laboratories, "the topic of biological responses to ELF-EMFs will continue to be regarded with great skepticism by the scientific community at large." This is still the predominant view today.

The ICNIRP's Standing Committee on Epidemiology reviewed the epidemiological literature in 2001 and concluded that although many earlier methods were flawed or biased, the quality of studies on the topic of EMF and health effects had improved over time. Among all the reviewed outcomes evaluated in epidemiologic studies of EMF at the time of their report, the strongest association between EMF and a health effect was postnatal exposures above 0.4 µT and childhood leukemia in a large pooled analysis, although the findings of that study were based on 0.8% of the children having been exposed to EMF above 0.4 µT. The committee suggested the associated relative risk "is unlikely due to chance but may be, in part, due to bias. This is difficult to interpret in the absence of a known mechanism or reproducible experimental support" (Ahlbom et al 2001).

In a summary of the findings of a workshop on childhood leukemia and EMF exposure sponsored by the Electric Power Research Institute and the Harvard School of Public Health, Brain et al (2003) discussed the widely-accepted factors predisposing children to the development of leukemia, as well as suspected risk factors. Known risk factors include underlying genetic disorders (such as Down syndrome), family history, ionizing radiation, and chemotherapeutic agents (treatment for one type of cancer may lead to another). Suspected risk factors include radon exposure from groundwater or indoor sources, prenatal radiation exposure, maternal or child medications, pesticides, second-hand cigarette smoke, factors associated with maternal pregnancy history (maternal age and birth weight, among others), and postnatal infections. The workshop reviewed the literature available on cancers and EMF exposure, and concluded that although epidemiologic associations between EMF and childhood leukemia have made EMF a suspected risk factor, the "overwhelmingly negative" animal data on the effects of EMF exposure negate EMF as a risk factor. The participants in the workshop sum up the general inability to observe laboratory effects from EMF exposure as possibly due to the electromagnetic and chemical "noise" of biological systems overwhelming the EMF "dose," and conclude that the scientific community "may fail to detect EMF effects in bioassay systems because EMFs themselves are not the causal exposure in the epidemiologic associations."

5.2 Childhood Leukemia Rates

The US Agency for Toxic Substances and Disease Registry (ATSDR, a public health agency of the US Department of Health and Human Services) performed a review of EMF literature as part of its public health assessment for a power plant in Texas in 1999. The ATSDR was unable to draw firm conclusions regarding potential health risks associated from EMF exposure based on the scientific literature at that time, citing the “inconsistent and even contradictory results” of epidemiological studies.

Their assessment also cited a 1995 Texas Department of Health report that plotted US power consumption trends together with cancer mortality trends in US children, noting that while the age-adjusted leukemia and CNS/brain cancer mortality rates among children have shown a 3-fold decrease since 1995, the US per-capita power consumption rate increased 4-fold over the same period. In the ATSDR’s view, “while this type of analysis cannot disprove an association between EMF exposure and cancer, it would tend to indicate that if such an association does exist, the effect must be relatively minor.” They concluded “because of numerous inconsistencies, methodological deficiencies, and contradictory findings, current evidence is insufficient for establishing a cause-and-effect relationship between EMF exposure and adverse health effects from which to quantify the risk (if any) which may result from exposure to EMF” (ATSDR 1999). Kheifets et al (2006b) were likewise unable to regard temporal trends in electricity consumption rates as meaningful evidence either for or against a causal link to childhood leukemia rates.

As previously mentioned, Kheifets et al (2006a) also estimated the mean attributable fraction of cases of childhood leukemia around the globe from EMF exposure as approximately 1% to 4% of cases in most countries (while emphasizing their doubt of the accuracy of epidemiological conclusions upon which their estimations were based). Furthermore, “for small countries with low exposure, the number of attributable cases is less than one extra case per year.” In a comparison of reviews on the scientific literature compiled by the International Agency for Research on Cancer and California’s Department of Health Services EMF, O’Carroll and Henshaw (2008) concluded that owing to the rarity of childhood leukemia, the risk (if any) associated with EMF exposure is negligible, both in terms of mortalities and impacts to society. Leukemia incidence and mortality rates in Oregon in 2005 for persons less than 20 years of age were 31 per 100,000 and 7 per 100,000, respectively (Oregon State Cancer Registry 2005).

5.3 Confounding Factors

Two repetitive themes discovered during the course of this literature review were the equivocal conclusions drawn from epidemiological and experimental reports, and the need for more – and better – data on health effects, if any, from EMF exposures.

One reason for the disagreement among epidemiological studies on EMF and cancer rates is an inconsistent approach to assess exposure. Some reports measured EMF at one time point in one location or a few locations in the home, others used personal dosimeters to measure exposure over a period of time, and then examined peak exposures, time-weighted averages, or a combination of exposures, and some inferred exposure based on residential distance from a power line (see also Section 2.1.2.2 above).

In an attempt to eliminate the errors inherent in the different approaches, Bowman (2000) at the National Institute for Occupational Health and Safety analyzed childhood leukemia rates of an EMF-leukemia study in Los Angeles County against a Geographic Information System (GIS) model that predicted the magnetic fields from residential wiring. The GIS procedure incorporated 24-hr measurements of magnetic fields in each child’s bedroom in the home where the subjects had lived since conception. The author admitted a potential source of selection bias in the Los Angeles County study, but nonetheless concluded that despite the result that measured fields showed no association with childhood leukemia, the risks were significant and increased with the highest GIS-predicted magnetic fields. In the author's view, "The GIS wire configuration model appears to assess the leukemia risks from a child's long-term residential magnetic field exposures better than the 24-hr measurements," and that the GIS exposure model would be an important tool in assessing cancer risks associated with EMF exposure in future studies (Bowman 2000).

Other confounding factors in the epidemiological evidence stems from the nature of epidemiology itself: many results obtained in these types of studies are limited by continued participant enrollment and the honesty of the participant's responses to questionnaires. Although many confounding factors, such as age, gender, race, and to some extent related behavioral or health factors, may be adjusted for in epidemiological studies, the degree of sample bias may seriously inhibit confidence in conclusions or a proposed association between a disease and an environmental factor.

These types of confounding factors or biases have been discussed throughout this report when noted in the literature reports. In the paper on risk of miscarriage mentioned in Section 2.1.2.1, Lee et al (2002) reported an approximately two times higher risk of miscarriage in women exposed to 2.3-µT EMF, although when the time-weighted average over a 24-hour period was analyzed, the risk was not higher, and measurements at 30 weeks did not correlate to measurements earlier in gestation. Even more questionable are the conclusions by Li et al (2002), who measured magnetic field exposure over a 24-hour period in women at approximately 10 weeks gestation, then tracked the outcomes of those pregnancies. Here again, the authors could not conclude an association between average magnetic field level and miscarriage risk, however they do suggest an association between maximum exposure levels (approximately 1.6 µT) and miscarriage risk. The authors concede the possible confounding variable that several of the women with miscarriages were recruited into the study after their miscarriage, resulting in EMF exposure measurements that did not represent levels prior to or at the time of miscarriage. What the authors do not discuss in a satisfactory manner is the plethora of other risk factors reported by women in their study exposed to the "threshold" magnetic field of 1.6 µT associated with miscarriage risk. Women in the suggested higher risk group from EMF exposure also had higher rates of the following risk factors during pregnancy: smoking (or living with a smoker), coffee ingestion, alcohol and drug use, fever incidence, performing strenuous exercise or heavy lifting, solvent use, and Jacuzzi tub use (Li et al 2002).

One last confounding factor that deserves noting is the multiple frequencies of EMFs to which humans are exposed on a daily basis from a variety of sources. Any electrical device or conductor emits EMF in some frequency, and therefore "control" group participants in certain studies are not un-exposed, but rather less exposed or unintentionally exposed. One type of EMF to which people are commonly exposed is the high frequency (radio wave) EMF emitted from mobile telephones. Unlike transmission lines, which are constructed within a right-of-way designed to minimize human EMF exposure, mobile phones are devices held to the head or in close proximity to the body. Although a thorough review of high-frequency EMF from mobile phones is outside the scope of this report, some limited evidence suggests these fields may damage the blood-brain barrier and brain cells (Salford et al 2003) and enhance cortical excitability or activity (Valentini et al 2007). However, a review of the epidemiology of brain tumors by Connelly and Malkin (2007) concluded that although several epidemiological reports proposed associations of radio waves with brain tumors, "none possessed the statistical significance to confidently ascribe causation." The US Centers for Disease Control and Prevention reports that weight of evidence from scientific research does not indicate a significant association between mobile phone use and health effects (CDC 2005).

5.4 Next Steps

The Oregon EFSC established an Electric and Magnetic Field Committee in 1991 to monitor information developed on electric and magnetic fields and report their findings to the Council. The committee – representing members from utilities, manufacturers, the public, and state agencies – presented its findings to the Council, which in turn endorsed the committee's report, submitting it to the Oregon Legislature for review. The report concluded with three recommendations, based on the state of the science and regulatory activities in 1993:

1) The EMF Committee should continue to monitor the EMF issue and report to the Council;

2) The EMF Committee encourages exploration of low-cost ways to reduce or manage EMF exposure during this time of uncertainty; and

3) The EMF Committee believes it is premature to set "health based" limits for exposure to low levels of 60 Hertz EMF at this time.

The "low-cost ways to reduce or manage EMF" language became the "prudent avoidance" approach which EFSC has endorsed for responding to public health/safety issues arising from magnetic field exposure (as summarized in the ODOE's Final Order on the Hermiston Power Project, dated March 25, 1996).

The information in this report is provided to the Council so that it may consider the state of the science and other current state, federal, and international regulatory positions regarding transmission facility siting and policy recommendations. As stated in the introduction to this report, this review is not completely comprehensive, but rather attempts to represent the breadth of scope of studies related to EMF exposures and health effects. For comprehensive analyses, the Council or its Electric and Magnetic Field Committee may wish to review the EMF-RAPID program's summary report (NIEHS 1999) or the ICNIRP's review of the literature (Ahlbom 2001). The ICNIRP's current summary of the literature and resulting exposure recommendations are available in draft form at http://www.icnirp.org.

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