GRAND COULEE– BELL 500-kV TRANSMISSION LINE PROJECT

APPENDIX B-2:

ASSESSMENT OF RESEARCH REGARDING EMF AND HEALTH AND ENVIRONMENTAL EFFECTS

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1.0 Introduction

Over the last 20 years, research has been conducted in the United States and around the world to examine whether exposures to electric and magnetic fields (EMF) at 50/60 Hertz (Hz) have health or environmental effects. EMF are produced by both natural and man-made sources that surround us in our daily lives. They are found throughout nature and in our own bodies, and the earth itself produces a static (0 Hz) magnetic field—it is this field that is used for compass navigation.

By contrast, electricity provided to homes and offices produces EMF that change direction and intensity 60 times, or cycles, per second—a frequency of 60 Hz. Fields at this frequency differ significantly from fields at the higher frequencies characteristic of radio and television signals, microwaves from ovens, cellular phones, and radar (which can have frequencies up to billions of Hz). Man-made EMF are found wherever electricity is generated, delivered, or used. Power lines, wiring in homes, workplace equipment, electrical appliances, and motors produce EMF.

One of the most important characteristics of electric and magnetic fields is that their strength diminishes as a person moves away from the source. This effect is similar to the diminishment of heat from a candle or campfire as a person walks away. However, electric fields and magnetic fields have different characteristics. For instance, ordinary objects do not block magnetic fields, but special materials and techniques can provide shielding. In contrast, such objects, especially those that can conduct electricity, can reduce the electric fields. For example, a typical house may block up to 90% of the electric field from outside sources. Because of this characteristic, exposure to electric fields is more difficult to calculate than exposure to magnetic fields. Magnetic fields have been more widely studied in the last 20 years than electric fields, in part because structures and vegetation reduce indoor electric-field exposures.

Among the large number of studies conducted are a number of epidemiology studies that suggested a link with childhood leukemia for some types of exposures, as well as a number of other epidemiology studies that did not. The research also included lifetime animal studies, which showed no evidence of adverse health effects. Comprehensive reviews of the research conducted by governmental and scientific agencies in the U.S. and in the United Kingdom (UK) have examined the research, and have found no basis for imposing restrictions on exposures (NIEHS, 1999; IEE, 2000; IARC, 2002).

The Bonneville Power Administration (BPA) asked Exponent to update BPA on research on EMF and health and environmental effects in relation to exposures that might occur near the proposed Grand Coulee – Bell Transmission Line Project. This update concentrates on recent major research studies to explain how they contribute to the assessment of effects of EMF on health (Section 2). The focus is on both epidemiologic and laboratory research, because these research approaches provide different and complementary information for determining whether an environmental exposure could affect human health. Section 3, Ecological Research, reviews studies of potential effects of EMF on plants and animals in the natural environment. This update includes those studies of effects from residential or environmental exposures to EMF that became available through May 2002.

2.0 Health

2.1 The NIEHS Report and Research Program

In 1998, the National Institute of Environmental Health Sciences (NIEHS) completed a comprehensive review of the scientific research on health effects of EMF. The NIEHS had been managing a research program that Congress funded in 1992 in response to questions regarding exposure to EMF from power sources. The program was known as the RAPID Program (Research and Public Information Dissemination Program). The NIEHS convened a panel of scientists (the "Working Group") to review and evaluate the RAPID Program research and other research. Their report, *Assessment of Health Effects from Exposure to Power-line Frequency Electric and Magnetic Fields,* was completed in July 1998 (NIEHS, 1998).

The director of the NIEHS prepared a health-risk assessment of EMF and submitted his report to Congress in June 1999 (NIEHS, 1999). Experts at NIEHS, who had considered a previous Working Group report, reports from four technical workshops, and research that became available after June 1998, concluded as follows:

> The scientific evidence suggesting that ELF-EMF [extremely low frequency-electric and magnetic field] exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults. . . . In contrast, the mechanistic studies and animal toxicology literature fail to demonstrate any consistent pattern. . . . No indication of increased leukemias in experimental animals has been observed. . . . The lack of consistent, positive findings in animal or mechanistic studies weakens the belief that this association is actually due to ELF-EMF, but it cannot completely discount the epidemiology findings. . . . The NIEHS does not believe that other cancers or other non-cancer health outcomes provide sufficient evidence of a risk to currently warrant concern (NIEHS, 1999: 9-10).

Although the results of the RAPID research are described in some detail in the 1998 report, many of the studies had not been published in the peer-reviewed literature. Recognizing the need to have these results reviewed and considered for publication, the NIEHS arranged for this research to be published in a peer reviewed special edition of the journal *Radiation Research* (Radiation Research, 153[5], 2000).[1]

2.2 Research Related to Cancer

This update includes studies of residential or occupational exposures to EMF and leukemia that became available through May 2002, including several epidemiology studies of childhood cancer and meta-analyses. The California Department of Health Services (CDHS) conducted a workshop in 1999 to discuss epidemiologic research on EMF and health. The reports presented at this workshop were published in January 2001 as a supplement to the journal, *Bioelectromagnetics*. Many of the papers were technical discussions of methodology issues in epidemiologic studies of EMF, including discussions of how to better understand the conflicting results reported in previous studies (Neutra and Del Pizzo, 2001). For example, one study evaluates the extent to which systematic errors (known in epidemiology as *selection bias* or *information bias*) occurred in EMF studies, and, if those errors occurred, whether the effect on results could be evaluated (Wartenberg, 2001a). Other researchers discuss epidemiologic approaches to study how possible confounding factors, such as the age and type of home and traffic

[1] See, for instance, the articles cited in the **List of References** under first author Balcer-Kubiczek, Boorman, Loberg, or Ryan.

density, might affect the interpretation of studies of EMF and childhood cancer (Langholz, 2001; Reynolds et al., 2001).

For this update, we reviewed epidemiology and laboratory studies of cancer and reproduction. Several of the studies are "meta-analyses," an approach that incorporates statistical methods to analyze differences among studies and aggregate the results of smaller studies. The sections below include a review of meta-analyses of the studies of childhood leukemia, and a meta-analysis of studies of breast cancer in adults (Erren, 2001).

2.2.1 Epidemiology Studies of Children

The question of the relationship between power lines and childhood cancer has been based on the assumption that the relevant exposure associated with power lines is the magnetic field, rather than the electric field. This assumption rests on the fact that electric fields are shielded from the interior of homes (where people spend the vast majority of their time) by walls and vegetation, while magnetic fields are not. The magnetic field in the vicinity of a power line results from the flow of current; higher currents result in higher levels of magnetic fields.

Epidemiologic studies report results in the form of statistical associations. The term "statistical association" is used to describe the tendency of two things to be linked or to vary in the same way, such as level of exposure and occurrence of disease. However, statistical associations are not automatically an indication of cause and effect, because the interpretation of numerical information depends on the context, including (for example) the nature of what is being studied, the source of the data, how the data were collected, and the size of the study. The larger studies and more powerful studies of EMF have not reported convincing statistical associations between power lines and childhood leukemia (e.g., Linet et al., 1997; McBride et al., 1999; UKCCS, 1999). Despite the larger sample size, these studies usually had a limited number of cases exposed over 2 or 3 milligauss (mG).

Epidemiology Studies

The following discussion briefly describes major studies.

- A study from Germany included 514 children with leukemia and 1,301 control children (Schuz et al., 2001). Measurements of magnetic-field intensity (50 Hz) were taken for 24 hours in each child's bedroom. The results were calculated separately for daytime or nighttime levels in the bedroom, rather than for a child's overall 24-hour exposure. The authors report an association with leukemia for mean daytime magnetic-field exposures that might have been due to chance. They reported an association between mean nighttime magnetic-field levels and leukemia for the highest exposed group (4 mG or higher; 9 cases). The assessment of exposure by mean field levels in the bedroom did not link magnetic-field levels to any specific source. The authors note in their conclusions that " . . . fewer than one-third of all stronger magnetic fields were caused by high-voltage powerlines . . . . " (Schuz et al., 2001:734).

  Several aspects of the study detract from the validity of the results: the estimate included a broad margin of error because only a small number of cases were exposed at the higher levels, and many eligible cases and controls did not participate. If the cases and controls were not sampled from similar populations, differences in their exposures could be biased. Another concern is that these magnetic-field measurements were taken in 1997, long after the relevant exposure period for cases diagnosed in 1990-1994. Magnetic-field levels might have changed over time, as electricity usage changed.

- A study from British Columbia, Canada, included 462 children who had been diagnosed with leukemia and an equal number of children without leukemia, for comparison (McBride et al., 1999). Magnetic-field exposure was assessed for each of the children in several ways: personal monitors were worn in a backpack for 48 hours, a monitor took measurements in the bedroom for

24 hours, the wiring outside the house was rated by potential exposure level (wire codes), and measurements were taken around the outside perimeter of the homes. (Wire codes are a method of estimating relative exposure intensity based on the configuration of the power lines.) Regardless of the method used to estimate magnetic-field exposure, the magnetic-field exposure of children who had leukemia was not greater than that of the children in the comparison group.

- A study conducted in Ontario, Canada reported on the magnetic-field exposure of a smaller group of children than that in other recent studies (Green et al., 1999a). No increased risk estimates were found with the average magnetic fields in the bedroom or the interior, or with any of the three methods of estimating exposure from wire-configuration codes. A still smaller group of 88 children with leukemia and children who served as controls wore personal monitors to measure magnetic fields (Green et al., 1999b). Associations with magnetic fields were reported in some of the analyses, but most of the risk estimates had a broad margin of error, and major methodological problems in the study preclude any clear interpretation of the findings.
- The United Kingdom Childhood Cancer Study, the largest study to date, included a total of 1073 childhood leukemia cases (UKCCS, 1999). Exposure was assessed by spot measurements in the home (bedroom and family room) and school, and summarized by averaging these over time. No evidence was found to support the idea of an increased risk of leukemia from exposures to magnetic fields inside or outside of the home.
- The UKCCS investigators had obtained magnetic-field measurements on only a portion of the childhood cancer cases in their study (UKCCS, 1999). To obtain additional information, they used a method to assess exposure to magnetic fields without entering homes; they were thus able to analyze 1331 child leukemia cases (UKCCS, 2000). For these children, they measured distances to power lines and substations. This information was used to calculate the magnetic field from these external field sources, based on power-line characteristics related to production of magnetic fields. The results of the second UKCCS study showed no evidence for an association with leukemia for magnetic fields calculated to be between 1 mG and 2 mG, 2 mG and 4 mG, or 4 mG or greater at the residence, in contrast to the weak association reported for measured fields of 4 mG or greater in the first report (UKCCS, 1999).

Researchers have proposed that the associations that are sometimes reported between childhood leukemia and power lines might be due to other factors that can confound the analysis (other risk factors for disease that may distort the analysis). One example is heavy traffic, which may occur near power lines and can increase the levels of potentially carcinogenic chemicals in the area. Earlier studies had reported associations between traffic density and childhood cancer (Savitz et al., 1988). If power lines were more common in areas that had higher traffic density, then the increased air pollution might explain an association between power lines and childhood cancer. However, more recent studies do not support this possibility. Reynolds et al. (2001) found no evidence of an association with traffic density in a study of 90 cases of childhood leukemia. In a larger study that included 986 cases of childhood leukemia, no association was found with high traffic-density exposure during pregnancy or childhood (Raaschou-Nielsen et al., 2001).

Meta-analyses of Studies of Leukemia

Recently, researchers re-analyzed the data from previous epidemiology studies of magnetic fields and childhood leukemia (Ahlbom et al., 2000; Greenland et al., 2000). The researchers pooled the data on individuals from each of the studies, in effect creating a study with a larger number of subjects and therefore with greater statistical power than any single study. A pooled analysis is preferable to other types of meta-analyses in which the results from several studies are combined from grouped data obtained from the published studies. These analyses focused on studies that assessed exposure to magnetic fields using 24-hour measurements or calculations based on the characteristics of the power lines and current

load. Both Ahlbom et al. and Greenland et al. used exposure categories of <1 mG (<0.1 microtesla [μT]) as a reference category. The statistical results of these analyses can be summarized as follows:

- The pooled analyses provided no indication that wire codes are more strongly associated with leukemia than measured fields.
- Pooling these data corroborates an absence of an association between childhood leukemia and magnetic fields for exposures below 3 mG (0.3 μT).
- Pooling these data results in a statistical association with leukemia for exposures greater than 3-4 mG (0.3 or 0.4 μT).

The authors are appropriately cautious in the interpretation of their analyses, and they identify the limitations in their evaluation of the original studies. Limitations include sparse data (few cases) to adequately characterize a relationship between magnetic fields and leukemia, uncertainties related to pooling different magnetic-field measures without evidence that all of the measures are comparable, and the incomplete and limited data on important confounders such as housing type and traffic density. Magnetic fields above 3 mG (0.3 μT) in residences are estimated to be rather rare, about 3% in the U.S. (Zaffanella, 1993).

A meta-analysis of the data from epidemiologic studies of childhood leukemia studies was presented at the California Workshop and recently published (Wartenberg, 2001b). This meta-analysis did not have the advantage of obtaining and pooling the data on all of the individuals in the studies, unlike those published before it (Ahlbom et al., 2000; Greenland et al., 2000). Instead of using individual data, Wartenberg (2001b) used an approach that extracted the published results, reported as grouped data from several published studies. He used 19 studies overall, after excluding 7 studies that had insufficient data on individuals or deficiencies in the exposure assessment data. He reported a weak association for a) "proximity to electrical facilities" based on wire codes or distance, and b) magnetic-field level over 2 mG, based on either calculations from wiring characteristics or on spot magnetic-field measurements. The results show more cases than controls exposed to measured or calculated fields above 2 mG. The author concludes that the analysis supports an association, although the size of the effect is small to moderate, but also notes "limitations due to design, confounding, and other biases may suggest alternative interpretations" (Wartenberg, 2001b:S-100).

The results of this meta-analysis are not directly comparable to previous ones regarding fields of 3 or 4 mG because the analysis was not based on individual data. The comparison of grouped data used different exposure cut points for the analysis and different criteria for the comparison group. None of these three analyses (Ahlbom et al., 2000; Greenland et al., 2000; Wartenberg, 2001b) included the results of the latest UK analysis (UKCCS, 2000) of 1331 child leukemia cases based on calculated fields, which found no association between EMF and childhood leukemia or other cancers, regardless of the exposure level.

2.2.2 Epidemiology Studies of Adults

Studies of adults with certain types of cancer, such as brain cancer, breast cancer, or leukemia, have reported associations with exposure to magnetic fields at residences, but results have not been consistent across studies. Contradictory results among studies argue against a conclusion that the association reflects a cause-and-effect relationship. In their assessments of risk, scientists give most weight to studies that include more people, obtain more detailed and individual exposure assessments, and/or include people who have higher exposures.

Brain Cancer

A study of 492 adult cases of brain cancer in California included measurements of magnetic fields taken in the home and at the front door, and considered the types of power-line wiring (Wrensch et al., 1999).

The authors report no evidence of increased risk with higher exposures, no association with type of power line, and no link with levels measured at the front door.

Breast Cancer

A number of recent studies of breast cancer focused on electric blankets as a source of high exposure. Electric blankets are assumed to be one of the strongest sources of EMF exposure in the home. Three studies of electric-blanket use found no evidence that long-term use increased the risk of breast cancer. Women who developed breast cancer reported no difference in total use of electric blankets, use in recent years, or use many years in the past:

- Gammon et al. (1998) reported that, even for those who kept the blanket on most of the time, no increase in risk was found for those who had longer duration of use (measured in months).
- A study of 608 breast cancer cases found no evidence of increased use of electric blankets or other home appliances in cases compared to controls, and no indication of increasing risk with a longer time of use (Zheng et al., 2000).
- In a cohort of over 120,000 female nurses, data were obtained on known risk factors for breast cancer as well as electric-blanket use (Laden et al., 2000). For a large subset of this group, the questions about exposure were asked before the disease occurred, a step taken to eliminate bias in recalling exposure. No associations with electric-blanket use were found.

Erren (2001) reported the results of a meta-analysis of the studies of breast cancer, in which the results of 24 different studies in women were statistically aggregated. When the results of all 24 studies, including studies of workplace exposures, were pooled, the estimate indicated an association between EMF and a small excess breast cancer risk. The pooled results for exposure to EMF in the vicinity of *electrical facilities such as power lines* did not show an association with breast cancer, nor did the results for exposure to EMF from appliance use. However, the meta-analysis also showed a lack of consistency among the results of the individual studies, a broad variation in the designs, and a wide range of methods used to assess exposure. No adjustments were made to the data to give increased weight to studies based on more comprehensive exposure assessments. The author also noted that the weak statistical association might be an artifact (a result of chance or unforeseen error) rather than an indication of a cause-and-effect relationship (Erren, 2001).

2.2.3 Laboratory Studies of EMF

Laboratory studies complement epidemiologic studies of people because the effects of heredity, diet, and other health-related exposures of animals can be better controlled or eliminated. The assessment of EMF and health, as for any other exposure, includes chronic, long-term studies in animals (*in vivo* studies) and studies of changes in genes or other cellular processes observed in isolated cells and tissues in the laboratory (*in vitro*).

Although the results of the RAPID Program were described in some detail in the NIEHS reports (NIEHS, 1998), many of the studies had not been published in the peer-reviewed literature. The RAPID research program included studies of four biological effects, each of which had previously been observed in only one laboratory. These effects are as follows: effects on gene expression, increased intracellular calcium in a human cell line, proliferation of cell colonies on agar, and increased activity of the enzyme ornithine decarboylase (ODC). Some scientists have suggested that these biological responses are signs of possible adverse health effects of EMF. It is standard scientific procedure to attempt to replicate results in other laboratories, because artifacts and investigator error can occur in scientific investigations. Replications, often using more experiments or more rigorous protocols, help to ensure objectivity and validity. Attempts at replication can substantiate and strengthen an observation, or they may discover the underlying reason for the observed response.

Studies in the RAPID program reported no consistent biological effects of EMF exposure on gene expression, intracellular calcium concentration, growth of cell colonies on agar, or ODC activity (Boorman et al., 2000b). For example, Balcer-Kubiczek et al. (2000) and Loberg et al. (2000) studied the expression of hundreds of cancer-related genes in human mammary or leukemia cell lines. They found no increase in gene expression with increased intensity of magnetic fields. To test the experimental procedure, they used X-rays and treatments known to affect the genes (chemical or heat). These are known as positive controls and, as expected, caused gene expression in exposed cells.

Scientists have concluded that the combined animal bioassay results provide no evidence that magnetic fields cause, enhance, or promote the development of leukemia and lymphoma, or mammary cancer (e.g., Boorman et al., 1999; McCormick et al., 1999; Boorman et al., 2000 a, b; Anderson et al., 2001).

2.2.4 Summary Regarding Cancer

Epidemiology studies do not support the idea that EMF from power lines increase the risk of cancers in adults. The latest epidemiologic studies of childhood cancer, considered in the context of the other data, provide no persuasive evidence that leukemia in children is causally associated with magnetic fields measured at the home, calculated magnetic fields based on distance and current loading, or wire codes. Recent meta-analyses reported no association between childhood cancer and magnetic fields below 2 or 3 mG. Although some association was reported for fields above this level, fields at most residences are likely to be below 3 or 4 mG. The authors of each of these analyses list several biases and problems that render the data inconclusive and prevent resolution of the inconsistencies in the epidemiologic data. For this reason, laboratory studies can provide important complementary information. Large, well-conducted animal studies, and studies of initiation and promotion, provide no basis to conclude that EMF increases leukemia, lymphoma, breast, brain, or any other type of cancer.

2.3 Research Related to Reproduction

Several epidemiology studies have examined effects on pregnancy, including miscarriages[2] in relation to exposures to magnetic fields. Previous epidemiologic studies reported no association with birth weight or fetal growth retardation after exposure to sources of relatively strong magnetic fields, such as electric blankets, or sources of typically weaker magnetic fields such as power lines (Bracken et al., 1995; Belanger et al., 1998; Lee et al., 2000).

- Belanger et al. provided results of a prospective study in 1998. They assessed the magnetic field exposure of 2967 women during their pregnancy in two different ways. Exposure to magnetic fields from electric bed-heating (electric blankets and water beds), sources of relatively strong magnetic fields, was estimated from the women's responses in an interview. In general, electric bed-heating results in higher magnetic field exposures than those from residential fields. Wire codes were assessed for each woman to estimate the contribution, to residential fields, of transmission and distribution lines within 150 feet of house. No evidence of an association between miscarriage and exposure to magnetic fields from living in a residence with "high wire code," or from using electric blankets or a waterbed around the time of conception or during pregnancy (at time of interview) was found. There was no indication of an increased risk with daily exposure, or longer hours, or using the electric bed at the high setting.
- Another study also focused on exposures from electric bed heating (electric blankets, heated waterbeds and mattress pads (Lee et al., 2000). The researchers assessed the women's exposure prior to the birth and included information to control for potential confounding factors. This study had a large number of cases and high participation rates. Miscarriage rates were lower among users of electric bed heating.

[2] The medical term for miscarriage is spontaneous abortion.

- The data collected in the large, prospective, epidemiology study by Belanger et al. had been analyzed previously for other endpoints. The results of this analysis showed no evidence of reduced birth weight in the infants, or slower fetal growth after exposure to sources of relatively strong magnetic fields, such as electric blankets, or sources of typically weaker magnetic fields such as power lines (Bracken et al., 1995).

Two recent studies of EMF and miscarriage reported a positive association between miscarriage and exposure to high maximum, or instantaneous, peak magnetic fields (Li et al., 2002; Lee et al., 2002). However, no associations were found with higher average magnetic field levels during the day, the typical way of assessing exposure. In these studies women wore magnetic-field monitors for a 24-hour period to assess exposure. Magnetic field levels similar to the peak levels are routinely found near electric devices such as hairdryers, photocopy machines, electric tools, shavers; in or near electric trains; and under some types of power lines. Neither study found that miscarriage was associated with residential wiring codes, another method presumed to identify higher magnetic fields from power lines. There are several possible issues to be considered in assessing whether these statistical associations with the maximum, or peak, exposure during the day are due to cause-and-effect. First, despite years of research, there is no biological basis to indicate that EMF increases the risk of miscarriage. Second, the studies include possible biases. For example, each of the studies had a low response rate, which means that the study groups may not be comparable because those who participate may differ from those who decline (selection bias). Third, these studies found no association with higher daily average exposure, that is, the average of the measurements recorded throughout the day.

Studies of laboratory animals exposed to pure 60-Hz fields have shown no increase in birth defects, no multigenerational effects, and no changes that would indicate an increase in miscarriage or loss of fertility (e.g., Ryan et al., 1999; Ryan et al., 2000). Exposed and unexposed litters were no different in the amount of fetal loss and the number and type of birth defects, indicating no reproductive effect of EMF.

In summary, the recent evidence from epidemiology and laboratory studies do not support the hypothesis that exposure to power-frequency EMF has an adverse effect on reproduction, pregnancy, or growth and development of the embryo. The results of these recent studies are not sufficiently persuasive to change the conclusions of the NIEHS.

2.4 Implanted Medical Devices and EMF

Advances in technology have led to the development of more medical devices that can be implanted to maintain or enhance organ function. Of these devices, most concern has focused on potential interference with cardiac pacemakers and defibrillators. A cardiac pacemaker monitors the electrical activity of the heart. If the heart fails to beat, the pacemaker administers a small stimulus to trigger the "missing" beats. An implanted cardiac defibrillator (ICD) similarly monitors the electrical activity of the heart but is designed to block disorganized contractions of the heart (arrhythmias) by administering a strong electrical shock to restore normal heart rhythms. Exposure to electric and magnetic fields could affect the function of these devices if induced signals on sensing leads are interpreted as natural cardiac activity (e.g., Griffin, 1986; CCOHS, 1988; Barold et al., 1991). However, the opportunities for exposure and interference from power lines are lower than for contact with ordinary household appliances.

Although scientific studies report that exposure to power-frequency electric and magnetic fields have not resulted in adverse responses in patients with pacemakers, the possibility cannot be completely ruled out. In order to reduce potential effects of environmental exposure to electrical and magnetic fields, the Center for Devices and Radiological Health of the U.S. Food and Drug Administration (FDA) has developed guidelines for both the development of pacemakers and the design of new electrical devices to minimize susceptibility to electrical interference from any source. Pacemakers today are designed to filter out electrical stimuli from sources other than the heart, e.g., muscles of the chest, currents encountered from touching household appliances, or currents induced by electric or magnetic fields. Used in both

temporary and permanent pacemakers, these electrical filters increase the pacemaker's ability to distinguish extraneous signals from legitimate cardiac signals (Toivonen et al., 1991). Most circuitry of pacemakers is encapsulated by titanium metal, which insulates the device by shielding the pacemaker's pulse generator from electric fields. Some may also be programmed to automatically pace the heart if interference from electric and magnetic fields is detected. This supports cardiac function and allows the subject to feel the pacing and move away from the source.

Due to recent design improvements, many pacemakers in use would not be particularly susceptible to low-intensity electrical fields. There remains a very small possibility that some pacemakers, particularly those of older designs, and with single-lead electrodes, may sense potentials induced on the electrodes and leads of the pacemaker and provide unnecessary stimulation to the heart. In persons wearing some types or brands of implanted cardiac pacemakers, the pacing of the heart might be affected by electric fields at field intensities above about 2 kV/m. The sensitivity of ICD's to external 60-Hz fields has not been studied, but might be expected to be somewhat lower than that for pacemakers. The American Conference of Governmental Industrial Hygienists (ACGIH, 1999) recommends that routine occupational exposure of persons with cardiac pacemaker and similar medical electronic devices should not exceed 1 kV/m and 1000 mG (0.1 mT).

2.5 Recent Reviews by Scientific Advisory Groups

Reviews of the scientific research regarding EMF and health by the Health Council of the Netherlands (HCN) were published in 2000 and updated in May 2001. The NRPB Advisory Group on Non-Ionising Radiation (AGNIR) published the most recent review in 2001. That review includes research published in 2000, and includes the most comprehensive discussion of the individual research studies. The most recent peer review was conducted by the International Agency for Research on Cancer (IARC) and published in 2002.

2.5.1 National Radiological Protection Board of Great Britain (NRPB) Advisory Group on Non-Ionising Radiation

The conclusions from the report prepared by the NRPB's Advisory Group on Non-Ionising Radiation (AGNIR) on ELF-EMF and the risk of cancer are consistent with those of previous reviews. Members from universities, medical schools, and cancer research institutes reviewed the reports of experimental and epidemiological studies, including reports in the literature in 2000. Their general conclusions are as follows:

> Laboratory experiments have provided no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children. In practice, such levels of exposure are seldom encountered by the general public in the UK [or in the U.S.] (NRPB, 2001: 164).

The group further recognizes that the scientific evidence suggesting that exposure to power-frequency electromagnetic fields poses an increased risk of cancer is very weak. Virtually all of the cellular, animal and human laboratory evidence provides no support for an increased risk of cancer incidence following such exposure to power frequencies, although sporadic positive findings have been reported. In addition, the epidemiological evidence is, at best, weak.

These conclusions of the Advisory Group are consistent with previous reviews by the NIEHS (1999) and the Health Council of the Netherlands (HCN, 2000). The NRPB response to the Advisory Group report states that "the review of experimental studies by [the Advisory Group] AGNIR gives no clear support for a causal relationship between exposure to ELF-EMFs and cancer" (NRPB, 2001: 1).

2.5.2 Health Council of the Netherlands (HCN)

The Health Council of the Netherlands has prepared updates of its 1992 Advisory Report on exposure to electromagnetic fields (0 Hz to 10 MHz) (HCN, 2000; 2001). Members of the Expert Committee who prepared the report include specialists in physics, biology, and epidemiology. The Expert Committee based its analysis on the review and summaries of the studies provided in the NIEHS (1998) and concurred with the views of the director of the NIEHS (1999). For the update, the Committee evaluated a number of publications that appeared after these reports, e.g., McBride et al., (1999) and Green et al. (1999a), and wrote:

> The committee thinks that the quality of the relevant epidemiological research has improved considerably since the publication of the advisory report in 1992. Even so, this research has not resulted in unequivocal, scientifically reliable conclusions (HCN, 2000: 15).

The Council emphasizes that the associations with EMF reported in epidemiologic studies are strictly statistical and do not demonstrate a cause-and-effect relationship. In their view, experimental research does not demonstrate a causal link or a mechanism to explain EMF as a cause of disease in humans. They concluded that there is no reason to recommend measures to limit residence near overhead power lines (HCN, 2000).

The 2001 update (HCN, 2001) includes three major studies (described above) published in 2000 and 2001 (Ahlbom et al., 2000; Greenland et al., 2000; Wartenberg 2001b). The Council concludes:

> Because the association is only weak and without a reasonable biological explanation, it is not unlikely that [an association between ELF exposure and childhood leukemia] could also be explained by chance . . . . The committee therefore sees no reason to modify its earlier conclusion that the association is not likely to be indicative of a causal relationship (HCN, 2001: 40).

2.5.3 International Agency for Research on Cancer (IARC)

The International Agency for Research on Cancer sponsored a review of EMF research by a Working Group of scientific experts from 10 countries. This multidisciplinary group reviewed health effects of ELF-EMF. The Working Group concluded that the epidemiologic studies do not provide support for an association between childhood leukemia and residential magnetic fields at intensities less than 4 mG. Overall, ELF-EMF were evaluated as "possibly carcinogenic to humans" (Group 2B), based on the statistical association of higher-level residential ELF magnetic fields and increased risk for childhood leukemia. IARC reviewers also evaluated the animal data and concluded that it was "inadequate" to support a risk for cancer. Their summary states that the EMF data does not merit the category "carcinogenic to humans" or the category "probably carcinogenic to humans," nor did they find that "the agent is probably not carcinogenic to humans." Many hypotheses have been suggested to explain possible carcinogenic effects of ELF electric or magnetic fields; however, no scientific explanation for carcinogenicity of ELF-EMF fields has been established (IARC, 2002; 338).

2.5.4 California Department of Health Services (CDHS)

As part of a project mandated by the California Public Utilities Commission, the California Department of Health Services (CDHS) was asked to review and evaluate the scientific research regarding EMF and health. A small panel of only three scientists from the department's EMF Program conducted the review. The CDHS released their fourth and final draft in April 2002 (CDHS, 2002).

The CDHS used two different approaches to conduct their evaluation. One of these approaches was characterized as following the IARC approach, described above, in which reviewers summarize the "quality of evidence." The other approach was a set of guidelines developed by the California EMF Program, which calls for each reviewer to express a degree of confidence that the disease may be caused

by high EMF exposures. However, the term "high" is not defined. For example, a reviewer who was certain, or thought it highly probable, that observed statistical associations indicated causality would present their judgment as "90-98% confident."

The CDHS evaluated data regarding 13 health conditions. Using their own method, EMF was not judged to be a highly probable cause of any of these health conditions, that is, none received a rating of 90%-98% confident. For five of the health effects (childhood leukemia, adult leukemia, adult brain cancer, miscarriage, and ALS [amyotropic lateral sclerosis]), the reviewers thought that it is "more than 50% possible" that residential or occupation EMF could cause the disease. However, for each of these evaluations, the CDHS included the caveat "…there is a chance that EMF have no effect at all" (CDHS, 2002:1).

Using the IARC classification, the CDHS reviewers rated EMF as a "possible carcinogen" for adult leukemia, childhood leukemia, and adult brain cancer. EMF was also rated a possible causal factor in miscarriage and ALS. None of the three agencies discussed above— the IARC, HCN, and the NRPB— concluded that EMF was a possible cause of adult brain cancer, miscarriage, or ALS. The CDHS comments that animal studies do not suggest that a problem may exist; however, this had little effect on their overall evaluation. The assessment of miscarriage was based on the studies by Li et al. (2002) and Lee et al. (2002) (discussed above in Section 2.3). Studies in animals and previous studies in humans show little evidence that EMF could increase the rate of miscarriage.

The Scientific Advisory Panel that reviewed the final CDHS report expressed a

> . . . consensus among the SAP members that different evaluators with the same or different professional backgrounds may use the DHS guidelines and arrive at different numerical confidence estimates, perhaps substantially different. . . . A minority of SAP members, while endorsing the integrity of the DHS evaluation process, was not sufficiently persuaded by the extensive discussions in the document on issues of biophysics, mechanistic research, and animal physiology to arrive at the same conclusions as the three DHS evaluators. These members believe. . . they might come to somewhat different conclusions and arrive at lower estimates of risks from EMFs" (Winkelstein and McKone, 2002: 2).

3.0 Ecological Research

Scientists have studied the effects of high-voltage transmission lines on many plant and animal species in the natural environment. This section briefly reviews the research on the effects of EMF on ecological systems to assess the likelihood of adverse impacts. In addition to the comprehensive review of research on this topic by wildlife biologists at BPA (Lee et al., 1996), a search of the published scientific literature for more recent studies published between 1995 and May 2002 was conducted.

3.1 Fauna

The habitat on the transmission-line right-of-way and surrounding area shields most wildlife from electric fields. Vegetation in the form of grasses, shrubs, and small trees largely shields small ground-dwelling species such as mice, rabbits, foxes, and snakes from electric fields. Species that live underground, such as moles, woodchucks, and worms, are further shielded from electric fields by the soil; aquatic species are shielded from electric fields by water. Hence, large species such as deer and domestic livestock (e.g., sheep and cattle) have greater potential exposures to electric fields since they can stand taller than surrounding vegetation. However, the duration of exposure for deer and other large animals is likely to be limited to foraging bouts or the time it takes them to cross under the line. Furthermore, all species would be exposed to higher magnetic fields under or near a transmission line than elsewhere, as the vegetation and soil do not provide shielding from this aspect of the transmission-line electrical environment.

Field studies have been performed in which the behavior of large mammals in the vicinity of high-voltage transmission lines was monitored. No effects of electric or magnetic fields were evident in two studies from the northern United States on big game species, such as deer and elk, exposed to a 500-kilovolt (kV) transmission line (Goodwin 1975; Picton et al., 1985). In such studies, a possible confounding factor is audible noise. Audible noise associated with high-voltage power transmission lines (with voltages greater than 110-kV) is due to corona. Audible noise generated by transmission lines reaches its highest levels in inclement weather (rain or snow).

Much larger populations of animals that might spend time near a transmission line are livestock that graze under or near transmission lines. To provide a more sensitive and reliable test for adverse effects than informal observation, scientists have studied animals continuously exposed to fields from the lines in relatively controlled conditions. For example, grazing animals such as cows and sheep have been exposed to high-voltage transmission lines and their reproductive performance examined (Lee et al., 1996). No adverse effects were found among cattle exposed to a 500-kV direct-current overhead transmission line over one or more successive breedings (Angell et al., 1990). Compared to unexposed animals in a similar environment, the exposure to 50-Hz fields did not affect reproductive functions or pregnancy of cows (Algers and Hennichs, 1985; Algers and Hultgren, 1987).

A group of investigators from Oregon State University, Portland State University, and other academic centers evaluated the effects of long-term exposure to EMF from a 500-kV transmission line operated by BPA on various cellular aspects of immune response, including the production of proteins by leukocytes (IL-1 and IL-2) of sheep. In previous unpublished reports, the researchers found differences in IL-1 activity between exposed and control groups. However, in their most recent replication, the authors found no evidence of differences in these measures of immune function. The sheep were exposed to 27 months of continuous exposure to EMF, a period of exposure much greater than the short, intermittent exposures that sheep would incur grazing under transmission lines. Mean exposures of EMF were 35-38 mG and 5.2-5.8 kV/m, respectively (Hefeneider et al., 2001).

Scientists from the Illinois Institute of Technology (IIT) monitored the possible effects of electric and magnetic fields on fauna and flora in Michigan and Wisconsin from 1969 – 1997 to evaluate the effects of an aboveground, military-communications antenna operating at 76 Hz. The antenna produces EMF at a frequency close to that of power lines, but of much lower intensity. This study, which included embryonic development, fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior, showed no adverse impacts of ELF electric and magnetic fields on the animals. The fish community examined in this study showed no significant differences in species diversity, biomass, or condition, when compared to the control site. The results of the other studies also demonstrated no convincing evidence for effects of EMF on any of the organisms or ecosystems they examined (NRC, 1997).

Another part of the IIT study examined the effect of the antenna system fields on the growth, development, and homing behavior of birds. Studies of embryonic development (Beaver et al., 1993), fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior showed no adverse impacts of ELF electric and magnetic fields on the animals (NRC, 1997). Fernie and colleagues studied the effects of continuous EMF exposure of raptors to an electric field of 10 kV/m in a controlled, laboratory setting. The exposure was designed to mimic exposure to a 765-kV transmission line. Continuous EMF exposure was reported to reduce hatching success and increase egg size, fledging success, and embryonic development (Fernie et al., 2000). In a study of the effects on body mass and food intake of reproducing falcons, the authors found that EMF lengthened the photoperiod as a result of altered melatonin levels in the male species, yet concluded that "EMF effects on adult birds may only occur after continuous, extended exposure," which is not likely to occur from resting on power lines (Fernie and Bird, 1999:620).

The hormone melatonin, secreted at night by the pineal gland, plays a role in animals that are seasonal breeders. Studies in laboratory mice and rats have suggested that exposure to electric and/or magnetic

fields might affect levels of the hormone melatonin, but results have not been consistent (Wilson et al., 1981; Holmberg, 1995; Kroeker et al., 1996; Vollrath et al., 1997; Huuskonen et al., 2001). However, when researchers examined sheep and cattle exposed to EMF from transmission lines exceeding 500-kV, they found no effect on the levels of the hormone melatonin in blood, weight gain, onset of puberty, or behavior in sheep and cattle (Stormshak et al., 1992; Lee et al., 1993; Lee et al., 1995; Thompson et al., 1995; Burchard et al., 1998).

Several avian species are reported to use the earth's static magnetic field as one of the cues for navigation. It has been proposed that deposits of magnetite in specialized cells in the head are the mechanism by which the birds can detect variations in the inclination and intensity of this direct-current (dc) magnetic field (Kirschvink and Gould, 1981; Walcott et al., 1988). In early studies of transmission lines, it was reported that the migratory patterns of birds appeared to be altered near transmission lines (Southern, 1975; Larkin and Sutherland, 1977). However, these studies were of crude design, and Lee et al. (1996) concluded that, "During migration, birds must routinely fly over probably hundreds (or thousands) of electrical transmission and distribution lines. We are not aware of any evidence to suggest that such lines are disrupting migratory flights" (Lee et al., 1996:4-59). No further studies on this topic were identified in the literature.

Bees, like birds, are able to detect the earth's direct-current (dc) magnetic fields. They are known to use magnetite particles, which are contained in an abdominal organ, as a compass (Kirschvink and Gould, 1981). In the laboratory, they are able to discriminate between a localized magnetic anomaly and a uniform background dc magnetic field (Walker et al., 1982; Kirschvink et al., 1992).

Greenberg et al. (1981) studied honeybee colonies placed near 765-kV transmission lines. They found that hives exposed to alternating-current (ac) electric fields of 7 kV/m had decreased hive weight, abnormal amounts of propolis (a resinous material) at hive entrances, increased mortality and irritability, loss of the queen in some hives, and a decrease in the hive's overall survival compared to hives that were not exposed. Exposure to electric fields of 7-12 kV/m may induce a current or heat the interior of the hive; however, placing the hive farther from the line, shielding the hive, or using hives without metallic parts eliminates this problem. ITT studied the effects of EMF on bees exposed to the 76-Hz antenna system at lower intensities and concluded that these behavioral effects of "ELF-EMF impacts are absent or at most minimal" (NRC, 1997:102).

Crystals of magnetite have also been found in Pacific salmon (Mann et al., 1988; Walker et al., 1988). These magnetite crystals are believed to serve as a compass that orients to the earth's magnetic field. However, other studies have not found magnetite in sockeye salmon (*Oncorhynchus nerka*) fry (Quinn et al., 1981). While salmon can apparently detect the geomagnetic field, their behavior is governed by multiple stimuli as demonstrated by the ineffectiveness of magnetic field stimuli in the daytime (Quinn and Brannon, 1982) and the inability of strong magnetic fields from permanent magnets attached to sockeye salmon to alter their migration behavior (Ueda et al., 1998). There are no data on the effects of ac EMF on salmon navigation; however, a study with honeybees suggests that organisms that use magnetite crystals to orient to the earth's magnetic field would be affected only when the field levels are very much greater than the levels expected from the transmission line. Given this evidence and the salmon's ability to navigate using multiple sensory cues, the proposed transmission line is unlikely to have an adverse impact on these species of concern and the aquatic ecosystems.

Reptiles and amphibians contribute to the overall functioning of the forest ecosystems. However, little research has been performed on the effects of EMF on reptiles and amphibians in their natural habitat.

3.2 Flora

Numerous studies have been carried out to assess the effect of exposure of plants to transmission-line electric and magnetic fields. These studies have involved both forest species and agriculture crops. Researchers have found no adverse effects on plant responses, including seed germination, seedling

emergence, seedling growth, leaf area per plant, flowering, seed production, germination of the seeds, longevity, and biomass production (Lee et al., 1996).

The only confirmed adverse effect of transmission lines on plants was reported for transmission lines with voltages above 1200 kV. For example, Douglas Fir trees planted within 15 m of the conductors were shorter than trees planted away from the line. Shorter trees are believed to result from corona-induced damage to the branch tips. Trees between 15 and 30 m away from the line suffered needle burns, but those 30 m and beyond were not affected (Rogers et al., 1984). These effects would not occur at the lower field intensities expected beyond the right-of-way of the proposed 500-kV transmission line.

3.3 Summary of Ecological Research

The habitat on the transmission-line rights-of-way and surrounding areas shields smaller animals from electric fields produced by high-voltage transmission lines; thus, vegetation easily shields small animals from electric fields. The greatest potential for larger animals to be exposed to EMF occurs when they are passing beneath the lines. Studies of animal reproductive performance, behavior, melatonin production, immune function, and navigation have found minimal or no effects of EMF. Past studies have found little effect of EMF on plants; no recent studies of plants growing near transmission lines have been performed. In summary, the literature published to date has shown little evidence of adverse effects of EMF from high-voltage transmission lines on wildlife and plants. At the field intensities associated with the proposed 500-kV transmission line, no adverse effects on wildlife or plants are expected.

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