INTRODUCTION
Electromagnetic fields (EMF) and their effects on the health of humans and livestock have been a source of debate. Since the early 1970s, there have been concerns about EMFs and possible negative effects on health. Many scientists have conducted EMF research to determine if there is a link between exposure to EMFs and adverse health events, most notably cancer. These studies indicate that EMF exposure can have a biological effect, but the effect is not always negative. This effect depends upon the strength of the EMF and the duration of exposure. The majority of research in this area has focused on human subjects, and therefore data documenting the effects of EMF exposure and livestock production are limited. Increased installation of transmission lines in novel areas is occurring due to an increase in renewable energy generation from wind and solar production methods. Areas of the U.S. not typically involved in energy production are becoming energy exporters, requiring the construction of new high-capacity transmission lines. These lines are a common source of EMFs in the environment. This has renewed conversations and debate as to whether transmission line exposure carries increased risk of adverse health effects for humans and livestock in proximity to transmission lines.

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WHAT IS AN ELECTROMAGNETIC FIELD?

There are invisible forces (also called radiation; NIH, 2020) that exist in nature and are associated with electrical appliances, power tools, electric cords, cell phones, computers, wires, power lines, and other objects that carry or use electrical energy. These forces are collectively referred to as EMFs. An electrical field is created when voltage is present in a cord that is plugged into a wall socket or power source. A magnetic field is created when the lamp, tool, or appliance is turned on and current flows through the cord. When the lamp, tool, or appliance is turned off, no current flows, so the magnetic field disappears, but the electrical field remains. The biological effect created is related to both the proximity and duration of exposure of the subject to the source, as well as the strength of the EMFs present.

The unit of measure for electrical fields is volts per meter (V/m). In areas where higher voltages occur, such as directly beneath transmission lines where the field is typically in the thousands of V/m, kilovolts per meter (kV/m) is most commonly used. In the U.S., the unit of measure for a magnetic field is the gauss (G), with exposure expressed as milligauss or mG (1/1,000 of a gauss). The international unit of measure for magnetic fields is the tesla, with exposures expressed as microtesla. One microtesla equals 10 mG. Most of the EMFs experienced in daily life range from 1 to 10 mG, but can be up to 1,000 mG near electrical appliances and equipment. By way of reference, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommends a limit of 9,100 mG (EPRI, 2015). Common examples of typical EMF daily exposures from household appliances (which vary depending on the distance from the appliance) include microwave oven (0–300 mG), hairdryer (0–700 mG), portable heater (5–150 mG), and computer (0–0.1 mG). Directly beneath a 765 kV transmission line (the largest transmission lines in the U.S.), the exposure may exceed 100 mG, and may be up to 30 mG directly beneath a heavily loaded distribution line (EPRI, 2015).

THE ELECTROMAGNETIC SPECTRUM

The electromagnetic spectrum is arranged from left to right in order of increasing frequency (the number of times every second that a field completes a full cycle or oscillation; EPRI, 2015) and is expressed in units of hertz (Hz) (Figure 1). The high end of the spectrum compromises ionizing radiation, such as x-rays and gamma rays, with frequencies in the range of billions of cycles per second. Ionizing radiation has enough energy to damage cells, and its use in medicine and nuclear energy is carefully managed. The middle of the spectrum (millions to billions of cycles per second) are the radio frequency fields we use every day for TV, radio, microwave ovens, walkie-talkies, and cell phones (including smart phones). Radiofrequency fields are non-ionizing, but at sufficiently high frequencies they are able to heat tissues in the body.

Various organizations, including most prominently the ICNIRP and the IEEE, issue guidelines and standards recommending exposure limits that protect against such effects. Power systems in Europe and the U.S. operate at the low end of the spectrum—50 Hz in Europe and 60 Hz in the U.S.—referred to as “power frequencies.” EMF exposure at power frequencies neither directly damages cells nor produces tissue heating (EPRI, 2015). We will focus on power frequencies for this guide.

EMFs AND HUMAN HEALTH

There is strong evidence that EMFs above certain levels can trigger biological effects. As defined by the World Health Organization (WHO), biological effects are measurable responses to a stimulus or to a change in the environment. These changes are not necessarily harmful to your health. The body has sophisticated mechanisms to adjust to the many and varied influences we encounter in our environment. Of course, the body does not possess adequate mechanisms to adjust for all biological effects. Changes that are irreversible and prolonged can stress the body systems and may constitute a health hazard. An adverse health effect causes detectable impairment of the health of an individual or their offspring; a biological effect, on the other hand, may or may not result in an adverse health effect. Experiments with healthy volunteers indicate that short-term exposure to EMFs at the levels present in the environment or in the home do not cause any apparent adverse health effects (WHO, 2020).

In 1996, the WHO launched a large, multidisciplinary research effort to address concerns over possible health effects related to EMF exposures. The International EMF Project brought together the current knowledge and available resources of key international and national agencies and scientific institutions. This worldwide research project concluded that in the
area of biological effects and medical applications of non-ionizing radiation, approximately 25,000 articles had been published.

Although people continue to suggest that more research is needed in this area, scientific knowledge regarding EMFs and human health is more extensive than that for most commonly used chemicals. A recent review of scientific literature by the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low-level EMFs. Furthermore, data can be summarized that exposure to EMFs at typical environmental levels does not increase the risk of adverse health outcomes.

It has been suggested in the literature that a small increase in risk of childhood leukemia and EMF exposure may be related. However, it has not been generally concluded that these results indicate a cause-effect relation between exposure to EMFs and disease (as opposed to artifacts in the study or effects unrelated to field exposure). In part, this conclusion has been reached because animal and laboratory studies fail to demonstrate any reproducible effects that are consistent with the hypothesis that EMFs cause or promote cancer.

The relationship of EMFs to cancer in humans is a current area of robust research activity. Studies searching for possible carcinogenic (cancer-producing) effects of power frequency fields are ongoing, although at a reduced level compared to that of the late 1990s (WHO, 2020). No mechanism by which extremely low-frequency (ELF) EMFs (which include power lines) or radiofrequency radiation could cause cancer has been identified. EMFs in the non-ionizing part of the electromagnetic spectrum cannot damage DNA or cells directly. Evidence against EMFs and childhood leukemia includes that magnetic fields do not have sufficient energy to damage cells and thereby cause cancer, and at present there is no clear biological explanation for the possible increase in childhood leukemia and exposure to magnetic fields.

The evidence that exposure to magnetic fields causes any other type of adverse health event in children or adults is far weaker (Public Health England, 2013). There have been many studies on the possible health effects from exposure to EMFs at ELFs. While it has been shown that EMFs cause weak electric currents to flow through the body, the intensity of these currents is too low to cause any known adverse health effects. The International Agency for Research on Cancer (IARC) has classified ELF-EMFs as “possibly carcinogenic to humans,” reflecting the fact that some limited evidence existed in early research data that ELF-EMFs might be a risk factor for childhood cancer. However, the vast majority of scientific research to date does not support a link between ELF-EMFs and human cancer. The guidelines established by the ICNIRP are not based on a consideration of

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*Figure 1. The electromagnetic spectrum (source: Berkeley Lab, n.d.).*
risks associated with cancer; rather, the point of the guidelines is to make sure that exposures to EMFs do not cause electric currents or fields in the body that are stronger than the ones produced naturally by the brain, nerves, and heart (Government of Canada, 2019). Studies of animals have not provided any indications that exposure to ELF-EMFs is associated with cancer (NIH, 2020).

**EMFs AND LARGE RUMINANTS**

There are anecdotal reports of health concerns in animals exposed to ELF-EMFs, but very little to no scientific evidence to support these claims. In 1974, a study was initiated by the American Electric Power Service Corporation consisting of a survey of livestock owners grazing animals under a 765 kV transmission line. Of the 125 owners surveyed, two reported specific observations. In 1974, the Agricultural Resources Commission of New York conducted an observational study of 18 farms looking at dairy production and behavior of grazing herds. Generally, no behavior differences were observed. Two of four dairies reported increased milk production compared with the three previous years. These studies were not designed to allow for the identification of subtle, difficult to observe effects.

From 1977–1979, two Americans, H.E. Amstutz and D.B. Miller, conducted a clinical study of the health of beef cattle, dairy cows, sheep, pigs, and horses on 11 farms located near a 765 kV transmission line. The authors concluded that the power line had no effect on the health, behavior, or productivity of the livestock (Hydro-Québec, 1999). Interestingly, work by Begall et al. (2008) suggested that cattle align their body axes along the field lines of the Earth’s magnetic field. Subsequent work from that same research group reported that the directional grazing and resting preference in cattle associated with magnetic alignment is altered when exposed to ELF-EMFs. In pastures beneath power lines, cattle showed random body alignment while grazing, but as distance increased away from the power lines, cattle resumed body orientation to the Earth’s magnetic fields (Burda et al., 2009).

More recent work utilized neodymium magnets in an effort to disrupt possible geo-magnetic-driven behaviors in cattle; results demonstrated that cows exhibited random distribution and orientation regardless of magnetic treatment. The results suggested that cattle behaviors were largely driven by sun orientation when resting, and researchers did not observe an effect of the Earth’s magnetic poles on cattle distribution or behavior (Weijers et al., 2018).

Additional authors in the mid-1980s investigated EMF exposure under transmission lines. In a Swedish project, researchers studying reproduction conducted a nationwide retrospective cohort study utilizing cattle on 106 farms reported to have been exposed to 400 kV lines. The cattle represented a dataset of 2,050 artificial inseminations of cattle. These inseminations were compared to results from all other farms belonging to the same livestock coopera-
tive, and there were no significant differences for AI data or culling frequency because of reduced fertility (Algers and Henrichs, 1985). In a follow-up experiment, 116 heifers were divided into two groups; one group was exposed to a 50 Hz, 400 kV transmission line, and the second group was housed away from the line. These authors detected no impacts on measured parameters of estrous cycle, mid-cycle plasma progesterone level, intensity of estrus, number of inseminations per pregnancy, or proportion of animals conceiving (Algers and Hultgren, 1987).

In addition to the research being conducted in Sweden, a research group in Oregon conducted a three-year study using 200 beef cows and 12 bulls, where half were confined in pens under a DC transmission line and the other half were maintained in pens 2,000 feet away from the line. Management was mirrored, and no significant effects were measured for feed, mineral or water consumption, breeding, conception, calving, calf birth date, calving interval, average daily gain, adjusted weaning weight, cow weight, body condition, carcass weight, or mortality (Reighleigh et al., 1986). In dairy cows, exposure to EMFs resulted in increased progesterone and dry matter intake, and a subsequent increase in milk fat, while other physiological parameters remained unchanged (Burchard et al., 1996). It is important to note that although changes were observed, progesterone, dry matter intake, and milk fat were well within normal ranges, and no indications of health hazards were observed. Complimentary to these results, when studying the effect of EMFs on forage production of alfalfa and winter wheat cultivated under a power line or 2,000 feet distant, there was no significant difference in production, seasonal growth stages or heights, hay or grain quality, or infectious diseases. However, it was noticed that wheat heights were slightly shorter under the line than away, but this was not significant or attributable to EMF effects.

**EMFs AND SMALL RUMINANTS**

A handful of studies have been conducted evaluating the effects of EMFs on health and reproduction in sheep. In a pair of studies, effects of EMFs on interleukin proteins (IL-1, IL-s) were evaluated in ewe lambs. Interleukins are proteins that are involved in cell-to-cell communication related to both growth and immunity in the animal. The treatment ewes were exposed to magnetic fields of 3.5–3.8 microteslas and mean electrical fields of 5.2–5.8 kV/m over the course of 27 months. Although there was a significant reduction in IL-1 in ewe lambs that were 8–10 weeks of age in the first study, no significant differences were found between the exposed group and the control group in the follow-up study (Hefeneider et al., 2001).

Another study focused on the hormone melatonin and puberty in ewe lambs. These authors hypothesized that exposure to EMFs from high-transmission lines would alter the secretion of melatonin and thus its impact on the initiation of puberty in ewe lambs. The lambs were exposed to 500 kV transmission lines located above their pens from the ages of 2–10 months. No significant differences were found in either circulating melatonin or age of puberty between the treated group and the respective control group (Lee et al., 1995).

Cortisol levels and growth parameters have also been measured in sheep exposed to EMFs. Cortisol is a hormone produced by the adrenal glands (just above the kidneys) and is used as a marker for animal stress. This hormone also plays a vital role in many functions in the body, including metabolism and immune response. In this study, treatment ewe lambs were exposed to 60 Hz, 500 kV transmission lines positioned directly above their pen for 8 months. Blood cortisol concentration, rate of gain, and wool growth were measured throughout the trial. There were no significant differences between ewes exposed to EMFs and the control group for cortisol levels, rate of gain, or wool growth (Thompson et al., 1995).

Collectively, these studies indicate that EMFs from transmission lines pose no health risk or negative effects on production in sheep. Though sample sizes were small, averaging 32 ewes per study, treatment groups were confined to chronic exposure to EMFs with no apparent impact on bodily function.

**SUMMARY**

To date, the body of scientific evidence studying the biological effects of exposure to EMFs on both human and livestock subjects has concluded that there is not an increased risk of adverse health events when exposure occurs to extremely low-frequency EMFs, such as those associated with power transmission and distribution lines. The need for research on livestock that includes performance and production values is certainly evident. Research studying
the effects of ELF-EMFs on livestock will require prolonged and costly projects that will need to look at multi-generational effects of exposure and whether the effects are only biological or if adverse health events can be scientifically documented.

REFERENCES


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