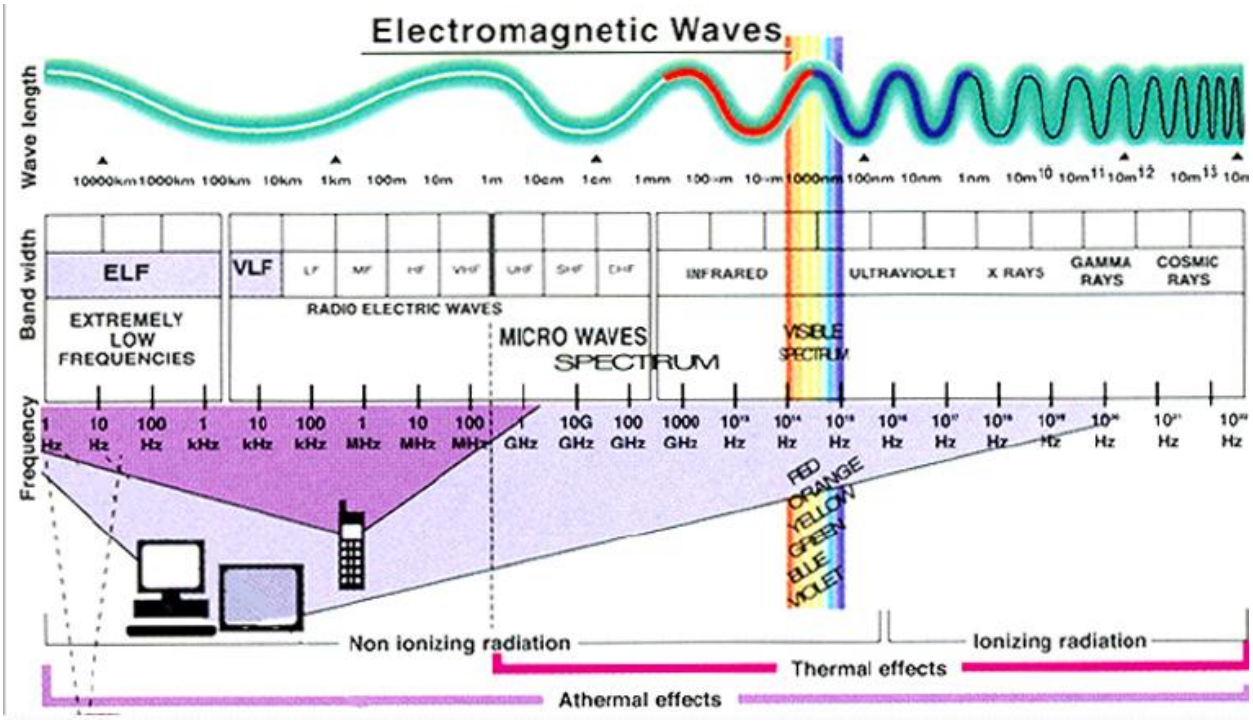
ELECTROMAGNETIC FIELDS (EMFs): SCIENTIFIC EVIDENCE REVIEW, REGULATORY ANALYSIS AND POLICY RECOMMENDATIONS.

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WHAT ARE ELECTROMAGNETIC FIELDS (EMFs):

Electromagnetic fields (EMFs) are sinusoidal packets of energy without mass that travel at the speed of light and vary in frequency and intensity. Sunlight consists of EMFs that vary slightly in frequency, which is the basis for our detection of colors (violet has a higher frequency than red). The frequencies that are associated with electricity, 60 Hz in the US and 50 Hz in most of the rest of the world, are usually described as “extremely low frequency EMFs” (ELF-EMF). At these frequencies one distinguishes an electric and a magnetic field, both of which are vectors (they have direction). Non-ionizing EMFs at higher frequencies used for communication are usually called “radiofrequency EMF” (RF-EMF). “Radar” uses sine waves of a variety of frequencies to detect movement, whether to follow movement of airplanes or weather or to control movement of autonomous driving vehicles. Microwave ovens use sine waves, usually at frequencies around 2.45 GHz, at sufficient energy to cause heating, and therefore to cook your potato. However, the communication frequencies use sine waves of varying frequencies but at lower intensities so as to not cause tissue heating with superimposed information on the sine wave. These include radio and television, cell phones, WiFi and 5G. Even higher frequencies include infrared, which heats the earth, visible light, ultraviolet and then the ionizing EMFs. These are shown in the figure below.



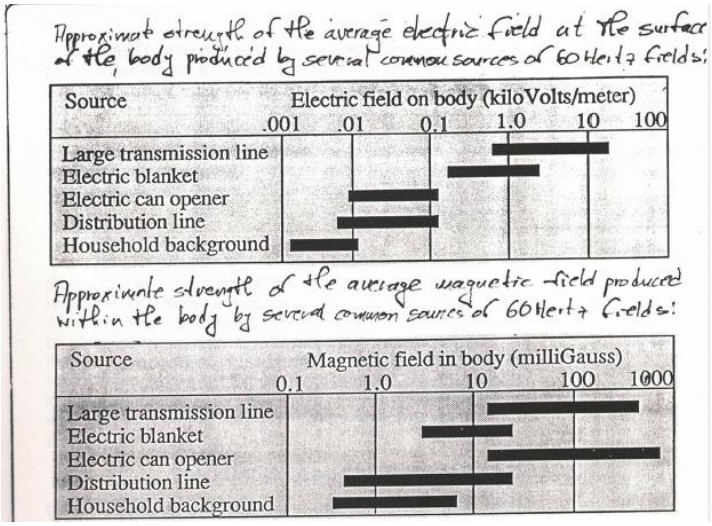
DOES HUMAN EXPOSURE TO EMFs HAVE ADVERSE HEALTH EFFECTS?

Ionizing EMFs are well to cause human cancer and damage DNA by breaking chemical bonds and the fetus and children are of greater risk than adults because their cells are more rapidly dividing and their bodies developing (Carpenter and Bushkin-Bedient, 2013). At the same time ionizing EMFs are very useful in clinical medicine for tissue imaging and sometimes for treatment for cancers but can also significantly increase exposure to ionizing radiation (Brenner and Hall, 2007). Ultraviolet (UV) radiation also increases risk of some cancers, especially skin cancers (Rocha et al., 2026). Since UV is a natural exposure source under most circumstances the only thing one can do is to limit excessive outdoor exposure and tanning solons and apply sunscreen lotions. We depend on visible light and there is no significant information indicating that it poses danger. Life on earth would not be possible without heating of the earth from infrared radiation. But the major concern in this report is whether there are adverse human health effects of those EMF frequencies below those associated in infrared radiation, especially those that are due to human activities. As detailed below there is strong and convincing evidence that excessive exposure to non-ionizing EMFs at all frequencies increases the risk of cancer and several other human diseases.

WHAT ARE THE SOURCES OF EXTREMELY LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS (ELF-EMFs)?

ELF-EMFs are always present in association with electricity and consist of electric and magnetic fields. The electric field is a function of the voltage, and is expressed in kV/m, while the magnetic field is directly related to the current flow and is expressed in milli-Gauss (mG) in the US or micro-Tesla (μT) in the rest of the world, where 1 mG = 0.1 μT. Therefore, any wire carrying electricity and any piece of equipment or appliance that uses electricity will have associated electric and magnetic fields. Neither is blocked by usual building materials, including stone and brick. But because they are vectors they can be blocked when wires carrying current in different directions are located close together. When powerlines are buried they do not generate large magnetic fields because the wires carry current in different directions and are placed close together.

The figure below, from a handbook prepared by the Department of Engineering and Public Policy of Carnegie Mellon University, shows the range and magnitude of the electric and magnetic fields from high voltage and neighborhood distribution powerlines as well as some appliances.



Both electric and magnetic fields fall off with distance from the source. This is shown in the Figure below from Deno and Carpenter (1994). Around a powerline the fields fall off over distances of several hundred feet, but around appliances they fall off within a much shorter distance. An electric can opener has a very high magnetic field right at the appliance because it uses high current, but it falls off over a short distance. Under most circumstances a person is not near it but for a brief time, so total exposure on a day-to-day is not great. However, while an electric blanket does not have as high a level of magnetic field it can result in significant exposure because individuals usually have it very close to their body all night.

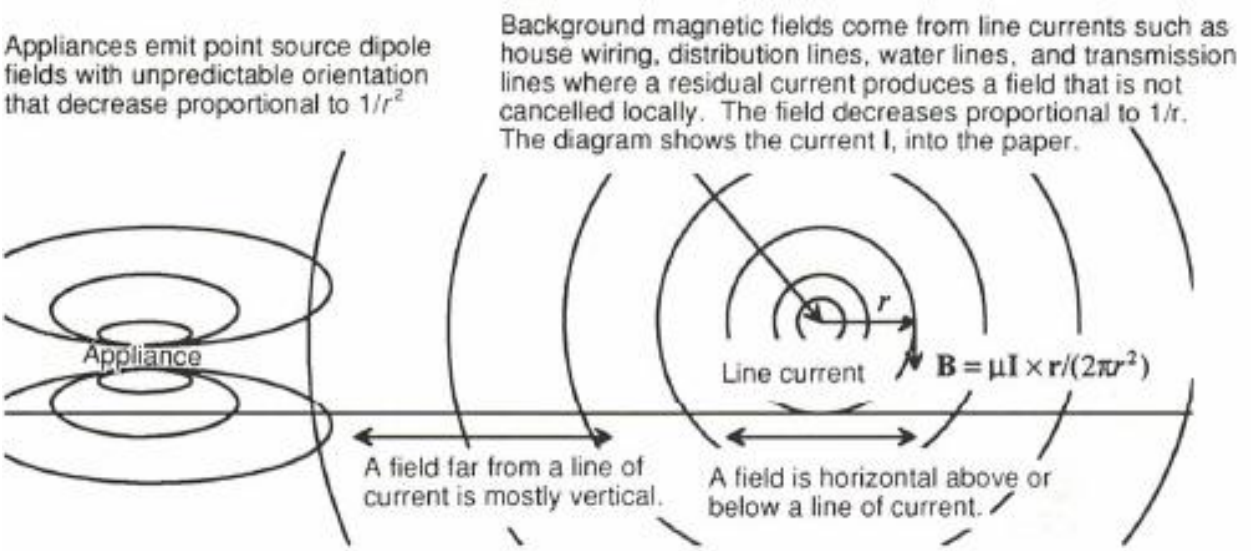


FIGURE 23 Characteristics of an ELF field spatial distribution in the environment.

If a home is located close to a powerline carrying high currents, the magnetic fields may cause human exposure at high levels for many hours per day, for as long as a person is at home. High voltage is used in powerlines for transport of electricity over long distances because it allows for more efficiency than those of lower voltage. High voltage powerlines also have higher magnetic fields because they carry much higher currents. Common high voltage powerlines operate at 765, 400 or 200 kV, while distribution lines are often at 23kV. Neighborhood distribution lines, although they operate at lower voltage, also generate magnetic fields that can be large at sites where they carry high currents. Transformers are places where the higher voltage is converted to lower voltage electricity. There can be very large magnetic fields around transformers, which have higher voltage lines coming in and lower voltage lines going out, both carrying large currents. When transformer stations are in urban areas they can result in significant levels of magnetic fields in nearby structures. There frequently are smaller transformers in larger buildings such as apartments and offices that cause quite high magnetic fields in the immediate vicinity. Since building structures do not block either the electric or magnetic fields, apartments or offices adjacent to these transformers will have very elevated magnetic fields that may not been known to nearby occupants. Even within a home there will be higher magnetic fields near walls that contain wiring than walls that do not.

Distribution lines are typically at 23 kV. Since it is the magnetic field, not the electric field, that is of greater health concern, it is important to understand that the current in distribution lines can be high, giving a large magnetic field. As a distribution line goes through a neighborhood it provides current to different sites along the way, and therefore the magnetic field will be highest near the beginning of the distribution line and

will decline further along the path. Within buildings or homes the voltage is reduced to 120 or 240 V, and there are often high magnetic fields near these smaller transformers.

The figure below (from Deno and Carpenter, 1994) shows the levels of magnetic fields in a typical office. Levels away from appliances are usually less than 1.0 mG, but they can be over 30 mG near to common office electrical appliances.

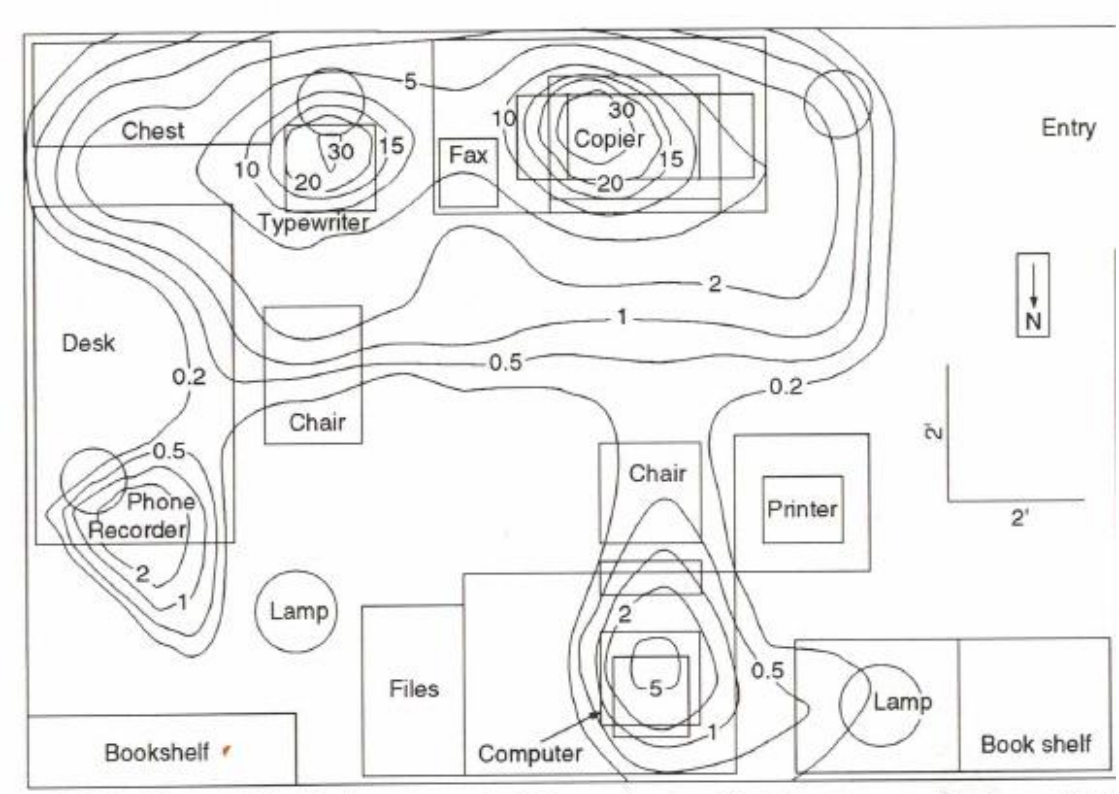


FIGURE 18 Spatial distribution of magnetic field in a real estate office. Note the general background field in most of the area is well below 1 mG in magnitude. The highest fields are at the copier, typewriter, and computer. Contours are shown for 0.1, 0.5, 1, 2, 5, 10, 15, 20, and 30 mG.

Most studies have shown that human health hazards are primarily due to magnetic fields, not electric fields. Health risk is a function of the magnitude of the magnetic field and the duration of exposure, as discussed below. It is the oscillating magnetic fields of concern. The earth has a static magnetic field that is orders of magnitude larger than that associated with electricity, but that is not known to be associated with adverse health issues, since we are all continuously exposed to the earth's DC magnetic field.

People living near to high voltage or distribution powerlines that carry high currents have much greater exposure to magnetic fields than most others who do not. This is true also for people who spend large periods of time near to transformers and other sources of high current flow. This may be the case in certain occupations. However, for most people exposure from household appliances is a significant source of exposure to magnetic fields (Behrens et al., 2004). Appliances that use high currents include hair

dryers, microwave ovens, and sewing machines but high exposure can also occur from use of electrical devices that are located close to the body for long periods of time, such as electric blankets or pillows, alarm clocks and water beds.

WHAT ARE THE HEALTH EFFECTS OF EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS (ELF-EMFs)?

All EMFs have energy and the level of energy increases with frequency. Because of this ELF EMFs might be expected to be less harmful than those EMFs at higher frequencies. However, there is strong evidence that excessive exposure to ELF frequencies contributes to and cause human disease.

The first convincing report of human harm from ELF-EMFs came from Wertheimer and Leeper (1979), who reported that children living in homes that had high magnetic fields coming from the neighborhood power lines had higher rates of leukemia than did children living in homes where the magnetic fields were low. The electric field did not appear to have this effect. These investigators did not directly measure the magnetic fields but developed a “wire code” method of determining relative magnetic field intensity. In addition to distance of the powerline to the house, they considered the thickness of the wire, because a thick wire reflected a line carrying high currents and the utility would not use a thick copper wire if a thin one would do. This report was published in the American Journal of Epidemiology, a very respected journal. While this report was greeted with skepticism, a second study in the same city but with a different population confirmed the finding of elevated leukemia in children living in homes with high magnetic fields both by applying the wire code method of Wertheimer and Leeper and by direct measurement of the magnetic fields (Savitz et al., 1988) .

Feychting and Ahlbom (1993) reported risk of childhood leukemia in relation to residence at various distances from high voltage powerlines in Sweden. Since a high voltage powerline goes over a long distance with constant voltage and current it is possible to identify a relatively large population of children living at various distances from the line. First they used the Swedish cancer registry to identify children under the age of 14 with any kind of cancer. They then identified four control children of the same age, sex and who lived in the same parish as the child with cancer. They used two ways to determine exposure to magnetic fields for both the cancer children and controls. First, they identified children living with 300 meters (984.3 feet) of any of the 220 and 400kV powerlines. This distance was chosen because the magnetic fields from the high voltage line fell off to background beyond this distance. Furthermore, they made measurements of the magnetic fields at various distances from the center of the powerlines and used these measurements to calculate the magnetic field exposure for each child. (Magnetic fields in the US are usually reported in milli-Gauss (mG) , while in

most of the rest of the world they are reported as micro-Tesla, where 1 mG equals 0.1 μT).

The results of this are shown in the table below from their publication. Most of the controls lived in homes that were not near to high voltage powerlines and did not have elevated magnetic fields. There was no significant association between calculated magnetic fields and children with any kind of cancer, with central nervous system cancers, and lymphoma. However, the pattern was different for leukemia. Of the 51 children with leukemia, 22 lived in homes with elevated magnetic fields from a high voltage powerline. The risk of development of leukemia was 3.8-fold greater in children where the magnetic field was greater than 0.3 μT (3 mG).

1.

TABLE 5. Cancer risk in relation to calculated magnetic fields closest in time to diagnosis, cutoff points at 0.1 and 0.2 μT,* and at 0.1 and 0.3 μT, children living close to 220 or 400 kV power lines in Sweden, 1960–1985

Diagnosis	≤0.09 μT		0.1–0.19 μT			≥0.2 μT			0.1–0.29 μT			≥0.3 μT		
	No.	RR*	No.	RR	95% CI*	No.	RR	95% CI	No.	RR	95% CI	No.	RR	95% CI
All cancer	117	1	12	1.5	0.7–2.9	12	1.1	0.5–2.1	14	1.2	0.6–2.3	10	1.3	0.6–2.7
Leukemia	27	1	4	2.1	0.6–6.1	7	2.7	1.0–6.3	4	1.5	0.4–4.2	7	3.8	1.4–9.3
Central nervous system tumor	29	1	2	1.0	0.2–3.8	2	0.7	0.1–2.7	2	0.7	0.1–2.6	2	1.0	0.2–3.9
Lymphoma	16	1	1	0.9	0.0–5.2	2	1.3	0.2–5.1	2	1.3	0.2–5.0	1	0.9	0.0–5.4
Controls	475		33			46			47			32		

* μT, microtesla; RR, relative risk; CI, confidence interval.

A later publication (Feychting et al., 1995) pooled the results from Sweden with those from Norway and found that in this larger sample the magnetic fields > 0.2 μT (2mG) increased risk of childhood leukemia with a risk ratio (RR) of 2 (95% confidence interval = 1.0-4.1). This means the risk of leukemia is significantly doubled. For children living in homes where the magnetic field was > 0.5 μT (5 mG) the RR was 5.1, a greater than 5-fold increased risk.

There have been several studies looking at risk of childhood leukemia only in relation to distance from high voltage powerlines with no monitoring of levels of magnetic fields. Some found elevations in childhood leukemia (Sohrabi et al., 2010; Tabrizi and Bidgoli, 2015; Malagoli et al., 2023). Crespi et al. (2016) reported a small elevation in childhood leukemia in California children living within 50 m of high voltage lines, but several others found no significant association. However, without some monitoring or at least calculation on the level of magnetic fields these reports are not very helpful because while distance is one important factor the actual magnetic fields vary due to additional factors.

Two studies, while each has limitations, raise additional concerns over prenatal and early life exposure to elevated levels of magnetic fields. Infante-Rivard and Deadman

(2003) reported that maternal exposure to magnetic fields during pregnancy significantly increased the risk of the child developing leukemia. Lowenthal et al. (2007) investigated blood cancers in Australian adults in relation to early life exposure to ELF-EMFs. They found that adults who had lived within 30m of a high voltage powerline during the first 15 years of life had a greater than 3-fold risk of developing blood cancers (leukemia, lymphoma and related conditions) later in life. For those who lived close to the powerline for the first 5 years of life the elevated risk was 4.74-fold. In neither study were magnetic fields directly measured.

Much of the evidence for leukemia in children from ELF-EMF exposure comes from studies of children living near to residential distribution lines. By 2000 there were three different meta-analyses of reports on childhood leukemia and magnetic fields exposure from either high voltage or distribution lines. Wartenberg (1998) reported on 16 epidemiologic studies, considering reports using the Wertheimer and Leeper (1979) wire codes as well as measured fields, and concluded that “the observed results identify a consistent risk that cannot be explained by random variations.” Two other meta-analyses found a statistically significant elevated risk of childhood leukemia from exposure to magnetic fields. Greenland et al. (2000) reported a significantly elevated risk of 1.68 based on pooled results from 12 studies, using a time-weighted average of exposure greater than 3 mG (0.3 μT). Ahlbom et al. (2000) reported on nine studies and found an elevated risk of 2.0 (doubling of incidence) for exposures equal or greater than 4 mG (0.4 μT) as compared with less than 1 mG (0.1 μT).

These reports are important in that they show consistency of a clearly elevated risk of leukemia in children with magnetic field exposure from power-line magnetic fields in their homes. Several studies documented a dose-dependent relationship between ELF exposure and leukemia and thus serve to confirm the likelihood of causation. All concluded that the evidence indicated that excessive exposure to residential magnetic fields (more than 4 mG) was associated with an elevated risk of childhood leukemia. There have also been several more recent meta-analyses, all showing that exposure to magnetic fields increases risk of leukemia in children (Kheifets et al., 2010; Zhao et al., 2014; Brabant et el, 2022).

It is important to realize that in none of these studies have other sources of exposure to magnetic fields have been considered. Those other exposures are from household wiring and especially from appliances. These exposures vary from person to person and home to home. Since there is every reason to consider risk of childhood leukemia to be related to aggregate exposure to magnetic fields from all sources, the result is that when one can monitor only exposure from one source, that being in this case that coming from the powerline in the street, the other exposures constitute noise and the result is likely significant underestimation of the magnitude of the true risk.

Carpenter (2019) published a review of all studies of childhood leukemia and ELF-EMFs published post 2000. Twelve such publications reported statistically significant positive associations. All but one were funded by academic investigators. Another five studies, all from academic institutions, reported an elevated risk ratio of 1.5 or larger, but the results were not statistically significant (the lower bound of the confidence intervals less than 1.0). Yet another seven studies found no elevation in risks. All were supported by industry. These observations show how obvious conflicts of interest can shape the results. The industry repeatedly states that the results from studies on childhood leukemia are inconsistent and inconclusive. Neither is the case if one ignores studies funded by industry where there is a clear conflict of interest.

ELF-EMF EXOSURE AND ADULT CANCERS:

The level of evidence showing a clear association between exposure to magnetic fields and adult cancer is somewhat less consistent than the relation with childhood leukemia. Elliott et al. (2013) looked for adult cancers in relation to residence near to high voltage powerlines, and found a non-significant association with melanoma, but not with leukemia, brain or breast cancers. Several studies show statistically significant associations between occupational exposure to magnetic fields and leukemia and brain cancer in adults despite limitations in exposure assessment. Elevations in the rates of leukemia following occupational exposure to elevated EMF have been reported in review articles (Savitz and Ahlbom, 1994) and in a meta-analysis (Kheifets et al., 1997). Minder and Pfluger (2001) report elevated leukemia mortality among Swiss railway employees exposed to high magnetic fields. Sun et al., (2013) reported significant elevation in rates of male breast cancer in a meta-analysis in relation to ELF-EMF exposure.

In a review study, Miller et al. (1997) reported that of 124 studies reporting odds ratios for leukemia in relation to occupations associated with electricity, 41 showed a significant elevation, and 4 showed a dose-response relation. Feychting et al. (1997) investigated adult leukemia in relation to magnetic field exposures in the home and at work. The investigators found no relation between residential exposure alone and only a non-significant elevation of risk of leukemia with occupational exposure alone. However, when both residential and occupational exposures were considered, the authors reported a significant elevation of risk of all leukemias with an odds ratio of 3.7 (more than 300 percent increase in risk).

In adults, the evidence for a relation between magnetic field exposure and cancers other than leukemia is strongest for brain cancer. Kheifets et al. (1995) performed a meta-analysis of 29 reports of brain cancer and found statistically significant elevations for electrical engineers, welders, and power station workers. Rodvall et al. (1998)

investigated glioma and meningioma in Sweden in relation to job title and reported only non-significant elevations of both cancers in relation to measured magnetic fields. Villeneuve et al. (2002) also reported only non-significant elevations in rates of overall brain cancers in relation to residential exposure to magnetic fields but found a highly significant relationship among men diagnosed with a specific brain cancer -- glioblastoma multiforme. A report from the International Agency for Research on Cancer found a 1.67-fold elevation in risk of gliomas (one type of brain cancer) in relation to exposure to ELF-EMFs based on a job exposure matrix (Turner et al., 2014).

The evidence for a relation between magnetic field exposure and breast cancer is relatively strong in men (Erren, 2001), and some (Kliukiene et al., 2004) but not all (Schoenfeld et al., 2003) studies show female breast cancer also to be significantly elevated with increased exposure. Peplonska et al. (2007) found increased risk of breast cancer in women occupationally exposed to elevated magnetic fields. A meta-analysis by Zhao et al. (2014) reported a statistically significant 1.25-fold elevated risk of breast cancer in post- menopausal women.

Overall, the weight of evidence shows that magnetic fields increase the risk of leukemia in children and there is suggestive evidence that magnetic fields also increase risk of leukemia, brain and breast cancers in adults. It is very difficult to get good exposure assessment in large groups of adults to ELF-EMFs since there are so many different sources and adults move around in their environment more than children do. Behrens et al. (2004) showed that much of the ELF exposure in homes comes from household appliances, and only Feychting et al. (1997) have been able to evaluate the effects of both residential and occupational exposures. Thus studies that look only at one source of exposure will underestimate the actual risk from total exposure As with any other hazardous exposure, one would expect that the level of harm will be a function of the intensity of all aggregate exposures and the duration of exposures. Because it is so difficult to do an accurate exposure assessment for total ELF exposure, even the less than totally consistent results for adult cancer suggest that excessive exposure to ELF-EMFs increases the risk of several kinds of cancer.

It is not only cancer risk that is increase upon ELF exposure. There is also a building body of evidence that Alzheimer’s Disease is elevated among people with excessive ELF exposure. Qiu et al. (2004) and Feychting et al. (2003) both found a statistically significant elevated risk of Alzheimer’s Disease with ELF-EMF exposure at approximately two or three times the incidence in a control population. Roosli et al. (2007) looked at neuro-degenerative diseases among Swiss railway employees exposed to magnetic fields. For every 10 μT years of cumulative exposure the authors found Alzheimer’s disease risk to increase by 9.4%. No elevated risk was found for Parkinson’s disease or multiple sclerosis. Garcia et al. (2008) analyzed 14 different studies of EMF exposure and Alzheimer's disease and found a consistent pattern of

elevated risk. Huss et al. (2008) reported on deaths from neurodegenerative diseases among Swiss people who live near to power lines. They found a dose-dependent increase in risk of Alzheimer's Disease. People living within 50 m of a power line had a 1.51-fold increased risk of Alzheimer's after five years residence and this increased to 1.78-fold after 10 years and 2-fold after 15 years.

Several national and international organizations have reviewed these data and have published conclusions.

1) The US National Academy of Science, National Research Council report (1997) stated that the link between power line wire-code rating and childhood leukemia "is statistically significant (unlikely to have arisen from chance) and is robust" in the sense that removing a study from the group does not alter the conclusion that an association exists. "Wire-code rating" was a surrogate way in which magnetic fields were measured in some early studies.

2) The introduction to the National Institute of Environmental Health Sciences EMF-RAPID program (1999) report summarized: "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. While the support from individual studies is weak, the epidemiological studies demonstrate, for some methods of measuring exposure, a fairly consistent pattern of a small, increased risk with increasing exposure that is somewhat weaker for chronic lymphocytic leukemia than for childhood leukemia."

3) The 2007 World Health Organization report, while questioning the experimental evidence of mechanism, stated that the epidemiological data "show an association between ELF magnetic field exposure and an increased risk of childhood leukemia."

4) In 2002 the International Agency for Research on Cancer (IARC, 2002), a part of the World Health Organization, rated ELF-EMFs as a possible human carcinogen (2B), based on the human evidence referenced above. They recognized "limited" evidence for ELF exposure and increased risk of childhood leukemia. One of the reasons it was not a stronger rating was that there was no convincing evidence that ELF causes cancer in animals at that time.

The conclusion that non-ionizing EMFs can cause harm to humans has been viewed skeptically by physicists and engineers, who believe as a matter of faith that the energy level in ELF-EMFs is too low to cause human harm unless they are associated with tissue heating. EMFs of sufficient intensity and frequency can cause tissue heating, as one gets in a microwave oven, if the intensity is sufficiently high. But the intensities associated with electricity do not cause measurable heating. Thus, the epidemiological ELF-childhood leukemia evidence was discounted by some from the hard science

community who believed that the only way ELF or RF EMFs could cause human health effects would be by tissue heating. This is demonstrably not the case.

STANDARDS:

The US does does not have any federal health-based standards for power-frequency magnetic fields. The International Commission on Non-ionizing Radiation Protection (ICNIRP), a self-appointed NGO to the World Health Organization, has a standard of 1000 mG (100 μT). New York State established a standard of 200 mG at the edge of the right-of-way around high voltage powerlines at the conclusion of the New York State Powerlines Project in 1987, because this was the highest level at existing powerlines. The Bioinitiative Report (www.bioinitiave.org; Carpenter and Sage 2008) recommended a safety limit of 2 to 5 mG for all and 1.5 mG for children under the age of 5 years. They recognized that even these low levels may not adequately protect human health, especially of children.

RECOMMENDATIONS FOR REDUCING EXPOSURE TO ELF-EMFs:

Do not place powerlines carrying high current near to homes where children live, schools or day-care centers.

Do not use electric blankets or pillows when in bed.

Do not use hair dryers, especially on children.

CONCLUSIONS:

Exposure of humans to elevated magnetic fields causes cancer, especially leukemia in children but also other cancers in adults and elevates risk of other diseases such as Alzheimer's.

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