



Risk in Perspective

Workers, EMFs, and Cancer

Over the last year, numerous stories in the print and electronic media have highlighted electric and magnetic fields (EMFs) as a possible cause of human cancer. Readers may recall reports about three specific types of cancer: leukemia, brain cancer, and breast cancer. These news stories followed publication of large-scale, epidemiologic studies of workers exposed to EMFs on the job.

In this expanded issue of *RISK IN PERSPECTIVE*, we discuss how the new human studies published in the last year contribute to the overall weight of evidence about EMFs and human cancer. Our assessment is based on a review of the related literature and discussions with HCRA's Advisory Committee on EMF and Human Health, a distinguished panel of scientists (named on the last page) from the fields of medicine, public health, engineering, biology, physics, and risk analysis. While there are significant differences of opinion on this issue among responsible scientists, including members of the HCRA panel, there are also important points of agreement about what is known and not known, and about what can be learned through future research.

Interest in the relationship between EMF and cancer was triggered in 1979 when an association was reported between utility wire configurations outside homes and the occurrence of childhood leukemia. This report, supported by some later reports, generated considerable scientific debate and public concern. Since then, numerous laboratory and human studies have been launched to study the possible health effects of low level EMFs, many of which are still in progress. It has been estimated that the public and private sectors in the U.S. are now spending \$25 to \$30 million per year on research into EMFs and human health.

WHY STUDY WORKERS?

If EMFs in homes are "potent" enough to cause leukemia in children (a hypothesis still under intense study), then it is prudent to examine whether more highly exposed workers are experiencing adverse health effects from EMFs on the job. Employees in the utility and manufacturing sectors of the economy are logical groups to study because they are exposed to various patterns, frequencies, and magnitudes of EMFs. Almost all of the chemicals known to cause cancer in people were identified through studies of exposures to workers. Scientists also find it easier to study workers than residents because of the health and demographic information that some businesses can supply to researchers.

If EMFs are not shown to cause cancer in adult workers, it is still possible that EMFs could cause childhood cancers. Not only is it possible that children are particularly susceptible to carcinogenic stimuli, but childhood and adult leukemia may be subtly different diseases with potentially different causes. New epidemiologic studies of children and adults exposed to EMFs at home are in progress and should be published in the years ahead.

ADULT LEUKEMIA

Leukemia in adults is an uncommon and often fatal form of cancer. The available treatments for the disease are not very effective. Roughly 1 in 10,000 Americans is diagnosed with leukemia each year. The most common forms of the disease are acute myeloid leukemia (AML), chronic myeloid leukemia (CML), acute lymphocytic leukemia (ALL), and chronic lymphocytic leukemia (CLL).

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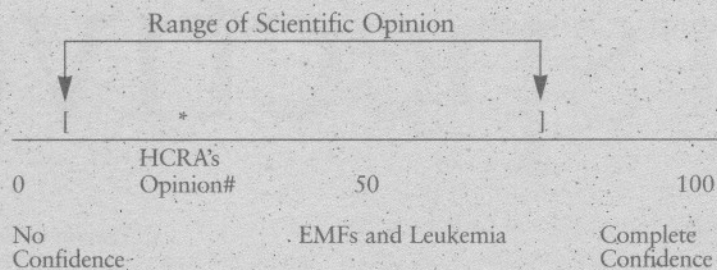
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DO EMFS CAUSE LEUKEMIA?

On a scale of 0 - 100, how confident are scientists that exposure to EMFs on the job is a cause of leukemia?



#The range reflects the breadth of viewpoints on HCRA's Advisory Committee on EMF and Human Health.

Despite decades of study, little is known about what causes leukemia. The disease arises from the hematopoietic (or blood cell forming) stem cells of the bone marrow. There is an interruption of normal cell differentiation in bone marrow cells and uncontrolled cell proliferation, causing abnormal cells in the marrow to accumulate and spill out into the peripheral blood system.

The only known environmental causes of adult leukemia are large acute exposures to ionizing radiation and certain chemicals, such as benzene. (The inheritance or acquisition of a number of diseases, such as Down's syndrome, is also associated with an increased risk of developing leukemia.) Less is understood about the potential relationship between chronic exposure to low levels of these environmental agents and the onset of leukemia. It has proven very difficult to devise good animal models of the leukemia disease process in the laboratory, thereby retarding biological understanding of the disease. Many hematologists who study and treat patients with leukemia do not regard EMFs as a plausible cause of the disease. They are more impressed with the hypothesis that particular viruses and/or genetic factors may explain the occurrence of leukemia. But clinicians are the first to acknowledge that they may perform better as healers than as researchers.

In the epidemiologic literature on EMFs and cancer, many types of cancers are studied, but leukemias are the most frequently reported disease. About half of the 30 or so published studies examining EMF and leukemia (including the first positive report

of leukemia in the workplace in 1982) have found a higher rate of various forms of leukemia among men in occupations with presumed exposure to EMFs. Many of these excesses are statistically significant by conventional measures, particularly when subgroups of exposed workers are examined for specific types of leukemia. The associations appear to be stronger for acute leukemia (particularly AML), but some studies also report associations with chronic leukemia. The associations are more consistent for certain occupational categories such as lineman, electrical engineers, and electricians. The magnitudes of the excess risks (technically called "relative risks or RRs") are typically modest, ranging from near 1.0 to 2.0. A RR = 1.5 implies that exposed workers experience 50% more cases of disease than other workers (or than members of the general adult population). The RR represents the best estimate of excess risk based on the study data, with the statistical uncertainty in the result expressed as the 95% confidence interval or CI. (The 95% CI estimates a range of values in which we are 95% certain that the "true" RR value lies, assuming that the data and models are unbiased.)

In the last year, three new studies reported information on EMFs and leukemia among workers. These studies are larger, better designed, contain more information on measurement of EMF exposure and potential confounding factors, and are more carefully documented than the previous studies. Yet, in light of the fact that leukemia is a rare disease in adults, even these larger studies have limited power to detect increases in this disease. The results of the new studies are not very consistent.

Theriault and colleagues studied 223,000 utility workers in Canada and France. For workers who had more than the median cumulative exposure to magnetic fields, they report excess risk for acute nonlymphoid leukemia (RR = 2.4; CI = 1.1 - 5.4) and AML (RR = 3.2; CI = 1.2 - 8.3). Clear dose-response relationships were not observed, and the results were not consistent across the three utilities in the study.

Armstrong and colleagues used a different measure of exposure ("pulsed" EMFs) in a study of two of the three utilities studied by

Theriault and colleagues. They found no association between pulsed EMFs and leukemia (RR = 0.7; CI = 0.4 - 1.2), although an unexpected association with lung cancer was reported.

Savitz and colleagues examined a population of 138,000 men from five electric power plants in the United States. They found no association between indices of magnetic field exposure and leukemia mortality in exposed occupations in general (RR = 1.1; CI = 0.6 - 2.1), although work as an electrician was associated with a 2.5 fold elevation in leukemia after 20 years of employment.

Overall, the available human data on EMFs and leukemia are too inconsistent to establish a cause-and-effect relationship, but there is enough evidence of association to raise concern. There is relatively little biological data to support the hypothesis that EMFs, by themselves, can cause leukemia. Some research investigators believe that the measured levels of EMF energy absorbed by the human body in household and occupational settings are far below what would be required to disrupt chemical bonds in the DNA, as would be required to cause leukemia or other cancers. Large-scale animal tests of EMFs are underway, as well as testing of tumor promotion hypotheses and effects on cell signaling, but there is no strong basis for believing that experimentalists will be able to resolve this issue in the near future.

BRAIN CANCER

Cancer of the central nervous system (brain and spinal cord) is also uncommon, with incidence in the U.S. now at about 6 in 100,000 per year. Primary central nervous system tumors are a diverse group of neoplasms that develop after transformation of cells within the brain or spinal cord. Because of their location within the skull and proximity to delicate brain structures, brain tumors may cause severe neurologic problems as well as death.

The causes of the disease are largely unknown and there are few known risk factors. Many of the factors associated with an increased risk for other types of cancer, such as smoking, diet, or excessive alcohol intake, have not been found to correlate with primary brain tumors. Ionizing radiation to the

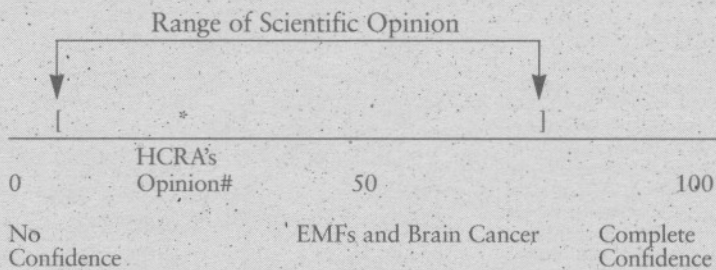
scalp is a known risk factor for brain cancer, but there is little or no evidence from direct biological experiments suggesting that non-ionizing radiation may be a risk factor.

Epidemiologists have examined whether EMFs are associated with brain cancer, but the body of data is smaller than exists for leukemia. While several early studies failed to reveal positive associations, others reported modest elevations in the risk of brain cancer among exposed workers. The RRs reported in some studies were 2.0 and greater among workers exposed to EMFs.

Three new studies reported in the last year examined the brain cancer hypothesis. Theriault and colleagues found that workers with the highest cumulative exposure to magnetic fields had an elevated risk of brain cancer (RR = 1.95) that was not statistically significant (CI = 0.8 - 5.0). Armstrong and colleagues found a similar association between pulsed EMF exposure at the highest cumulative exposure level and brain cancer that again was not statistically significant (RR = 1.9; CI = 0.5 - 7.6). Savitz and coworkers reported a consistent association between indices of magnetic field exposure and brain cancer. The relative risk of mortality from brain cancer was 2.3 (CI = 1.2 - 4.6) in the category of workers with the highest exposure to magnetic fields. The most persuasive aspect of the Savitz finding was some evidence of a dose-response relationship between amount of EMF exposure and risk of brain cancer. When compared to the general population, there was no overall excess brain cancer among the 138,000 workers in the study population.

DO EMFS CAUSE BRAIN CANCER?

On a scale of 1 - 100, how confident are scientists that exposure to EMFs on the job is a cause of brain cancer?



#The range reflects the breadth of viewpoints on HCRA's Advisory Committee on EMF and Human Health.

TABLE 1. Mortality in relation to magnetic field exposure: US Utility Worker Mortality Study, 1950-1988

Exposure level (uT-years*)	Leukemia			Brain Cancer		
	No. of cases	RR#	95% CI#	No. of Cases	RR	95%CI
Total exposure						
0 - < 0.6	54	1.00		41	1.00	
0.6 - < 1.2	34	1.04	0.66-1.63	34	1.61	0.99-2.63
1.2 - < 2.0	35	1.13	0.70-1.82	26	1.47	0.84-2.56
2.0 - < 4.3	27	0.95	0.56-1.60	27	1.65	0.92-2.95
≥ 4.3	14	1.11	0.57-2.14	16	2.29	1.15-4.56

*uT-years = microtesla years, an index of magnetic field exposure.

#RR = rate ratio (adjusted for age, calendar year, race, social class, work status (active/inactive), polychlorinated biphenyl exposure, and solvent exposure); CI = confidence interval.

Source: Adapted from Savitz, DA and Loomis, DP, "Magnetic Field Exposure in Relation to Leukemia and Brain Cancer Mortality among Electric Utility Workers," *American Journal of Epidemiology*, 1995, 141:123-134.

Overall, the body of evidence on EMFs and brain cancer is sketchy. Although the lack of consistency in study findings precludes a confident cause-effect inference, the results of the Savitz study are likely to fuel greater interest in the hypothesis that EMFs can cause brain cancer. Ongoing animal tests may shed further light on this issue, but the biggest missing piece of the puzzle is a plausible biological mechanism to explain the positive associations reported by the epidemiologists.

BREAST CANCER

Annual incidence of breast (mammary) cancer among women in the United States is about 1 in 1000 and appears to be increasing. Male breast cancer is far less common. Numerous risk factors for breast cancer in women have been documented — such as breast cancer in a mother or sister, early onset of puberty and late onset of menopause, and late age at birth of first child — but the etiology of the majority of breast cancer in men and women remains unknown.

Several epidemiologic studies published in the early 1990s reported an excess of breast cancer among adult male workers exposed

to EMFs. The relative risk was as high as 6.0 — based on 13 reported cases — for some potentially exposed workers (electricians, telephone linemen, and electric power workers) in one study. Until recently, however, there has not been a large enough population of women employed in occupations with EMF exposure to facilitate study of breast cancers in females.

The hypothesis that EMFs can cause breast cancer (and other hormone-related cancers) is biologically interesting. EMFs might, for example, influence cancer risk through alterations in the normal nocturnal rise in melatonin production in the pineal gland in the brain. Experimental evidence indicates that an increase in melatonin levels may reduce the levels of estrogen, a hormone whose level is thought to play an important role in the induction of breast cancer. A decrease in melatonin production in the pineal gland from exposure to EMFs would result in an increase in estrogen in the system, which may, in turn, result in an increased risk of breast cancer.

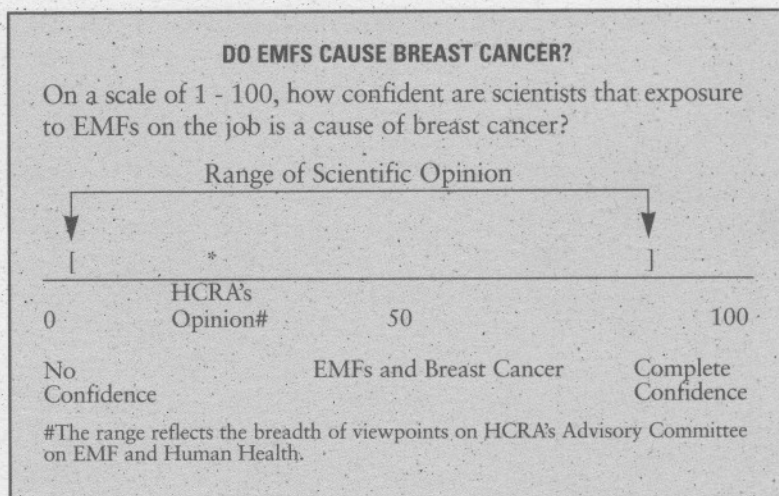
Animal tests have provided limited support for the EMF-breast cancer hypothesis. Experimentalists report substantial reductions in nocturnal pineal melatonin synthesis

in rats exposed to rapid time variations in an applied static magnetic field or to 60-Hz magnetic fields. Both types of field exposures induce electric currents in body tissues, and this effect appears to be related to altered pineal melatonin synthesis at night. Positive associations between magnetic field exposure and mammary tumors have been reported in rats, while a 60-Hz magnetic field has been shown to reverse the growth inhibition of human breast cancer cells by melatonin. There have also been other studies on melatonin, however, which have failed to show positive associations.

Interest in the breast cancer hypothesis has been fueled by recent publication of the first large epidemiologic studies of female workers exposed to EMFs. Loomis and coworkers found that women in traditional electrical occupations had a higher mortality risk from breast cancer compared to women in occupations without strong exposure to EMFs (RR = 1.4; CI = 1.04 - 1.8). Using a similar data set, Cantor and colleagues found a slightly elevated mortality risk for women with a medium level of exposure to EMF (RR = 1.1, CI = 1.03 - 1.2 for white women; RR = 1.29, CI = 1.1 - 1.5 for black women), but no significantly elevated risk at the high level of EMF exposure (RR = 0.97, CI = 0.8 - 1.2 for white women; RR = 1.19, CI = 0.7 - 2.1 for black women). Since the results of these studies are difficult to interpret and the data are crude (e.g., death certificate information and EMF exposure inferred from job title), it will be interesting to see what new insights future studies will bring to these findings.

PROSPECTS FOR SCIENTIFIC PROGRESS

If EMFs in the workplace do cause modest increases (i.e., RRs of 1.5 to 2.0) in the risks of leukemia, brain cancer, and/or breast cancer, it is unlikely that epidemiology alone will be able to establish such effects. Even large and well-designed observational studies of workers are unlikely to detect with consistency modestly elevated relative risks due to the inevitable sources of measurement error in epidemiology. There are some notable instances where epidemiologic discovery of carcinogens has preceded experimental confirmation and delineation of biological mechanisms (e.g., smoking and lung cancer, benzene and leukemia), but the



relative risks for these agents were typically well above 2.0.

Thus, while the need persists for continued improvements in epidemiology, it seems likely that a critical element in furthering scientific progress in this field is more biological understanding of the effects of EMFs and the operating mechanisms of action. The current biological database is incomplete and scientists disagree about whether such progress is likely.

Some scientists argue that low level ambient exposures to EMFs are unlikely to cause cancer because the energies imparted by such exposures are far below both those that cause damage by heating body tissue and those that damage DNA. Other scientists argue that disruption of normal cell growth and differentiation, recognized features of carcinogenesis, may be influenced by low level EMFs. There is some evidence that non-ionizing radiation (including very low intensity EMFs in the 50-60 Hz range) can affect cells, but studies using whole animals have indicated few adverse effects of long-term exposure to EMFs. There has been little reproducible evidence of chromosomal damage caused by exposure to EMFs. If EMFs do play a role in cancer formation, it may be as promoters or co-promoters after the process is initiated by exposure to chemical substances. At the cellular level, numerous studies have demonstrated various biological responses following exposure to EMFs, but it remains unclear how they may contribute to the carcinogenic process. The results of these studies have also been inconsistent, and many have yet to be replicated.

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FURTHER READING:

Armstrong B, Theriault G, Guenel P, Deadman J, Goldberg M, and Heroux P, "Association between Exposure to Pulsed Electromagnetic Fields and Cancer in Electric Utility Workers in Quebec, Canada, and France," *American Journal of Epidemiology*, 1994, 140:805-820.

Cantor KP, Dosemeci M, Brinton LA, and Stewart PA, "Correspondence Re: Breast Cancer Mortality Among Female Electrical Workers in the United States," *Journal of the National Cancer Institute*, 1995, 87:227-228.

Loomis DP, Savitz DA, and Ananth CV, "Breast Cancer Mortality Among Female Electrical Workers in the United States," *Journal of the National Cancer Institute*, 1994, 86:921-925.

Savitz DA and Loomis DP, "Magnetic Field Exposure in Relation to Leukemia and Brain Cancer Mortality among Electric Utility Workers," *American Journal of Epidemiology*, 1995, 141:123-134.

Theriault G, Goldberg M, Miller AB, Armstrong B, Guenel P, Deadman J, Imbernon E, To T, Chevalier A, Cyr D, and Wall C., "Cancer Risks Associated with Occupational Exposure to Magnetic Fields among Electric Utility Workers in Ontario and Quebec, Canada, and France: 1970-1989," *American Journal of Epidemiology*, 1994, 139:550-572.

One key issue complicating the investigation of exposure to EMFs is the question of how to measure them. Not only is there imprecision in the technology currently used to assess EMFs in the field, there is also disagreement over what constitutes exposure and what elements the exposure monitors should be measuring. EMF is a very broad category, and scientists contend that any effects seen in epidemiologic or laboratory studies may depend on what elements of electric and/or magnetic fields (e.g., wavelength or frequency, intensity of the field, degree of polarization, whether the field is continuous, intermittent, or transient) are being measured, and what exposure parameters (such as time-weighted average, peak field levels, or lifetime exposure) are being investigated. Each element may play a role in the potential impact of EMFs, yet there is little consensus on what parameters we should be capturing. In other words, scientists agree that how EMFs are measured may matter a lot, but they do not yet know which exposure measures, if any, are physiologically meaningful.

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