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Environmental Protection
Agency

Air And Radiation
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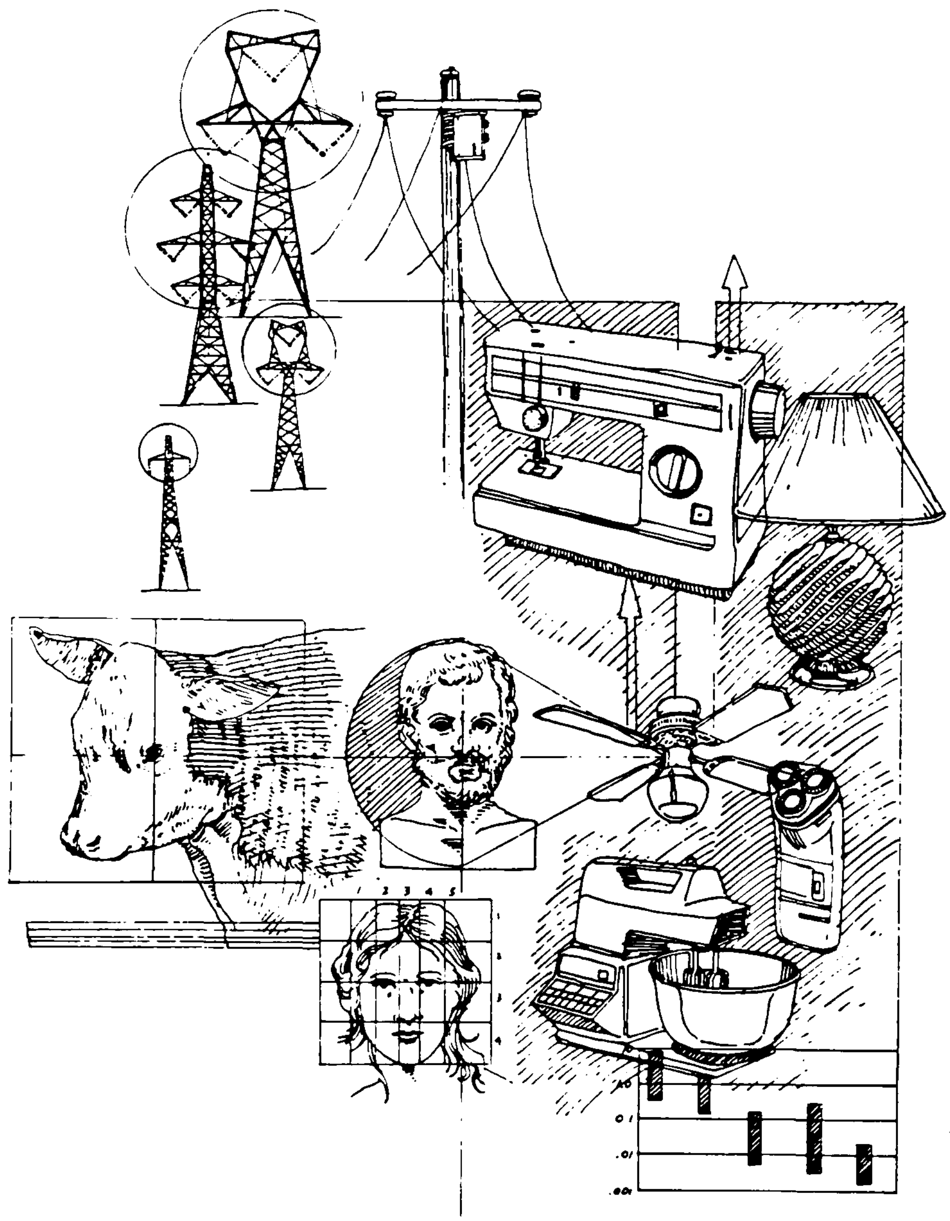
EPA

Electric And Magnetic Fields From 60 Hertz Electric Power

What Do We Know About Possible Health Risks?



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This brochure was written by Prof. M. Granger Morgan who is Head of the Department of Engineering and Public Policy and a Professor of Electrical and Computer Engineering at Carnegie Mellon University. He was assisted in the preparation of the brochure by Ms. Connie Cortes, Ms. Wendy Davis, Prof. Baruch Fischhoff, Dr. Keith Florig, Mr. Gordon Hester, Prof. Jim Hoburg, Prof. Lester Lave, Dr. Indira Nair and Dr. Emilie Roth, all of Carnegie Mellon University, and by Dr. Paul Slovic and Dr. Don MacGregor of Decision Research (Eugene, Oregon). While the author and his associates are solely responsible for the contents of this brochure, thanks are due to the following for assistance with reviews: Dr. Anita Curran, Mr. Jack Lee, Prof. Kai Lee, Mr. Hamilton Oven, Prof. Gilbert Omenn, Mr. Jack Sahl, Prof. David Savitz, Dr. Asher Sheppard, Dr. Maria A. Stuchly, Prof. Ola Svenson, Mr. Richard Tell, Ms. Susan White, Ms. Susan Wiltshire, Dr. Nancy Wertheimer, and several dozen non-expert concerned citizens. The drawings in the brochure were done by Frederick H. Carlson.

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What is the point of this brochure?

There are electric and magnetic fields wherever there is electric power. This means there are fields associated with big and small power lines, wiring in homes and places of work, and all electrical appliances. Increasingly scientists, regulators and lay people are asking whether human exposure to these fields involves risks to health or the environment. A lot of good scientific research has now been done. However, because the biological effects of fields are complicated and still not fully understood, answers to simple questions about whether there are risks are not straightforward. This brochure discusses in non-technical language what is known, what is still not known, and things that might be done about this potential risk. We have tried very hard to be balanced in our treatment, but we have not avoided expressing judgments or opinions when we think that is necessary. The brochure is long, and sometimes a little complicated, because the subject is complicated.

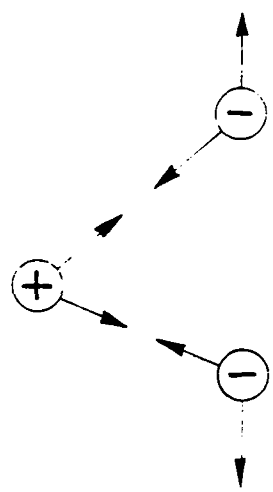
Why is it called 60 hertz electric power?

The electric power that we use in our homes, offices and factories uses AC, or alternating current. This is in contrast to the DC, or direct current, that is produced by batteries. An alternating current does not flow steadily in one direction. It alternates back and forth. The power we use in North America alternates back and forth 60 times each second. Scientists call this 60 hertz (Hz) power. In Europe and some other parts of the world the frequency of electric power is 50 Hz rather than 60 Hz.

What are 60 Hz electric and magnetic fields?

They are fields associated with 60 Hz power. These fields are created by electric charges. Charges produce two kinds of fields; *electric fields* which result just from the strength of the charge and *magnetic fields* which result from the motion of the charge. Taken together these are often referred to as electromagnetic fields.

Electric fields represent the forces that electric charges exert on other charges at a distance *because they are charged*. You may recall from school that charges with



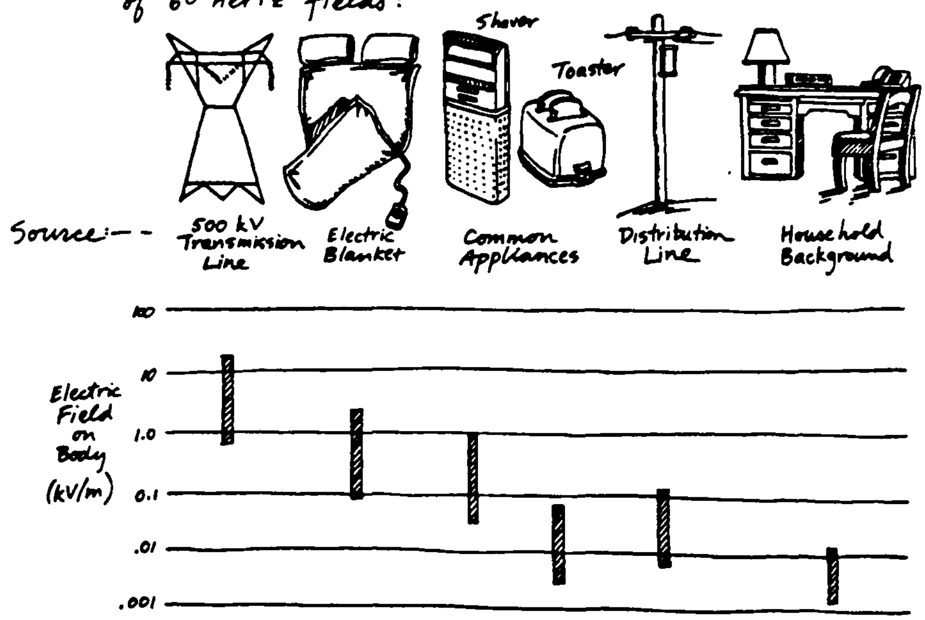
the same sign (two positive charges for example) repel each other. Dissimilar charges (a positive and a negative charge) attract each other. These forces of attraction or repulsion are carried from charge to charge through space by the electric field.

When charges move they create additional forces on each other. These additional forces are carried through space by magnetic fields. A magnetic field represents the forces that a moving charge exerts on other moving charges *because they are moving*. A group of charges all moving in roughly the same direction is called an electric current. All currents produce magnetic fields.

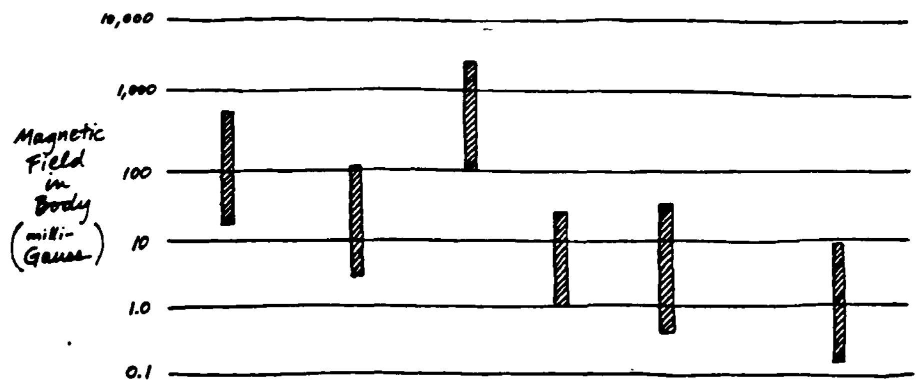
Electric fields begin on positive charges and end on negative charges. Magnetic fields form closed continuous loops around currents. Everything that has an electric charge has fields associated with it. Hence, electric and magnetic fields are found throughout nature and in all living things. The magnetic field of the earth, which makes a compass needle point north, is made by flowing charges, or currents, in the earth's molten interior. The molecules in our bodies and in all other living and non-living things are held together by fields. The messages that flow in our nervous systems involve fields. When you get a shock from static electricity by touching someone on a rug on a dry winter day, the spark is caused by strong electric fields from the many charges you have picked up from the rug (in more humid weather these charges from the rug leak off, so they don't build up as much).

Fields may be steady (DC) or they may change their strength and direction regularly in time (AC). Sixty Hz electric power involves charges which move in currents that have a frequency of 60 Hz. Thus, *all* 60 Hz power produces electric and magnetic fields that change their strength and direction with a frequency of 60 Hz. For example, wiring and appliances in the home and office produce such fields. Because 60 Hz power is so widely used in our modern society, there are 60 Hz electric and magnetic fields almost everywhere we go.

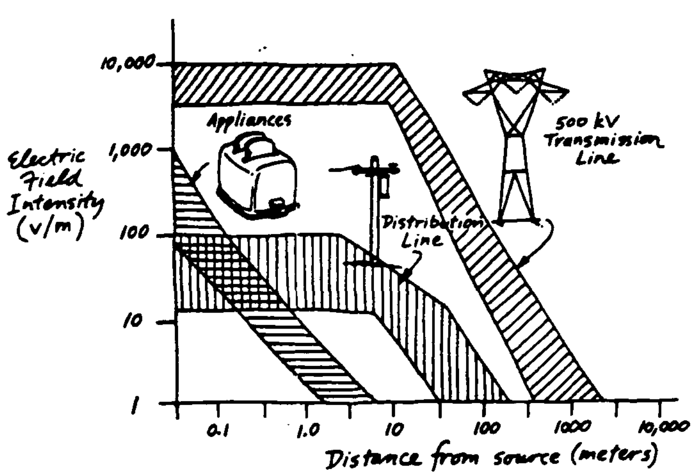
Approximate strength of the average electric field at the surface of the body produced by several common sources of 60 hertz fields:

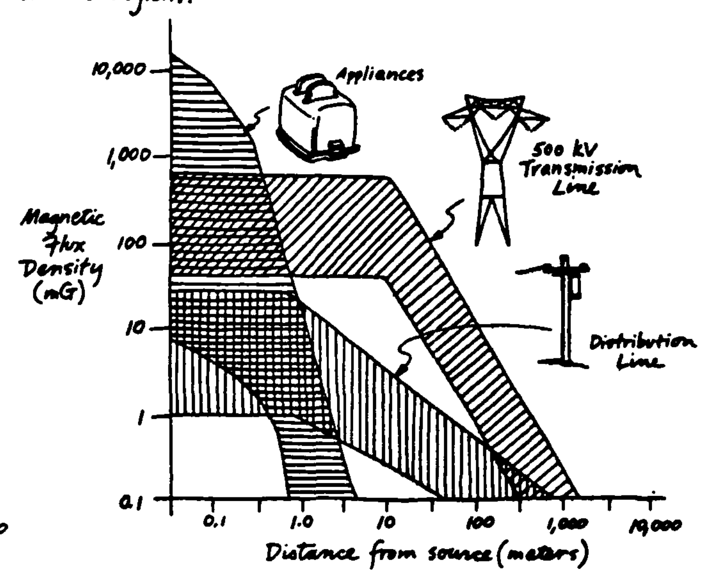


Approximate strength of the average magnetic field produced within the body by several common sources of 60 Hertz fields:



The strength of the electric or magnetic field at different distances from power lines and appliances lies somewhere in these shaded regions.





Do fields get weaker as you move away from electrical objects?

Yes, the strengths of electric and magnetic fields diminish as you move away from electrical objects just as the light from a candle grows dimmer as you move away from it or the heat from a campfire falls off with greater distance. The drawing to the left shows roughly how the strengths of fields decrease with distance from transmission lines, distribution lines, and household appliances. The different patterns result from the different electrical properties of the objects.

What else affects the strength of a field?

The strength of an electric field depends on the voltage of the object creating it. For example, a high voltage power line usually produces stronger electric fields than a low voltage power line. Current does not have to be flowing in the object for an electric field to exist. Thus, a toaster or an electric blanket that is plugged in, but not operating, may still produce an electric field.

Currents produce magnetic fields. Stronger currents produce stronger fields. For example, the magnetic field generated by a hair dryer will be higher when the dryer is operated on its "high heat" setting (when it draws lots of current) than when it is operated on its "low heat" setting (when it draws much less current). However the electric field from the dryer will be about the same in both cases since the electric field comes from the amount of charge (voltage), not from the movement of charge (current). Since magnetic fields are created only when current is flowing, appliances which are plugged in but turned off do not produce magnetic fields.

Fields and currents that occur at the same place can interact to add or subtract. Thus the strength of the electric and magnetic fields associated with objects like power lines, wiring, and appliances depends upon things such as the location of the object, the location of other near-by objects, and the electrical conditions of use. Some details are provided in the box on the next page.

Magnetic fields pass through most common objects without being significantly affected. Electric fields are affected by objects, especially objects that can conduct electricity. Some of the field lines can end on charges in the object. For example, things like trees or a garden gazebo can partially block or shield out electric fields from a power line. Normal houses can also partially shield electric fields. The amount of shielding varies somewhat with construction material. A typical house shields about 90% of the electric field from outside. If such a house is next to a power line that makes an electric field of 1 kV/m[1] just outside the house, the electric field inside the house will be only about 10% as large or about 100 V/m. The fraction of the electric field that a house blocks can be increased with the proper use of shielding materials such as grounded aluminum roofing and siding.

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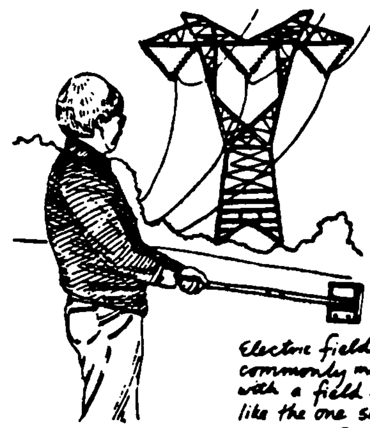
[1] kV/m = 1000 volts/meter. (See the question "How are fields measured?" in the box on page 6 for a discussion of the units in which electric and magnetic fields are measured.)

More Details About 60 Hertz (Hz) Electric And Magnetic Fields.

How are fields measured?

The strength of 60 Hz electric and magnetic fields can be measured with special instruments. The words used in describing measurements of field strength sound technical, but the basic ideas are no more complicated than measuring weight in pounds or distance in miles. The strength of an electric field is measured in units of volts per meter, abbreviated V/m. When the field is strong, larger units of a thousand volts per meter or "kilo" volts per meter are used. This is abbreviated as kV/m. Several different units are commonly used to report the strength of magnetic fields. The two most common units are the gauss and the tesla. Like gallons and ounces or miles and feet, gauss and tesla are just different units for measuring the same thing. The gauss is a fairly large unit so magnetic field strength is often reported in thousandths of a gauss or "milli" gauss (abbreviated mG). There are 10,000 gauss in one tesla. In this brochure we will use gauss.

A number of electric utility companies now own field measuring instruments and are willing to send trained technicians to make measurements in homes or other locations for concerned customers. There are also a number of engineering consulting firms that make measurements as a commercial service. Your local utility should be able to identify the ones nearest to you. Before you go to any significant effort to get measurements made, ask yourself what you will do with the information once you have gotten it.

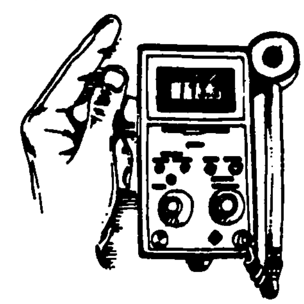


Electric fields are commonly measured with a field meter like the one shown at left. Since the human body is a conductor which can distort the field, the meter is held on a large insulating stick in order to get a measurement of the "unperturbed" electric field.

Can the strength of fields be calculated or does it have to be measured?

In simple situations, like a transmission line crossing an open field, field strengths can be calculated very accurately using formulas from physics and electrical engineering. Such calculations are often done in designing or approving transmission lines. In more complex settings it may be harder to compute the fields because of the complex shapes of some of the objects involved, or because the patterns of currents and voltages are complex. In these cases, it may be easier just to measure the field rather than to try to calculate it.

Magnetic fields are usually measured with a simple coil and a meter such as those shown to the right. Since the presence of the human body does not distort the magnetic field, the meter can simply be held in the hand. Recently, miniaturized field instruments have been developed. These instruments are small enough to be easily carried around in a pocket, or even worn like a watch.



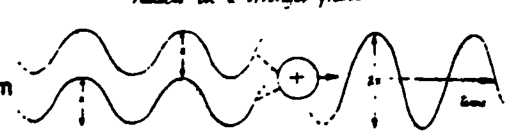
Can fields add together or cancel each other out?

Yes. Fields can add to and subtract from each other. Suppose we have set up two separate 60 Hz electric fields at the same place in space. Each has a strength of 4 V/m (volts per meter) and they are exactly in phase, that is, they are alternating in strength and direction *together* at 60 Hz. If we measure the field we will measure 8 V/m. The two 4 V/m electric fields have added. On the other hand, if the two fields are exactly out of phase, that is if one reaches its greatest strength in one direction exactly when the other reaches its greatest strength in the reverse direction, we will measure a field of 0 V/m, because the two fields will cancel. This same kind of adding and subtracting also works for magnetic fields.

Can 60 Hz fields make currents flow in objects or change their voltage?

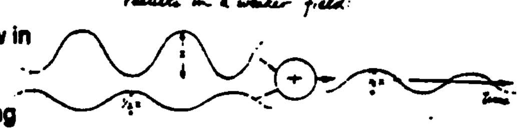
Yes. Sixty Hz electric and magnetic fields move charges in conducting objects (including our bodies). This makes currents flow. Such redistribution of charges can also change the voltage of an object. Strong fields "induce" stronger changes than weak fields.

Combining two 60 Hertz fields that go up and down together (in phase) results in a stronger field.



If you touch a conducting object that carries an induced voltage, a "contact current" will flow. If it is large enough you will get a shock. Contact currents from most electrical devices, such as refrigerators or other appliances, are usually too small to feel. Occasionally, they are large enough to be noticeable. For example, a high enough voltage might be induced on a long ungrounded fence wire that runs parallel to a high voltage transmission line to give someone an electrical shock. Similarly, a large rubber-tired farm vehicle parked under a transmission line might give an operator a shock when he first touches it. There are safety regulations which control the field strengths of transmission lines to limit such "induction effects" in order to guard against injury or accidents. Responsible utilities also take steps to correct unsafe situations along their high voltage transmission lines and to inform people who work and live along such lines about safe practices.

Combining two 60 Hertz fields that go up and down oppositely (out of phase) results in a weaker field.



Our bodies are conducting. Hence, whenever we are in a 60 Hz field, currents will flow in our bodies because of induction. The patterns of current flow induced by electric and magnetic fields are different. In the case of electric fields, the size of the current also depends on whether and how the body is grounded. Except when we are in very strong fields, the currents that are directly induced are typically small when compared with the contact currents we get when we touch large appliances such as a refrigerator.

Are 60 Hz fields like X-rays or microwaves?

Not really, although they are all forms of electromagnetic energy. X-rays (and other forms of "ionizing radiation" such as gamma rays) produce effects in living systems because the energy carried by the X-rays is so large that it can break molecular bonds. It can actually break apart DNA, the molecules that make the genes. This is the way X-ray exposure can lead to cancer. However, the energy carried in 60 Hz fields is *much* too small to break molecular or chemical bonds.

Microwaves do not carry enough energy to break chemical or molecular bonds but they are absorbed by the water in tissue where they can also set up strong currents. This causes heating. This heat is what makes a microwave oven work.[2] If a person like a maintenance worker gets right in front of a very powerful microwave antenna, such as some of those used for radar or communication, significant health damage can result from heating body tissue. There are safety standards designed to protect people from such exposure.

While 60 Hz fields can also set up currents in tissue, these currents are much weaker. The amount of heat they generate is trivial compared to the natural heat that comes from the cells of the body. There is no reason to believe that health effects can be caused by such minuscule amounts of heat.

For many years some scientists and engineers argued that because 60 Hz fields cannot break molecular or chemical bonds and cannot produce significant heat in the body they could not possibly produce significant biological changes or effects. As we explain below, this argument has turned out to be incorrect because there are other ways in which fields can interact with individual cells to produce biological changes. Whether these changes can lead to health risks remains unclear.

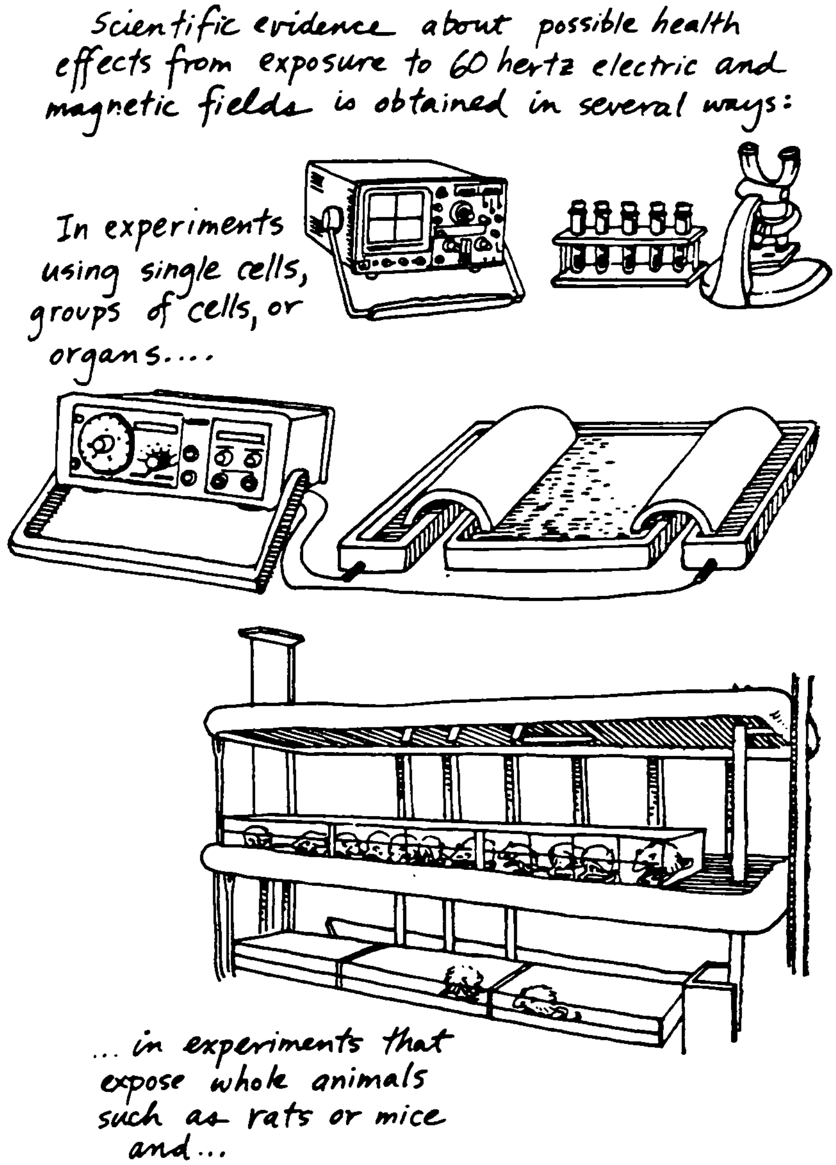
Do 60 Hz fields pose health risks?

The honest answer is that nobody knows for sure. Scientists have found that fields can produce a variety of biological effects, like changes in the levels of specific chemicals the body makes and changes in the functioning of individual nerve cells and the nervous system. Whether any of these changes can lead to health risks is less clear. We discuss many of the specifics in the sections that follow.

Scientists have also studied the statistics on death and disease for people who are exposed to fields in their normal course of living and work. Such studies are termed "epidemiological studies." Some of them suggest that there may be an association[3] between field exposure and certain forms of cancer. Other similar studies show no such association. The evidence is not conclusive.

[2]Modern microwave ovens are designed to keep all the microwaves inside. As soon as the oven turns off, the currents in the food stop. So, once the food is taken out of the oven it is just like any other cooked food. It has not "picked up" any radiation.

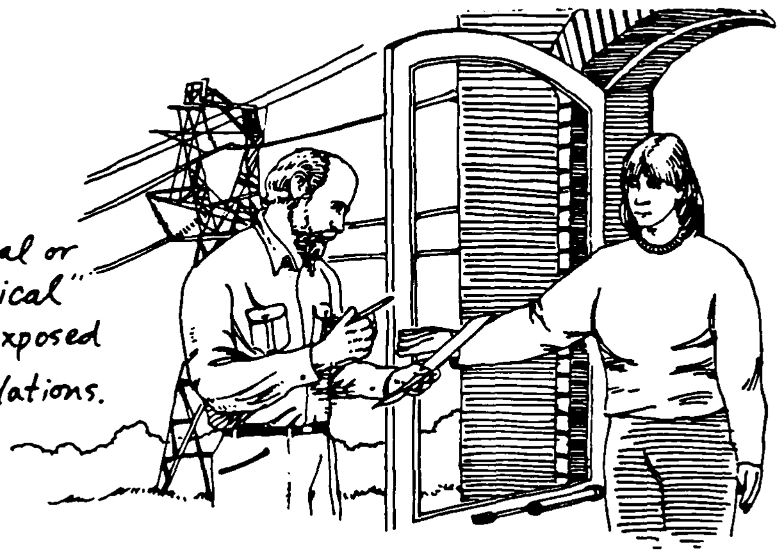
[3]In epidemiology the word "association" is not a synonym for "causes" or for "contributes to." It means that statistically the things occur together but not necessarily that one causes the other. A more complete discussion of this point occurs on page 17.



Some careful responsible scientists examine all the scientific evidence and remain unconvinced that there are any significant health risks from 60 Hz fields. Others, equally careful and responsible, look at the same evidence and conclude that there may be risks.

The disagreements result because the available scientific evidence is complex. Current knowledge is fragmentary and insufficient to explain everything that is observed. Responsible scientists can have legitimate disagreements about how the available evidence should be interpreted. Until more scientific studies are done, these disagreements will remain and simple yes or no answers to questions about possible health risks will not be possible.

As with many controversial technical problems, there are a handful of "experts" who are less careful and responsible than they should be. They are the source of the confident but contradictory statements you may have heard which make it sound like the experts are completely confused. These people complicate life because in addition to having to come to grips with a very complicated subject, lay people and public officials have to identify and sort out these biased experts from the majority who are careful and responsible.

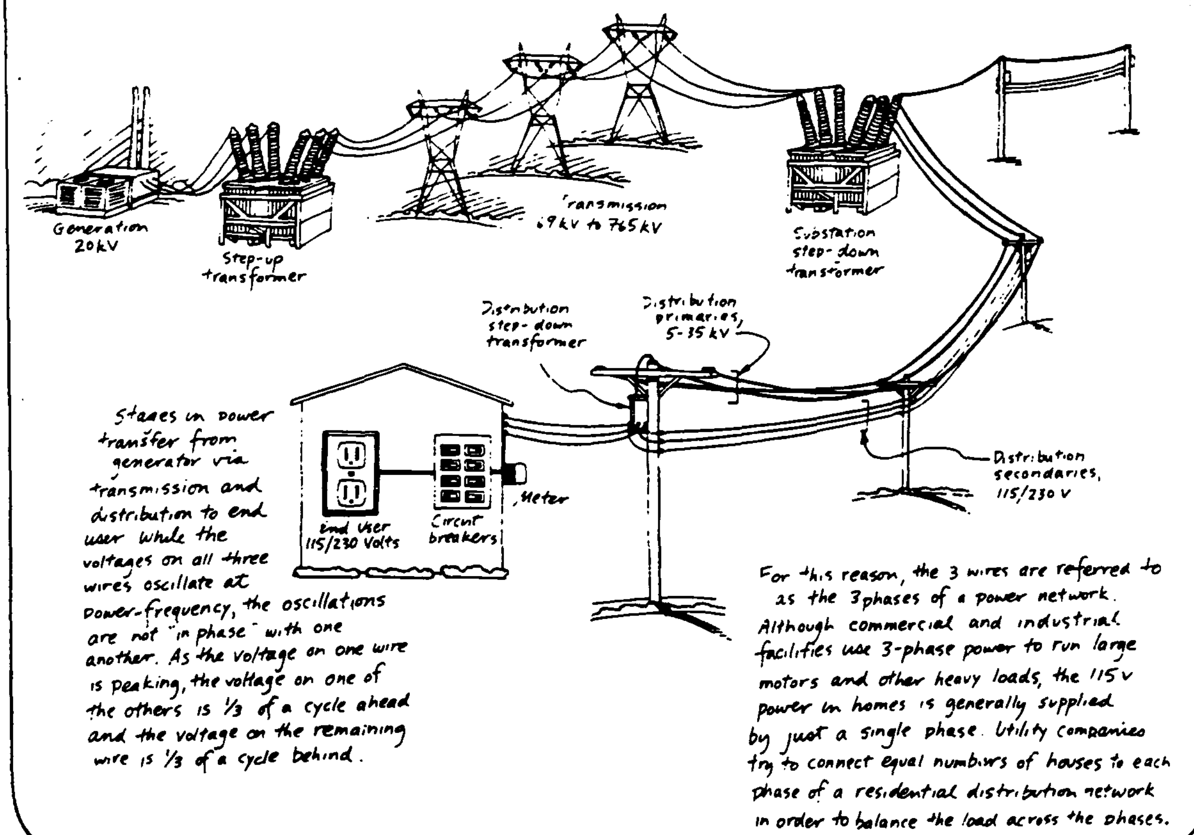


... in statistical or "epidemiological" studies of exposed human populations.

The electric power system.

Electric power is produced by large generating plants and then transferred to homes, businesses, and factories by a transmission and distribution system. Transmission lines use very high voltages and go long distances. Distribution lines consist of primaries which operate at intermediate voltages and serve a region and secondaries which bring power to individual homes. Transmission lines, and many distribution lines, use three "hot" wires. While the voltages on all three wires oscillate at 60 Hz, the oscillations are not "in phase" with one another. As the voltage on one wire is peaking, the voltage on one of the others is one-third of a cycle ahead and the voltage on the remaining wire is one-third of a cycle behind.

For this reason, the three wires are referred to as the three phases of a power network. Although commercial and industrial facilities use three-phase power to run large motors and other heavy loads, the 115V power in homes is generally supplied by just a single phase. Utility companies try to connect equal numbers of houses to each phase of a residential distribution network in order to balance the load across the phases. Throughout the system there are circuit breakers (not shown in the drawings) which will automatically disconnect if a short circuit or other safety problem occurs.

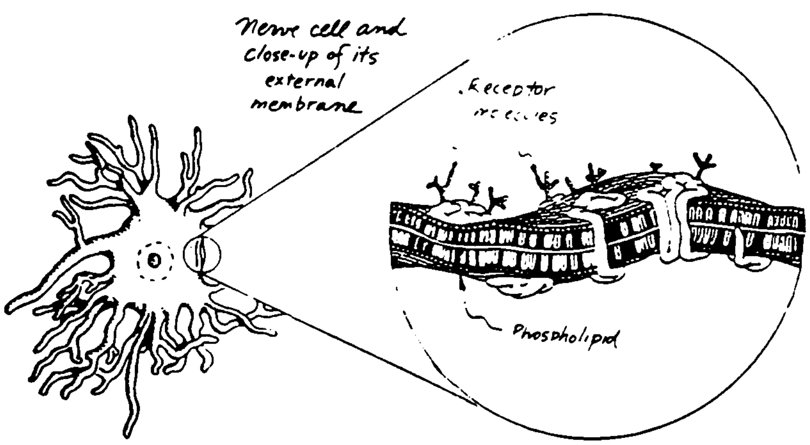


What kinds of studies of possible biological effects from 60 Hz fields have been done?

Basically three kinds of studies have been done: 1) laboratory studies that expose single cells, groups of cells, or organs to fields under a variety of conditions and look for effects; 2) laboratory studies that expose animals or humans to fields and look for effects in body function, chemistry, disease, or behavior; and 3) epidemiological studies of various human populations which look for an association between exposure to 60 Hz fields and various diseases.

You said that 60 Hz fields can have some biological effects. Just what do you mean by that?

There are two basic kinds of effects that have been observed. Strong electric fields can stimulate the skin of animals, by vibrating hairs or by triggering various sensors in the skin. If a person stands in an electric field of



more than about 20 kV/m he or she is likely to feel a slight tingling sensation. There have been a variety of studies which indicate that animals can also feel strong electric fields. People cannot sense the presence of magnetic fields.[4] While these "perception" effects are interesting, and have received quite a lot of research attention, few people ever spend time in fields that are strong enough to be felt.

Potentially more important results come from experiments which show that under certain circumstances fields can interact with the surfaces of cells and trigger changes inside these cells. Modern biology tells us that the surface of the cell is made up of a double layer of "phospholipid" molecules, similar to a double-layered soap bubble. In this "bi-layer" float various large complex molecules which act as receptors to communicate between the cell and its surroundings and to serve as channels that can move selected material into and out of the cell.

While the details remain unclear, a variety of experiments have shown that fields, even fairly weak fields, can interact with the cell surface, or with some of the receptor molecules in that surface, and produce changes in how the cell operates. The fields contain very little energy. In some way the cell surface or its receptors act as an amplifier to send a signal into the cell that can change things like the rate at which the cell makes hormones, enzymes and other proteins. These chemicals play roles in the operation of the cell and in signaling to other cells and tissues.

What kinds of specific findings have been reported from the laboratory studies?

While a number of biological effects have now been observed, they haven't been easy to find. Early studies of fields exposed large numbers of rats, mice and other animals, as well as various individual cells to see if anything happened. Most of these "screening studies" didn't find any differences between animals or tissues exposed to fields and those not exposed to fields. The few studies that did find interesting changes have been followed up with more detailed experiments. Effects that have been reported include: changes in the production of various chemical messengers, including chemicals like melatonin that are important in daily biological cycles called circadian rhythms, and chemicals called neurotransmitters which send signals between nerves; changes in the rate at which the genetic material DNA is made and in the rate of errors when RNA is copied from it; changes in the amount of calcium found inside or on the surface of cells; and changes in the rate of growth and cell division of some cells. While all of these effects may prove significant for our eventual understanding of how fields affect cells, it is important to understand that some of the experiments involve conditions that are very different from those that occur when people are exposed to fields.

Most studies have used individual cells or animals, but there have also been a few which have used people. Studies of people exposed to fairly strong fields in special exposure rooms have reported effects on heart rate and on reaction time. There is some indication that some people respond more than others. Some of the effects appear to be more pronounced when the fields are turned on and off repeatedly rather than left on continuously. Studies which have sent weak currents through volunteers with electrodes attached to their skin report no observed effects after exposures of several hours. Studies of people sleeping with electric blankets report changes in the level of the hormone melatonin.

All these different effects or biological changes are interesting. However, it is not clear if they have significant implications for people's health.

If you would like to look at some detailed reviews of the health effects literature you can find an introductory guide to reviews of that literature in the Appendix at the end of this brochure.

[4]There are exceptions. People can sometimes sense the presence of extraordinarily strong magnetic fields because these fields cause flashes of light in the eye. However, fields this strong are found only in laboratories and other special situations. Some animals have developed special exquisitely sensitive sense organs that can sense the presence of very weak electric or magnetic fields. These organs are used in navigation and in looking for prey. While they are very special, the existence of these organs makes it clear that at least some biological systems can be affected by very weak fields.

What about the studies of cancer?

There have been two kinds of "epidemiological" studies which have looked for an association between exposure to 60 Hz fields and cancer. The first set of studies has looked at the death rates from different diseases for people who are employed in "electrically related" occupations and compared them with the death rates from the same diseases for all other people. The second has compared the magnetic field exposures received by people with specific cancers, especially leukemia, with the exposures received by other similar people who did not have cancer. Most of these latter studies have involved exposure at home from power distribution lines (lines on the big poles in the street). The cancer that has been studied the most is childhood leukemia.

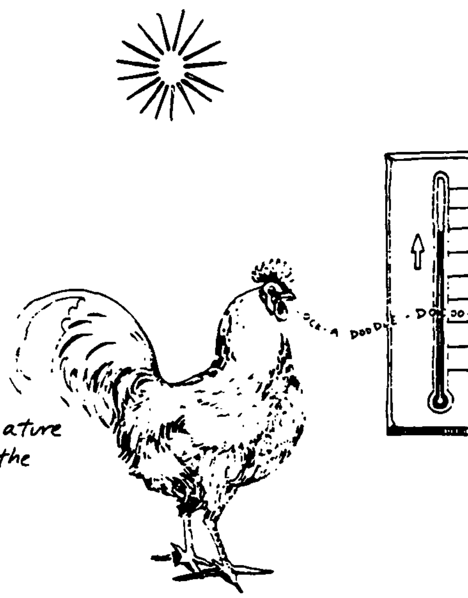
Some of these studies of both kinds have found a statistical association between increases in field exposure and increased cancer rates. As we discuss on the next page in an example involving roosters and sunrise, the phrase "statistical association" is not a synonym for "causes" or for "contributes to." Depending on the study and the type of cancer, the incidence of cancer in exposed populations may be up to two to three times higher than that experienced by unexposed or less exposed populations.[5] Most of these cancers are fairly rare, for example childhood leukemia affects about one in every 14,000 children per year or about 1 in 1,100 per lifetime. A two-fold increase would raise the incidence to one in 7,000 per year or 1 in 550 per lifetime.

Many investigators believe that if they play some role, fields alone will not turn out to cause cancer (i.e, fields will not be an "initiator"). Rather they are more likely to work together with one or more other environmental factors (i.e., fields will be a "promoter").

All of the epidemiological studies involve some level of statistical uncertainty. The results are summarized in the figure on the next page with bars that show "confidence intervals." Studies in which the confidence interval includes the result "no change in the rate of cancer incidence" are generally referred to as negative studies. The others are generally referred to as positive studies.

The two most widely discussed positive studies involve childhood leukemia. Both were conducted in the Denver, Colorado, area, the first by Nancy Wertheimer and Ed Leeper, the second by David Savitz and several colleagues. Both these two studies, which involve different groups of children, report an increase in the incidence of childhood leukemia in homes close to heavy duty distribution lines—the big wires found on the tops of many large poles in the street. Other studies demonstrate that these lines typically produce strong magnetic fields.

It is important to remember that the positive epidemiological studies show a statistical association. They cannot prove that fields are involved in causing cancer. For an illustration of a statistical association that does not show causation, consider the fact that roosters crow every morning and on most mornings a little while after the rooster crows the temperature rises. A statistical study would show a correlation between roosters crowing and rising temperatures. In this case we know that the sunrise causes both of these phenomena. Despite the statistical association, the crowing rooster is not causing the temperature to rise!



The statistical association between a rooster crowing in the morning and the usual rising temperature does not mean that the rooster causes the temperature to rise.

There is great controversy about whether the various epidemiological studies show any true relation between field exposure and cancer. Some careful responsible scientists argue that they do. Other responsible scientists point to a variety of very real problems in the design and interpretation of these studies. They argue that the reported findings may be the result of statistical problems or that the cancers may come from various other causes. For example, most of the occupational studies have not "controlled" for other important known carcinogens such as smoking and chemicals in the work place. The number of people exposed to the strongest fields in the Denver studies is small. This increases the chance that the results are due to coincidence rather than to a real association between field exposure and cancer. Such uncertainty, and the resulting debate about the meaning of data, are fairly common occurrences in epidemiological studies. Resolution of these issues will require more and better data. Additional epidemiological studies are now in progress. However, in the past when epidemiological studies have succeeded in clearly identifying a hazard (e.g., cigarettes or asbestos) the risks have involved increases of more than tenfold. If fields present a risk of cancer, but the increase in risk is something like two or three, epidemiology may never be able to resolve the uncertainty. For this, large expensive animal studies may be necessary.

You can find references to more detailed introductions to some of the epidemiological literature in the Appendix at the back of this brochure.

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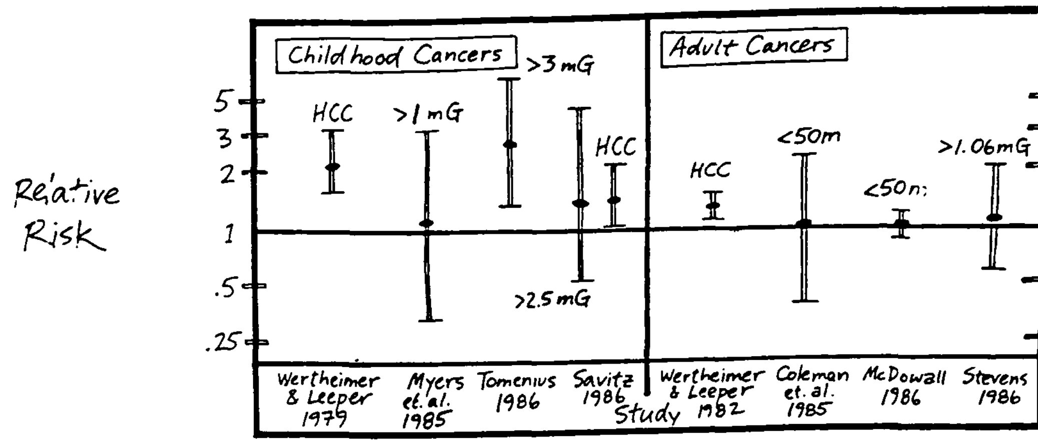
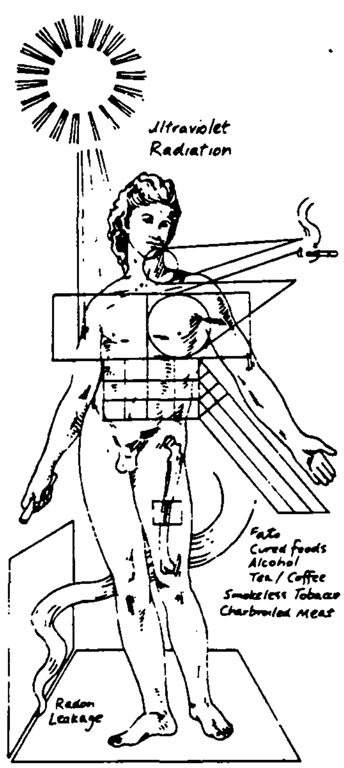
[5] In contrast, cigarette smoking increases the risk of lung cancer by 20 to 60 times.



Results from a number of epidemiological studies of cancer risk for persons exposed to magnetic fields from power lines near their homes. The vertical scale shows the ratio of the number of cancer cases among groups exposed to stronger fields to the number of cases among groups exposed to weaker fields. A relative risk of one means "no change in the cancer incidence rate." The vertical lines indicate the statistical uncertainty that results from the relatively small number of people in each study. HCC — high current configuration, < 50 m — persons living within 50 meters of a transmission line or substation, mG — milligauss. Adapted from Ahlbom et al., 1987.



How can I reduce my risk of cancer?

Later in this brochure (pp. 25-28) we discuss a few prudent steps people might take to limit some of their exposure to 60 Hz fields. But fields may not turn out to have anything to do with cancer. If you are concerned about cancer risks, be careful to keep things in perspective. Remember that there *are* a number of steps you can take which will almost certainly have a greater impact on reducing your cancer risk than anything you might do involving fields. Cigarettes are the leading contributor to cancer today *by a very large margin*. People who stop smoking, even after many years, greatly lower their cancer risk. Smokers who aren't concerned about their own health but are worried about their children or other family members, should also stop. Associations between smoking and health impacts on non-smokers in the home have been established. This evidence is significantly stronger than that for fields and cancers. While most lung cancer comes from smoking, perhaps as much as 20% results from exposure to radon, a colorless, odorless, naturally occurring radioactive gas found in all buildings. You can check your home for radon with a simple test kit. If the level measured is more than the EPA action limit of 4 picocuries per liter of air, contact a qualified contractor to discuss ways in which the concentration can be reduced by increasing ventilation and sealing cracks in the basement.

Beyond smoking, diet is probably the most important factor in cancer. Current evidence suggests that for most people the basic make-up of their diet is much more important than possible food additives or contamination by toxic materials. Things to *reduce* include: fats; charbroiled meat; smoked, cured and pickled foods (things like salami); pepper; celery; mushrooms; alcohol; smokeless tobacco products; and perhaps tea and coffee. On the other hand things to *increase* include the amount of fiber; fresh fruits and selected vegetables, especially raw cabbage, broccoli and cauliflower; and foods that are rich in vitamins A, C and E.

Finally there is sunlight. While light is essential to well being, strong direct sunlight, especially at mid-day in the summer, is a leading contributor to skin cancer. If you are concerned about your risk of cancer you should try to avoid exposing your skin to strong sunlight and use an effective sun screen when you can not avoid exposure.

If you would like to learn more about the causes of cancer we suggest you get the very readable book by Leslie Roberts titled *Cancer Today: Origins, prevention and treatment*, National Academy Press, 1984 (address: 2101 Constitution Avenue, NW, Washington D.C., 20418). A second very useful book is *Cancer Rates and Risks*, published by the U.S. Department of Health and Human Services, NIH Publication 85-691, 1985. (Available through the U.S. Superintendent of Documents, Washington, D.C., 20402).

Suppose 60 Hz field exposure does promote cancer. How serious could the problem be?

There are just under half a million deaths each year from cancers of all kinds in the United States. Cancers account for roughly a quarter of all deaths. Cancer deaths occurred in significant numbers well before 60 Hz fields became a common feature of everyday life. Their number has not shown any dramatic increase as the country has electrified. Hence, it seems unlikely that fields could be a major contributor to cancer today. However, with the evidence now available we cannot rule out the possibility that 60 Hz fields are a significant factor in cancer risks. Frustrating as the uncertainty may be, we also cannot rule out the possibility that fields have *nothing to do* with cancer.

Besides cancer, are there other health effects of possible concern?

Research on cancer has received most of the attention. However, work has also been done to explore the possibility of birth defects using mice, rats and small pigs. The mouse and rat studies showed no convincing evidence of birth defects from exposure to fields. Results in the pig study are more ambiguous and are complicated by several problems in the way the experiment was designed and conducted.

A large study, recently completed in several laboratories, exposed chicken eggs to short pulses of magnetic fields that repeated at 100 times per second (100 Hz). The pulses used turned on rapidly. This study observed a larger fraction of defects in exposed eggs than in eggs that were not exposed to fields. Because the fields were very different from 60 Hz fields and the defects were not found in all the laboratories, the implications of these results for 60 Hz field exposure are not clear. There are many electronic products like video displays, TVs, speed controllers and dimmer switches which produce low frequency pulsed fields which turn on rapidly, so these results cannot be ignored.

Scientists are now conducting a large study of the possible effects of electric blankets on human pregnancies. Earlier studies of this issue have been suggestive but have involved too few women to allow reliable conclusions.

Some animal studies suggest 60 Hz fields may interact with the system that runs the body's biological clock (circadian rhythm) or with the nervous system. There is some reason to think that field exposure might be involved in chronic depression or other systemic neurological disorders. However, there is so little evidence about these effects that, at this point, such arguments are really just speculation.

If there is a risk, are weaker fields safer than stronger fields?

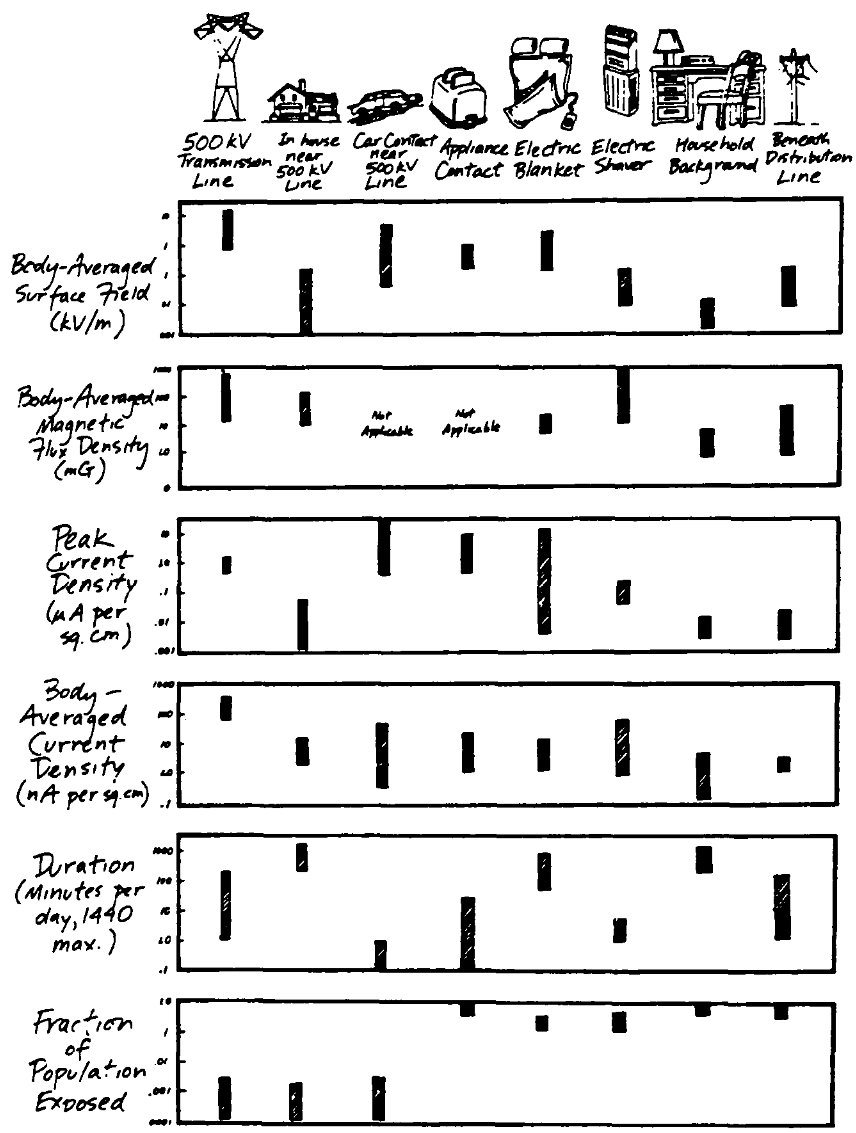
Experience with hazards like air and water pollution lead most people to answer yes. But we must be careful. If we are talking about *very weak* versus *very strong* fields the answer probably is yes. But suppose we are talking about smaller differences. For example, if fields pose any risk, is an electric field of 50 V/m safer than a field of 200 V/m? Is a magnetic field of 3 milli-Gauss safer than a magnetic field of 10 milli-Gauss? We do not know. Some people use the epidemiological evidence to argue yes. But there are also reasons to believe the answer could be no. If fields do pose a risk, at these levels of exposure, weaker fields may not be safer than stronger fields. In short: *more may not be worse*. This is a hard point to understand because more *is* worse for most pollutants. More is worse for chemicals in drinking water, or for air pollution. How could this simple rule not hold for 60 Hz electric and magnetic fields?

The reasons for doubt come mainly from the laboratory experimental studies. Some of these studies show very complex relations between exposure patterns and effects. For example there are experiments that show "resonant" processes. That is, effects appear for fields with some frequencies and field strengths (amplitudes) and not others. A simple way to understand this is to think of a yo-yo. A yo-yo is a "resonant system." To make it go you must move your hand up and down at the right times (that is at the right frequency) with just the right amount of distance (the right amplitude). If you do use the right frequency and amplitude, the yo-yo works. If you don't, the yo-yo doesn't work. Some of the processes by which fields interact with the surfaces of cells appear to have these same "resonant" characteristics. Thus, for example there are experiments that show no effect with a strong field but, when the field strength is reduced a little bit the effect appears. In at least some of these experiments it appears that the frequencies and amplitudes at which the resonant responses occur depend upon the strength of the DC (i.e. steady) magnetic field that is present.

There are other experiments in which biological effects are seen only after being in the field for a very long time. In other cases, effects appear above a certain field strength but then show no additional changes as field strength increases further. Some effects appear only for the first few moments in the field. Others are seen only with pulsed fields that have special pulse shapes. It will be some time before scientists can sort out all this complicated evidence and explain it. In the meantime, it seems wise not to assume that weaker fields are necessarily safer than stronger fields, at least across the range of commonly experienced fields.

What is dose?

We do not know what aspect of fields (if any) is important in determining human risks from exposure to 60 Hz fields. It could be the average peak field strength; it could be the peak field strength; it could be the average or the peak current which the fields set up in the body; it could be a variety of other things like time spent in the field, or number of times you pass into or out of the field. The problem is that since we do not know which is the right measure we have difficulty saying which source of exposure gives people the greatest "dose." The word "dose" means exposure that produces effects. As the figure below shows, you get different answers to the question "which source of fields produces the biggest exposure" depending on what measurement you look at.

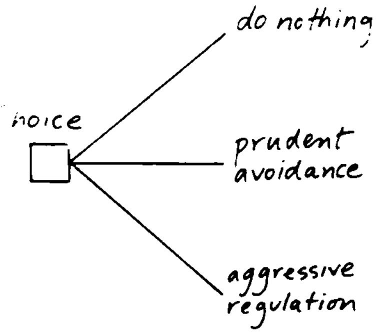


What can be done? What should be done?

First, continue and expand the research, focusing especially on issues of human health, so that we can have some clear answers. Almost everyone who has thought carefully about the issues of 60 Hz fields agrees that this is needed. Unfortunately, many of the busy decision makers who control the resources that are needed for this support have not thought as much about this issue as they need to. They need to be better informed.

Second...well, here things get difficult. It would be nice if we could spell out a few clear conclusions about actions. We can't. The reason is that the science is not complete enough today to support such conclusions. Anything more we say will go beyond science and involve judgments and values. Basically there are three approaches available:

1. Conclude that there is not yet enough evidence to warrant any action. Don't make any changes in the way we do things until new research tells us clearly whether there is a risk and, if so, how big it is.
2. Conclude that there is some basis for concern. Adopt a position of "prudent avoidance," which means limiting exposures which can be avoided with small investments of money and effort. Don't do anything drastic or expensive until research provides a clearer picture of whether there is any risk and, if there is, how big it is.
3. Conclude we have a real problem and spend some serious time and money on an aggressive program of limiting field exposures *now*, while recognizing that we may eventually learn that some or all of this effort and money has been wasted, either because it wasn't needed or we spent it the wrong way because we didn't understand the science well enough to spend it effectively.



In the three questions that follow we discuss the pros and cons of each of these possible conclusions.

Can we justify doing nothing?

Some people answer yes. They argue that doing nothing is the right response given the scientific ambiguity that exists today.

Whether we should do nothing, exercise "prudent avoidance," or take more dramatic action is not a scientific question. It is a matter of making a value judgment. Individuals and state regulators have to look at the available evidence. They must also consider the attitude they want to take toward risk. Then they must make a judgment about whether they find the evidence sufficiently troubling to warrant taking action and spending resources that might be spent on other things. Different attitudes toward risk can lead to different actions even among people who agree about the evidence. Some people have concluded that the current scientific ambiguities about possible health effects from fields are so large that no action is justified at this stage. They argue that we should limit our safety efforts and expenditures to *demonstrated* hazards where we can really be sure we are getting some benefits for our efforts.

What are the arguments for "prudent avoidance"? Why do you use the word prudent?

If exposure to fields involves risks, we'd like to be able to set some safety standards. We'd like to be able to say which field conditions are safe and which are not and should be avoided. If you have read the earlier discussion you've learned that the available scientific knowledge won't allow us to do this.

But suppose an individual or a regulator is concerned, thinks the evidence points toward the possibility of some risk, and feels that something should be done. In this case, they can try to exercise some prudence by keeping people out of fields when this can be done with modest amounts of money and trouble. However, in circumstances where the cost and problems associated with doing anything would be large, these people would argue that the prudent thing to do is wait until better information is available.

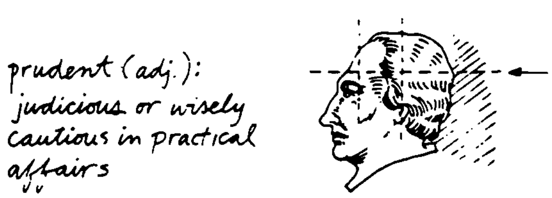
In our private lives we exercise prudence all the time when we face an uncertain risk. In public decision making we have more trouble being "prudent" about uncertainty. Public risk management activities tend to treat things as either dangerous or safe, with no middle ground. It may take some guts for a regulator to adopt a "prudent avoidance" strategy.

Prudence means "exercising sound judgment in practical matters." It means being "cautious, sensible, not rash in conduct." How, for example, are people prudent about cancer in their private lives? They don't smoke. They eat diets with little charbroiled food and lots of fiber. *But* prudent people do not: refuse to go to an important business meeting because one of the participants occasionally smokes; go without breakfast when all that is available on the menu is regular cereal rather than their usual high fiber cereal; or, order lobster for their children because it is the only food on the menu that isn't charbroiled. Prudence means you take steps to control risks but at a modest cost. You keep some sense of proportion and you don't go overboard.

How could prudent people manage their risks from 60 Hz electric and magnetic fields if they wanted to? Not by tearing all the wiring out of their house. That would be extreme. But, they could put away their electric blanket (or electrically heated water bed) and go back to using regular blankets.[6] Or, they could use the electric blanket to pre-heat the bed, and then unplug it before going to bed (the magnetic field disappears when the blanket is switched off, the electric field may remain as long as the blanket is plugged in). Small electric motors produce strong magnetic fields. If you want to reduce your field exposure you might look around for small electric motors that you are often close to. For example, a motor driven electric clock on your bedside table may produce a fairly strong magnetic field by your head. If you want to practice prudent avoidance you could move it to a dresser across the room or replace it with one of the newer digital clocks or with a travel clock or wind-up clock.

If you are buying a new home it might be prudent to consider the location of distribution and transmission lines as one of *many* things you consider. However, remember that even if fields are ultimately demonstrated to pose a health risk, things like traffic patterns in the streets and radon levels in the house are likely to be more important for your own or your children's overall safety than anything related to fields. If you are already in a home, moving in order to get away from existing lines goes beyond what we would consider prudent.

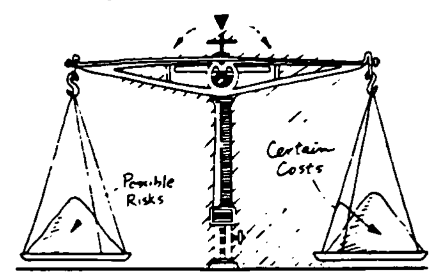
State regulators who wish to exercise prudence about the exposures that people receive from power lines should, until more is known, limit their concern to new facilities. This is because even under the most pessimistic assumptions it is hard to justify the costs of modifying old facilities. Regulators who want to exercise prudence should site new facilities so as to keep people



out of fields, but only up to some practical limit. Spending amounts as high as a few thousand dollars to avoid exposing someone might be justified.[7] Much larger expenditures can almost certainly *not* be justified. There are various ways to implement prudent avoidance.[8] Setting a field strength limit for the edge of the right of way may not be the best strategy. However, if this approach is chosen, regulators should make it clear that they are motivated by a desire to achieve "prudent avoidance" and that the levels chosen do not constitute "safe field levels." We just don't know how to choose such levels today.

Can an aggressive program of regulation and control be justified?

Taking more drastic action than that indicated by "prudent avoidance" will cost a lot of money and create a fair amount of disruption. Few people would object if they were confident that 60 Hz fields pose a serious health risk. But, because our understanding of the science of this problem is still very incomplete, there is a real chance that some or all of the expense and associated trouble that would result from "aggressive action" taken now, would ultimately turn out to have been ineffective. There are two ways this could happen. First, it could turn out that there are no health risks from fields or that there are risks but they are very small. Second, it could turn out that while there are risks, we've done the wrong things to control them and gotten little or no improvement for our money because of our incomplete understanding of dose (see the discussion on "more may not be worse" on page 11).



In our discussion of the strategy of "prudent avoidance" we argued that today it is hard to justify spending more than a few thousand dollars per person exposed in order to reduce exposures. We said this because we believe that if fields pose health risks, only a very small fraction of all the people exposed can be expected to develop adverse health consequences (probably no more than one in many thousands). That means that spending a few thousand dollars per exposure avoided amounts to spending millions of dollars *or more* per possible health effect avoided.[9]

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[6]There may be a few people, such as those who have circulatory problems, for whom an electric blanket is very important. For these people the cost of going without an electric blanket may be too high to make this a prudent step.

[7]*If* exposure to fields does involve health risks, only a small fraction of those exposed are likely to have their health affected. Hence, an investment of $1000 per exposure avoided could amount to an investment of millions of dollars or more per health effect avoided.

[8]Readers interested in more detailed discussions of this issue and the judgments involved can find them in two articles by Granger Morgan, Keith Florig, Indira Nair and Gordon Hester: "Controlling Exposure to Transmission Line Electromagnetic Fields: A regulatory approach that is compatible with the available science," which appeared in *Public Utilities Fortnightly*, March 17, 1988, pages 49-58 and "Power Frequency Fields: the regulatory dilemma," which appeared in *Issues in Science and Technology*, Summer 1987, pages 81-91.

[9]The U.S. spends up to a few million dollars per death avoided in job safety programs. However, it only spends a few hundred thousand dollars per death avoided on more common risks like preventing motor vehicle accidents. The amount most people want to spend to avoid risks depends on other things besides the odds of death. Considerations such as equity, controllability and the extent to which exposure is voluntary are all important. Thus, the arguments that follow are approximate.

If someone concludes that drastic action on fields is appropriate today, and does not wish to make safety expenditures for fields which are dramatically larger than the expenditures we make to guard against other risks in our society, they must have concluded that the health risks from fields are significantly more common than one in several thousand people exposed.[10]

In order to understand what this means, consider the table on the next page which lists the approximate number of deaths that occur each year in the United States from a variety of causes. For example, auto accidents kill about 50,000 of the roughly 2,100,000 Americans who die each year. This means that when the average American dies, the chances are about 1 in 40 that his or her death will result from an auto accident.

[10] Remember that there have not been dramatic increases in the numbers of deaths or illnesses as electrification has occurred. Of course, on the other hand, some might argue that the improvements in life expectancy that have occurred over the past half century might have been even greater without field exposure.

We argued above that someone could justify "aggressive action" today only if they believe that the lifetime risk faced by people exposed to fields is well above one in several thousand. Electrocution has an average lifetime mortality risk of about 1 in 2500. Appendicitis has an average lifetime mortality risk of about 1 in 4000. That means that someone would have to believe that the risk of death in populations exposed to fields is as large as those risks faced by the general population that lie well above the shaded band in the table before they would be justified in calling for "aggressive action" today. If you think the risk, if any, for exposed people probably does not lie well above this shaded band, you should seriously consider selecting either the strategy of "prudent avoidance" or "no action," at least until the situation is better understood. Otherwise you will end up calling for society to spend far more to protect its members against possible deaths from this uncertain risk than it does to protect its members against deaths from other known risks.

Data on Deaths in the United States.

Cause of death.	Approximate number of Americans who die each year from this cause.	Approximate odds that when the *average* American dies it will be from this cause.
Disease (all kinds)	2,000,000	1 in 1.1
Heart disease	770,000	1 in 2.7
Cancer (all kinds)	480,000	1 in 4.4
Accidents (all kinds)	95,000	1 in 22
Auto accidents	48,000	1 in 44
Diabetes	37,000	1 in 57
Suicide	31,000	1 in 68
Homicide	21,000	1 in 100
Drowning	5,900	1 in 360
Fire	4,800	1 in 440
Asthma	4,000	1 in 530
Firearm accidents	**1,500**	**1 in 1400**
Viral hepatitis	**1,000**	**1 in 2100**
Electrocution	**850**	**1 in 2500**
Car-train accidents	**570**	**1 in 3700**
Appendicitis	**510**	**1 in 4100**
Pregnancy and related	**470**	**1 in 2200**
Lightning	78	1 in 27,000
Floods	58	1 in 36,000
Tornado	58	1 in 36,000
Fireworks	8	1 in 260,000
Botulism	2	1 in 1,100,000

Notes: The total population of the United States is about 242,000,000. About 2,100,000 Americans die from all causes each year. The table reports data for some of these causes. The numbers in this table have been rounded to two figures (for example, 67.742 is reported as 68). The odds reported in the right-hand column are for the *average* American. Note the odds reported for pregnancy and related causes are only for women. Since people have different backgrounds and behaviors the *individual* risks they face will generally be somewhat different than these numbers. For example, someone who never smokes will probably have a smaller risk of dying from cancer than the 1 in 5 odds reported here. Someone who scuba dives frequently probably stands a higher chance of drowning than the average American. Numbers based on *Vital Statistics for the United States, 1986*, U.S. Dept. of Health and Human Services publication PHS88-1122, Washington, DC, 1988.

Haven't some states passed standards for fields from transmission lines?

Yes, several states have established standards for the strength of electric fields from high voltage transmission lines and Florida has also established magnetic field standards. While some of these have been set as "safe field" standards, some states, especially Florida, have understood that with the incomplete science now available only "prudent exposure avoidance" can be used as a justification for establishing a standard. Current state standards are summarized in the table on the top of the next page. No states have set standards for distribution lines.

State regulations that limit field strengths on transmission line rights of way

State	Field Limit
Montana	1 kV/m at edge of RoW in residential areas
Minnesota	8 kV/m maximum in RoW
New Jersey	3 kV/m at edge of RoW
New York	1.6 kV/m at edge of RoW
North Dakota	9 kV/m maximum in RoW
Oregon	9 kV/m maximum in RoW
Florida	10 kV/m (for 500 kV), 8 kV/m (for 230 kV) maximum in RoW 2 kV/m at edge of RoW all new lines, 200 mG (for 500 kV single circuit), 250 mG (for 500 kV double circuit) and 150 mG (for 230 kV) maximum at edge of RoW

Other Things People Sometimes Ask About.

How about cardiac pacemakers? Can strong fields affect them?

Most modern cardiac pacemakers are unaffected by even the fairly strong fields produced by high voltage transmission lines. The operation of a few models, including a number manufactured by Cordis, reportedly have been affected by strong 60 Hz fields. If you use a cardiac pacemaker, it is best to consult with your physician before going into strong fields.

What about being close to water? Would that figure in any health risk from 60 Hz fields?

No. There *is* an electrical hazard associated with being close to water: a greater chance of shock and electrocution. If you are in water you are usually well grounded. If, while you are well grounded, you touch something like a defective electric appliance you could get a much more severe shock than you would get if you touched it when you were not well grounded. This is one reason why you should never use appliances in the bath (another is the electrocution risk if the appliance is dropped in the bath water, which would have the effect of connecting you to the electric line).

But, none of this has anything to do with possible health risks from 60 Hz fields. If there are such risks, there is no reason to think that being close to water, such as lakes or rivers, would have significant consequences.

Is there some link between fields and ozone?

None that is of any environmental importance.

If an electric field is strong enough it can break down or "ionize" molecules in the air and cause sparks or "corona." This can generate small amounts of ozone. It also makes the crackling noise you may have heard around some high voltage lines. It takes energy to make corona. Since energy costs money, electric companies try to design high voltage power lines so as to minimize corona. The conditions under which air will break down depend a bit on weather. Sometimes, especially in foggy or humid weather, very high voltage lines will produce corona. When this happens small amounts of ozone are generated.

The amount of ozone generated by a power line is much less than the amount generated by other sources such as factory emissions and motorvehicle exhaust. Ozone produced by power lines is not a significant contributor to local or regional air pollution problems and poses no significant risk to people or the environment.

While some places have an air pollution problem resulting from too much ozone in the low atmosphere (the troposphere), you may also have heard that there is not enough ozone in the high atmosphere (the stratosphere). Ozone in the stratosphere is important because it blocks out ultraviolet light from the sun. Air in the troposphere does not usually mix with air in the stratosphere. Power lines and 60 Hz fields have nothing to do with the issue of stratospheric ozone.

Are there standards for field exposure outside the U.S.?

Standards or guidelines for exposures to power-frequency electric fields exist in Britain, Japan, Poland, and the Soviet Union. These foreign standards are not significantly different than state standards in the U.S. For example, guidelines in the Soviet Union recommend that fields in publicly-accessible areas be no greater than 10 kV/m and that fields in permanently occupied areas be no greater than 2 kV/m. There are presently no national regulations in any country limiting exposures to power-frequency magnetic fields from power lines or appliances.

The International Radiation Protection Association, whose mission is to review scientific evidence and propose safety standards, has issued draft exposure guidelines for power-frequency electric and magnetic fields. They call for a limit of 5 kV/m for continuous exposures to electric fields and 2 Gauss (2000 mG) for magnetic fields.

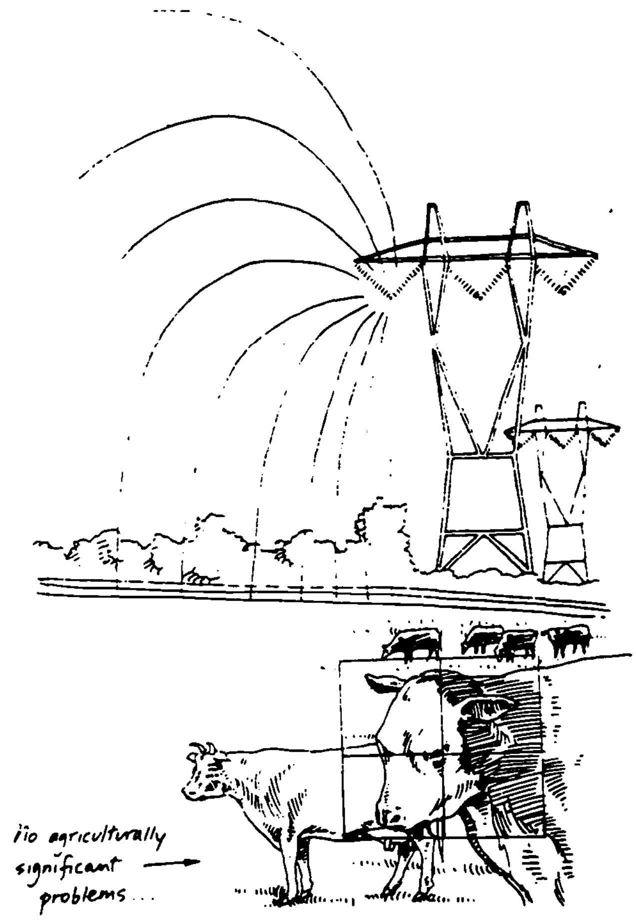
Do 60 Hz fields from power lines pose significant risks to farm crops and animals?

The answer is a simple no. There have been quite a number of studies of field crops grown in strong fields. There have also been quite a number of studies of things like meat and milk production. All of these studies show no significant effects.

If it turns out that fields do pose health risks to people, similar effects may of course be seen in farm animals. But even under the worst assumptions, these effects would be pretty rare. They might be common enough for us to worry about them as a health risk in people, but they will be rare enough that they will have no significant economic implications for farmers. For example, skin cancer from sunlight is something we as people worry about. But farmers don't worry about their pigs getting skin cancer. It's just too rare to matter. That is why we say the answer to this question is a simple no.

There is one aspect of electric power that can have very real implications for dairy farmers. This is the so-called stray voltage problem. When metal feeders, water troughs, or milking machines are inadequately grounded, cows can be subjected to small but perceptible electrical shocks. This can lead to changes in animal behavior (reluctance to enter a milking stall for instance) and reductions in milk production. The problem can usually be fixed with proper grounding or other technical procedures. The problem does *not* come from the direct effect of exposing the cows to fields.

The only other situation that has been identified in which power lines can be important in agriculture is when bee hives are installed *directly* underneath *very* high voltage power lines. Again the problem is not from exposing the bees to the field. Rather it comes from voltages that are induced in the hive. Effectively, the bees get shocks as they walk around and, not surprisingly, honey production can drop substantially. If a shield, such as a piece of grounded chicken wire, is



installed over the hive, then the problem is eliminated and honey production returns to normal. Still, it is best not to locate bee hives under transmission lines.

Do 60 Hz fields pose significant risks to the environment?

As with agriculture, the answer is again a simple no. Studies of trees and ecosystems have shown no significant effects from 60 Hz or other low frequency electric and magnetic fields. As with agriculture, if there do turn out to be health risks for people we might expect to see occasional effects in other living things as well. But even under the worst conditions these effects will be so rare that they will only involve individual plants and animals and will not affect the operation of the overall ecosystem.

Some migratory animals like birds and fish appear to use naturally occurring fields as one of their cues in navigation. However there is no evidence of manmade fields from power lines, radio antennas or other field creating objects causing serious disruptions.

There are experimental studies in which coniferous trees (pines, spruce, firs, etc.) grown *right next* to very high voltage power lines have experienced needle damage. This is because the fields at the tips of the needles on these trees were so high that they caused the air to break down electrically (like the blue flashes you may see when you stroke a cat in the dark on a dry winter night). Normally trees are trimmed far enough back from transmission lines to preclude this effect.

Who is supporting research on possible health risks from 60 Hz electric and magnetic fields?

In the United States major support for research on possible health risks from low frequency electric and magnetic fields comes primarily from the Electric Power Research Institute (EPRI), the U.S. Department of Energy and the U.S. Navy. In the past there was substantial support from the State of New York but most of this has now ended. In the past there was also modest support from the Environmental Protection Agency but that has stopped. Several individual utilities, including Bonneville Power Administration and Southern California Edison, support research.

After a number of years of growing support, the past few years have witnessed a marked decline in the level of federal support. Department of Energy expenditures fell from a high of just under $5 million in 1985 to about $2 million in 1988 but have apparently now begun to recover. The drop in funding was not because the problem had been solved. Quite the contrary. The funding drop simply resulted from general federal budget cutting. If the 60 Hz fields problem is ever going to be properly understood, a strong and stable program of federal research support will be necessary.

Outside of the United States there are significant research programs underway in a number of other countries including (in approximate descending order of funding levels) Sweden, the United Kingdom, West Germany, Canada, Japan, Italy, France, Finland, and Norway. Some research is also being done in the Soviet Union, Eastern Europe and China.

Most research has focused on possible health effects. Recently EPRI has begun research on how fields associated with electrical systems might be reduced. More work on this issue is needed, especially for distribution lines, house wiring, and appliances.

Who wrote this brochure?

As we explained on the inside of the front cover, the primary author for this brochure was Dr. Granger Morgan of Carnegie Mellon University. He had help from a number of colleagues. Before the brochure was published it was reviewed by a large number of experts and lay people who offered extensive advice on how the brochure could be improved. While we followed much of this advice, the final product is Dr. Morgan's responsibility. The judgments expressed in the brochure are his.

Granger Morgan is Head of the Department of Engineering and Public Policy at Carnegie Mellon University where he is also a professor in the Department of Electrical and Computer Engineering. He was trained in science and engineering at Harvard, Cornell and the University of California. He has worked for many years on environmental problems and in risk analysis. Most of his work on these topics has been funded by the U.S. National Science Foundation. He has served as a member of a number of scientific advisory panels for the U.S. Environmental Protection Agency. He is currently a consulting member of the EPA's Clean Air Science Advisory Committee. He is a Fellow of the Institute of Electrical and Electronics Engineers.

In 1982 Dr. Morgan was asked by the U.S. Department of Energy to put a group together at Carnegie Mellon to do risk analysis on the issue of possible risks of 60 Hz fields. The group studied the problem intensively for three years, carefully reviewing the scientific literature, visiting many of the key investigators in their laboratories, and participating in many national research conferences. The Carnegie Mellon group has published a number of research papers on the risk and public policy aspects of this subject. However, because of the many scientific ambiguities in the field, the group concluded that it would not be possible to perform a meaningful risk assessment on 60 Hz fields until more complete scientific understanding was available. Rather than continue to use up scarce DoE research money they informed DoE of their conclusion and the work ended.

More recently, both the Department of Environmental Resources of the State of Florida and the Office of Technology Assessment of the United States Congress have contracted with Dr. Morgan and his associates for help in dealing with assessment and regulatory problems related to 60 Hz fields.

Dr. Morgan has worked hard to remain impartial on this very controversial topic. He has never testified on behalf of any electric utility company. He has never been a participant in any power line siting controversy. The bulk of his research support has been, and remains, in areas outside of the topic of 60 Hz fields.

Summary of This Brochure

Here's a brief summary of the key points in this brochure.

- Electric and magnetic fields are found throughout nature and in all living things. They hold matter together. They are necessary for the operation of the nervous system.
- 60 Hz (60 cycles per second) electric and magnetic fields come from electric power. They are found around all electrical appliances, house wiring, power lines in the street, and high voltage transmission lines.
- There is clear evidence that 60 Hz fields can produce various hormonal and other changes in living things. It is not yet clear if these changes can result in risks to public health.
- Possible risks of concern include the promotion of cancer (i.e. helping the growth of existing cancer); developmental abnormalities (i.e. birth defects); and various neurological effects such as chronic depression.
- There have been many very good scientific studies of the possible health risks of fields. Taken together, the results are very complicated. Careful and responsible scientists do not yet agree on whether 60 Hz fields pose a risk to public health and, if they do, how serious that risk might be.
- It is not clear what aspect of 60 Hz fields (if any) poses a risk. There is evidence that suggests that across the range of field strengths commonly encountered by people, *stronger fields may not pose greater risks than weaker fields.* This means that the usual assumption that "more is worse" may not be correct for the case of 60 Hz fields. With the scientific evidence that is now available, it is not possible to establish a "safe field" standard.
- If individuals and society are concerned about the possible risks from fields they can take prudent steps to avoid exposure to fields, while avoiding large unjustified expenditures. For example, individuals can stop using electric blankets, and society can try to avoid building new lines very close to people.
- 60 Hz fields do not pose a significant risk to agriculture or to ecosystems.
- There is a great deal of research going on to learn more about the possible health risks of 60 Hz fields. New evidence from this research should help to reduce some of the current uncertainty.

Glossary

AC: The abbreviation for alternating current. An AC current, or an AC field, changes strength and direction in a rhythmically repeating cycle.

amp: The units used to measure current. Abbreviated A.

charge: The electrical property of matter which is responsible for creating electric fields. There are two kinds of charge labeled positive and negative. Electric fields begin on positive charges and end on negative charges. Like charges repel each other. Unlike charges attract each other.

circadian rhythm: The rhythmic biological cycle (of things like hormone concentrations in the body) that usually recurs at approximately 24 hour intervals.

contact current: The current that flows in the body when a person touches a conducting object (e.g., a metal refrigerator) that has a voltage induced on it because it is in an AC field.

current: An organized flow of electric charge. Current in a power line is analogous to the rate of fluid flow in a pipeline. All currents produce magnetic fields. Current is measured in amps.

DC: The abbreviation for direct current. A DC current, or a DC field, is steady and does not change strength or direction over time.

distribution line: A power line used to distribute power in a local region. Distribution lines typically operate at voltages of between 5 and 35 kV, much lower than the voltages of transmission lines. However, the currents on some distribution lines can be comparable to transmission line currents.

DNA: Deoxyribonucleic acid, the complex, usually helically shaped chemical compounds from which the genetic material of genes and chromosomes is made.

dose: The amount of exposure of a kind that produces effects. In the case of chemical pollutants, dose is usually the amount of chemical that gets into the body. In the case of fields, it is often unclear what aspect of the field, if any, is involved in producing effects. Hence, it is not clear how to measure dose from electromagnetic fields.

electric field: A representation of the forces that fixed electric charges exert on other charges at a distance. The electric field has a strength and direction at all points in space which is often represented diagrammatically by field lines. Electric field lines begin on positive charges and end on negative charges.

electromagnetic field: A field made up of a combination of electric and magnetic fields.

epidemiology: The study of the distribution and factors that cause health related conditions and events in groups of people, often making use of statistical data on the incidence of disease or death.

gauss: A common unit of measure for magnetic fields. Abbreviated G. There are 10,000 gauss in one tesla.

hertz: A cycle per second. A unit used to measure frequency. In America, AC power has a frequency of 60 Hz. In most of Europe, AC power has a frequency of 50 Hz. Radio waves have frequencies of many thousands or millions of hertz. Abbreviated Hz.

Hz: The abbreviation for hertz. A cycle per second.

hormone: A chemical substance produced by a part of the body and used to send information to some other part of the body. Many people associate the word hormone with sex hormones, substances produced by the sex glands. There are many other kinds of hormones such as insulin which helps the body use sugar, and cortisol which helps to control inflammation.

impedance: The electrical property of a conductor or circuit which resists the flow of an electric current. Impedance is similar to resistance (see below) but may involve a change in the current's phase.

initiator: Any agent, such as ionizing radiation and some chemicals, which can start the process of turning normal cells into cancer cells.

kV: The abbreviation for kilovolt. A thousand volts.

kV/m: The abbreviation for kilovolt per meter. A thousand volts per meter. The strength of an electric field is measured in volts per meter.

leukemia: A general word used to refer to a number of different types of cancers of the blood forming tissues.

magnetic field: A representation of the forces that a moving charge exerts on other moving charges *because they are moving*. The magnetic field has a strength and direction at all points in space which is often represented diagrammatically by field lines. Magnetic field lines form closed continuous loops around currents. All currents produce magnetic fields.

microwaves: Electromagnetic waves which have a frequency of between roughly 1 billion and 300 billion Hz (a wave length of between roughly 30 centimeters and 1 millimeter). Microwaves have a frequency higher than normal radio waves but lower than heat (infrared) and light. In contrast to x-rays, microwaves are a form of non-ionizing radiation (see x-rays below). Strong microwaves can produce biological damage by heating tissue. Sixty Hz fields cannot do this.

phase: The timing with which an alternating current, voltage or field is changing strength and direction. See "three phase power" below.

pineal melatonin: The endocrine hormone melatonin that is produced by the pineal gland in the brain. Melatonin is involved in the control of circadian rhythm in at least some animals.

promoter: any agent, such as some chemicals, which can aid or accelerate the growth of cancer.

radiation: Any of a variety of forms of energy propagated through space. Radiation may involve either particles (for example alpha-rays or beta-rays) or waves (for example, x-rays, light, microwaves or radio waves). Ionizing radiation such as x-rays carries enough energy to break chemical and electrical bonds. Non-ionizing radiation like microwaves does not. Most of the energy in the 60 Hz fields associated with power lines, wiring and appliances does not propagate away from them through space. Hence, it is best not to refer to these fields as radiation.

resistance: The electrical property of a conductor that resists the flow of an electric current without changing its phase.

RNA: Ribonucleic acid. Complex chemical compounds in cells that are copied from DNA. RNA carries information and material that cells use to make proteins.

stray voltage: A condition occurring on dairy farms in which cows are subjected to small but perceptible electrical shocks which can lead to changes in animal behavior and reductions in milk production. The problem can usually be fixed with proper grounding of equipment. The problem is *not* a direct effect of exposing the cows to fields and can occur without large power lines being involved.

three phase power: Ordinary 60 Hz current involves only one "hot" wire or phase. Most high voltage transmission lines involve three "hot" wires or phases. The voltage and current in these three wires do not all reach their peak values at the same time. First one, then the next, then the third, reaches maximum, 1/180th of a second apart. The three work together as one line for transmitting electric energy. Three phase power is used because it is a more efficient way to transmit electric power than single phase power.

tesla: A unit of measure for magnetic fields. Abbreviated T. There are 10,000 gauss in one tesla. A microtesla (μT) is one millionth of a tesla or .01 gauss.

transmission line: A power line used to carry large quantities of electric power at high voltage, usually over long distances. Transmission lines typically operate at voltages of between 69 and 765 kV. They are usually built on steel towers or very large wooden poles.

voltage: A measure of electric potential, the amount of work that must be done to move a charge from ground to a location in space such as a power line conductor. Voltage in a power line is analogous to pressure in a pipeline. Voltage is measured in volts. Abbreviated V.

V/m: Abbreviation for a volt per meter. The strength of an electric field is measured in volts per meter, or sometimes in thousands of volts per meter (kV/m).

X-rays: A form of electromagnetic waves similar to light but with a shorter wavelength (higher frequency). X-rays are a form of ionizing radiation. They can damage biological systems by breaking chemical or molecular bonds. Sixty Hz fields cannot do this.

Appendix: How to learn more.

The scientific literature on 60 Hz fields is large and is growing rapidly. Published every three months by the Bioelectromagnetics Society, *Bioelectromagnetics* is the single most important scientific journal in this field. Many of the most important results are published here. There are two commercial newsletters (both fairly expensive but both well done) *Transmission and Distribution Report* (720 Washington Avenue, Southeast, Suite 201, Minneapolis, Minnesota 55414-2917) and *Microwave News* (P.O. Box 1799, Grand Central Station, New York, NY 10163) which carry non-technical reports on the latest scientific, regulatory and other developments in this field. There are two large scientific meetings each year at which many of the scientific investigators present their latest research findings: the annual meeting of the Bioelectromagnetics Society (usually in June) and the annual DoE/EPRI Research Contractors Meeting (usually in November). Both are open to the public.

There are a number of published reviews of the scientific literature. They vary considerably in coverage and level of technical detail. Unfortunately the best reviews are in the form of reports, not books. It may take a bit of effort to track down copies of some of them.

At the request of the Office of Technology Assessment of the United States Congress we have recently completed:

U.S. Congress, Office of Technology Assessment, *Biological Effects of Power Frequency Electric and Magnetic Fields — Background Paper*, prepared by I. Nair, M.G. Morgan, H.K. Florig, of the Department of Engineering and Public Policy, Carnegie Mellon University, OTA-BP-E-53 (Washington, DC: U.S. Government Printing Office, May 1989).

This report, written for a Congressional audience, explains what 60 Hz fields are, discusses human exposure to fields, summarizes many of the biological effects, discusses the epidemiological evidence and discusses alternative policies that might be adopted.

Another recent review intended for a general audience is:

Electrical and Biological Effects of Transmission Lines: A Review, Technical Report prepared by J. Lee, J.H. Brunke, G.E. Lee, G.L. Reiner and F.L. Shon of the Bonneville Power Administration of the U.S. Department of Energy (Portland, Oregon 97208), 1989.

The Bonneville Power Administration (BPA) is the big federal power system in the Pacific Northwest. This report reviews 60 Hz biological effects as part of the BPA documentation required by the National Environmental Policy Act dealing with environmental impacts of electrical transmission facilities. The report focuses heavily on high voltage transmission lines and their associated fields.

While they are getting a bit old, two special reports prepared for the states of Florida and Montana contain fairly comprehensive semi-technical reviews. They are:

Biological Effects of High Voltage AC transmission lines with reference to the Colstrip Project: Garrison-Spokane HVTL, Technical Report prepared by Dr. Asher Sheppard for the Montana Department of Natural Resources and Conservation, Helena, Montana, 1983. Available from the National Technical Information Services (5285 Port Royal Road, Springfield, Virginia 22161) as Report No. PB83 207241.

Biological Effects of 60 Hz Power Transmission Lines, Technical Report prepared by Florida Electric and Magnetic Fields Science Advisory Commission for the Florida Electric Power Coordinating Group, Inc. (Tampa, Florida 33609), March, 1985.

Dr. Sheppard is a scientist in the research group at Loma Linda Veteran's Hospital working on the biological effects of fields. His report provides a critical review of experimental results up to 1982 from the perspective of determining their implications for human health. The review includes a fairly extended discussion of results obtained from experiments on cells. The Florida report was prepared by a six-member committee appointed by the Department of Environmental Regulation of the State of Florida. It contains a fairly complete review of the literature up to 1985. It places somewhat less emphasis on cellular level results than the Sheppard review.

One other general review is:

Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields, Technical Report prepared by the Committee on Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields, American Institute of Biological Sciences, Arlington, Virginia, March 1985. Available from: National Technical Information Service, U.S. Department of Commerce (Springfield, Virginia 22161) as Report No. AD/A152 731.

This report was prepared by a committee of twelve scientists, organized by the American Institute of Biological Sciences in response to a request from the Naval Electronics Systems Command. The Navy has an interest because powerful low frequency radio transmitters are used to communicate to submarines at sea. Thirty-one scientists, with very different experience and opinions about the potential biological effects of low frequency fields, acted as consultants to the Committee. The report summarizes research done between 1977 and 1985 in all aspects of the biological effects of electromagnetic fields in the frequency range from 1 to 300 Hz.

The details of interactions between fields and biological systems at the level of individual cells has emerged as an especially important portion of the literature on low frequency fields. While most of the reviews of this topic are quite technical, the Veteran's Administration has produced a 15-minute video tape (made at the Walt Disney studios with illustrations by Frank Armitage who did "The Fantastic Voyage"). The video tape is intended for semi-technical and non-technical audiences. It is:

"Cell Membranes and Intercellular Communications," U. S. Veterans Administration, distributed by National Audio Visual Center (8700 Edgeworth Drive, Capital Heights, MD 20743-3701, tel: 301-763-1896).

Some of the ideas presented in this movie are still quite controversial within the research community.

Dr. Ross Adey, who heads the Research Service at Jerry Pettis Memorial Veteran's Hospital in Loma Linda, California, has produced two detailed technical reviews of this topic. They are:

Tissue Interactions with Nonionizing Electromagnetic Fields by W. Ross Adey in the scientific journal, *Physiological Reviews*, Volume 61, Number 2, April 1981, pp. 435-514.

"Electromagnetic Fields: Cell membrane amplification and cancer promotion," W. Ross Adey, Review paper presented at the National Council on Radiation Protection and Measurements Annual Meeting, National Academy of Sciences (Washington, D.C. 20418), 1986.

Dr. Jerome Beers, a radiologist of the Boston University Medical Center, has prepared an extensive review of the biological effects of magnetic fields. It is:

Biological Effects of Weak Electromagnetic Fields from O Hz to 200 MHz: A survey of the literature with special emphasis on possible magnetic resonance effects by G. Jerome Beers in the scientific journal *Magnetic Resonance Imaging*, Volume 7, 1989, pp. 309-331.

Readers without significant biological and other technical training will find these reviews very hard going.