Hazard at a Distance: Effects of Exposure to the Electric and Magnetic Fields of High Voltage Transmission Lines ☆

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OVERHEAD ELECTRICAL TRANSMISSION LINES are so commonplace in the United States, it is sometimes difficult to believe that none existed prior to 1882. Today there are about 100,000 miles of overhead high voltage transmission lines in operation in the United States and countless thousands of additional lines which operate at lower voltages. The majority of high voltage transmission lines operate at a frequency of 60 hertz, which falls approximately in the middle of the frequency region of the electromagnetic spectrum known as the extremely low frequency (ELF) region. The ELF region is usually considered to be 1 to 100 hertz. By the term high voltage transmission line, we mean an overhead electrical transmission line operating at 60 hertz, at or greater than 100,000 volts (Figure 1).

Figure 1. The confluence of four 345 kV transmission lines in Clay, New York.

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Our electrical transmission and distribution system makes relatively cheap electricity available almost everywhere, in virtually unlimited amounts. We are among the most electrified nations in the world. Lately however, questions have been raised concerning the price, in terms of human health and environmental degradation, that we as a society are paying for this privilege.

High voltage transmission lines are usually built by private utility companies on land acquired by forced sale. Once the line has been built, the only historically recognized health hazard appears to have been electrocution produced by direct contact. As our demands for electricity increased and technology made it possible, however, the operating voltages of successive generations of high voltage transmission lines increased.[1] The standard operating voltage of the 1920's was 138,000 volts or 138 kilovolts (kV). This led to operating voltages of 345 kV, then 500 kV in the 1950's and then 765 kV in 1969. The technology necessary to permit operation at voltages of 1100 kV is currently being developed and still higher operating voltages are being planned. This tendency towards higher operating voltages has raised more questions concerning possible health effects and has focused attention on some heretofore neglected areas.

There are some health problems associated with high voltage transmission lines that have been recognized. It is well known that high voltage transmission lines can cause electrical breakdown of the air in the immediate vicinity of the wires via a process known as corona. Corona is a noisy process and accounts for the crackling sound that can frequently be heard in the vicinity of high voltage transmission lines. A 765 kV transmission line proposed by the Rochester Gas and Electric Corporation, Rochester, New York, for instance, will interfere with the sleep of people as far as 625 feet beyond the edge of the right-of-way.[2] Constant exposure to noise is medically known to constitute a hazard to the physiological and psychological well being of the victim. Corona also results in the production of ozone, a highly reactive and toxic gas which in sufficient concentrations is harmful to plants and animals. When walking underneath or near high voltage transmission lines, one may experience annoying and

shock currents. This occurs in a variety of situations including one in which an individual touches a large grounded metallic object such as an automobile or a tractor. Noise, ozone and induced shock currents are human health problems associated with high voltage transmission lines which become progressively more serious as the operating voltage of the transmission line is increased. The simple act of walking underneath an overhead 1100 kV transmission line, for example, becomes a painful experience due to repeated shocks brought about by blades of grass touching the ankle. More recently, however, research has begun to indicate that the electric and magnetic fields produced by high voltage transmission lines may pose a much more direct and significant biological problem.

Electric and Magnetic Fields

When the flow of electricity is initiated in a transmission line, the space around the wire becomes filled with energy. This energy is composed of an electric field, measured in volts per centimeter (volts/cm) and a magnetic field, measured in gauss. These fields exist *outside* the wire and must be distinguished from the electricity or current, measured in amperes, which flows *inside* the wires. The electric and magnetic fields from transmission lines extend for thousands of feet on both sides of the wire. Typical values of the strength of these fields, which become weaker as one moves away from the wires, are shown in Figure 2. Generally, the higher the transmission line operating voltage, the stronger will be the electric and magnetic fields at each point in the air around the wires.

What happens to people when they are exposed to the electric and magnetic fields of transmission lines? Is chronic or acute exposure hazardous to health? It should be noted that an appreciable segment of the population lives near a high voltage transmission line right-of-way, or works or plays in the vicinity thereof. Do the electric and magnetic fields injected by the transmission lines into the environment constitute an ecological danger? Historically, transmission lines have been built under the assumption that their electric and magnetic fields are biologically innocuous. The assumption has two bases, The first is a theory[3, 4] which amounts to a prediction based on the laws of physics and certain assumptions of how living things work, that electric and magnetic fields from transmission lines wouldn't affect biological organisms. Secondly, based on the operating experience of the electrical companies, no health problems have appeared which they feel are attributable to power line field exposure. In a sense, therefore, theory and experiment were in agreement.

Biological Effects

In the United States, reports describing biological effects in animals due to exposure to ELF fields began to appear in 1968. In that year, McElhaney reported that rats developed bone tumors when exposed to electric fields of 70 volts/cm.[5] Also in 1968, Marsh found that electric fields of about 4 volts/cm interfered with the growth pattern of flatworms, thereby producing abnormal individuals.[6]

About 1970, interest in the area of the biological effects of ELF fields began to increase markedly as a result of an influx of federal funds brought about by the Navy's plan to build a submarine communications system known as Project Sanguine. The operating characteristics of Sanguine are comparable to high voltage transmission lines, except that the latter have an electric field which is about one million times stronger. Because ELF field biological research was almost non-existent in 1970, the Navy funded a variety of research projects to evaluate the environmental impact of Project Sanguine. The implications of the Sanguine research for the high voltage transmission lines are truly ominous,

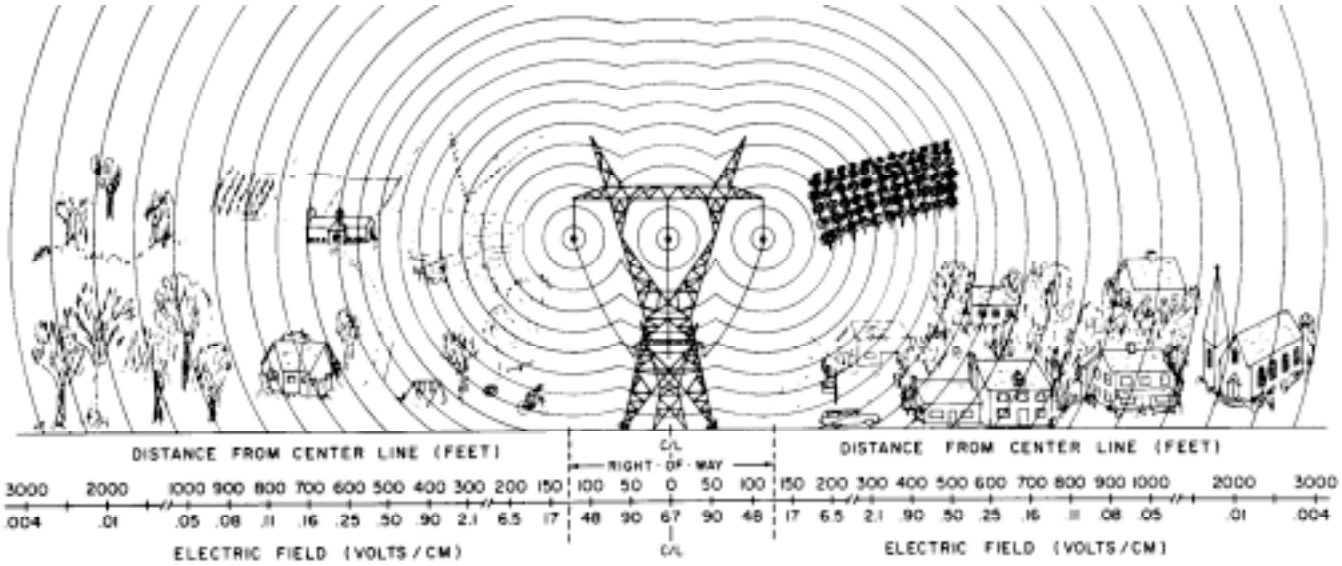

Figure 2. A 765 kV transmission line such as proposed by the Rochester Gas and Electric Corporation, Rochester, New York, illustrating the existence of the electrical energy which is being transported by the line. The energy is transported continuously and much of it moves through space in a region beyond the right-of-way. The energy is composed of an electric and magnetic field. For simplicity, only the electric field magnitude is shown at each lateral distance.

because the Sanguine research as been done at very low field strengths — much lower than that associated with power lines — and has unquestionably demonstrated biological effects.

Goodman studied the effect of Sanguine level fields on the growth properties of slime mold.[7] He found that exposure to such fields introduced a time delay into the normal reproductive cycle of the slime mold and slowed its intracellular activity. Giarola also studied the effect of ELF field exposure on the growth of animals and reported that exposure to 35 volts/cm depressed the growth rate of chicks.[8] In 1975, we raised three successive generations of mice in an electric field of 150 volts/cm.[9] In each generation, we found that the exposed mice were significantly smaller than the control mice (Figure 3).

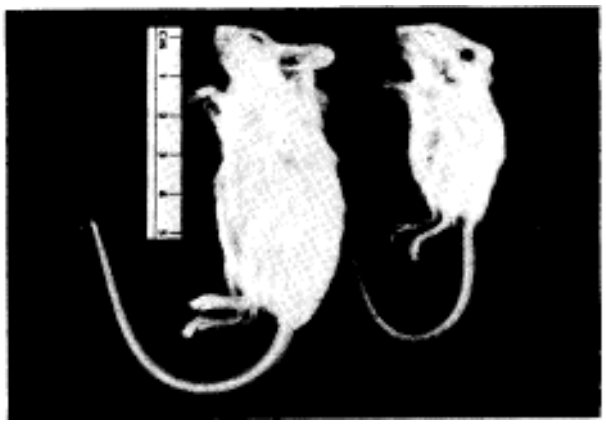

Figure 3. Both mice were thirty-five days old at the time of the photograph. The control mouse is shown on the left. The other mouse is a second generation, electric field exposed individual. That is, conception, gestation and rearing of the mouse and of its parents took place in the electric field.

The reports above show that in a variety of biological systems, ELF fields can interfere with growth processes, either by depressing growth rate or otherwise adversely effecting growth. Other research has opened the possibility that carefully controlled exposure may produce beneficial effects; as for instance, in accelerating the healing process. Mamontov found that cells in the eye and the liver of mice were three times more active when the mice were exposed to an electric field for just four hours.[10] Watson found that chick leg bones grew quicker when exposed to an electric field[11] and Bassett found that ELF fields increased the rate of fracture healing in dogs.[12] Thus, human exposure to ELF fields, under proper medical supervision, may be of considerable benefit to mankind. There exists research, however, indicating that people exposed to very high fields, such as linemen, are undergoing the most serious health risks. Blanchi found cardio-vascular effects in mice and rats which were exposed to an electric field of 1000 volts/cm.[13] Solovev found that mice and insects exposed to electric fields of 5000 volts/cm died after several hours.[14] An electric field of 6000 volts/cm has been reported to kill mammalian cells in cell culture.[15]

A question of interest to scientists is whether and to what extent animals or people are "aware" of the presence of ELF fields. Lott exposed rats to an electric field of 0.4 volts/cm and measured their brain electrical activity.[16] From an analysis of such activity, he concluded that the rats were aware of changes in their external electric field, even when under anesthesia. Lott's observations were extended to yet lower electric fields by McCleave, who reported that fish were aware of electric fields as small as 0.00007 volts/cm.[17]

Workers have now begun to study the behavioral and physiological consequences of electric field exposure and the perception thereof. Spittka found that rats trained to perform simple tasks did not perform as well in the presence of an ELF electric field.[18] In a subsequent study they found that rats, given a choice between a region in which there existed an ELF electric field and a field-free region, chose the field-free region.[19] A similar phenomenon was observed by Altman,[20] in mice. Employing 27 human volunteers, Hamer found that electric fields of 0.04 volts/cm can affect human reaction time performance.[21] Gavalas-Medici has observed similar effects in monkeys at comparable electric field strengths.[22] Earlier work by Konig,[23] presaged the observations of Hamer and Gavalas-Medici.

The ecological hazards associated with the injection of power line fields into the environment, as distinguished from the hazards to human health, have not yet been studied. There are indications, however, that problems exist in this area. Warnke studied the effect of power line electric fields on bees.[24] He found that the fields caused grossly abnormal behavior. At 110 volts/cm, the bees ceased to store honey and pollen and began to kill each other. In a few days the hive was either abandoned or completely sealed off by the bees, resulting in their death due to lack of oxygen. Southern has found that the fields of Project Sanguine are capable of disrupting the orientation of birds.[25] Each linear mile of 765 kV power line will create a zone of about $1\frac{1}{2}$ square miles within which the electric field is higher than that employed in Southern's experiments. The effect of such a zone on bird migration has apparently not been considered.

Thus, it has been shown that biological organisms are able to perceive incredibly weak electric fields and that very strong electric fields can cause death. Intermediate strength electric fields can depress or accelerate growth, alter body physiology and affect behavior. Since individuals who live near high voltage transmission lines undergo chronic exposure to fields of comparable intensity to those which produce biological effects in the laboratory, it must be concluded that such lines probably cause biological effects in the exposed subjects.

Federal Government

Many agencies within the federal government are interested in various parts of the electromagnetic spectrum; however, no agency has the authority to regulate exposure to the electric and magnetic fields of 60 hertz, which ironically is the most common frequency.

The EPA published a notice in the Federal Register[26] in March, 1975, requesting data on the health hazards of high voltage transmission lines, but has not yet begun to analyze the information submitted.

Soviet Union

In the Soviet Union, the situation with respect to the health hazards associated with power line electric and magnetic fields is quite different than that in the United States. It is recognized by the Soviet government that ELF electric fields of high voltage transmission lines do cause undesirable biological effects in exposed workers. Consequently the Soviet government, in 1970, promulgated nationwide rules and regulations governing the nature and extent of the permissible exposure.[27] According to the rules, working conditions are not limited or controlled where the electric field is less than or equal to 50 volts/cm. If the electric field is greater than 250 volts/cm, all workers must wear protective clothing or employ some protective device. For electric fields between the two values, the permissible duration of exposure without protective measures is time limited. Presently, rules governing permissible exposure to transmission line fields apply only to maintenance personnel. However, rules for agriculture workers and for the general public are being developed.[28]

In the Soviet Union, the electric field associated with high voltage transmission lines is a design parameter.[28] In the Soviet view such fields affect people, with the development of symptoms after a comparatively short exposure, such as two months. They further believe that the effects of exposure are cumulative, dose related and strongly depend on individual physiological differences. Such effects include disturbances of the cardio-vascular system, the central nervous system, blood composition and lower sexual capability.[28,29,30,31] The present designs for their generation facilities reflect their concern over these biological effects.

Conclusion

High voltage transmission lines cause ELF electric and magnetic fields. ELF electric and magnetic fields cause biological effects. Presently, in the United States, high voltage transmission lines are designed and built with no regard or weight given to the biological effects being caused by their electric and magnetic fields. The next generation of high voltage transmission lines is now materializing. It would appear appropriate to determine the spectrum of biological effects and to adequately assess the hazards to man of exposure to such fields.

In view of the large population at risk, all of the health hazards associated with the electric and magnetic fields of high voltage transmission lines should be carefully examined in the context of the specific design for each facility, prior to construction.

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