Biological Effects from Exposure to Transmission Line Electromagnetic Fields

by Morton W. Miller

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The right of way agent is often the first utility contact a landowner has when plans call for the routing, construction, and operation of a transmission line across his property. Once public need and necessity are determined the proposed line's routing becomes an important issue. Construction follows route selection, and operation and maintenance considerations come last.

Clearly, the construction of a transmission line involves a number of potential impacts to the land and its owner. The land must often be cleared within a right of way, an access road must sometimes be made to insure maintenance capability, the soil can often be compacted due to the use of heavy equipment involved in tower erection and line stringing. Additionally, there is the possibility of some interference with agricultural practices due to the presence of the towers, and aesthetic qualities can be compromised by the presence of such lines. These "effects of construction and maintenance" are well recognized by the utilities and landowners alike.

A second "effect" which is recognized by the utilities is the issue of electric shock. The lines are strung so as to be normally out of reach of individuals, and signs are posted on towers warning of "high voltage." Occasionally, accidents such as an irrigation worker inadvertently manipulating a pipe into the lines occur, often with lethal consequences. Again, this is a recognized problem by all parties. Additionally, there is the problem of people getting shocked from touching ungrounded structures and vehicles which are in the high fields associated with transmission lines [51]. And again, the problem is recognized and procedures and regulations exist for obviating harmful effects.

The issue of corona effects is also well recognized [51]. Transmission lines, particularly the very high voltage ones, can sometimes be somewhat noisy during foul weather. The noise results from the development of surface irregularities on the wire and the consequent very local enhancement of electric fields at that point. These conditions result in a very localized, on-the-wire breakdown of air, with the resultant production of a slight hiss and the potential developement of radio and television interference. The most noticeable interference usually occurs in areas of normally fringe reception. Again, these are recognized problems associated with the operation of transmission lines,

and steps can be taken to mitigate against them.

The issue of biological effects from exposure to transmission line electric and magnetic fields is NOT a recognized problem. To date, no specific deleterious biological effect has been identified as having been caused by the electric and magnetic fields associated with transmission lines. Yet, strangely, this issue has received considerable press coverage and has been strongly contested in a number of hearings and trials across the country. The purpose of this article, then, is to discuss this latter issue in light of what is known about the effects and mechanisms of action of electric and magnetic fields on people, plants, and animals.

It's very important to recognize that transmission line electric fields can cause biological effects. They in no way can be construed as detrimental, and include the following: 1) Hair Vibration: Under some very large transmission lines it may be possible to feel the hair on one's neck (or face, or out-stretched arm) vibrating. This effect is caused by electrostatic repulsion of the charge on the surface of the hair at unperturbed electric field strengths of about 7 kV/m or more [51] and has a slightly greater chance of occurrence if the arm is raised over the head. The effect of hair vibration has been likened to that of a gentle breeze across the arm. 2) Leaf Tip Corona: Trees and shrubs, if they grow high enough under or very near the wires, may experience "leaf tip corona" on the very tallest leaves. Only the tallest leaves (and generally they must be pointed) experience this effect, which amounts to a 1-2 mm "burn" at the tip of the leaf [49, 52]. This effect is about equivalent to an insect bite or fertilizer burn, and does not appear to interfere with the growth of the plants. Indeed, if left to grow unheeded, trees and tall shrubs will grow to a size where flashover from the line to the tree can occur [51]. Trees and shrubs are normally periodically cut down or chemically treated to prevent such growth. 3) Shock: Transient and steady state shocks may result from a person's contacting a vehicle parked in the maximum field of the line [51]. Clearly, this a recognized problem, and the National Electrical Safety Code requires that the steady state short circuit current from the largest anticipated vehicle under the line NOT exceed 5 milliAmps (a level which is considered below the let-go level for adults). Thus, even this recognized problem does not appear to have serious consequences since allowance is made for release of the vehicle. 4) Cardiac Pacer Interference: Some cardiac pacers may be sensitive to the electric fields of transmission lines; many pacers appear insensitive to them [53]. Some types of modern cardiac pacers are built to sense the electrical signals from the heart when it is beating; but, absent a normal heart beat, the pacer will provide an electrical stimulus to the heart to initiate its contraction. Thus, some pacers are designed such that they are inherently sensitive to electric fields. Obviously, a person walking in the environment of a large transmission line, can have an induced electric field. If the induced field is sufficiently large, the pacer may revert to a fixed mode of operation--i.e., provides "beats" whether or not they're needed. Competitive pacing can result, which means that the heart and the pacer both provide electrical signals. This is obviously not optimal but does not appear to be considered a serious hazard to the patient. That some pacers are insensitive to the electric fields of transmission lines signifies that this particular problem of possible interference can be solved by the designers of pacers. Transmission lines represent only one of many sources of possible electromagnetic interference to pacers. People who wear pacers should probably consult with their physician if they expect to be in the right of way of large transmission lines.

We come now to the issue of the potential for the electric and magnetic fields of transmission lines to cause biological effects, for

PE and Conrail sign agreement

Consolidated Rail Corporation and Philadelphia Electric Company (PE) recently signed a $5.1 million contract under which Conrail will provide permanent easements to replace more than 542 license agreements PE holds for occupancy of Conrail land and facilities.

This contract eliminates the need to negotiate periodically and process annually the rental payments on the 542 agreements covering PE's transmission and distribution facilities which run over and along Conrail land and facilities in the five-county area of southeastern Pennsylvania. As a result, PE will gain permanent easement rights, and Conrail and PE both will eliminate costly and time-consuming administrative and negotiating expenses," announced John Austin, president of Philadelphia Electric, and L. Stanley Crane CEO at Conrail in a joint statement.

The agreement reflects PE's long-standing policy to obtain permanent rights for its electric transmission and distribution facilities in order to minimize long-term occupancy and relocation costs.

This is the largest such agreement Conrail has negotiated. (See RIGHT OF WAY, April 1982) In the past two years, Conrail has completed more than 100 similar, but smaller, conversions of license agreements to permanent easements. Since public utilities make substantial use of railroad land, Conrail believes its action with PE will lay the groundwork for other such permanent agreements.

example, changes in growth, physiology, or reproduction. Four approaches are used to investigate the problem area; these are 1) studies dealing with people, crops and animals exposed to transmission line environments and people exposed under laboratory conditions to electromagnetic environments comparable to or greater than those associated with transmission line environments, 2) studies of plants and animals exposed under laboratory situations to electric and/or magnetic fields, often of magnitudes considerably greater than those associated with large transmission lines, 3) threshold studies, which indicate the field strength levels at the cellular level needed to cause a biological effect, and, 4) relative comparisons between normal household exposures to electric fields and transmission line electromagnetic fields. None of these approaches indicates that deleterious biological effects have been observed or would be expected. The internal agreement among the four approaches is reassuring. Yet, from a scientific point of view, despite the internal consistency of the approaches it is not possible to state categorically that the transmission line environment is "safe"--i.e., that there will be no effects. Science cannot prove that nothing ever will happen. This particular point is troublesome from a public perception point of view since the utility can be placed in the position of trying to prove an impossibility.

The first approach--results dealing with people, crops, and animals exposed to transmission line environments--indicates there are no gross effects induced by exposure to these fields (see Table 1). Included in this category are linemen and switchyard personnel, who by virtue of their occupation, are exposed to very high electric and magnetic fields. The totality of the western literature in this area does not indicate any health problem among the various categories of surveyed people. The Table is composed of reports listing the Author, Setting of the study, and the Result [1-11]. The results are uniformly negative. Similarly, there has been no demonstrated effect on crop plants or farm animals. Honey bees in hives are known to be affected by electric fields of about 4000 V/m and higher; under these conditions, the hive production is less than under control conditions [8,11]. The effect is not related to the bees' comings and goings in the electric field, but rather to what appears related to some factor in the hive which, possibly through some shock-type mechanism, affects the bees.

The Soviet literature in this area does not agree with the results obtained in the west [12-17]. Health surveys of 400 kV substation workers indicated a number of subjective "effects": these included listlessness, tiredness, less sexual potency, etc. There is a strong indication in the data base that transient shocks were a confounding variable in the surveys. The Russians have proposed for their electrical industrial personnel a "standard" for limitations in different electric field intensities; these include unlimited exposure for fields up to 5,000 V/m; at fields of 5,000 -10,000 V/m, 10,000 - 15,000 V/m, 15,000 - 20,000 V/m, and 20,000 -25,000 V/m the permissible durations (minutes per day) are 180, 90, 10, and 5, respectively. It's not known to what extent these "standards" are enforced. There are no exposure standards for the general public.

Studies with humans exposed under controlled laboratory conditions have likewise revealed a lack of effects on a variety of blood and behavioral tests (see Table 2). Experiments have been done with people exposed (or sham exposed) to 50 Hertz electric fields of up to 20,000 V/m, magnetic fields of up to 15G Gauss, or induced currents of

200 microAmperes--all yielding negative results [18-26].

Studies with animals and plants have been much more interesting since in a few cases positive results have been obtained (see Table 3). In this category a variety of animals (rats, mice, pigs, pigeons, rabbits) has been exposed to electric fields up to 160,000 V/m [27-42]. The number of assays undertaken has been very large, and the number of positive or claimed effects very small. There is nothing among any of the results to indicate a deleterious effect upon the organisms. For instance, it appears likely that pigs can detect an electric field of 30,000 V/m--the mechanisms has not been identified [29]. Likewise, it appears likely that rats can detect fields of, say, 5,000 V/m; again, the mechanism of this detection is unknown but hair movement is suspected to play some role [28]. Some effects appear to be real and not just "chance" events. For example, Phillips [27] and Marino [10] have both indicated that bone fracture repair of rats exposed to electric fields of 100,000 and 5,000 V/m is slightly retarded. The mechanism for this effect is not yet known but Phillips has suggested that detection processes (from other research in his laboratory it was demonstrated that rats in a field of 100,000 V/m have more movement) may cause the rat to be more active and thus the activity and not the field per se may be causing the slight but temporary delay in healing of the uncasted, fractured leg. Phillips has also shown that bone growth processes per se do not appear to be affected in rats exposed to electric fields of 100,000 V/m [27]. In general, there have been no effects on growth or reproduction, and no pathological effects noted.

The fourth approach involves a determination of the maximum electric fields in the body from exposure to transmission line electric fields (Figs. 1, 2) and information on the levels of electric fields known to perturb mammalian cells. Consider first a person standing in an electric field of 10,000 V/m -- approximately the largest electric field under any existing transmission line (e.g., a 765,000 Volt transmission line). For a well grounded person approximately 160 microAmperes of current is induced in the body; about ⅓ of the current comes in through the head, with the remainder coming from the shoulders and lower extremeties. Knowledge of the amount of current per area (e.g., current in the thorax) identifies the current density (Amperes/m^2); knowledge of tissue conductivity--such information is readily available for most tissues [e.g., 50] (given in Siemens/m)--allows for calculation of the electric fields via the formula (Ohm's Law) that the electric field (in the body) is equal to the current density divided by the (tissue) conductivity. From this type of analysis it can be determined that the maximum field in the thorax (of a person standing in a 10,000 V/m electric field) is roughly about 0.01 V/m. The highest induced field strength would be in the ankles, roughly about 0.1 V/m. The ankles are very small in cross sectional area and would have nearly the total induced body current flowing through them. For smaller transmission line electric fields the fields induced in the body would be correspondingly less.

We can now ask what levels of electric fields are known to affect mammalian cells? The system most sensitive to electric fields appears to be the nervous system; fields of the order of about 100 V/m at the tissue level are needed to indicate perception (see Table 4; Schwan [50]). This value (100 V/m) is about 10,000 times greater than the intensity of the electric field induced in the thorax of a person standing in a transmission line's electric field of 10,000 V/m. Table 4 lists "Threshold studies" for electric field effects; a "threshold" being defined as the highest exposure intensity not producing an effect. All of the studies in this category [except 49] have one thing in common: they were conducted with electrodes in the conducting medium which contained the organism (Table V). With electrodes in the conducting medium, very high current densities and electric fields in the extracellular fluid surrounding the cells can be obtained. A common feature among these reports [43-50] is that the field strengths

used in the studies are orders of magnitude (i.e., factors of ten) greater than can be achieved by exposure to transmission line electric fields. For example, if one were to expose the root growth exposure medium to an air electric field of 10,000 V/m, the field in the medium would be only 0.0003 V/m, or about 1/1,000,000 of the level needed to achieve a threshold exposure.

The fourth approach is based on relative exposures between those occuring from transmission lines and those occuring from normal living. As seen above, the total body current induced in a person in a transmission line electric field of 10,000 V/m is about 160 micro-Amperes [51]. The American National Standards Institute allows the maximum leakage current from portable and fixed appliances to be up to 500 and 750 microAmperes, respectively (ANSI C101.1). Thus, appliances represent a potential source of electric current in the body far greater than that from transmission lines. Such comparisons in no way prove the safety of transmission line electric fields but serve merely to indicate one aspect of relative exposure and "safety."

The above discussions have focused on electric field considerations. A magnetic field is also produced by an operating transmission line and is a function of the amount of current flowing in the line. The highest magnetic field associated with the largest transmission line is about 0.5 Gauss; for comparison, the earth's magnetic field is about 0.5 but is a steady (d.c.) field whereas the magnetic fields of 60 H_z transmission lines are alternating and thus have the capacity to induce a slight electric field in the human body. The fields in the body result from the production of "eddy currents", whose amounts depend principally on loop radius. Thus, the largest loop in the human body is generally in the chest (assume a radius of about 20 cm) and the largest magnetically-induced electric field would be about 0.002 V/m--or, about an order of magnitude less than that induced by the transmission line's electric field [51]. Thus, the likelihood for a transmission line magnetic field to induce a biological effect appears less than that for the associated electric field.

Let me comment briefly on the involvement of the popular press in this area. Do, for example, the electromagnetic fields associated with our power delivery systems cause bodily harm, as suggested by the Reader's Digest [54]? This suggestion was based on a report by Wertheimer and Leeper [55] who postulated that young persons living near high current configuration distribution lines (backyard distribution lines) had an increased incidence of cancer due to the magnetic fields of these lines. The Reader's Digest failed to point out that 1) there were no field measurements taken at the residences, 2) an attempt was made to verify the result but failed [56], and that in the totality of research in this area, including all the epidemiological investigations throughout the world of linemen and switchyard personnel (people who would be exposed to very high fields) plus all the animal research there is no suggestion of carcinogenic activity from exposure to electric fields.

If there are health risks associated with exposure to transmission line electric field and magnetic fields, the risks appear to be very small. Firstly, there is not one specific deleterious biological effect that has been identified from exposure to transmission line electromagnetic fields despite their long term presence (about 4 generations) and long term exposures as represented by maintenance and switchyard personnel. Secondly, animal studies involving exposures comparable to or greater than those associated with transmission lines have not revealed deleterious effects. And, thirdly, from a mechanistic point of view, which involves an understanding of how electric fields interact with cells, it's difficult to see how such low internal electric fields can affect cells.

There are a number of useful review references which can be consulted for greater in-depth analyses of the literature pertinent to this field. Sheppard and Eisenbud's [57] book Biological Effects of Electric and Magnetic Fields of Extremely Low Frequency indicates "...there is no

evidence that the public health or ecological systems have been jeopardized in the slightest by artificial electromagnetic fields . . ." The United States Environmental Protection Agency has published a final report [58] in this area which contains the following statement "It also appears to be reasonably well established that the normal environment produced by such transmission lines does not produce any significant health or environment risk." The Electric Power Research Institute has likewise published a final report [59] entitled Biological Effects of High-Voltage Electric Fields, which concludes "the findings of this update indicate that power frequency electric fields have no important biological effect on healthy individuals who encounter such fields under ordinary conditions." Bridges and Preache [60] have published an excellent tutorial and concluded ". . . It does not appear likely that power-frequency electric fields from existing transmission lines can cause any important biological effects on humans at ground level." The 1982 "red book"

(Transmission Line Reference Book) [51] indicates "To date, no specific biological effect of ac electric-fields of the type and value applicable to transmission lines has been conclusively found and accepted by the scientific community.....It appears that biological effects of ac electric fields, if any, are masked by the normal dispersion of the behavior of biological systems." Finally, Hauf [61] concludes that "experimental studies show that E fields of intensity up to 20 kV/m and H fields of intensity up to 240 A/m, i.e., 0.3 mT [note: 0.3 mT = 3 Gauss], whether individually or in combination, do not constitute a danger to health."

One Call Symposium

The American Public Works Association's Utility Location and Coordination Council in cooperation with 27 different associations represented on the Council is presenting a One-Call Systems and Damage Prevention Symposium in Washington, D.C. on June 26-29, 1983.

The Symposium features a variety of workshops designed to substantially reduce accidental dig-in damage to gas, water, sewer, telephone, electric,and other utility structures.

Symposium headquarters are at the Hyatt Regency located on Capitol Hill. Contact the APWA in Chicago for further information.

TABLE 1: ILLUSTRATIVE WORKING SITUATIONS: A. C. TRANSMISSION LINE EXPOSURE INVESTIGATION FOR BIOLOGICAL EFFECTS

Author(s)	Setting	Results
Kouwenhoven et al. Singewald et al. [1]	9-yr survey 345 and 765 kV transmission linement	negative
Roberge [2]	735-kV switchyard personnel	negative
Strumza [3]	residents near, far from, 200-400 kV	negative
Krupme et al.; Houck [4]	5-yr survey for Seafarer, controls	negative
Hodges et al. [5]	765-kV TL, crops	negative
Amstutz et al. [6]	TL, animals	negative
Knave, B. [7]	5-yr survey 400 kV substation workers, controls	negative
Greenberg et al. [8]	765-kV TL, bees	Behavior correlates with hive construction features
Stopps et al. [9]	High-voltage equipment and TL workers	negative
Greene [10]	765-kV TL, crop plants	negative
Lee et al. [11]	1100 kV prototype trees,+ shrubs and plants,* small mammals,* livestock* bees.**	*negative +leaf tip on tall plants; **confirms Greenberg et al. [8]

TABLE 2: ILLUSTRATIVE HUMAN LABORATORY EXPOSURES, INVOLVING ELECTRIC FIELDS, MAGNETIC FIELDS, ELECTRIC CURRENTS AND BIOLOGICAL ASSAYS

Author(s)	Setting	Results
Hauf, R. [18]	1-20 kV/m, 50 Hz, 3 hr: Behavior, blood	negative (some slight but within normal range)
Manntell [19]	3G, 50 Hz, 3 hr: Behavior, blood	negative
Johannson et al. [20]	30 kV/m, 50 Hz, 75 min: Behavior	negative
Beischer et al. [21]	10, 45 Hz, 24 hr: Behavior, blood (including triglycerides)	negative
Eisemann [22]	200 uA 50 Hz, 3 hr: Behavior, blood	negative
Tucker et al. [23]	15G, 60 Hz, 150 trials: Perception	negative
Gibson et al. [24]	1G, 45 Hz, 24 hr: Behavior	negative
Arnon [25]	20 kV/m, 50 Hz, 5 hr: Physiology	negative
Rupilius [26]	3G, 20 kV/m, 50 Hz: Behavior, blood (including triglycerides)	negative

TABLE 3: ILLUSTRATIVE ANIMAL LABORATORY EXPOSURES

Author(s)	Setting	Results
Phillips et al. [27]	Rats and/or mice; 60 Hz, 100 kV/m Hematology,* Immunology,+ Growth,* Bone Growth,* Bone Fracture Repair,+ Endocrinology,* Cardiovascular Function,* Neurophysiology,+ Reproduction,* Behavior,+ Perception+	negative* +some positive results
Stern [28]	Rats, 60 Hz, 100 kV/m	threshold 4 kV/m
Kaune et al. [29]	Field perception (pigs)	threshold 30kV/m
Grissett [30]	Growth, physiology (monkeys, 147 weeks, 75 Hz, 2G, 20 kV/m)	negative
Smith et al. [31]	Growth (rats, 60 Hz, 25 kV/m, 30 days)	negative
Seto [32]	Growth (rats 60 Hz, 20 kV/m)	negative
Knickerbocker et al. [33]	Growth, reproduction (mice, 60 Hz, 160 kV/m, P_1, F_1)	negative
Mathewson et al. [34]	Growth (rats, 45 Hz, 100 kV/m, 28 days)	negative

Krueger et al. [35]	Growth (mice, 45-75 Hz, 100 kV/m, 28 days)	negative
Grissett et al. [36]	Behavior, physiology (monkeys, 10-75 kV/m, 3G, 20 V/m)	negative
Graves et al. [37]	Physiology, behavior (mice, 60 Hz, 50 kV/m, 6 weeks; pigeons 21 kV/m)	Corticosterone level elevated first 5 minutes at 50 kV/m (maybe), pigeon perception
Marino et al. [38]	Growth, physiology (rats, 60 Hz, 15 kV/m, 28 days)	decreased water consumption
Cerretelli et al. [39]	Cardiac, physiology, growth, immunology (mice, rabbits, rats, dogs, 50 Hz, 100 kV/m, 2 months)	no effects at 10 kV/m
Marino et al. [40,41]	Growth, reproduction, 3 generations (mice, 60 Hz, 3.5-15 kV/m)	increased and decreased weights, increased mortality
Marino et al. [42]	Bone fracture healing (rats, 60 Hz, 5 kV/m, 14 days)	healing depressed, 5 kV/m

TABLE 4: ILLUSTRATIVE THRESHOLD LEVELS* OF ELECTRIC FIELDS OR CURRENT DENSITIES FOR INDUCING BIOLOGICAL EFFECTS

Author(s)	Setting	Results
Marsh [43]	60 Hz, flatworm, biopolar regeneration	threshold 310 V/m, 0.6-0.8 mA/cm^2
Riesen et al. [44]	60 Hz, brain organelle function	perturbation 155 V/m 1.8 mA/cm^2 not at 0.07 mA/cm^2
Miller et al. [45]	60 Hz, root growth	perturb. threshold 300V/m, 2mA/cm^2
Friend et al. [46]	1-100 Hz, Amoeba cellular alteration	threshold 300 V/m, 1 mA/cm^2
Coate et al. [47]	45-75 Hz, 1 and 2G, bacterium mutation	negative at 20 V/m, 0.5 mA/cm^2
Straub et al. [48]	25-7500 Hz, marine organisms	perception at 1 mA/cm^2
Johnson et al [49]	60 Hz, leaf tip damage	inception at 20 kV/m for pointed leaves
Schwan [50]	60 Hz, perception	100 V/m

*at cellular level, except Johnson et al. [49]

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