J. ENVIRONMENTAL SYSTEMS, Vol. 10(4), 1980-81

IMPACTS OF OVERHEAD HIGH VOLTAGE TRANSMISSION LINES

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ABSTRACT

As the demand for electrical energy has risen, there has been a concomitant trend towards the use of higher transmission line voltages. The environmental impacts of the electrical and physical properties of such high voltage transmission lines is outlined in this paper. In particular a review is made of the latest available literature and research regarding this problem.

INTRODUCTION

In this paper we review the environmental impacts of transmission of bulk electricity by overhead high voltage transmission lines (HVTLs). An assessment of the environmental impacts is necessary when considering the tradeoffs involved between the various alternatives for movement of energy over long distances such as coal by rail or pipeline for local electricity generation and distribution. Here we are concerned with two types of impacts. First, we consider those environmental impacts which are of an electrical origin; these are impacts due to the electric field, magnetic field and the corona discharge which are produced when electrical energy is transmitted via HVTLs. The second type of environmental impacts deals with those problems which are not electrical in origin, but are due more to the physical presence of the transmission system. These are concerns around such issues as right-of-way (ROW), routing, and land use; we classify such problems as siting environmental impacts.

The paper is divided into four sections. In Section I a discussion is presented giving the background of the problem including the dimensions of this country's demand and useage of electrical energy. Included in this discussion are estimates of present HVTL circuit-miles as well as projections up to the year 1987.

doi: 10.2190/UEED-TV7W-EGJW-92RR
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In Section II we review the basic theory behind the electrical phenomena which gives rise to the various environmental problems. This discussion included electric fields, magnetic fields, and corona.

In Section III an assessment is presented of both types of environmental impacts. The section is divided into two parts with most of the emphasis of work reported on the impacts of electrical origin.

The final section summarizes the results and presents our view of areas of needed research.

I. BACKGROUND

As the U.S. demand for electrical energy has risen, there has been a concomitant trend towards the use of higher transmission level voltages. Over the last twenty-five years, we have seen introduced 345 kilovolts (kV), 500-kV, and 765-kV high voltage transmission systems. In addition, lines are under development which could support transmission systems from 1000 to 1500-kV [1]. The public has become increasingly concerned over the health and environmental impacts of high voltages transmission systems. In these times of increasing energy cost, the impacts of high voltage transmission must be weighted against the problems of local production of electrical energy.

The annual growth rate for electricity is expected to range between 5.1 per cent to 6.1 per cent between the years 1976 and 1979; the annual growth rate for the years 1970 through 1976 was 5.4 per cent [2]. There appears to be a leveling of demand for electricity brought about in some part due to the national effort to promote energy conservation. Projections by the Department of Energy, assuming a moderate demand and supply scenario, have national electricity generation at 3,009 and 3,615 billion kilowatts by the year 1985 and 1990 respectively [2]. The HVTL will be an important part of the ultimate distribution of the energy to the consumer.

The bulk electricity transmission system for North America consists of several highly developed networks interconnecting essentially all utilities in the United States and Canada.

The basic operating voltages for bulk transmission lines range from 230-kV through 800-kV. These networks constitute the basic framework of the bulk power supply system [3]. At present there are 121,079 miles of bulk transmission lines operating at alternating voltages ranging from 230-kV through 765-kV and 2,598 miles of high voltage direct current (HVdc) lines. During the next ten years, the utilities in North America are planning to add to the bulk transmission network over 20,700 miles of 345-kV, 13,700 miles of 500-kV, 2,400 miles of 765-kV, and 3,100 miles of HVdc [3].

The transmission system is designed to provide intraregional and interregional transfer capability. The interconnections provide operating flexibility thereby providing a more reliable power supply, i.e. emergencies can be handled routinely with problems being confined to as small an area as possible. When breakdowns occur at different points in the network either simultaneously or sequentially such as during storms, tornados, etc., only a small part of the system is affected without causing a domino effect disabling a large portion of the system.

The transmission line technologically represents the weakest link in the electric power system. As we shall see later, transmission lines produce many negative impacts on the environment, they cause noise, pollution, are bulky, vulnerable in storms, and are the cause of many accidents. Their energy transmission capability is questionable when compared with some other methods of transporting energy. However, what ever their shortcomings we will be forced to live with transmission lines for some years to come.

Efficiency requires that electric energy be transmitted at very high voltages. Rarely is the voltage on a transmission line less than 69-kV (69,000 volts). Voltages on distribution lines are almost always significantly less than that figure. Transmission lines of 135-kV and above have the greatest impact on the environment. Transmission lines of 345-kV to 800-kV are extra-high voltage (EHV) lines; lines with voltages above 800-kV are ultra-high (UHV) lines. The basic levels for transmission line voltages are 230-kV, 345-kV, 765-kV.

High Voltage Transmission in the United States

Almost all high voltage transmission in this country is by means of alternating current (ac). The past decade has seen a rapid expansion in the use of 345 and 500-kilovolts as the primary transmission levels. The Spring of 1969 saw the introduction of the first 765-kilovolt equipment in the United States. High voltage direct current (dc) is also a means of moving electrical energy over long distances. The first high voltage dc transmission system in the United States was the Pacific Intertie line running from the Dalles Dam on the lower Columbia River (Oregon-Washington), to the Sylmar Station in Los Angeles about 1300 kilometers long. This line was placed in commercial service in May 1970. The trend to higher voltages, accelerated in the past primarily by the economic advantages of transmitting large blocks of power, is now influenced significantly by the need to make maximum use of right-of-way and thereby to minimize environmental intrusion [4].

AC Versus DC Transmission

For a line which is not tapped frequently a dc transmission line is more economical than an ac line. The primary economic gain in high voltage direct current (HVdc) transmission is that only two conductors per circuit are needed, rather than the three required for alternating current. As a result, dc transmission towers carry less conductor dead load and they can be smaller, less costly to fabricate, and easier to erect.

High voltage dc lines must not be tapped frequently if the economy is to be realized because dc transmission requires expensive terminal facilities (converters/inverters stations) to convert ac at the generator to dc for transmission and inversion at the load centers to invert dc to ac for ultimate distribution to the consumer.

The losses are smaller with dc than with ac. For the same amount of power over the same size conductor at the same peak load gradient for the same distance, ac line losses are 33 per cent greater for the same conductor voltage stresses and same power transmitted [5].

A disadvantage of HVdc transmission, however, is in both electro-magnetic interference and radiation, since the corona effects are a function of the maximum voltages. Thus RF interference can be up to 41 per cent higher than for ac transmission.

Finally, if terminal equipment capital costs are kept at a minimum, HVdc lines can be economically built as electrical energy super highways with few turn offs.

II. BASIC PHYSICS OF HIGH VOLTAGE TRANSMISSION

Voltages on transmission lines induce electric fields in the vicinity of the lines. The intensity of this field is measured in kilovolts per meter (kV/m) and is strongest in the near vicinity of a line. In addition to distance from a line, the electric field intensity is directly proportional to the transmission-line voltage. Under a 765-kV line at its closest proximity to the ground, the field intensity is about 8 kV/m at a measurement point about 1.5 m (5 feet) above ground [6]. A person standing on the ground in this field would have approximately 120 microamperes flowing through him, about 1/10,000 of the current flowing through a 100-watt light bulb. Leakage currents from metallic household appliances cause 20-300 microamperes of current flow in grounded persons holding them [6]. (The ANSI standard maximum leakage current is 500 microamperes for stationary appliances.) Perception of a current flow in humans begins around 500 microamperes [6]. At least 5 milliamperes are required to produce shock which is disabling and 60 milliamperes or more is needed to cause fibrillation of the heart in adult humans [7].

Whenever current flows in an electrical conductor, there is an associated magnetic field which surrounds the conductor. A magnetic field resulting from an ac current can induce a voltage at the open ends of parallel conductive circuits. The intensity of a magnetic field at a given point is directly proportional to the magnitude of the current and is inversely proportional to the lateral distance of the point from the conductor. With dc, static magnetic fields are produced; therefore, no induced voltages occur; the transmission static magnetic field is not a major concern.

Magnetic field intensity is measured in units of gauss. The magnetic field produced by ac transmission lines are low. The Underwood, ND-to-Deleano, Mn ± 400-kV dc line is estimated to produce a maximum static magnetic

Table 1. 60-Hertz Electric Feilds in the Vicinity of Electrical Appliances

Appliances	*Electric Field Strength (Volts/Meter)*[a]
Electrical Range	4
Toaster	40
Electric Blanket	250
Iron	60
Broiler	130
Hair Dryer	40
Vaporizer	40
Refrigerator	60
Color TV	30
Stereo	90
Coffee Pot	30
Vacuum Cleaner	16
Clock	15
Hand Mixer	50
Incandescent Light Bulb	2
Phonograph	40

[a]Measured at a distance of 30 cm from the appliance.
Source: Bridges, 1975 (from *Public Health and Safety Effects of HV Overhead Transmission Lines: An Analysis for the Minnesota Environmental Quality Board,* Minnesota Department of Health, October 1977, pp. 10-11).

field flux density of 0.20 gauss at ground level for bipolar operation and 0.23 gauss for monopolar operation at design levels [8]. Recommended exposure standards are two to three orders of magnitude (100 to 1,000 times) or greater [8]. The dc magnetic field of the earth has flux density of about one-half gauss.

The low magnitudes of magnetic field intensities measured around transmission lines indicate that long-term deleterious biological effects are not anticipated [8].

Table 1 gives typical electric field intensities produced by common electrical appliances. Notice that the values given in this table for the electric field are in volts per meter not kilovolts, that is, the largest electric field is produced by an electric blanket which is, 250 volts per meter or 0.250 kilovolts per meter. Recall that a 765-kV line produces a field intensity of approximately 8-kV per meter about 5 feet above the ground or about 8000 volts per meter, which is 32 times as great as the field produced by the electric blanket.

Table 2 gives the magnetic field intensities produced by common electrical appliances. The largest magnetic intensities are in the range of 10 to 25 gauss; hairdryers produce magnetic fields in this range. This is relatively large when compared with the magnetic field produced under a 765-kV ac transmission line,

Table 2. Localized 60-Hertz Magnetic Flux Densities Produced By Electrical Appliances

10–25 Gauss	*0.01–1.0 Gauss*
325 Watt Soldering Gun	Toy Auto Transformer
Magnetic Stirrer	Garbage Disposal
Power Feeder Cable	Clothes Dryer
Hair Dryer	Black/White Television Set
	Vacuum Cleaner
5–10 Gauss	Heating Pad
Can Opener	Electric Toaster
140 Watt Soldering Gun	Bell Transformer
Flourescent Desk Lamp	
Kitchen Range	
Electric Shaver	*0.01–0.1 Gauss*
	Home Electric Service Unit
1–5 Gauss	Kitchen Fluorescent Lamp
Bench Grinder	Dishwasher
Arc Welder	Laundry Washer
Food Mixer	Phonograph
Power Transformer	Calculator
Induction Motor	Electric Iron
Color Television Set	
Food Blender	
Electric Drill	*0.001–0.01 Gauss*
Portable Heater	Refrigerator

Source: *Public Health and Safety Effects of HV Overhead Transmission Lines: An Analysis of the Minnesota Environmental Quality Board, Minnesota Department of Health,* October 1977, pp. 11-15.

since, the magnetic field intensity peak at about 0.16 gauss is about 50 feet from the line conductors at approximately 10 feet above ground; at ground level the maximum magnetic field is about 0.12 gauss at the same distance from the conductors [9]. These values assume a line current of 1000 amperes.

In Table 3 we summarized results from research over the years in the physiological response to electric shock. The total current induced by the electric field between ground and a man standing in electrical contact with the ground, known as the short-circuit current is about 16-20 microamperes per kV/m [7]. This means that at an electric field intensity of 10 kV/m we would have a maximum total current of 200 microamperes. Note that the values of currents given in Table 3 start at .3 milliamperes or 300 microamperes. According to Table 3, 200 microamperes or .2 milliamperes would not be perceptable. A rule of thumb for calculating the maximum transmission line electric field intensity at ground level is 1.6 kV/m for each 100 kV of line voltage for single circuit ac lines [8]. This would mean that the field intensity at ground level for a 500-kV line would be:

Table 3. Physiological Response Thresholds for Electric Shock

Effect	*Current, Milliamperes* *Direct Current* *Men*	*Women*	*60 Hertz, rms* *Men*	*Women*
1. No sensation on hand. Perception threshold for 0.5% of men tested; extrapolated for women.	1.0	0.7	0.4	0.3
2. Slight tingling. Perception threshold for 50% of men tested and extrapolated for women.	5.2	3.5	1.1	0.7
3. Shock. Not painful and muscular control not lost. Perception threshold for 99.5% of men tested and extrapolated for women.	9.5	6.4	1.8	1.2
4. Painful shock. Let-go threshold for 99.5% of persons tested.	62.0	41.0	9.0	6.0
5. Painful shock. Let-go threshold for 50% of persons tested.	76.1	50.3	16.0	10.5
6. Painful and severe shock muscular contractions, breating difficult.	90	60	23	15
7. Possible ventricular fibrillation from short shocks.				
a) Shock duration 0.03 sec	1300	1300	670	670
b) Shock duration 3.0 sec	500	500	67	67
8. Certain ventricular fibrillation (if shock duration is over one heart beat interval).	1375	1375	275	275

Source: *Public Health and Safety Effects of HV Overhead Transmission Lines: An Analysis of the Minnesota Environmental Quality Board, Minnesota Department of Health,* October 1977, pp. 11-26.

$$1.6 \times \frac{500}{100} = 8 \text{ kV/m}$$

This implicit proportionality has been true for lines designed in conformance with conventional practice; however, controlling capacitive coupling effects constrains the ground-level field strength so this proportionality may not be applicable to the higher operating voltages of the future [8]. That is, line voltages above about 500-kV.

The third phenomenon associated with deleterious effects from HVTL's is Corona. Corona is an electrical discharge produced when the electric field intensity at a conductor surface exceeds the electric breakdown potential of the surrounding air. Corona action may be summarized as follows:

> Corona is an electrical discharge produced when the electric field intensity at a conductor surface exceeds the electric breakdown potential

of the surrounding air. When this happens, an avalance of electrons will collide with the molecules of the air, causing energy to be released in the form of visible light, lower frequency electromagnetic energy, and acoustic energy. That is to say, the corona discharges can be heard, they can produce radio and television interference, and sometimes they may cause a visible glow at night. In addition, a molecular transformation of oxygen will occur in which normal molecular oxygen (O_2) is converted to the toxic gas ozone (O_3). Besides these environmental consequences, corona also causes an unrecoverable loss of electrical power.

Corona will usually take place at discrete places on the conductor where the electric field is concentrated by surface irregularities such as nicks, scratches, contaminants, insects, and water drops. In general, the intensity of the corona related phenomenon is made more severe as these irregularities increase in number. Because of this, corona effects are usually most severe during periods when water drops adhere to the conductors.

Corona will also become more intense if the conductors contain an abnormal number of irregularities, such as caused by improper manufacturing or handling during installation of the conductors. However, even when utmost care is exercised in manufacturing and installation, corona will occur at 500-kV levels. In other words, corona is generally not caused by a malfunction of hardware in the sense that it can be eliminated by replacing faulty equipment. It is a normal and unavoidable consequence of transmission line design [10].

III. ENVIRONMENTAL IMPACTS OF TRANSMISSION LINES

This section discusses several of the environmental effects which have an origin either in the electric or magnetic fields or corona phenomenon. Specifically the following effects are discussed:

(a) Audible Noise
(b) Biological Effects
(c) Effects on Cardiac Pacemakers
(d) Ozone Production
(e) Spark Discharges
(f) Helliwell Effect

In the discussion which follows we use some of the testimony in the New York State Public Service Commission Hearings [9,11] regarding the building of 765-kV lines in that state. These hearings were held for more than four years and centered on the health and safety aspects of HVTL's.

Some of the country's leading experts presented testimony on the technical aspects of the health and safety issue. The testimony was more than 15,000 pages and presented a forum for the airing of some of the national concerns about transmission lines. The information presented in these hearings is an important part of the current data base for the assessment of the potential environmental impacts of high voltage transmission lines.

Audible Noise from Transmission Lines

Corona discharge along a transmission line can produce an audible noise. The Department of Energy is currently sponsoring research to determine the appropriate scales and procedures for making measurements of transmission line audible noise [11]. The New York Public Service Commission Common Record Hearings had extensive testimony regarding the transmission line noise problem. The following is a summary of some of the testimony regarding noise compiled by SRI International [9].

> What is the major controversy in the noise testimony?
> Whether the transmission line meets EPA guidelines.
>
> Corona discharge creates high levels of audible noise only during foul weather, which is limited to rain, occurring 3-10% of the time along the right-of-way in New York, fog about 4% of the time, and snow about 5-10% of the time. EPA (1974) has suggested that 55 dB L_{DN} [1] divides acceptable from unacceptable noise environments. Using these guidelines as a starting point, the experts argued about whether to average the noise over twenty-four hours or over one year. The noise from a 765-kV transmission line is 58 dB L_{DN} average over twenty-four hours (the maximum 24-hour average) while the noise is 53 dB L_{DN} averaged over one year. Unfortunately, the EPA document does not specify averaging times for L_{DN} measurements, and witnesses debated the EPA's intent in setting the 55 dB L_{DN} Limit.
>
> More recent studies by EPA and others show that an L_{DN} of between 53 dB and 58 dB cause at least sporadic complaints and possible widespread complaints in certain types of communities, if the lines pass close to the community and it has had little exposure to high noise levels.

Biological Effects of Transmission Lines

This is a very active area of research. Several literature reviews exist on the research in this area Janes [12] and Phillips and Kaune [7] are two of the most recent. Most of the studies do not involve humans; perhaps, in most cases mice are used along with swine, chicken, and meadow voles and birds.

Phillips and Kaune cite several studies which have attempted to examine the effects of 60 Hz fields produced by EHV lines on farm crops and animals. Some eighteen farmers on land near a 765-kV line were questioned regarding possible effects. Responses by the farmers indicated no alterations in crop productivity, cattle, hogs, or in dairy production of grazing animals could be attributed to the electric fields from the transmission line [7]. Another survey involving 125 farms on land near a 765-kV transmission had 116 reporting no problems relating to the grazing of their animals [7]. A major study by Battelle

[1] L_{DN} is a noise average over a twenty-four-hour period (or longer) that weights nighttime noise more heavily than day time noise.

Labs, Pacific Northwest on HV lines [13] looked at major areas[2] to screen for biological effects over a wide range of parameters in rats and mice exposed to 60-Hz electric fields at 100 kV/m for up to sixty days. Summarizing their study we find:

> . . . exposure of rats and mice to 60-Hz electric fields for up to sixty days had no statistically significant, reproducible effects except in the behavioral experiments . . . The results of three experiments showed trends which suggest the possibility of effects on decreased cell-medicated immunity, increased prostatitis and increased excitability of synapses [13].

Work reported in Phillips and Kaune suggest there may be an effect on laboratory animals.

> Marino et. al. (in press) reported on a total of ten experiments which suggested that exposure of rats to vertical, 60-Hz electric fields at 15 kV/m for thirty days may result in decreased corticosterone levels, increased serum albumin and serum glutamic oxaloacetic transaminase, increased pituitary and adrenal weights, decreased water consumption and decreased body weight. However, only the decrement in water consumption was regularly demonstrated, suggesting the animals may have received shocks or perceived current flow when they drank during exposure. The other results were inconsistent [7].

The expert testimony in the New York State Commission hearings was in violent disagreement regarding effects on animals. Many claimed effects including the following [9].

In rats, mice and guinea pigs

–Decreased weight gain
–Altered enzyme levels in various organs
–Altered blood steriod levels
–Increased bone growth
–Bone tumor induction
–Electrocardiogram phasing
–Hematologic alteration
–Serologic alterations
–Perception of electromagnetic field
–Locomoter activity changes
–Lethality
–Weight loss in progency
–Organ weight changes
–Water consumption changes
–Changes in lactation
–Changes in litter size

In miscellaneous species and organisms (dogs, cats, birds, invertebrates, and plants)

[2] These areas were: hematology and serium chemistry, immunology, metabolic status and growth, bone growth and structure, endocrinology and male reproduction, cardiovascular function, central nervous system, neuro-physiology, reproduction growth and development, and animal behavior.

–Cell cycle alteration
–Mitotic index alteration
–Perception of electromagnetic fields
–Leaf tip burning
–Reduction in calcium release from brain tissue
–Orientation to electromagnetic fields
–Decreased compensation to stress induction

Some experts claimed no significant effects on animals of any consequences. The analysis of these hearings by SRI made the following important points.

- At the present time the disagreement over whether there are biological effects cannot be satisfactorily resolved.
- The electromagnetic fields have not been shown to be hazardous (nor have they been shown to be without effect). Little evidence offered at the hearings indicate that people are adversely affected at home or at work by electric fields at power line frequencies.
- Many data gaps remain on health and environmental effects.
- The majority of the research discussed in the hearings, because it purports to show effects, creates an impression in the lay reader that effects are there for even the simplest scientific experiment to display. *Such is not the case* [9].

There have been relatively few results of studies on humans involving HV electromagnetic fields. A study by the American Electric Power Company is reported by Phillips and Kaune.

> In 1962 studies were initiated by the American Electric Power Company on safety practices, field intensities, body currents and working environments related to high voltage transmission lines. In one of these studies medical examinations were conducted over a nine-year period on eleven linemen working on 138 and 345-kV transmission lines (Kouwenhoven 1967, Singewald, 1973). Four of the men regularly worked on live lines while wearing conducting clothing and gloves, exposing their heads to 60-Hz electric fields up to 470 kV/m. The other men worked mostly with hot sticks and were exposed to maximum fields of 70 kV/m. During the period seven extensive medical examinations were conducted at Johns Hopkins Hospital. No significant changes of any kind were found [7].

Janes summarizes the "state of the art" in the human research of biological effects of high electric fields. Quoting from Janes:

> Only a small amount of work has been done to explore the possible effects of electric fields from transmission lines on biological systems. Bridges lists seven American and Western European studies that relate to effects on humans. Four of these studies are on effects of short term exposures to electrical treatment experiences of people living within

25m of a transmission line, another examines the experiences of farm workers on 18 farms traversed by a 765-kV line, and the final study investigates the physiological state of transmission line workers intermittently exposed to intense electric fields during maintenance work. No prompt, acute, or permanent effects were noted in any of these studies, which is reassuring. However, only two of these studies look at long-term exposure [12].

Transmission Line Effects on Cardiac Pacemakers

The cardiac pacemaker is an electrical device which provides electrical stimulus which maintains or reestablishes normal heart rhythm in a person afflicted with a so-called "heart block". There are four different types of pacemakers with varying degress of sensitivity to an external field.

The first type of pacemaker called fixed rate or asynchronous stimulates the heart at a fixed rate, about seventy beats per minute. This type of pacemaker is designed without a sensing circuit and therefore is not influenced by external fields.

The three types of pacemakers which are sensitive to external fields are the P-wave synchronous, R-wave synchronous, and R-wave inhibited. The R-wave synchronous pacemaker senses the electrical activity in the atrium of the heart and provides a pulse in synchronism with it only when normal heart action is absent. R-wave synchronous pacemakers, similar to P-wave, are used where conducting fibers in the heart ventricles are defective and there is no risk of competing with a natural heart pulse. R-wave inhibited pacemakers remain dormant for a fixed period of time, about 0.24 seconds out of the 0.857 seconds required for each heart beat. The devise is alert for the next 0.617 seconds and if no natural heart beat is detected, it will provide stimulus to the heart [11].

The two R-wave types, known as demand pacemakers, can be affected by radar pulses, television transmitters, automobile ignition systems, anti-theft systems and many other devices. The catheter of any pacemaker, introduced into the heart through a vein or by open-heart surgery, may be either bipolar or unipolar. The latter type appears to be more sensitive to external fields. In general, however, the two types of R-wave pacemakers are only moderately susceptible to outside influences [11]. On the other hand, the P-wave type may be significantly affected by high-frequency, modulated fields like those produced by a radar station. Power transmission lines do not produce high ferquency modulated fields. About 80 per cent of the pacemakers now implanted are of the demand type (R-wave) [11].

During its investigation of the proposed 765-kV transmission line through New York State, the NYPSC concluded that educational programs on the potential hazards to pacemaker users from high voltage lines are justified and can provide reasonable protection. It also concluded, however, that the potential hazard from high voltage lines was not sufficient to warrant a delay in the construction of the line.

And in its report the NYPSC further commented:

> We acknowledged that under certain circumstances the fields produced by extra-high voltage transmission lines on some portions of the 250-foot right-of-way could interfere with the operation of cardiac pacemakers, but noted that such lines were only one of a number of comparable hazards, such as radio transmitters, microwave ovens, certain electric shavers, etc., to which pacemaker wearers are exposed. Also, most pacemakers are designed to shift their mode of operation in order to cope with interferences from ambient electric fields.

SRI's analysis of the New York State Commission Hearings supported the NYPSC results and concluded that there are no adverse medical implications of a pacemaker's reaction to a 765-kV line under most circumstances. The exceptions are for people who have coronary artery disease, or a serious electrolyte imbalance, who experience drug toxicity or who are subject to ventricular fibrillation. It was claimed in the Hearings that ample evidence indicates that if a pacemaker stimulus occurs during a brief period of hyperexcitability in the heart's electrical cycle, serious disturbances of the heart rhythm may be induced, including: rapid heartbeat (ventricular tachycardia), or possible ventricular fibrillation, which requires immediate medical attention [9]. This testimony was stricken from the record because the witness was not a cardiac specialist.

Ozone Production—Ozone, a gase which can be toxic in sufficient quantities, is produced by the corona discharge of a transmission line. At normal temperatures, ozone is an extremely reactive gas with a characteristic pugent odor. Ozone in sufficient concentration is toxic. Ozone at ground level from EHV transmission lines will be maximum when the production rates are the greatest, and when atmospheric conditions maximize the dispersion to ground levels. A progressive accumulation might occur under a hypothetical situation where a steady, low-velocity wind blows parallel to the lines. The simultaneous occurrence of this condition and heavy rain is extremely unlikely [10].

The Johns Hopkins APL Study was substantially in agreement with the analysis of the results of the New York State Commission Hearings by SRI, namely:

i) Ozone production along power lines could not be detected at ground level above ambient levels at any statistically significant level.

ii) Ozone production along EHV line operation will not likely violate air quality standards.

iii) Ozone production along the line will not likely damage plants along the right-of-way.

Spark Discharge Under Transmission Lines

People near transmission lines may experience a spark when near a large metallic object such as a parked vehicle. This spark is a capacitive action. The electric arc which results can range from imperceptable to uncomfortable. These discharges are similar qualitatively to the static discharges which occur when walking across a rug in a dry room [10].

An important concern in determining the seriousness of field induced current flows between people and metallic objects (like automobiles) is to establish the levels of currents which would be large enough to cause harm and to establish the levels of currents induced by the HV lines. Most people will experience steady-state currents of 2 milliamperes or more as painful or objectionable. These sensations will cause a person to be startled enough to withdraw involuntarily from the current source-much as withdrawing quickly after touching a hot object.

Transient currents are the currents which are associated with sparks. It is difficult to establish magnitudes of unacceptable spark (transient) currents. From the analysis of the New York State Hearings we get:

> Less is known about the physiological reactions to transient currents than to steady-state currents. Thus, the testimony heavily emphasizes the effects of steady-state currents. Fewer data exist on transient current effects, and experts disagree about which mathematical model accurately describes the physics of transient discharge. The experts at the hearings and the authors to whom they referred agree that more data on the nature of transient currents are necessary to characterize the phenomenon completely. Thus, the energy levels in a spark discharge that are necessary to cause the various shock effects are tentative [9].

In Table 4 we summarize results from the New York State Hearings on the levels of currents to be expected from a 765-kV transmission line. This table also summarizes the expected effects on humans of various magnitudes and types of currents.

In summary it appears that the effects of sparks was mostly secondary. Magnitudes vary considerably and depend on the type of metallic object (car or truck) and the surface on which the vehicle may be parked. The reactions are mostly one of sudden startlement and people could be injured by falling or moving into the path of a moving vehicle.

Helliwell Effect—It has been recently reported that electromagnetic radiation from transmission lines leak into the magnetosphere and strongly interact with the energetic electrons trapped in the earth's magetic field [14]. The magnetosphere is an important part of the environment of the planet earth and has influence on life on earth. As reported in a paper by Marino and Becker:

Table 4. Comparison of Shock Currents From 765-kV Transmission Line and Currents Causing Various Effects in Humans

Type of Current	Shock currents and energies received by touching a vehicle parked under 765-kV lines*		60-Hz shock currents and spark energies that cause various effects in humans**	
Steady-state	Calculated worst case (theotetical):*		0.5-2.0 mA	Threshold of perception
	Lowest value	0.1 mA		
	Highest value		1.5 mA	Threshold for startie reaction
	Probable case:			
	Lowest value	0.003 mA	2 mA	Objectionable (EPRI, 1975)
	Highest value	0.12 mA		Release currents:
	Highest measured value:**		5 mA	Suspected for small child
	Bus parked on asphalt	3.5-4 mA		
			10.5 mA	For average adult female
			16 mA	For average adult male
			18-22 mA	Respiratory paralysis
			50-100 mA	Ventricular fibrillation
Transient	Calculated worst case†			
	Lowest value	0.02 mJ	0.1 mJ	Threshold of perception
	Highest value	65 mJ	0.5-1.5 mJ	Threshold of annoyance
	Probable case:†			
	Lowest value	0.0003 mJ	25,000-	Ventricular
	Highest value	1.0 mJ	50,000 mJ	fibrillation

Note: *Source: Dr. D. W. Deno, Exhibit RR.
**Source: Testimony by witnesses in the NYPSC Hearings
***Source: Testimony by D. W. Deno
†Transient current energy levels calculated from Exhibit RR, Tables 3 and 4, using $E = 1/2\ CV^2$ where
E = transient current energy
C = capacitance of vehicle
V = voltage to which vehicle is charged

Source: Environmental Effects of Overhead HV Transmission Lines; SRI Project No. 6339, Center for Resource and Environmental Systems Studies, Report # 57; SRI International, June 1978 (DRAFT).

> A team from Stanford Radioscience Laboratories headed by Robert Helliwell, has also found evidence that these power-line emissions are amplified within the magetosphere and cause the precipitation of electrons from it . . . Together with the results of earlier experiments, the new findings indicate that this "rain" of electrons affects the ionosphere, which is at the bottom of the magnetosphere, in a number of ways, including the production of ion pairs, and bremsstrahlung X-rays . . . what possible benefits and environmental impact do these results point to [15]?

The straight answer is that no one knows. Marino and Becker raise serious questions regarding this phenomenon as shown in the following quote:

> . . . what changes in the magnetosphere are due specifically to radiation from OH-HV lines and what is the biological significance of such changes? We know, for instance, that the X-rays produced by the electron rain ultimately result in ultraviolet light which reaches the earth's surface. In addition, changes in the electron rain might have the effect of altering global weather patterns. There are thus a number of speculative but highly important aspects of the Helliwell phenomenon caused by OH-HV lines [16].

The existence of the basic man-made physical process has been unequivocally verified. There is no general agreement on whether the "effect" is a "hazard". These and related questions are under intensive study in this country and in Europe.

Land Use Environmental Problem

HV transmission lines pose non-electrical problems as well. Right-of-way (ROW) requirements are a major environmental impact of the non-electrical type. Interestingly, ROW requirements are lessened by the use of high transmission voltages. (It is not possible to discuss land-use effects without some concern for electrical requirements.) A single 765-kV line can carry as much power as thirty 138-kV lines or fourteen 230-kV lines. The resultant conservation in land alone is substantial—a 765-kV requires only 1/13 of the land per kilowatt of capacity as its equivalent 138-kV lines. The demand for transmission line ROW is part of the problem experienced by other parts of the infrastructure such as highways, interstate gas lines, water supply lines, and so forth.

The Department of Agriculture and Department of Interior publish guidelines relating to the non-electrical environmental impacts. These guidelines, "Environmental Criteria for Electric Transmission Systems," were published in 1970. Surprisingly, discussions with the Department of Agriculture Transmission Systems Branch officials and others revealed that there is very little published information regarding guidelines or policies for the siting of power transmission lines. Even in the New York State Public Service

Commission Hearings, there was no attention given to this problem. SRI noted that among others the issues below were virtually unexplored.

–Right-of-way construction and maintenance
–Siting and routing procedures
–Public involvement in siting
–Land-use trade-offs, particularly routing of lines across farm lands

However, in spite of the lack of research in this area, the Forest Service of the Department of Agriculture published a relatively recent book "Land Suitability Pattern for Electrical Transmission Lines," [17] which gives broad guidelines for transmission line planning. Among other uses, this booklet acts as a vehicle to analyze individual electrical transmission line proposals to determine their suitability and it gives specific policies which will assist the utilities in selecting the best corridors.

The corridor identification process is not based, solely on environmental, social, and economic factors; equal weight is given to electrical system alternatives [17].

The suitability determination process begins by a mapping of units land and a subsequent rating in terms of degrees of suitability of land and a subsequent rating in terms of degrees of suitability for electrical transmission. In determining suitability, it is not the intent to infer that lower levels of suitability necessarily prohibit consideration for electrical transmission lines. These ratings do show, from the physical standpoint, which land units are more suitable than others and point out the impacts which must be mitigated should lands of lesser suitability be crossed [17].

A total determination of suitability includes other environmental, social, and economic assessments. These considerations are often of greater significance than the physical factors. Table 5 outlines the items considered in the three additional assessment categories.

In addition the Forest Service outlines what considerations must be observed in the phases of transmission line development as follows. The considerations are designed to minimize environmental impacts during:

–Design Investigation and Survey
–Construction and Survey Staking
–Clearing
–Road Construction
–Tower Direction and Construction
–Cleaning and Restoration
–Operation
–Maintenance

An environmental planning firm in Denver, Colorado, Harman, O'Donnell and Henninger (HOH), has begun work in this area. They have done a study

Table 5. Non-electrical Assessment Factors for Transmission Line Suitability Determination

Environmental or Natural Elements

Zones of seismic risk
Hydrologic concerns (stream and lake densities, water quality, runoff patterns)
Impacts on fish and wildlife (critical habitat, migration routes, threatened and endangered species habitat)

Economic

Cost of line
Change in land values
Economic stability
Cost effects of public service (schools, housing, sanitation) during construction phase
External benefits and costs (relocation of businesses, industries, etc.)
Impact on rates
An assessment of the above concerns or factors in land use planning along with the physical inventory in this

Social

Community growth, culture change and cohesion
Demands on community services (law, welfare, health, sanitation)
Population densities
Patterns of existing and potential land use
Special concerns—historical and archaeological
Public amenities/facilities (parks, entertainment facilities, public transportation, etc.)
Displacement of people
Land ownership patterns
Physical presence of line
Electromagnetic, electrostatic, and electrochemical effects
Visual impacts

Source: Land suitability Patterns for Electrical Transmission Lines, U.S. Department of Agriculture Forest Service/Northern Region, December 1976, p.3.

[18] which examined the specific interactions between agricultural practices and activities in eastern Colorado and the specific activities and characteristics of power transmission facilities. The study then evaluated the interaction as to their significance in the planning, design, and operation of power transmission facilities. In particular, these specific power transmission facility activities were considered:

—Location and siting
—Design and Engineering

–Construction
–Operation and Maintenance.

In Minnesota the building of one transmission line has created a major crisis in the farming community. A 400-kV line running 427 miles from the lignite coal mines in North Dakota to the vicinity of Minneapolis and St. Paul is being built by two rural power cooperatives [19]. After a two year court fight, the line is beginning to slice a 160 foot-wide swath through the dairy and grain country. Besides all of the possible negative environmental effects discussed earlier, this line, which is to be 150 feet high, is alleged to pose a threat to pilots who do aerial spraying and seeding of the farms. There has been some violence in the area of Pope County Minnesota where farmers have allegedly assaulted survey crews and menaced workers to prevent the building of the line. The following quote from Time Magazine aptly describes the dilemma around the environmental impact of HV transmission.

> The clash is a result of society's increasing demand for energy and the refusal by some of its members to meet that demand by despoiling the land. The companies protest that the only alternative, burying the line, would be economically and technically infeasible. Farmers have suggested running most of the line through state-owned land. But the state does not want the line either. The Minnesota Department of Natural Resources claims that the line might "affect the behavior of animals and change wildlife habitat and affect the physiological state or conditions of plants and animals." Harrumps Farmer Art Jackson, "I guess a skunk is worth more than a farmer." [19]

SUMMARY AND CONCLUSION

The use of electric power which has been doubling about every ten years is expected to slow considerably in the next decades. The relatively new interest in the environment, increases in fuel costs, and new attitudes toward the growth of our economy will probably slow the historical rate of demand. However, in the near future, say up to the year 2,000, it appears that a continuing increase in the baseload electricity output will be required, as well as replacement of out-dated facilities.

The prospect of an ever-increasing demand for electricity has alarmed the environmentalists because of perceived environmental dangers associated with its generation and transmission. No method of electricity generation is completely free of environmental or ecological impacts. All thermal generation methods produce waste products either as heat, solids, liquids, or gases. Nuclear plants produce radioactive wastes. Control technologies applied at the sites are being used to decrease the environmental impacts of such wastes. Nevertheless, there is public concern about the effects of discharges on the environment as well as ecological and aesthetic questions concerning power plants and transmission lines. In the last few years greater emphasis on pollution control, planning, construction and licensing procedures have led to an increase in the time to provide new power plant facilities and an increase in cost.

Presently, about 30 per cent of the nation's primary energy sources are used to produce electricity; this is expected to grow to about 40 per cent by the late 1980's. If the nation is the reduce its dependence on foreign oil and natural gas, then there must be an increased use of coal and uranium for electricity generation. Of particular significance is the abating of the demand for electricity. The expected growth rate for the years 1985 to 1990 is between 2.97 and 4.03 per cent. This is a projected decrease in the growth rate of up to 45 per cent when compared with the 5.4 per cent growth rate between the years 1970 and 1976.

Long distance transmission of electricity will continue to be one of the primary means of bulk energy transport. There is a planned increase of transmission line circuit-miles of approximately 57,603 by the year 1987. This will increase the present 123,677 circuit-miles of high voltage lines (from 230-kV to 800-kV) to 181,280 including dc lines which will range up to 1000-kV. High voltage dc lines are expected to consist of about 5699 circuit-miles in 1987 or about 3 per cent of the total.

Transmission lines may have the greatest impact of all electricity subsystems. One reason being that HVTL's are usually over very large distances. Therefore, they require an enormous amount of right-of-way.

Right-of-way requirements intrude upon the remote scenic parts of our country, and the rural and farming communities. Suitability determinations for transmission line routings include, in addition to electrical transmission factors, environmental, economic, and social considerations.

There are a number of environmental effects which originate from the electro and magnetic characteristics of energy transmission along transmission lines. Transmission lines are known to be noisy, particularly during rainy or stormy weather, and can cause interference in AM radio reception in areas along the right-of-way. However, the most controversial impacts due to the electrical properties of HVTL's have to do with biological effects.

There is agreement in the scientific community that there are "effects" from the electric and magnetic fields produced by HVTL's. However, there is violent disagreement over whether these "effects" are "hazardous".

Many experiments have shown some change (sometimes death) in physiological or behavioral characteristics in animals. The question remains whether these results can be extrapolated to human beings. There is disagreement over whether the electric and magnetic field experiments involving animals necessarily represent field conditions to be expected under HVTL's.

Research involving humans in this country has been somewhat limited. The major human research has been done in the USSR and Eastern Europe. The American scientific community is not in agreement over the relevance of some of this work. One major experiment in the USSR which proported to show serious problems with HVTL's is somewhat disputed because the experiment took place in an electrical switch-yard; a switch-yard poses another set of environmental factors, such as acoustical noise, which may be more serious than field effects.

It is clear that there is a need for research to determine when an effect due to a HVTL becomes a hazard. Research should include experimentation to systematically determine threshold intensities and the relationship between the magnitude of the effect and the intensity of the field.

Finally, there is a need for independent funding and review of research on the biological impacts of electric and magnetic fields of transmission lines.

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