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Potential Environmental Effects of 765-kV Transmission Lines: Views Before the New York State Public Service Commission, Cases 26529 and 26559, 1976-1978

November 1979

U.S. Department of Energy
Assistant Secretary for Environment
Environmental Control Technology Division

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November 1979

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16. Abstract

This report reviews testimony given before the New York Public Service Commission in two recent cases on the potential environmental effects of 765-kV overhead ac transmission lines. The testimony focused on the potential effects of audible noise, on the potential biological effects of the electromagnetic fields, on the potential for electric shocks to people who touch vehicles parked under the proposed lines, on the potential effects of the electromagnetic fields on electronic cardiac pacemakers, and on potential effects of ozone produced by corona discharge from the lines. The testimony fully explored these questions; however, it did not resolve all of them. The testimony indicates potential impacts from the audible noise and from the electrostatic shocks that people can receive when they touch a large vehicle parked under the lines. The testimony also indicates that certain cardiac pacemaker and lead combinations may, under certain circumstances, undergo reversion to a fixed rate of pacing in the presence of the fields under the lines, but that little risk to cardiac patients results except possibly for those patients for whom competition between the heart's own rate and the pacemaker rate presents a health risk. The testimony fails to demonstrate biological hazards from the field; further research is necessary to understand better the effects of the fields on biological systems. The testimony indicates that ozone produced by the lines will not significantly affect the environment.

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High-Voltage Transmission Lines, Electric Fields, Audible Noise, Ozone, Pacemakers, Electrical Shocks.

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ABSTRACT

SRI International reviewed the testimony given before the New York Public Service Commission in cases 26529 and 26559 on the potential environmental effects of 765-kV overhead ac transmission lines. The testimony focused on the potential effects of audible noise, on the potential biological effects of the electromagnetic fields, on the potential for electrical shocks to people who touch vehicles parked under the proposed lines, on the potential effects of the electromagnetic fields on electronic cardiac pacemakers, and on potential effects of ozone produced by corona discharge from the lines. The testimony explored these questions; however, it did not resolve all of them. Because the testimony on the technical issues occupied 14,000 pages and because of the controversies among expert witnesses, the Department of Energy asked a multidisciplinary team at SRI International to review the testimony; clarify issues raised; resolve technical questions that remained unanswered, if possible; and to recommend research to resolve data deficiencies.

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PREFACE

Dr. Barry Scott-Walton, a Resource Analyst in SRI International's Center for Resource and Environmental Systems Studies, was Project Leader of the study. Dr. James R. Young, Senior Research Engineer in SRI International's Engineering Sciences Laboratory, was the author of the noise effects chapter. Dr. David C. Jones, Director of SRI International's Toxicology Department, Dr. John S. Krebs, Senior Biophysicist in the Toxicology Department, and Dr. Peter Polson, Senior Biomedical Engineer in the Toxicology Department, were the authors of the chapter on electromagnetic field effects on biological systems. Dr. Samuel D. Kaplan, Senior Medical Scientist in the Center for Health Studies, and Ms. Kristin Clark, Research Analyst, in the Center for Resource and Environmental Systems Studies, and Dr. Scott-Walton were the authors of the spark and current effects chapter. Mr. Richard A. Shepherd, Senior Research Engineer in the Telecommunications Science Center, and Dr. Kaplan were the authors of the pacemaker chapter. Dr. Buford R. Holt, Senior Ecologist in the Center for Resource and Environmental Systems Studies, and Dr. Scott-Walton were the authors of the ozone chapter.

This report was purposely organized to mirror the question and answer format of the New York State Public Service Commission Common Record Hearings in Cases 26529 and 26559. The quotations from the testimony throughout the report are intended to convey to the reader the flavor of the hearings and to cast light on the discussion in the adjacent text. The quotes represent varying opinions among experts and thus convey the sense of controversy, at the same time indicating to the reader the kinds of questions and answers that comprise the transcript.

The first phase of the hearings (the first five volumes of testimony) brought out the basic operating characteristics of 765-kV transmission lines as they were designed for the New York sites. Witnesses in phase one described the size and configuration of the towers, and lines' electric and magnetic fields, noise characteristics, and ozone production rates. Witnesses in phase two of the hearings (the final 70 volumes) attempted to explore the meaning and implications of the data presented by phase one witnesses.

To orient the reader, each chapter in this report begins with a brief statement of the background of the topic area. Next, the chapter summarizes the key data from phase one of the hearings. Finally, the chapter presents an overview of the experts' views regarding the importance and meaning of the data. SRI International has occasionally added background information that was not presented in the hearings to increase the reader's understanding of the issues that the experts argued about. In particular, the biological effects chapter presents considerable background information. When SRI International project members drew their own conclusions, these instances are indicated. The reader should note that many recent sources of data, particularly current DOE research programs, were not addressed in the hearings. Therefore, those current programs are not described in much detail in this report. The bibliographies at the end of each chapter indicates to the reader much of the relevant literature in each topic area examined during the hearings.

The SRI International project team did not assess or discuss the many exhibits presented by the witnesses, including hundreds of research reports, except for those few exhibits that it was necessary to read to understand expert testimony. For example, when a witness described a picture or drawing, or a number from a table of data, the particular exhibit was obtained from DOE.

SRI International undertook this project before the testimony was complete. The draft final report was completed about 1 week before the final judgement of the New York State Public Service Commission (PSC). Appendix A briefly describes the history of the hearings, and quotes the final judgement of the PSC.

This report greatly benefitted from the many review comments on the draft final report that were submitted. Reviews of the draft final report were solicited from the following individuals:

Dr. John W. Blake, Power Authority of the State of New York
Mr. Douglas W. Boehm, Department of Energy
Mr. Norman Caplan, National Science Foundation
Mr. William Feero, Department of Energy
Mr. Robert Flugum, Department of Energy
Mr. Ralph Gens, Department of Energy—Bonneville Power Administration
Mr. David N. Keast, Bolt, Beranek and Newman
Dr. Russ J. Kevala, The Aerospace Corporation
Dr. Andrew A. Marino, The Veterans Administration
Dr. Martin Minthorn, Department of Energy
Dr. John Molino, National Bureau of Standards
Dr. Elliot Postaw, Department of Defense
Dr. William Wisecup, The Aerospace Corporation

The project team has taken these comments into careful consideration in preparing the final report.

This report was made possible through the efforts of many SRI International staff members. In particular, thanks are due Lorraine Staight for preparation of the manuscript, Michael Smith for editing, and Lung-Hsin Wu for preparation of the art work.

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Appendix: A BRIEF HISTORY, INCLUDING A LIST OF THE LEGAL FIRMS AND WITNESSES THAT APPEARED, OF THE NEW YORK STATE PUBLIC SERVICE COMMISSION COMMON RECORD HEARINGS IN CASES 26529 AND 26559 AS EXERPTED FROM THE FINAL JUDGMENT A-1

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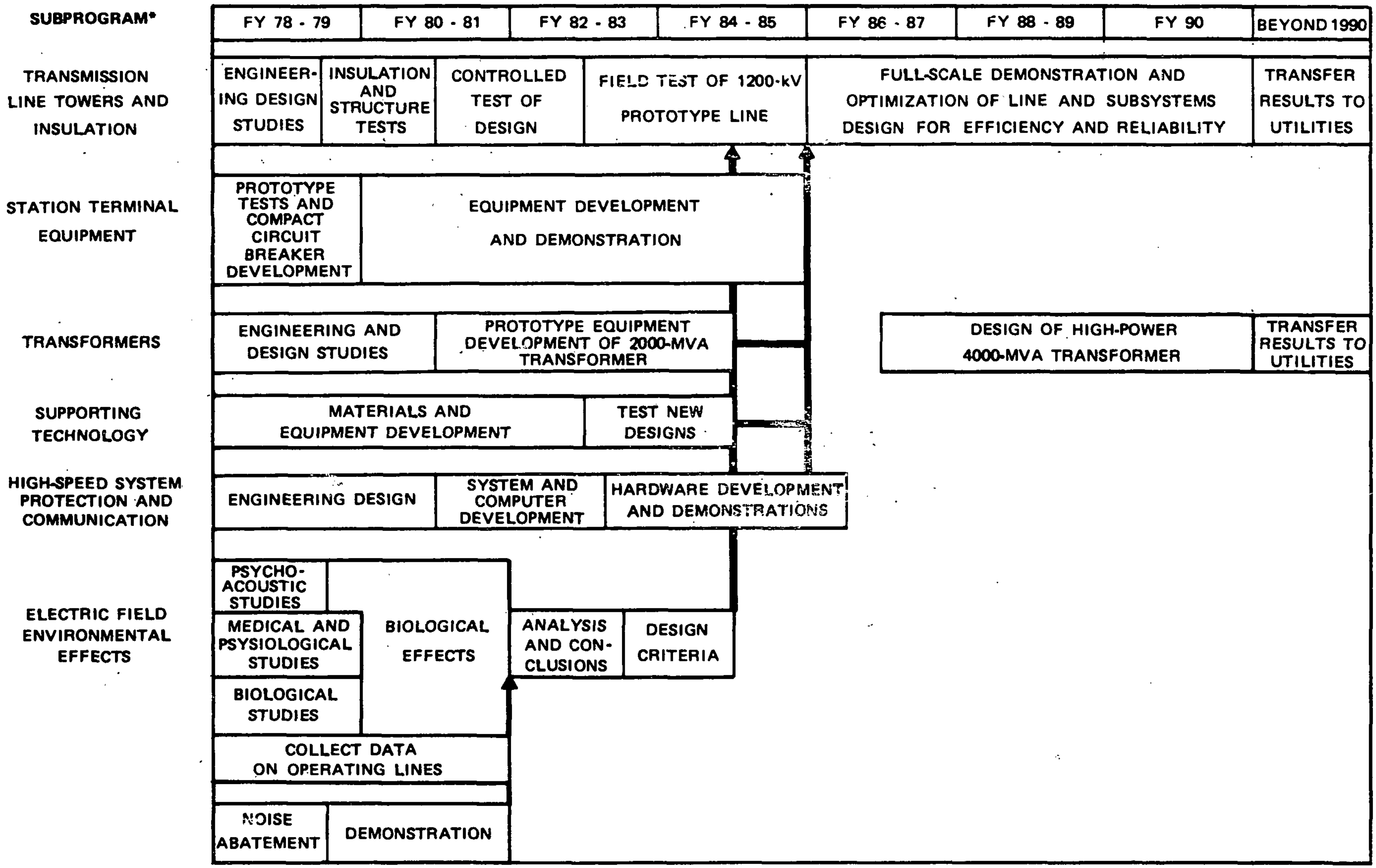
DEPARTMENT OF ENERGY ENVIRONMENTAL PROGRAMS AND SCHEDULE FOR OVERHEAD TRANSMISSION LINE DEVELOPMENT

Demonstration of a 1200-kV ac overhead transmission line system is a Department of Energy (DOE) R&D goal. Materials, components, and systems development for meeting this goal were scheduled soon after DOE (then the Energy Research and Development Administration) was established, and many of the milestones have been met. Demonstration of one or two 1200-kV systems between 1985 and 1990 will help improve design and make the technology available commercially to electric utilities by 1990.

Figure A provides an overview of the DOE R&D schedule for 1200-kV transmission systems, which is the particular responsibility of the Electrical Energy Systems (EES) Division. In addition, EES funds considerable research on the potential environmental effects of overhead transmission lines, including literature reviews to determine current understanding; systems studies to assist program and research planning; psychoacoustic studies to understand better human response to transmission line noise; and biological studies to understand better the potential for effects from exposure to electromagnetic fields. DOE seeks to complete environmental research by about 1981 to allow equipment modification to meet environmental needs. Two important features of the schedule shown in Figure A are: (1) DOE involvement in developing 1200-kV systems will largely end in the 1980s and (2) DOE environmental research is primarily directed toward investigating the potential biological effects of operating the lines (e.g., potential problems from noise or electromagnetic fields).

The Environmental Control Technology (ECT) Division of DOE assists in independently assessing if technologies under development by other DOE divisions require new control technology to meet environmental needs. In particular, DOE is concerned with meeting environmental needs for current 765-kV overhead transmission lines, as well as for the higher voltage systems under development. To better assess the possibility of new or poorly understood impacts from 1200-kV lines, the ECT Division charged SRI International with independent review of the controversy over possible environmental impacts from 765-kV transmission lines. The data selected for this study was the testimony in New York Public Service Commission Cases 26529 and 26559, which resulted in 72 days of hearings over a 3-year period and which produced approximately 14,000 pages of testimony and 147 exhibits from 31 witnesses. Appendix A briefly describes the history of the hearings. This report, which reviews the testimony in the hearings, is designed to help the ECT Division plan new programs and to assess the transmission line program in the EES Division.



*THESE PROGRAMS ARE PRIMARILY THE RESPONSIBILITY OF THE ELECTRICAL ENERGY SYSTEMS DIVISION

FIGURE A. OVERVIEW OF DOE 1200-KV AC, OVERHEAD TRANSMISSION LINE RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM (The heavy arrows indicate when feedback from the programs will occur.)

EXECUTIVE SUMMARY AND RECOMMENDATIONS

In 1973-74, Rochester Gas and Electric Company, Niagara Mohawk Power Corporation, and the Power Authority of the State of New York applied to build two 765-kV electric power transmission lines. Public concern about the first U.S. lines of such voltage—concern fueled by many articles and a widely read book by Louise B. Young, *Power Over People**—caused the New York State Public Service Commission to convene hearings on the potential health and environmental effects of operating the lines. These hearings served, in effect, as a forum for experts and concerned scientists to discuss the potential effects of very high voltage lines. Testimony, which took place from October 1975 to June 1977, focused on the following general questions:

- What are the effects on people and communities from the audible noise produced by 765-kV transmission lines during foul weather?
- Do the electromagnetic fields under the lines affect biological systems and are such effects potentially hazardous to people?
- Do people receive hazardous sparks and currents when touching a vehicle parked under a 765-kV line?
- Can the electromagnetic fields under the lines disturb cardiac pacemakers and are such effects potentially hazardous?
- Will the ozone produced during corona discharge damage plants?

Although testimony explored these questions, issues remain and some controversies are unsolved. Because the testimony on the technical issues occupied 14,000 pages and because of controversies among expert witnesses, the Department of Energy (DOE) asked SRI International to review the testimony, clarify issues raised, resolve technical questions that remained unanswered, if possible, and to recommend research to resolve data deficiencies.

Many questions raised in the hearings can be answered by credible research programs. Other issues are primarily philosophical, although decision-making bodies such as courts, Congress, or the Environmental Protection Agency (EPA) must frequently take positions on them. The SRI International Project team has not tried to resolve these philosophical questions; rather, team efforts have been exerted in examining the testimony and key exhibits to set forth and clarify these issues.

The Expert Testimony

Audible Noise

Noise from a 765-kV transmission line sounds like humming or buzzing, and is loudest during periods of high corona discharge (that is, air ionization on the surface of the conductor wires). The electric field at the surface of the conductor ionizes the air where

*L. B. Young, Power Over People, Oxford University Press (New York, 1973).

water condenses on the conductors. The ionization process produces the noise, and at night a corona glows on the conductor surface. The experts agreed that the noise would not cause physiological damage nor cause any direct physiological effects.

The noise might disturb some people within 250 m (750 ft) on either side of the right-of-way.

How much noise do the lines produce outdoors?

Noise from the lines is highest during rain, snow, and fog.

Energy equivalent noise levels over the year are about 53 dB (the levels would be higher during foul weather, but lower during fair weather) at the edge of the right-of-way (that is, 38 m, or 125 ft, from the center of the transmission line), while on peak noise days the energy equivalent day/night weighted level is 58 dB.* Transmission line noise near the right-of-way will typically be greater than noise created by the storm activity of rain and wind alone and will be more apparent during fog and snow than during rain. Transmission line noise levels decrease quickly as distance from the line increases, and will disappear into background noise levels at distances of 250 to 300 m (750 to 1000 ft) from the center of the right-of-way.† Even in fair weather, 765-kV lines would produce some noise.

How will these noise levels disturb people?

Outdoors—they will occasionally interfere with understanding speech.

People standing outdoors at the edge of the right-of-way will have some difficulty understanding one another if they are standing more than 2.4 m (8 ft) apart when the transmission line noise is the loudest (that is, in periods of heavy rain or snow). During fair weather, no interference will occur.

Indoors—line noise will sometimes disturb sleep.

Relying on data presented in the hearings, the SRI International project team suggests that residences within 150 m (500 ft) of the center of the right-of-way could have unacceptable indoor noise levels (those steady nighttime noise levels above 35 dB). At 150 m the energy equivalent noise level from the transmission line would be about 35.5 dB. However, it would be necessary for bedroom windows to be open for line noise to interfere with sleep beyond the right-of-way, and only some people would have their sleep disturbed.

If lines pass close to communities, noise complaints may follow.

Based on the testimony, the SRI International team suggests that the noise levels at the edge of the right-of-way appear to be high enough that they may result in some complaints to authorities or threats of legal action. Higher income communities and rural communities appear more likely to voice their complaints than lower income and urban communities.

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*A-weighted levels are indicated throughout. Chapter I defines noise terms.

†The utilities requested a right-of-way for the 765-kV transmission lines of 76 m (250 ft) in width. As Appendix A indicates, the New York Public Service Commission provisionally ordered the utilities to acquire a 107 m (350 ft) right-of-way that excludes all residences. The term "right-of-way" throughout this report refers to the 76 m (250 ft) right-of-way described in the testimony.

What is the major controversy in the noise testimony?

Whether the transmission line noise meets suggested EPA guidelines.

High levels of audible noise occur only during foul weather. Such weather is limited to rain, which occurs 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* has suggested 55 dB L_{dn}† as an upper limit for an acceptable noise environment. Using these guidelines as a starting point, the experts argued about whether to average the noise over 24 hours or over 1 year. The noise from a 765-kV transmission line is 58 dB L_{dn} averaged over 24 hours (the maximum 24-hour average), whereas the noise is 53 dB L_{dn} averaged over 1 year. Unfortunately, the EPA document only suggests 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 suggest that 765-kV transmission line noise could 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.

What questions are left?

How do we best use the noise data?

The question remains of how best to use transmission line noise measurements to predict whether communities will be disturbed by 765-kV transmission line noise. In addition, better data are needed on how houses, particularly house walls with windows, attenuate transmission line noise. The hearings did not consider whether transmission line noise has characteristics (buzzing or crackling) that are particularly annoying.

Effects of Electromagnetic Fields on Biological Systems

The fields are not strong enough to cause excessive tissue heating, the primary hazard from electromagnetic fields. Nevertheless, the main controversy in this area of the hearings is whether or not biological effects are possible from transmission line fields other than unimportant heating. About two-thirds of all the testimony centers on this hotly contested topic. The witnesses concentrated on potential effects from the electric field.

How strong are the fields?

The electric field is about 10 kilovolts per meter (kV/m) at ground level, and the magnetic field is about 0.6 gauss (G).

These are peak fields directly under a 765-kV line. A field of 2500 kV/m will ionize air to cause corona discharge. These fields decrease rapidly as distance from the lines increases, and drop to about 2.5 kV/m at the edge of the right-of-way 38 m (125 ft) from the lines' center. The peak ac magnetic fields at ground level are about 0.6 G with 4000 amperes (A) per conductor and about 0.15 G with 1000 A per conductor. The earth's magnetic field, which is constant, is about 0.5 G. The magnetic fields also decrease rapidly as distance from the lines increases.

---

*Environmental Protection Agency, "Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA 550/9-74-004 (1974).

†L_{dn} is an average of noise levels over a 24-hour period (or longer) that weights nighttime noise more heavily than daytime noise. Chapter I describes noise averaging.

Can the disagreements over whether there are biological effects be settled at this time?

Not satisfactorily.

The experiments claimed to support the existence of effects are challenged, with poor experimental design and inadequate statistical treatment of results cited. Effects may nonetheless exist; however, if they do, they are subtle, they are difficult to detect, and they require careful experimentation.

Have electric fields under transmission lines been shown to be hazardous?

No; on the other hand, neither have the fields been shown to be without effect.

It is impossible to demonstrate absolutely that any environmental agent is without effect because an infinite number of experiments on all biological systems would be required. (Only one positive experiment, on the other hand, is required to prove a hazard.) Most of the studies referred to by witnesses in the hearings are not useful for hazard determination, primarily because the effects are as yet poorly understood. For example, although no dose-response relationships between field levels and exposure times have been demonstrated experimentally, such data are necessary for determining whether the fields are hazardous.

Little evidence offered in the hearings indicates that people are adversely affected either at home or at work by electric fields at power line frequencies. This absence of evidence cannot be construed to mean that no effects occur. However, it does imply that if effects take place, they are more subtle than commonly encountered occupational diseases or than diseases resulting from common environmental agents such as urban smog.

What are the difficulties encountered in resolving the question about health and environmental hazards?

It is difficult and expensive to undertake credible experiments.

The experts disagree about whether low-frequency electromagnetic fields cause biological effects at levels under transmission lines. Nor do such disagreements lend themselves to ready settlement; difficult and time-consuming effort would be required to perform better experiments than those available to the witnesses. However, those experimental results that seem to have indicated a "stress response" to exposure to low-frequency electromagnetic fields may, in the absence of careful experiments, indicate that biologic systems respond to the fields. The testimony revealed no systematic studies of the threshold of intensity or the duration of exposure required to produce alleged effects. Such systematic studies must be performed before it can be determined whether or not the fields under 765-kV transmission lines present hazards.

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 scientic experiment to display. Such is not the case.

Will these field levels affect biological systems?

The experts disagree vehemently.

The witnesses described and examined many claimed effects, including:

- In humans and primates
  - –Increased triglycerides in the blood
  - –Accelerated bone fracture healing
  - –Altered psychomotor reaction times
  - –Shifts in the timing of normal daily rhythms
  - –Lack of a feeling of well-being
  - –Sensations of fatigue, depression and headache
  - –Changes in the electrical activity patterns of the brain
- In rats, mice, and guinea pigs
  - –Decreased weight gain
  - –Altered enzyme levels in various organs
  - –Altered levels of steroids in the blood
  - –Increased bone growth
  - –Bone tumor induction
  - –Electrocardiogram phasing
  - –Changes in blood cell count
  - –Alterations in the concentration of blood chemicals
  - –Perception of electromagnetic field
  - –Locomotor activity changes
  - –Lethality
  - –Weight loss in progeny
  - –Organ weight changes
  - –Water consumption changes
  - –Changes in milk production in nursing females
  - –Change in litter size
- In miscellaneous species and organisms (dogs, cats, birds, invertebrates, and plants)
  - –Cell cycle alteration
  - –Alterations in the cell division rate
  - –Perception of electromagnetic fields
  - –Leaf tip burning
  - –Reduction in calcium release from brain tissue
  - –Orientation to electromagnetic fields
  - –Decreased compensation to stress induction

Many of the experiments described by witnesses involved electric and/or magnetic fields with strengths much greater or frequencies substantially different than ground level fields under 765-kV lines. Some experts claimed that no effects exist (apart from unimportant heating); others recommended that the likelihood of hazards was sufficient to justify the New York Public Service Commission halting construction of the proposed lines.

Sparks and Currents Received When a Person Touches a Vehicle Parked Under the Lines

Just before a person touches a vehicle parked under a 765-kV transmission line a series of small sparks will be felt, similar to those felt when walking across a carpet on a dry day. When someone firmly contacts a vehicle, a continuous 60-Hz current will flow through the body.

What are the magnitudes of the sparks and currents?

The magnitudes vary considerably.

The maximum theoretically possible (worst case) current is about 7.5 milliamperes) (mA) when a well-grounded person touches a tractor-trailer truck parked under a line with a 12.8 m (42 ft) minimum clearance above the ground. Higher line clearances reduce the current. In addition, smaller vehicles generally result in smaller currents. For the proposed New York lines, which are to have a minimum ground clearance of 15 m (48 ft), the maximum theoretically possible current is about 5 mA when touching a tractor-trailor or a large bus.

Measured currents for actual vehicles are frequently 12% or less of the maximum theoretically possible. However, one witness did measure a value in one experiment that was 90% of the theoretical value. Hence, actual currents of 4-5 mA might result if a large vehicle were touched under unusual circumstances (e.g., the vehicle were well-insulated from the earth and the person were in good electrical contact with the earth).

Witnesses disagreed about the theoretical description of the sparks felt when a person touched a vehicle parked under the lines. The energy present in each spark appeared to be the most appropriate indicator of effects. Vehicle voltage can reach well over 1000 V with respect to the ground. A person within a few millimeters of the vehicle discharges the built-up voltage and sparks begin. Spark energies as high as 65 millijoules (mJ) are theoretically possible from touching a tractor-trailer truck parked under a line with a 12 m (42 ft) clearance. However, witnesses argued over what energies would occur in an actual situation. Measured values ranged from less than 0.1 mJ for sedans to more than 1 mJ for trailer-trucks.

What are the effects?

Adults will be startled, but children may be more seriously affected.

Witnesses agreed that adults will occasionally be startled by the currents and sparks they feel when they touch a large vehicle parked under the lines or even at the edge of the right-of-way. The witnesses also agreed that the only danger from the sparks and currents are secondary ones with a person possibly recoiling into moving machinery or falling. However, no statistical description of these possibilities was presented in the hearings, and no cases of such secondary injury to adults were cited in connection with transmission lines.

As levels of current increase, people experience a series of reactions: first, a tingling sensation at the point of contact with currents of 0.5-2.0 mA; then a startle reaction with currents of 1.5 mA and greater (people find currents of 2.0 mA to be objectionable);

finally, as the current becomes great enough (the release current) a person is unable to release the current source because of tetany in the arm muscles. The average release current for adult males is 16 mA and for adult females is 10.5 mA, but it may be as low as 5 mA for small children. Greater currents result in respiratory paralysis and finally in ventricular fibrillation. Respiratory paralysis begins at 18-22 mA for adults, and could be as low as 7-8 mA for children.

The physical reaction to electric currents depends on body size, with small children more affected by smaller currents than adults. For the obvious reasons of safety, little research has been done on the reaction of children to electrical currents. The release current for children is thus not known, but the witnesses theorized, based on extrapolation of data on adults, that it may be about 5 mA for small children. It is not known how much amperage above the release current causes respiratory arrest in children. In two recorded cases, children who came in contact with an 8-mA current (which had nothing to do with a transmission line) died. It appears that the 5-mA current possible under transmission lines under worst-case conditions is close to the suspected release current for small children.

What is the important unresolved question?

The release current for children.

Clearly, the major gap is uncertainty about what constitutes release currents and currents that induce respiratory arrest in children. Nor is it accurately known how much the current that causes respiratory arrest exceeds the release current. If the two currents differ by only a few milliamperes it becomes possible that currents under 765-kV lines might, indeed, under rare circumstances approach the respiratory arrest current for children.

Effects of Electromagnetic Fields on Cardiac Pacemakers

The fields under 765-kV transmission lines may affect some cardiac pacemakers, although the testimony cited no cases of transmission line interference. In fact, data are limited about pacemaker interference from 60-Hz electromagnetic fields and therefore only tentative conclusions are possible.

How do pacemakers respond to electromagnetic interference from transmission lines?

Three responses are possible:

- *Nothing happens*
- *The rhythm or rate intermittently changes*
- *They cease responding to the natural heart rate but continue to pace the heart at an acceptable fixed rate (that is, they revert to a fixed rate).*

Transmission line fields are too small to cause pacemaker dysfunction—operation at an extreme rate, either fast or slow, or failure to send a pacing signal to the heart for a significant time.

Are any of the three ways the pacemaker may react physically important?

Only intermittent changes in rhythm or rate and reversion to a fixed rate of pacing are.

Some pacemakers are sensitive to 60-Hz interference at voltages of about 0.27 to 3.0 mV on the pacemaker lead to the heart. Sensitivity appears critically dependent on the type of lead, the type and brand of pacemaker, and the position and orientation of the person in relation to the transmission line.

The most sensitive pacemakers might revert to a fixed rate of pacing even beyond the right-of-way—as far as 50 m (150 ft) from the center, under conditions of maximum coupling and a sensitive pacemaker with a unipolar catheter.

Are there any medical implications of the pacemaker's reaction to 765-kV transmission line fields?

None, except for certain individuals.

The exception appears to be for those patients 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 (although the testimony was striken because the witness was not a cardiac specialist) 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 possibly ventricular fibrillation, which requires immediate medical attention.

The testimony suggests that pacemaker wearers who are likely to be harmed by competition with the pacemaker signal would be unlikely, because of their general health, to be moving about in the vicinity of the lines.

What impedes resolving the major uncertainties remaining about hazards to pacemaker wearers?

Data are lacking.

No definitive answer as to how 765-kV power lines might endanger pacemaker wearers emerged from the testimony. Only a very few pacemakers were tested against 60-Hz voltages, with no indication about how this small sample relates to the population of pacemakers. Nor was it clear whether a pacemaker that entered into competition with an intrinsic heartbeat would endanger the wearer.

Plant Damage from Ozone Produced During Periods of High Corona Discharge

Transmission lines produce relatively little ozone, and possible effects are limited to the vicinity of the right-of-way. Atmospheric diffusion and mixing rapidly reduce the concentrations as the distance from the line increases.

How much ozone is produced?

Very little, compared with other contributing sources such as sunlight or automobiles in urban areas.

The maximum rate of ozone production occurs less than about 0.3% of the time during fog or heavy rain and the minimum rate occurs during fair weather.

How much do ozone concentrations along the right-of-way increase as a result?

The most when it is raining and a calm wind is blowing parallel to the line, and much less during fair weather or more wind.

During fair weather, the maximum concentration increase would be only about 0.25 ppb. Background concentrations vary from 8 ppb to more than 150 ppb. During rain, snow, or hail, the maximum concentration increase would be 7-9 ppb, but background concentrations would peak below about 100 ppb.

Will these increases damage plants along the right-of-way?

No.

No damage to plants from ozone production by transmission lines has been found because the increases are highly variable and small compared with the ozone background. The maximum increases of the 7-9 ppb produced by the lines occur very infrequently and then only during heavy rains accompanied by very slow wind that blows exactly parallel to a long stretch of transmission line [more than 1.5 km (1 mile)]. Even under these conditions, roughly 10 hours are required for the concentration to build up to the 7-9 ppb level.

Will increase in ozone concentration from line operation violate air quality standards?

It is unlikely.

The National Ambient Air Quality Standard for ozone is 120 ppb, not to be exceeded as a peak 1-hour concentration on more than 1 day per year. The air quality along the proposed New York State right-of-way frequently violates this standard during fair weather when the ozone background is highest. Moisture in the air during foul weather reduces the ozone background so that even the peak addition from the transmission lines would not cause violations of the air quality standard. The atmospheric conditions of a stable wind blowing parallel to a long stretch of line for several hours during heavy rain would be infrequent enough that further violations of the air quality standards, already occurring from other sources, would be unlikely.

What data gaps and unresolved questions about ozone remain?

No new measurements are needed.

Measurements were completed to confirm the primarily theoretical results presented in the hearings. Measurements are difficult owing to the relatively small concentration increases produced by the lines and to the variations in ozone production during weather and in the ozone background.

Recommendations

The SRI International project team recommends the following research:

- On audible noise from 765-kV and higher voltage systems:
  - –Develop data on costs and methods of reducing noise impacts
  - –Develop further methods of deciding when noise levels are unacceptable by gathering survey and complaint data
  - –Refine the method for using AN measurements
  - –Make provision for processing complaints on audible noise.
- Although available evidence indicates that electric fields do not present a serious hazard to human health or well-being, DOE should consider a research program aimed at allaying public concern about the possible hazard. From our review of the testimony at the hearing, we suggest the following program on potential biological effects from the electromagnetic fields under 765-kV and higher voltage systems. The DOE is already supporting much of this work:
  - –Include repetition of experiments showing "effects," with careful attention to experimental design, including exposure conditions and field characterization. This will ensure that experiments meet adequate statistical criteria and avoid results due to experimental artifacts
  - –Include in the design of new experiments additional studies suggested by conclusions drawn from the earlier experiments (e.g., "stress")
  - –Include in the design of new experiments a systematic study of threshold intensities and the dependence of the magnitude of the effect on field strength
  - –Consider in the experimental design, when proposed experiments involve human subjects, the variability of response among individuals, and the existence of the exceptionally sensitive or resistant individual
  - –Prepare experimental designs that are useful for hazard determination as opposed to effect determination. Given the experimental uncertainties currently surrounding the effects research, it may be some time before such experiments are possible
  - –Keep funding and review of the experiments independent to ensure credibility
  - –Distribute research results widely to encourage broad comprehension of significant results
  - –Review the advisability of setting edge of right-of-way standards that make the electromagnetic fields equivalent to those present at the edge of the right-of-way of current systems.*

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*This recommendation is also discussed in R. S. Banks et al., "Public Health and Safety Effects of High-Voltage Overhead Transmission Lines: An Analysis for the Minnesota Environmental Quality Board," Minnesota Department of Public Health (October 1977).

- On potential effects resulting from receiving a spark or current when a person touches a vehicle parked under a transmission line:

  –Resolve the data gaps with respect to shock thresholds of children by appropriate modeling or animal studies

  –Develop siting and routing procedures that account for electrical shocks from vehicles parked under lines.

- On potential effects on cardiac pacemakers:

  –Collect better data on pacemaker sensitivity to 60-Hz electromagnetic interference

  –Define better the relationship between the electromagnetic fields under transmission lines and the voltages and currents likely to be induced on the leads of an implanted pacemaker

  –Estimate the future population of the various types of catheters and pacemakers

  –Understand the probability of a pacemaker being affected by transmission line fields at various distances from the center of the right-of-way.

- On ozone from 765-kV and higher voltage lines:

  –Measure ozone concentration increases from 765-kV lines to confirm model calculations. DOE recently undertook these measurements.

As can be seen, these recommendations relate to effects caused potentially either by corona discharge (with noise and ozone resulting) or by the electromagnetic fields at ground level (effects on biological systems, on people touching vehicles parked under the lines, and on cardiac pacemakers). The extensive research programs now under way will improve the understanding of corona phenomena and their conclusions should aid in lessening corona, thereby reducing both noise effects and potential ozone effects.

Research that improves the understanding of right-of-way design and that provides technical options for reducing ground level electromagnetic fields will become important if regulatory standards for permitted ground level fields are issued. Options for reducing the ground level fields include:

- Increasing right-of-way widths
- Increasing tower height
- Shielding the right-of-way from the fields by adding ground wires beneath the main conductors
- Using alternative technologies such as overhead dc, or underground ac systems.

Trade-offs between costs and environmental benefits will result from implementing any of these options, including increased system cost, increased visual and aesthetic impacts (if tower height were increased) and increased right-of-way width. These trade-offs need systematic exploration.

Issues Not Examined in the New York Hearings

The hearings address several important issues. However, important issues are left unexplored, including:

- Right-of-way construction and maintenance
- Visual impacts of large towers
- Radio and TV interference
- Siting and routing procedures
- Public involvement in siting
- Land-use trade-offs, particularly routing of lines across farm land
- Social and institutional trade-offs between 765-kV and alternative systems, such as dc overhead and multiple lower voltage lines
- Liability for environmental effects resulting from line operation
- Power system effects such as reliability and cost.

These issues must also be considered as part of a comprehensive evaluation of 765-kV and higher voltage transmission lines.

I AUDIBLE NOISE

Alternating current (ac) transmission lines produce a hissing or buzzing noise that is caused by corona discharge from wet conductors during foul weather. This noise is both broadband and composed of the harmonics of 120 Hz. In fog, rain, or heavy snow, the transmission line noise will be louder than typical ambient noises in the vicinity of the right-of-way. During rain, for example, a listener standing outdoors 40 m (130 ft) from the center of the right-of-way could easily distinguish the transmission line noise from other ambient noises. During fog, ambient noise levels would be lower than during rain or snow; therefore, transmission line noise would be even more readily distinguishable from the ambient noises.

The testimony focuses on four central questions:

- What are the outdoor noise levels produced by 765-kV lines during various weather conditions?
- How are noise levels related to distance from the lines?
- How high are noise levels indoors?
- How do 765-kV transmission line noises affect sleep, speech understanding, and general annoyance?

These questions are addressed in about 2,000 pages of testimony. V. L. Chartier, B.S., of the Bonneville Power Administration, and M. G. Comber, M.E., of General Electric Co., addressed the first question. D. A. Driscoll, Ph.D., of the Department of Environmental Conservation of the State of New York; K. D. Kryter, Ph.D., of Stanford Research Institute (now SRI International); and K. S. Pearsons of Bolt, Beranek, and Newman, Inc., addressed the last three questions.

The experts agree that the audible noise from 765-kV transmission lines will not damage hearing or cause any direct physiological effects. For people near the right-of-way, however, Kryter and Driscoll predict adverse effects that result from sleep interference, interference in understanding speech, and general annoyance. Kryter bases his opinion on data contained in the EPA "levels document" (EPA, 1974).* Driscoll draws on International Standards Organization (ISO) document R1996 for the substance of his argument. The differences in these two documents lead Driscoll to anticipate a greater impact than does Kryter.

Pearsons uses the EPA levels document to conclude that the 765-kV lines will produce audible noise well within EPA suggested noise guidelines and thus reasons that the noise impacts that do occur will be minimal and acceptable.

Confusion and controversy in the expert testimony in this area arise from many sources. The major ones are: the appropriate use of the EPA levels document to interpret community

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*This document is frequently referred to here and in the testimony as the "levels document."

response to transmission line noise; the ISO document's technical validity; disputes about raw data on the attenuation of noise by typical structures; and disparate interpretations of several quite technical areas of psychoacoustics.

The Terminology Used to Describe Sound Levels

Acoustic noise perceived as sound by the ear is a pressure fluctuation in the air, usually described mathematically as $p(t)$. Although many noises are rapid, random pressure fluctuations, they are more or less steady over a period of seconds, minutes, or hours (e.g., the roar of a waterfall or the peculiar humming and crackling noise of a high-voltage transmission line in foul weather). The noise level, L, in decibels (dB) of such sounds is defined as

$$L = 10 \log_{10}(\bar{p}/p_o)^2$$

where $\bar{p}$ is the root-mean square (rms) value of $p(t)$ and p_o is a reference rms pressure of 20 micropascals (μP). (One Pascal is a pressure of one Newton per m^2.)

Most noises of interest are composed of many frequency components. Some components, notably those in the 500-2000 Hz region, are more bothersome to listeners than are others in higher or lower regions. To accommodate this fact, noise measurements used for annoyance or interference prediction purposes are frequency-weighted with filters that simulate the frequency response of the human ear. This type of filter is called an *A-weighting* filter, and levels measured with such a filter are named L_A or said to be in *dBA* units.

When the level of a noise varies significantly over the interval of time in which measurements are desired, the energy equivalent, L_{eq}, can be computed. The mathematical definition of L_{eq} for an interval between times t_1 and t_2 is:

$$L_{eq} = 10 \log_{10} \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_o^2} dt \qquad (dB)$$

All L_{eq} values quoted in the hearings were A-weighted levels.

Equivalent levels over 24 hours are often described by the day-night sound level, L_{dn}. L_{dn} values are calculated with the formula:

$$L_{dn} = 10 \log_{10} \frac{1}{24} \left[15 \left(10^{L_d/10} \right) + 9 \left(10^{(L_n+10)/10} \right) \right] \quad (dB)$$

where: $L_d = L_{eq}$ for the daytime (0700-2200 hr)

and: $L_n = L_{eq}$ for the nighttime (2200-0700 hr).

Note that a 10-dB "penalty" is added to L_n. All of the noise data described here are derived from A-weighted measurements of sound pressure level.

The Transmission Line Noise Spectrum

The witnesses were in agreement about the data presented in the hearings for audible noise (AN), including outdoor L_{dn} data, for the transmission lines. Witnesses in the second phase of the hearings used data on house attenuation, together with the outdoor AN data, to derive indoor AN levels. Although the witnesses hotly debated the question of how much houses attenuate AN, they did not resolve this issue.

"Transmission line audible noise is primarily a wet conductor phenomenon occurring during rain, snow or fog. Water droplets on the conductor surface will increase the conductor surface gradients to a point which causes ionization of air resulting in corona discharges from water droplets at the conductor's surface. This corona occurs randomly along the length of the conductors, primarily near the peaks of the power frequency voltage wave, emitting acoustic energy (audible noise). During fair weather, when there is no condensation on the transmission line conductors, the electric field gradients on the conductors' surfaces are insufficient to cause corona except where occasional burrs or other protrusions occur on the conductor surfaces."
–Chartier

Near the Lines. Corona causes AN from high-voltage power transmission lines. AN is loudest during foul weather because water drops on the lines increase the amount of corona discharge. Of course, foul weather in a given place is unpredictable within seasonal variations. In four communities near the proposed lines in upper New York State, rain is present from 3.2 to 9.7% of the year; snow, 4.5 to 10.2%; and fog, 3.7 to 4.1%.

Variability, or randomness of AN, during fair weather, fog and rain is illustrated in Figures I.1, I.2, and I.3, supplied by Chartier in his direct testimony. He presents cumulative statistics for AN measured 15 m (50 ft) from the outer conductors of a 765-kV test line. (The test line is located in West Virginia at the Apply Grove Test Project facility sponsored by American Electric Power Service Corporation and the Westinghouse Corporation.) Low-frequency noise in the range 63 to 250 Hz is dominated by tonal components–hum–and is not particularly sensitive to weather conditions. Weather conditions affect most AN frequency components at 250 Hz and above. For instance, at 1000 Hz, fair weather AN levels shown in data for the Apple Grove line are less than 35 dBA 50% of the time. In fog, the comparable level is 45 dBA and in rain, 50 dBA.

Figures I.1-3 include ambient noises. Ambient noise during rain and fog have little effect on the results shown here because transmission line noise dominates (Kolcio et al., 1977). However, the results shown for fair weather are primarily ambient noise because the transmission lines are relatively quiet during fair weather (although the 120-Hz fundamental and harmonics might be heard). Of course, ambient noises greatly depend on the presence or absence of surfaces or structures (e.g., rain on a tin roof), but surfaces that would have altered the measured levels were excluded from the tests described above.

The operating voltage of a line also influences the AN generated. In general, AN increases with increasing operating voltages.

The witnesses used data like those shown in Figures I.1-3 to develop L_{eq} and L_{dn} data for the proposed 765-kV transmission line. The witnesses agreed that at the edge of

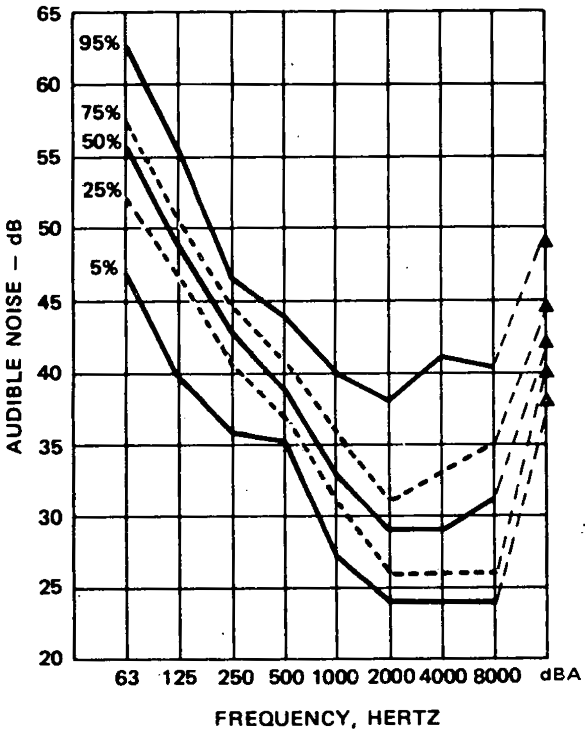


FIGURE I.1. AUDIBLE NOISE FREQUENCY SPECTRUM FOR LINE A* IN FAIR WEATHER

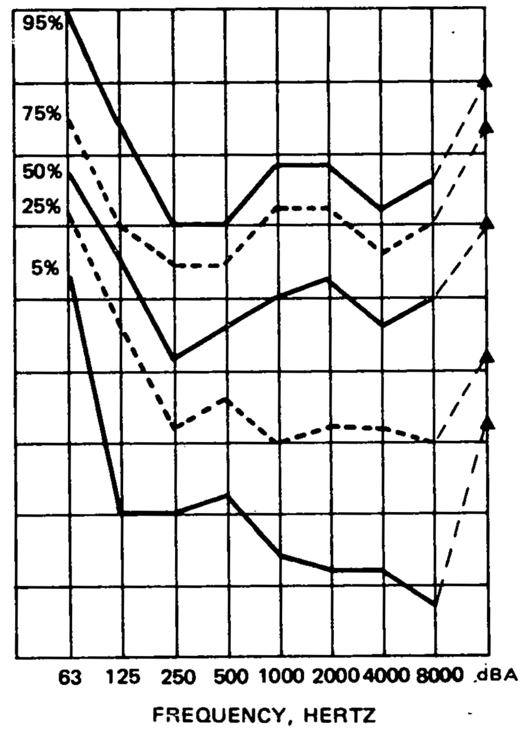


FIGURE I.2 AUDIBLE NOISE FREQUENCY SPECTRUM FOR LINE A* IN FOG

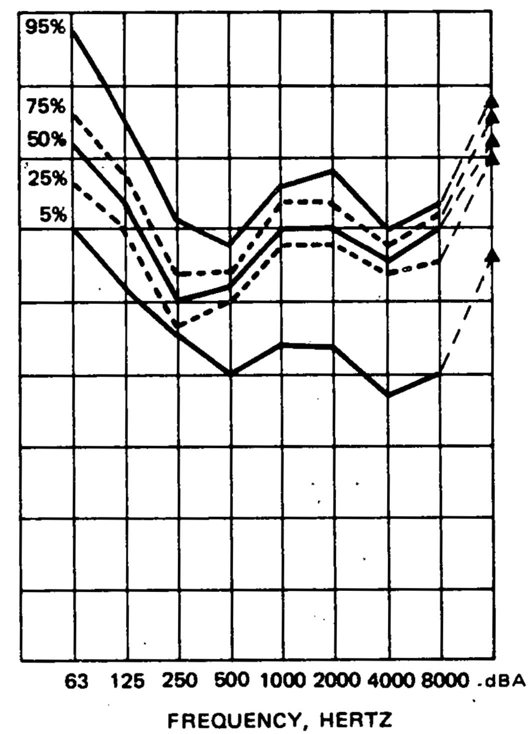


FIGURE I.3 AUDIBLE NOISE FREQUENCY SPECTRUM FOR LINE A* IN RAIN

(In Figures I.1, I.2 and I.3, the noise level was measured about 15 m (50 ft) from the outer conductor of the right-of-way. The data show the fraction of the time the noise level is below the indicated value. The A-weighted value of the noise level is shown on the right side of each figure with Δ's. The data show that more than 95% of the time during fair weather the noise level will be below 48 dBA, while during fog and rain the level will be below 60 dBA and 59 dBA, respectively. The data include the ambient noise.

*Line A is a test line at the Apple Grove test facility.

Source: Testimony by V. L. Chartier

the right-of-way, L_{eq} averaged over one year is 53 dBA. They also agreed that the peak 24-hr L_{dn} is 58 dB, whereas the 1-yr L_{dn} is 53 dB.

Outdoors. Levels of AN decrease as distance from the transmission line increases. For 765-kV lines, at distances beyond about 38 m (125 ft) from the center conductor, A-weighted noise levels decrease 3 dB per doubling of distance because of radial divergence of the AN energy radiated from the transmission line. AN components are also absorbed as they propagate. For transmission line sounds traveling through air, the absorption is 0.7 to 1.0 dB per 30 m (100 ft); the actual value depends on the noise spectrum and on the atmospheric conditions at the time of observation. Figure I.4 shows how AN levels decrease away from the lines. Witnesses indicated that transmission line AN is likely to disappear into ambient or background noises at distances that exceed 200 to 300 m (750 to 1000 ft) from the centerline—Figure I.4 shows that AN levels will decrease by at least 12 dB at 200 m (750 ft).

Without resorting to actual data, witnesses discussed the effects of adding transmission line AN levels to the background or ambient levels. Figure I.5 shows how AN levels would add to ambient levels. Only when the AN level is equal to or greater than the ambient level is the increase in loudness easily heard.

Indoors. The AN level indoors constituted a major controversy in these hearings. At issue was the AN level expected in homes with closed or open windows adjacent to the rights-of-way.

Pearsons argued that 15-30 dB would span the actual range of noise attenuation in community housing typical of the areas in New York in which the proposed lines would be erected. With windows open, he argued that 30 dB was a practical upper limit for house attenuation.

Kryter argued that 10 to 30 dB would span the actual range of noise attenuation, thereby engaging the hearings in a lengthy and detailed examination of the 5-dB discrepancy in the lower limit of house attenuation that should be applied when windows are open and AN is present. The 5 dB at issue were critical (as is discussed further below) because a lower attenuation value, 10 dB, would cause indoor noise estimates to exceed EPA noise guidelines (EPA, 1974); a high attenuation value, 15 dB, would cause indoor estimates to fall within noise guidelines.

The hearings reached no clear conclusion on how much house structures reduced outside noise because measurement methods and the adequacy of prior data were questioned. Kryter argued, in effect, for the use of a measurement procedure that would yield *insertion loss* values. The insertion loss provided by a structure of sound barrier is calculated by subtracting the average sound level in a space protected by the barrier from the average level in that space that would exist in the absence of the barrier. ASTM Standard E336-71 specifies a suitable procedure for this approach. Pearsons argued for a modification of another measurement procedure that uses an indirect measure of the free-field level. Other structural attenuation data cited in the direct testimony were generally derived from studies of aircraft noise. Kryter and Driscoll challenged the propriety of applying such data to transmission line noise.

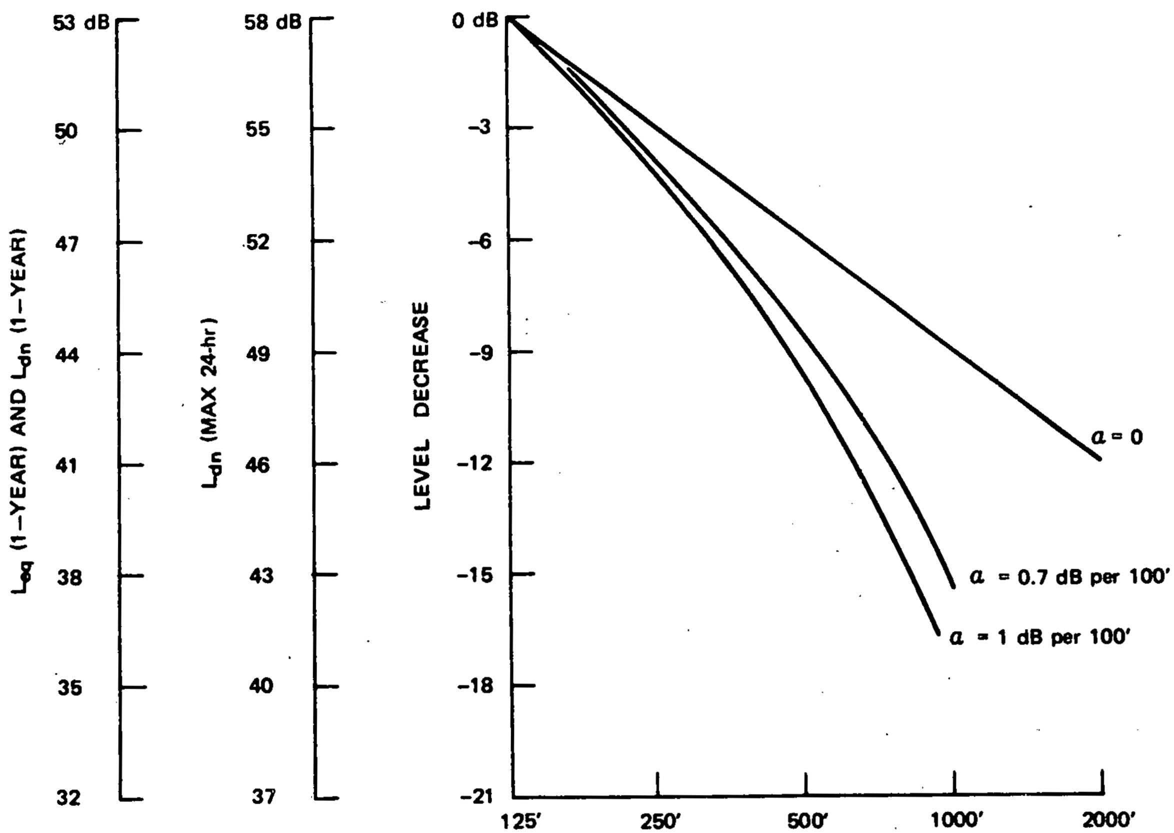


FIGURE I.4 TRANSMISSION LINE NOISE AWAY FROM THE LINES (The attenuation coefficient, a, reduces the noise levels below those due to the doubling of distance (a = 0). Atmospheric conditions and the AN spectrum determine the oppropriate value for a.)

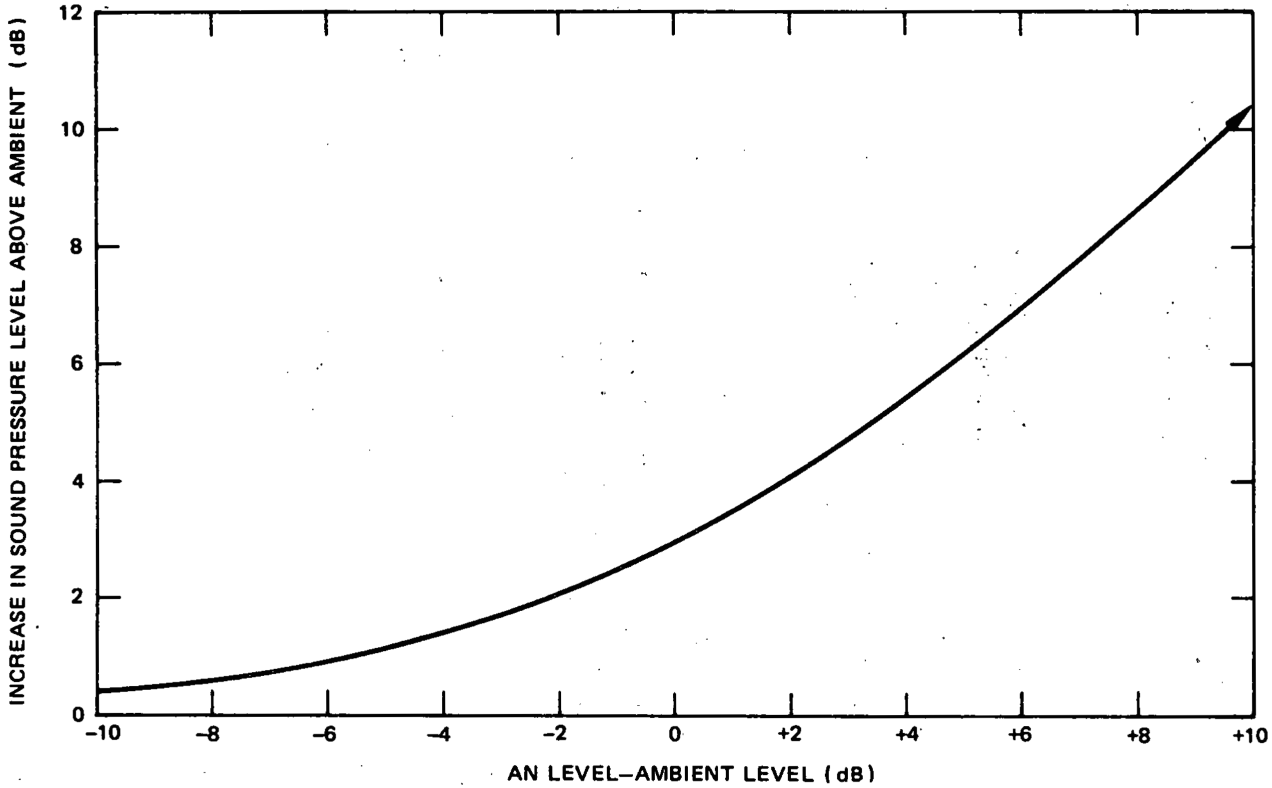


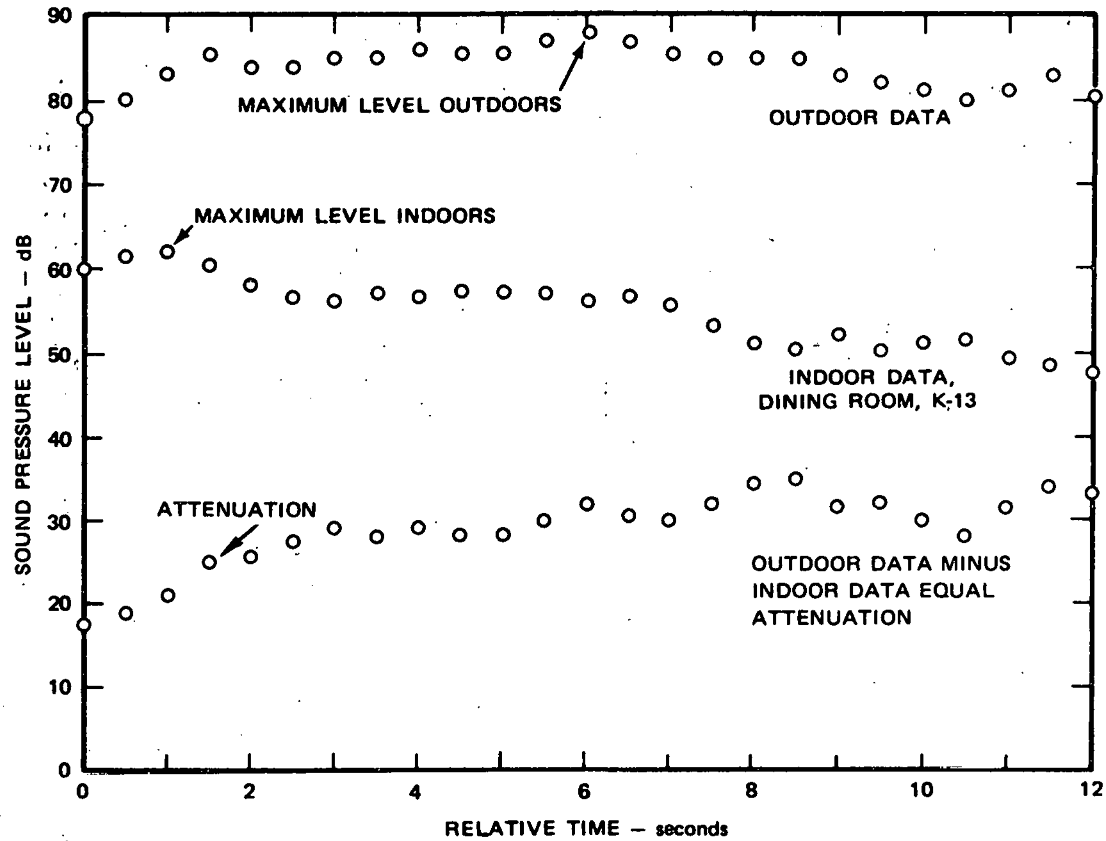
FIGURE I.5 INCREASE IN OBSERVED NOISE LEVEL DUE TO AN (At high AN levels, relative to ambient noise levels, the sound pressure level is completely determined by the AN level.)

The data based on aircraft flyovers came from Society of Automotive Engineers document SAE 1081, in which average house attenuation data are tabulated for housing in warm and cold climates. The average results were obtained from outside/inside noise level comparisons during aircraft flyovers. Kryter states that these data were biased toward higher attenuation values than would be obtained from comparable data for transmission line noise. He argues that an aircraft is a moving source and that most of a flyover noise effect comes from propagation of the noise through roofs and ceilings rather than side walls and windows, which are considerably more vulnerable to noise penetration. Noise from transmission lines, which are linear sources at comparatively low angular elevations as opposed to an aircraft point source, primarily penetrates walls and windows, rather than roofs.

The SRI International team adds the following data that were not brought out in the hearings to help clarify some of the problems with interpreting data that are based on aircraft flyovers: Figure I.6 indicates sequence of noise level measures obtained at 0.5-s intervals as a jet aircraft flew over a brick veneer house. At the start of timing, the aircraft was at a low angular elevation where noise could directly penetrate side walls and closed dining room windows. At that time the attenuation measured was about 18 dB. Attenuation values (controlled by roof and ceiling and later by other rooms in the house) thereafter were consistently higher. An arithmetic average of all attenuation values in these data (as would be calculated by procedures used in SAE 1081) of about 30 dB would greatly overstate the acoustic protective ability of this house, if a transmission line were the noise source.

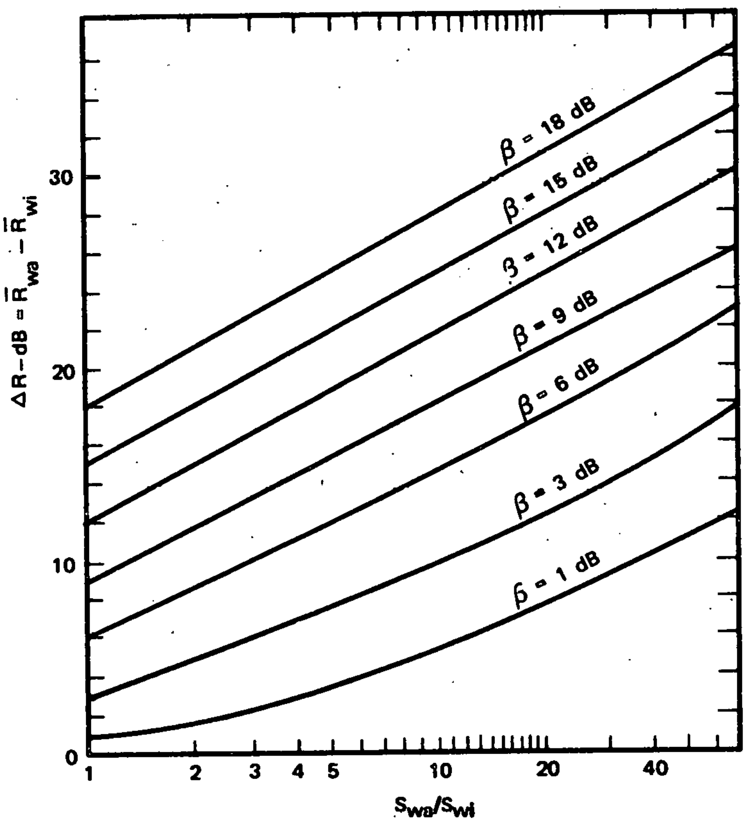
Pearsons' rebuttal testimony relied on experimental attenuation data he obtained after he, Kryter, and Driscoll had undergone the direct and cross examinations. Pearsons simulated a transmission line noise source by an array of three loudspeakers; the external source field at each test dwelling facade was measured simultaneously with the sound field inside the test dwelling (he used 14 dwellings). He found that the data gave strong support for a 15-dB noise reduction figure. However, Kryter, in a memorandum to Counsel, used the same data with corrections he derived from American Society of Testing ASTM E336-71 to arrive at values ranging from 16.1 dB for 0.18 m^2 (2 ft^2) window openings to 12.5 dB for 0.18 to 0.45 m^2 (2 to 5 ft^2) window openings.

Because extensive testimony about, and examination of, this matter failed to produce a satisfying resolution to the question of estimating the amount of protection provided by houses with open windows, it is worth noting that techniques are available for providing useful estimates. For particular cases, the findings recorded in the noise control literature can be used as methods of estimating the noise reduction of walls with openings or with panels having noise reduction values that differ from the main wall structure. Figure I.7 summarizes a specific estimation scheme. $\bar{R}_{wa}$ is the average noise level reduction for a wall having area S_{wa}. R_{wi} is the average noise level reduction for a window with area S_{wi}. β is the noise reduction of the composite. An open window has $\bar{R}_{wi} = 0$; hence, a structure having $\bar{R}_{wa} = 24$ dB and an open window ($\bar{R}_{wi} = 0$) representing one-sixteenth of the total wall-window area would transmit 12 dB more noise than a solid wall. This method has been shown to predict actual results reasonably well and suggests theoretical approaches that could be used with housing surveys in estimating the impact of transmission line AN on communities near rights-of-way. This estimating method was not described in the hearings.



Source: Young, 1970

FIGURE I.6 TYPICAL TIME HISTORIES OF SOUND PRESSURE LEVELS MEASURED WITH 630-Hz ONE-THIRD-OCTAVE BAND FILTERS DURING AIRCRAFT FLYBY. (At the start of timing, the aircraft noise is penetrating primarily the building walls and yields a lower difference between indoor and outdoor sound levels than when the aircraft is over the building at the end of timing.)



Source: Shaudinischky, 1976

FIGURE I.7 METHOD FOR PREDICTING ATTENUATION OF WALLS WITH WINDOWS. (ΔR is the difference in attenuation between the wall material and the window material. For example, an open window would have an attenuation of 0 dB and a wall 20 dB. S_{wa}/S_{wi} is the ratio of the wall area to the window area. The difference in attenuation of the composite relative to the solid is indicated by the line nearest the intersection if vertical and horizontal lines were projected from the ΔR and S_{wa}/S_{wi} values.)

Pearsons' data showing 15 dB of attenuation are reduced to 12.5 dB by the correction factors applied by Kryter. Thus, the SRI International project team considers 11-12 dB to be a conservative lower limit for house attenuation; it takes into account the low angular elevation of the transmission line source and the variability of noise fields within rooms. This lower limit is useful for estimating worst case interior noise levels resulting from transmission line noise.

Effects of Transmission Line Noise on Understanding Speech and on Sleep

Interference in Understanding Speech. The witnesses agreed that speech interference caused by AN from transmission lines will probably occur along the edges of the rights-of-way where the L_{eq} is 53 dB. Pearsons testifies that such interference will not be "unreasonable." Kryter states that 16 to 20% of people will be annoyed indoors and outdoors, and Driscoll also predicts speech interference within 106 m (350 ft) from the center of the right-of-way.

The witnesses used two methods in arriving at these predictions: The first, used by Pearsons and Driscoll, is described in Table I.1, the speech interference level (PSIL). This method is elaborated on in Figure I.8, which is adapted from a more recent document. The abscissa values in parentheses are taken from the most recent work by Pearsons.

Table I.1

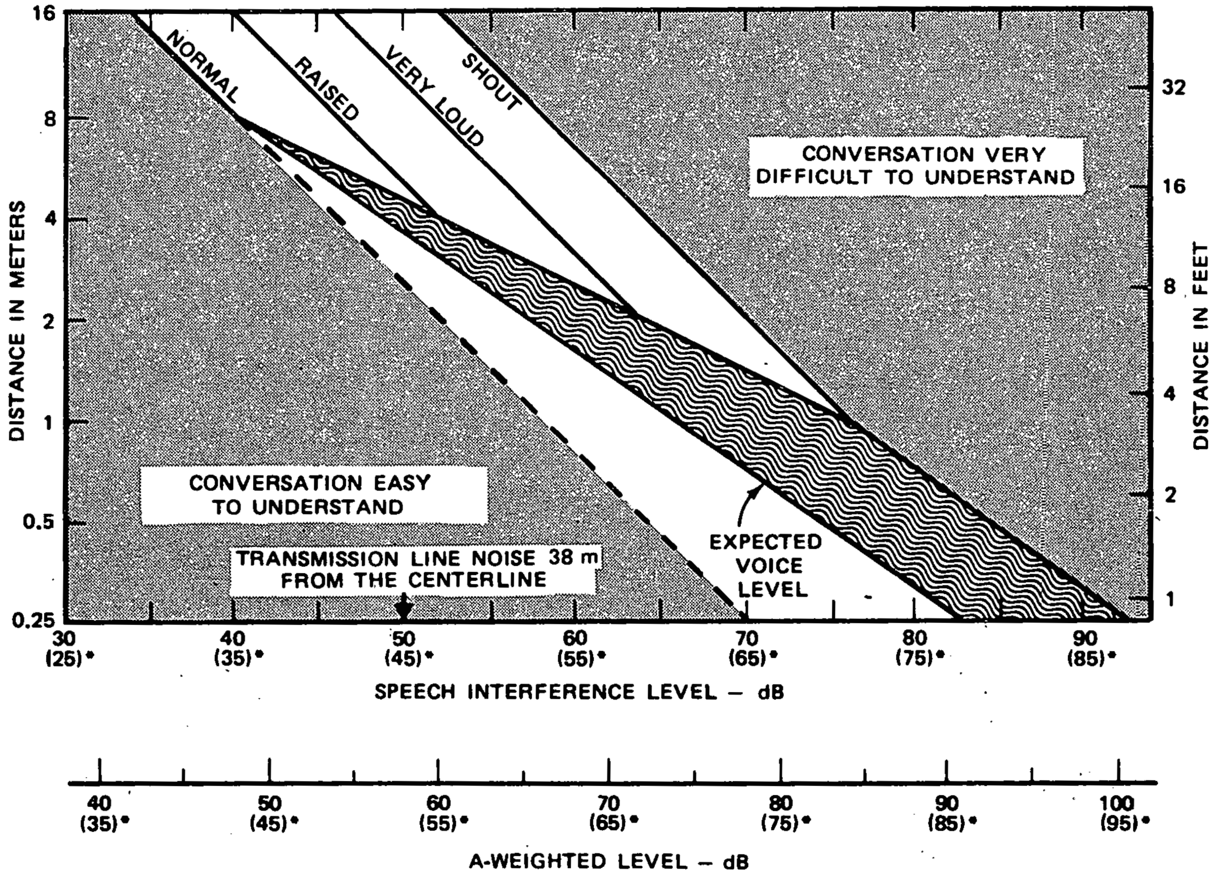
RELATIONS AMONG PSIL, VOICE EFFORT, AND BACKGROUND NOISE*

Distance Between Talker and Listener ft (m)	PSIL, dB† Talker's Voice Effort			
	Normal	Raised	Very Loud	Shouting
0.5 (0.15)	74	80	86	92
1 (0.3)	68	74	80	86
2 (0.6)	62	68	74	80
4 (1.2)	56	62	68	74
6 (1.8)	52	58	64	70
12 (3.7)	46	52	58	64

*PSIL of steady continuous noises in decibels at which reliable speech communication is barely possible between persons at the distances and voice efforts shown. The interference levels are for average male voices (reduce the levels 5 dB for female voices), with speaker and listener facing each other, using unexpected word material. It is assumed that there are no nearby reflecting surfaces.

†PSIL equals SIL (calculated from old octave bands) + 3 dB.

Source: Beranek, 1971



Source: ANSI, 1974

*1977 estimates based on new data from K. S. Pearsons et al., 1977.

FIGURE I.8 REACTION OF TALKER TO INTERFERING NOISE AS FUNCTION OF DISTANCE BETWEEN TALKER AND LISTENER. (The speech interference level (SIL) describes the noise field in which the conversation takes place. The values in parentheses are based on recent data. The same noise field measured with an A-weighted filter is indicated by the lower horizontal axis. A speaker standing more than 10 m (32 ft) from a listener would have to shout to be heard over the transmission line at the edge of the right-of-way during periods of high corona.)

The second method, used by Kryter, is the Articulation Index (AI) method in which the speech and noise frequency spectra are compared in critical frequency bands. Weighted differences in level between the speech level and the noise level in each band are combined to yield a single AI value. Values of AI greater than 0.7 are judged to be completely adequate; those less than 0.4 are usually judged inadequate for communication. The AI method is described in French and Steinberg (1947).

Predicting actual speech interference caused by noise is rather complicated. People instinctively adjust vocal effort to overcome the interference presented by background noise. To help explain the argument between Kryter and Pearsons, SRI shows the ANSI data in Figure I.8 (corrected by the addition of Pearsons' 1977 results). The SIL values on the abscissa describe the level of the noise field in which conversation takes place. To establish the appropriate SIL value, the noise level, present in four octave bands centered at 500, 1000, 2000, and 4000 Hz, is averaged. Chartier testified that the average band level value 38 m (125 ft) from the center of the right-of-way is 45 dB. Reading upward on the figure from (45) to the intersection of the line marked "Normal," it can be seen that normal conversation becomes difficult to understand at a distance between speaker and listener of 2.4 m (8 ft). If he is standing farther than 2.4 m from the listener, the speaker will have to raise his voice to become understood clearly. The anticipated voice level at varying background noise levels and distances between speaker and listener is indicated by the area in wavy lines on Figure I.8. Speakers who must raise their voice levels to communicate may find the effort tiring and annoying.

Kryter, in his testimony, calculates that at 38 m (125 ft) from the center of the right-of-way the transmission line noise will be sufficient to interfere with listening at distances as close as 1 m (3 ft) between speaker and listener. He therefore implies that the transmission line noise during periods of foul weather will interfere with conversation even more than the ANSI method would predict. His estimate arises from the fact

"It is my opinion that [the transmission line noise] will not [unreasonably interfere with speech]. Three principal factors influence speech intelligibility: the vocal effort of the talker; the noise level of the environment; and the distance between the talker and the listener. With a transmission line L_{eq} noise background of 53 dBA, two people can communicate outdoors with a normal vocal effort at a distance of 12 ft, based on the relationship between communicating distance and noise level developed by Beranek. This prediction ignores any speech masking due to other sound sources, such as weather."
–Pearsons

"In my opinion 15 to 20% of people in residences up to 150 ft away from the centerline, with windows or doors open and facing the line, will be highly annoyed because of speech interference from the corona noise, and some complaints could be expected. Under some circumstances people outdoors up to 800 ft from the centerline would, on occasion, experience speech interference and annoyance because of the noise . . ."
–Kryter

"An L_{eq} of 53 dBA at the edge of the right-of-way will cause some speech interference. The term speech interference as used in noise control refers to a continuum of effects from slight to complete speech interference. With a sound level of about 53 dBA at 125 ft from the line, conversation is barely possible with normal voice effort at

that he describes normal vocal effort at 1 m separations at 45 dBA, whereas Pearsons claims 55 dBA and the earlier data on which the original ANSI method was based implies 60-65 dBA. The louder that speakers normally talk, the less important the background interfering noise.

spacings of 12 ft for males and about 6 ft for females. During the worst conditions of heavy fog or snow (10% of the time), this degree of speech interference will be experienced as far as 200 ft from the centerline of the transmission line, or 350 ft if the speakers are near the reflecting side of a building."
—Driscoll

The SRI project team believes that the modified ANSI method shown in Figure I.8 is quite reasonable for assessing the speech interference effects of transmission line noise because it is reliable, as shown in the recent work cited by Pearsons, and because it does not involve the analysis and computation required by the AI method.

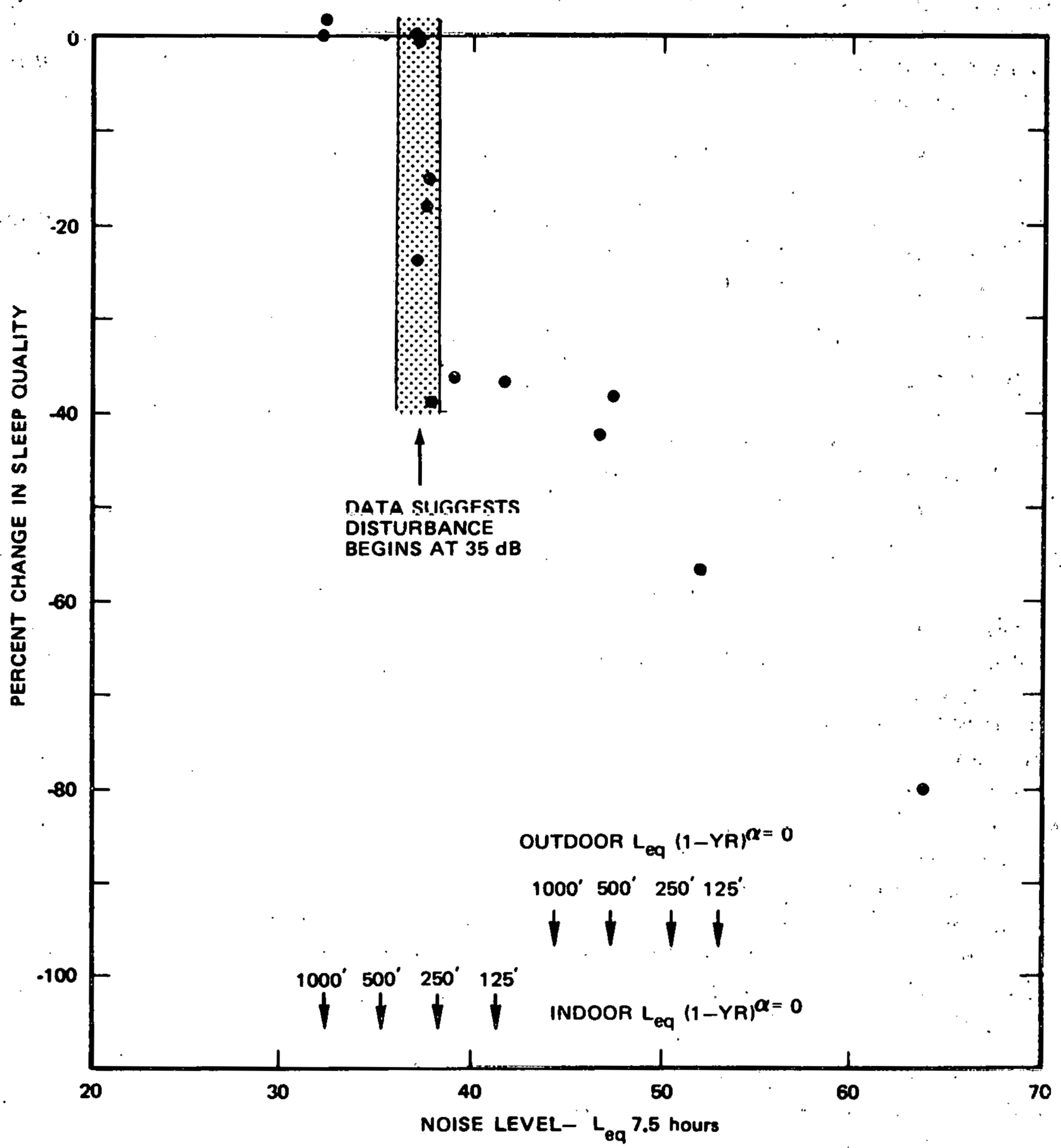
The ANSI method predicts that during periods of maximum noise from the lines, normal speech levels will be unintelligible if speaker and listener are standing outdoors 2.4 m (8 ft) or more apart and at the edge of the right-of-way. No speech interference would occur indoors because even as little as 10-dB attenuation for residences at the edge of the right-of-way would reduce speech interference levels indoors to 35 dB or less—below the level likely to interfere with radio, TV or conversation.

Effects on Sleep. The experts do not completely agree on the amount of sleep disturbance that will result from 765-kV transmission line noise in foul weather because they do not all agree to the same noise thresholds for sleep disturbance; nor do they agree about the noise levels that might exist in a bedroom. The witnesses also struggled somewhat unsuccessfully to use sleep disturbance data to suggest a level for a steady noise below which no sleep disturbances would occur. The issue here is complex. The noise from transmission lines is rather steady during periods of foul weather. Even though a steady noise level might not prevent a person from going to sleep or awaken a person from sleep, the noise might disturb sleep. Such "sleep disturbance" takes the form of altering the sleep pattern and may or may not include awakening, which is usually called "sleep interference." There are four distinct sleep stages, and a person changes from one sleep stage to another many times during a night's sleep. If the frequency of these changes increases, the quality of sleep decreases. For this reason, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has devoted considerable effort to defining noise limits for air-conditioning equipment for homes.

To further highlight some of the difficulties the witnesses encountered in interpreting data on sleep disturbance, the SRI team describes some sleep disturbance data not brought out at the hearings and the problems associated with interpreting sleep disturbance data. Data generally plotted in Figure I.9 strongly suggest that sleep disturbance is related to a threshold phenomenon in which the threshold lies somewhere between an L_{eq} of 35 and 40.* The area of

"(1) . . . from annoyance and complaint data collected in communities with [indoor levels] of 33 dBA, 20% of the people will feel highly annoyed as the result of arousal from sleep.
(2) Architectural standards and various guidelines and regulations recommend maximum levels in a bedroom of about 35 dBA; and
(3) Studies conducted in the laboratory indicate about a 10% reduction in sleep

*The noise measure L_{eq} denotes sound pressure level in dBA averaged over 7.5 hr.



Source: Derived from Lukas, 1977

FIGURE I.9 RELATIVE SUBJECTIVE DISTURBANCE OF SLEEP AT VARIOUS TOTAL NIGHTTIME NOISE LEVELS CALCULATED IN UNITS OF L_{eq}

(The data suggest sleep disturbance begins at noise levels in the vicinity of 35 dB. Sleep disturbance means the increased frequency of changes from one sleep stage to another and it may include awakening. The shading is meant to be suggestive only.)

this threshold is indicated by the vertical shaded bar (added by the project team). Two primary difficulties arise, however, in interpreting these data.

First, there are four distinct stages of sleep ranging from light to heavy. Sleep disturbance ranges from awakening to a mere change in sleep from one sleep stage to the next lighter stage. Sleep interference, however, is usually considered to be awakening coincident with the occurrence of noise. Because the data in Figure I.9 include all disturbances, they must be adjusted when used in directly addressing the questions the experts were trying to answer.

Second, the abscissa on the figure is in units of L_{eq} averaged over 7.5 hr. Because the noises were not steady, as those from transmission lines would be, sleep disturbance becomes a probabilistic event requiring that the noise stimulus occurs coincidentally with sleep light enough to permit a response. Because transmission line noise is steady, however, it is presumably coincident with all stages of sleep. The importance of this coincidence was not developed in the testimony. Had it been, more weight would have been given to opinions that permissible bedroom noise levels should be near the lower levels of 25-35 dBA, suggested by the American Society of Heating, Refrigeration, and Airconditioning Engineers, rather than near levels in the range 35-40 dBA indicated in the plotted data.

Kryter and Driscoll testify that noise levels in bedrooms would be approximately 45 dBA at edges of rights-of-way during foul weather. They assume an attenuation of outside noise levels by 10 dB when windows are open. Pearsons, however, starts from the same assumptions of outdoor levels, 53 dBA, and applies a 19-dB attenuation to allow for an open window; the resulting indoor level is then 34 dBA. He testifies that this is a satisfactory level and will not disturb sleeping residents. Pearsons later concedes under cross examination that a more proper attenuation level would be 15 dB, yielding indoor levels of 38 dBA.

quality as the result of a night's sleep in about 33 dBA noise or an . . . L_{dn} indoors of 40."
–Kryter

"In my opinion the majority of people living at the edges of the rights-of-way will not feel that their sleep is disturbed even with their windows partly open during foul weather. It has been suggested that the 'threshold' for sleep disturbance due to noise is 35 dBA . . . As previously noted, at the edges of the rights-of-way, the transmission line noise [indoors] will be 34 dBA with windows partially open and only 23 dBA with windows closed."
–Pearsons

"Sleep interference due to transmission line noise is probably the most significant problem to consider in residential areas. A level of 45 dBA or less at night in residential areas is specified by the United States Environmental Protection agency as 'requisite to protect public health and welfare with an adequate margin of safety.' For an area to be considered 'acceptable' for housing development by the Federal Housing and Urban Development Department the sound level of 45 dBA cannot be exceeded for more than 30 minutes in each 24 hours. In addition, 45 dBA has been specified by the New York State Department of Environmental Conservation as the nighttime residential limit in its proposed noise regulations . . . The L_{eq} exceeds 45 dBA within 450 feet in the absence of a reflecting surface. Ten percent of the time during fog or snow sleep interference may be experienced up to a distance of 900 feet."
–Driscoll

Any relatively steady noise at levels equaling or exceeding 35 dBA can probably disturb sleep. In conjunction with data on how transmission line AN attenuates with increasing distance from the lines (see Figure I.4) and data on the lower limits of house attenuation (11-12 dB), it appears that houses within 150 m (500 ft) of the center of the right-of-way would have unacceptable indoor noise levels. This estimate assumes a 3-dB level decrease for each doubling of distance. Figure I.8 shows the outdoor L_{eq} and indoor L_{eq} using 12 dB of attenuation.

Community Response to Transmission Line Noise

Community Annoyance. The witnesses agree that, whatever the mechanisms causing it, annoyance with noise is best measured in the community by observing complaints from the population affected, rather than by attitude surveys. Complaints are defined loosely as spontaneous appeals by the affected population to authorities thought to have noise control abilities or responsibilities. These appeals can range from simple telephone protests, to threats of legal action, to actions such as peaceful or violent demonstrations.

The witnesses agree that sleep and speech interference are major effects of environmental noise that exceed certain criterion levels. They also agree that environmental noise can cause annoyance. It is not clear, however, that they view "annoyance" *per se* as the identical psychological response. Pearsons evidently sees it as a response apart from a reaction to interference; Kryter sees it as a response to frustration brought about by sleep or speech interference. Pearsons states:

> "The meaning that a noise conveys is an important factor, as evidence by the fact that low level sounds such as a baby's cry or a door opening could well disturb a person's sleep. At the other extreme, it is not uncommon for people to sleep through artillery barrages in battle. It has been further suggested by some researchers that steady, periodic, or rhythmic sounds may improve the quality of sleep."

"The standard definition of 'noise' is 'unwanted sound.' The most important effect of noise is that it can alter one's hearing sensitivity either temporarily or permanently. Other important effects include speech interference and sleep interference. Noise exposure can also cause annoyance."
—Pearsons

"The adverse effects of noise that cause feelings of annoyance will obviously depend on what a given individual is doing (i.e., is engaged in a conversation or trying to go to sleep, etc.); and . . . the amount of annoyance felt will depend somewhat upon the importance to the individual of the particular act interfered with by the noise and his or her personality and attitudes."
—Kryter

Kryter agrees, for the most part, with Pearsons, but declines to admit meaningful sounds into the general consideration of noise control:

> "Annoyance from and reactions to many so-called noises can be attributed to the meaning the noise conveys to the person rather than the physical amount of noise itself. For example, the buzz of a mosquito or the roar of an airplane may both create a feeling of fear of injury from the thing creating the noise. By and large, the feelings engendered because of these connotations are not

usually given consideration in the evaluation of, and setting tolerable limits for, noise environments inasmuch as familiarity with the noise and individual attitudes can cause highly variable reactions to the noise. Further, controlling or reducing the noise level *per se* does not necessarily reduce the danger or the annoyance.

"Rather, noise control for general public health purposes should be based on consideration of the adverse effects of the noise which to a substantial degree universally affect the people exposed. The two adverse effects most clearly identifiable are interference with speech communication and sleep."

Annoyance in the absence of complaints can also be measured by surveys that query respondents about their feelings toward the environment. Questions usually cover many aspects of the physical, aesthetic, social, and (perhaps) political environments about which a respondent may have feelings. Driscoll, Kryter, and Pearsons seem to believe that interpreting noise attitude surveys is frequently difficult because the physical facts about noise exposure for individual respondents are rarely known with adequate accuracy. Furthermore, both Kryter and Pearsons testify that about 10% of respondents will rate the noise environment "unsatisfactory" regardless of environmental levels. Both Kryter and Pearsons have little faith in the results of these surveys.

Driscoll testfies about the probable relationship between complaints and annoyance measured by attitude surveys. He submits evidence that, if 50% of the respondents to an attitude survey say they are annoyed, 15% of the same population will be sufficiently motivated by their annoyance to register some form of complaint.

Criterion Setting. Kryter and Pearsons refer to the EPA levels document (EPA, 1974) for guidelines that limit environmental noise at the edge of the right-of-way. According to the levels document, ". . . an L_{dn} level of 55 dB is identified as an outdoor level in residential areas compatible with the protection of public health and welfare. The level of 55 dB is identified as a maximum level compatible with adequate speech communication indoors and outdoors. With respect to complaints and long-term annoyance, this level is clearly a maximum satisfying the large majority of the population. However, specific local situations, attitudes, and conditions may make lower levels desirable for some locations. A noise environment not annoying some percentage of the population cannot be identified at the present time by specifying noise level alone."

In a noise environment with an L_{dn} of 55 dB, it is agreed that a percentage of the exposed population will be "highly annoyed"; however, this percentage is somewhat uncertain. Kryter is inclined to state it at about 17%, but Pearsons in his rebuttal testimony appeals to recent data that place the percentage closer to 10-15%. In any case, Kryter and Pearsons agree that 10% of the population (as determined by attitude surveys) will be highly annoyed by their noise environments regardless of the actual noise levels.

Kryter states that a criterion L_{dn} of 55 dB is inconsistent with the attitude implied in the title of the levels document because at that exposure some people are still highly annoyed:

". . . the EPA did not reach its mandate [to protect the public health and welfare with an adequate margin of safety] in what is generally considered a sound use of the English language.

"In the first place, saying that 17% of the people will be highly annoyed is hardly protecting the health and welfare of the people with an adequate margin of safety . . . Can you have 17% of the people highly annoyed and say you are protecting the whole population? This is utter nonsense!"

Pearsons is sympathetic to Kryter's position, but his refined percentage of 12-15% seems to indicate that, for practical reasons, an L_{dn} of 55 dB is as close to the ideal level to divide acceptable from unacceptable noise levels as can be attained.

Driscoll also finds an L_{dn} of about 55 dB divides acceptable and unacceptable noise environments. He derives this criteria from an analysis of an ISO draft recommendation ISO R 1996 (ISO, 1971), which incidentally neither the United Kingdom nor the United States approved. In this document, noise annoyance is predicted by measuring the extent to which an intruding noise exceeds existing ambient noise.

Driscoll, applying his criterion from ISO R 1996, encountered considerable difficulty in cross examination because the document had not been sanctioned by U.S. representatives to ISO and because the criterion level prescribed would vary and thus not be subject to an absolute maximum. In principle, the document would permit any intruding noise level, provided it did not exceed an ambient level (which in itself might be excessive) by more than a certain amount. This type of criterion permits a "racheting" or escalating effect that the U.S. ISO representatives objected to and that they thought was an important defect when they considered the standard in 1971. Driscoll finds from his interpretation of the AN data according to ISO R 1996 that at 38 m (125 ft) from the center conductor of the transmission line 50% of the people exposed to AN would be highly annoyed and 15% would complain.

Interpreting Quantitative Measures of the AN Environment. The witnesses generally agreed about using energy equivalent measures such as L_{eq} or L_{dn}. However, there was considerable disagreement about the duration of time that should be used for calculating these average measures. Kryter argues for examining the peak 24-hr levels; Pearsons argues for examining 1-yr averages. This hotly contested issue is quite significant because the two levels differ by about 5 dB, one being higher than EPA-recommended levels and the other lower.

During foul weather, AN can be as high as L_{dn} = 58 dB at the edge of the right-of-way when calculated on a 24-hr basis. On an annual basis, however, days of fair weather (with low AN levels) are averaged in with the days of foul weather, and the resulting L_{dn} is 53 dB.

Kryter argues that people are annoyed and complain when the noise is present; they do not average their psychological annoyance over a whole year arguing, in effect, that one night's disturbance is not compensated by other nights of no disturbance. Pearsons argues that people do average their annoyance over longer periods–weeks, months, or perhaps a year. The hearings did not produce telling arguments for either side of the issue.

Two different views among psychoacousticians help explain the importance of averaging times. In particular, if noise annoyance is viewed as a threshold problem (i.e., a nonlinear response that does not take place until a stimulus reaches a certain value), Kryter's procedure seems valid; on each day that environmental noise exceeds L_{dn} = 55 dB, an insult is deemed to have occurred. On the other hand, if the noise annoyance response is viewed as a linear response to a stimulus, with the response level directly proportional to the stimulus level, then Pearsons' analysis and the annualized L_{dn} is a correct procedure. Presumably, there will be times when either daily L_{dn} or annualized L_{dn} values will be appropriate; daily L_{dn} might be better for very low ambient noise levels and a relatively low incidence of foul weather, and annualized L_{dn} might be better for the same ambient levels with a relatively high incidence of foul weather.

Predicting Complaints from L_{dn} Data. Case histories of complaints and reactions to measured levels of noise were introduced into evidence during the hearing. Table I.2 summarizes these data by types of noise sources and reaction categories. Estimated L_{dn} values over 24 hr were added to the table data and are plotted in Figure I.10. The data in each of the reaction categories are laterally dispersed. For example, the 14 cases of widespread complaints or 22 single threats of legal action occur in noise environments with L_{dn}s ranging from 49 to 67 dB.

The correction values in Table I.3 can be used to normalize these data to account for seasonal variations, type of ambient noise environment, previous community noise exposure, and the presence of pure tones or impulsive sounds. The normalizing data (data corrected by table values) are plotted in Figure I.11. Clearly, normalization reduces the variance of the case history data along the noise exposure dimension.

Kryter introduced Figure I.12 not only to demonstrate the general noise vs. complaint behavior tendency, but also to suggest the different complaint behaviors of "high income neighborhoods" and "low income heighborhoods." From these data, which are not normalized in any sense, the threshold of complaints in high income neighborhoods is 50 dB but rises to 55 dB in low income neighborhoods.

In the view of the SRI team, the EPA case history evidence seems to indicate that the noise at the edge of the right-of-way of a 765-kV transmission line could cause at least sporadic complaints and possible widespread complaints in certain types of communities if the proposed transmission lines pass close to quiet suburban communities with no prior noise exposure of the AN type. The L_{dn} data on AN levels from 765-kV transmission lines are in the region where according to the EPA levels document, ". . . specific local situations, attitudes, and conditions may make lower levels desirable for some locations."

Conclusions

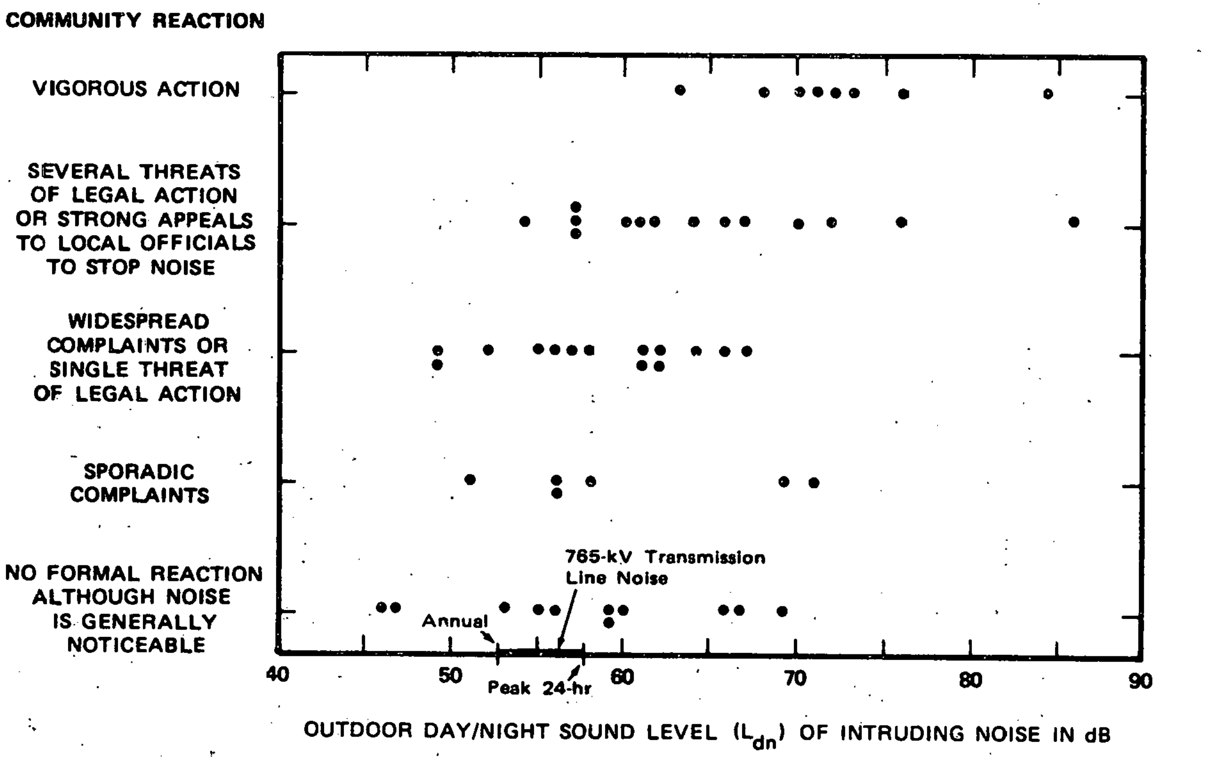
The hearings showed that transmission line audible noise levels will not damage hearing or cause any direct physiological harm. However, the levels are high enough to interfere with understanding speech in the vicinity of the right-of-way during periods of foul weather. During periods of fair weather, the lines produce little AN and no speech interference will occur. The AN levels appear to be high enough to disturb sleep occasionally for those whose homes lie within 150 m (500 ft) of the right-of-way and whose bedroom windows face the transmission line because the indoor energy equivalent sound pressure level averaged over the year might exceed 35 dBA. The noise levels from the transmission line are in that portion of the L_{dn} range where complaints by persons living near the right-of-way are quite possible, depending on the type of community that the line passes near. Rural and high-income neighborhoods have complained more frequently than urban or low-income neighborhoods.

Table I.2

COMMUNITY REACTION CASES
AS A FUNCTION OF NOISE SOURCE
(These cases are the most thoroughly documented cases that were available to EPA in 1974.)

Type of Source	Community Reaction Categories: Legal Action	Wide-Spread Complaints	No Reaction or Sporadic Complaints	Total Cases
Transportation vehicles, including:				
Aircraft operations	6	2	4	12
Local traffic			3	3
Freeway	1			1
Rail		1		1
Auto race track	2	—	—	2
Total transportation	9	3	7	19
Other single-event or intermittent operations, including circuit breaker testing, target shooting, rocket testing, and body shops	5			5
Steady-state neighborhood sources, including transformer substations and residential air conditioning	1	4	2	7
Steady-state industrial operations, including blowers. general manufacturing, chemical and oil refineries	7	7	10	24
Total cases	22	14	19	55

Source: EPA, 1974



Source: EPA, 1974

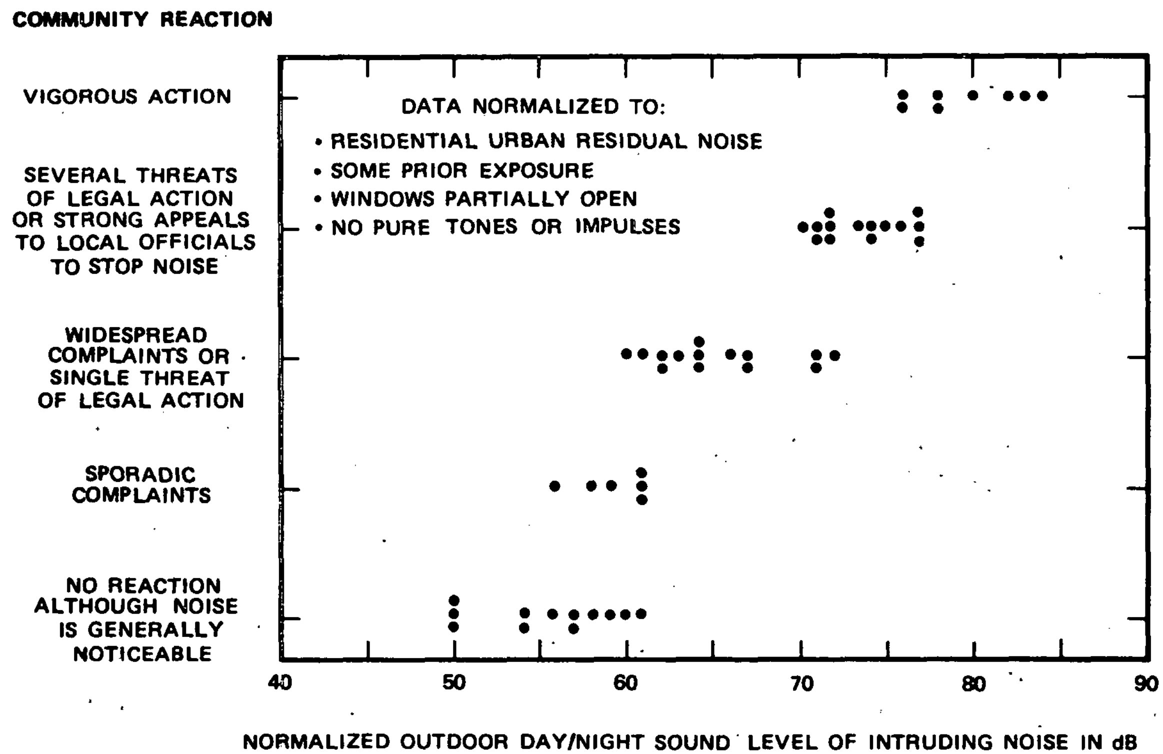
FIGURE I.10 COMMUNITY REACTION AS A FUNCTION OF OUTDOOR DAY/NIGHT SOUND LEVEL
(These data compare the community reaction cases from Table I.2 with the sound level present. The sound data are 24-hr L_{dn} measurements.)

Table I.3

CORRECTION FACTORS WHICH ADJUST MEASURED L_{dn} DATA FOR LOCAL CONDITIONS

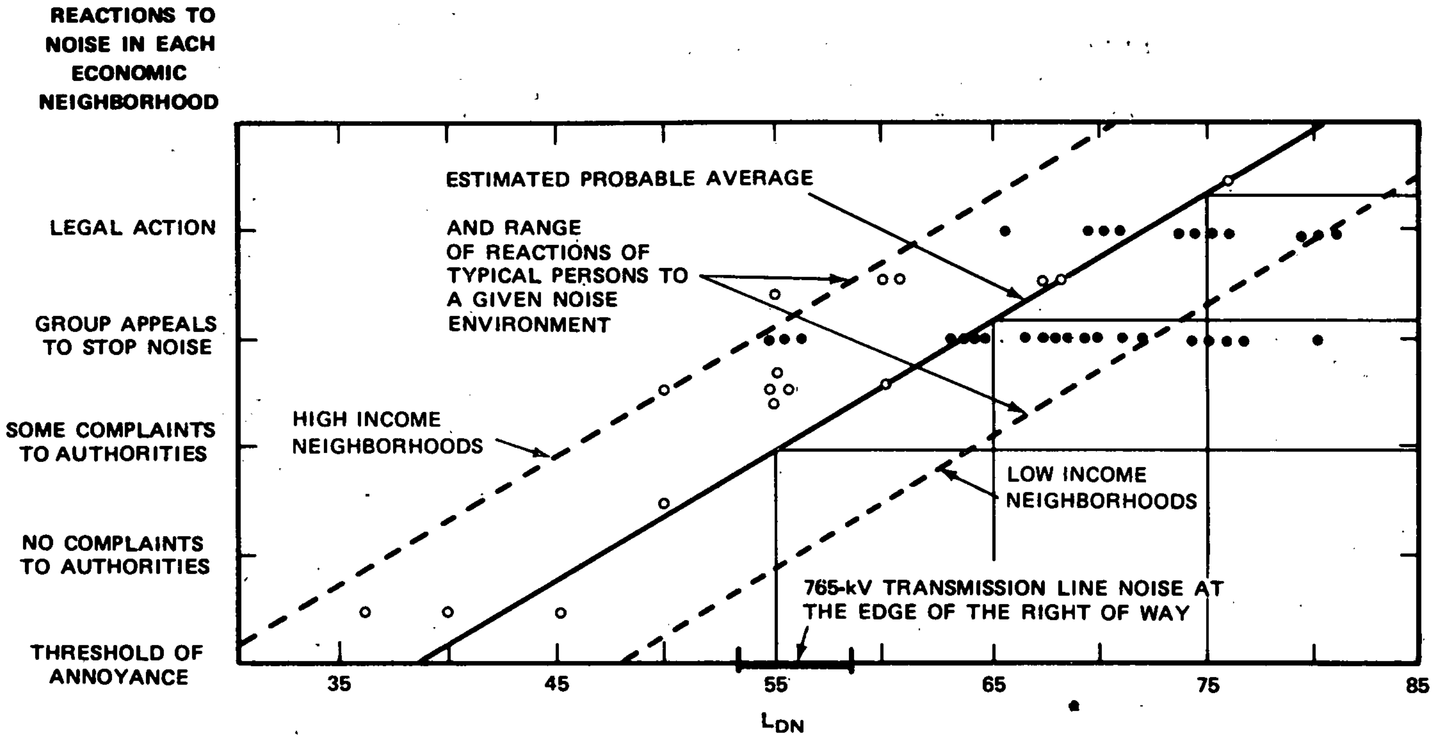
Type of Correction	Description	Amount of Correction To Be Added to Measured L_{dn} in dB
Seasonal correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	–5
Correction for outdoor noise level measured in absence of intruding noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	–5
	Very noisy urban residential community	–10
Correction for previous exposure and community attitudes	No prior experience with the intruding noise	+5
	Community with some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied when a community has not been previously exposed to the noise, but when the people are aware that bona fide efforts are being made to control the noise.	0
	Community with considerable previous exposure to the intruding noise and the noise maker's relations with the community are good.	–5
	Community awareness that operation causing noise is both necessary and will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	–10
Pure tone or impulse	No pure tone or impulsive character	0
	Pure tone or impulsive character present	+5

Source: EPA, 1974



Source: EPA, 1964

FIGURE 1.11 COMMUNITY REACTION AS A FUNCTION OF THE NORMALIZED OUTDOOR DAY/NIGHT SOUND LEVEL (L_{dn}). (This figure shows the data from Figure 1.9 after adjustment for local conditions. The data show a definite trend after the adjustment. More recent data surveyed by EPA and SRI International support the trend in the figure.)



Source: Kryter, 1970

FIGURE I.12 REACTIONS OF PEOPLE IN DIFFERENT INCOME NEIGHBORHOODS TO ENVIRONMENTAL NOISE (Socioeconomic status appears to play a major role in community response to noise. The range of 765-kV transmission line noise at the edge of the right-of-way is indicated on the figure. The upper value assumes an L_{dn} averaged over 24 hr and the lower value assumes an L_{dn} averaged over 1 yr. Cases from high income neighborhoods are plotted as open circles and those from low income neighborhoods are plotted as closed circles.)

Recommendations

- Develop data on costs and methods of reducing noise impacts
- Develop further methods of deciding when noise levels are unacceptable by gathering survey and complaint data
- Refine the method for using AN measurements
- Make provision for addressing complaints on audible noise.

The hearings developed testimony about ways in which technology could be used to reduce audible noise from transmission lines during foul weather. Increasing conductor diameters decreases the electric fields at the surface of the conductors and decreases the level of AN generated during precipitation. Of course, operating transmission lines at reduced voltages will also reduce AN, but at the expense of operating efficiency.

Larger conductors diminish the noise impact of transmission lines, but their effects would only reduce noise by a few decibels in L_{eq} measures. Nevertheless, even a few decibels may be significant in a marginal exposure situation; both Kryter and Pearsons state that 2-3 dB is a noticeable difference. From an exposure standpoint, Kryter and Pearsons differ on predicted L_{eq} values by about 2 dB, owing to their opinions about proper averaging of variable noise patterns (daily vs. annual averaging). Hence, technology application could presumably provide—even under Kryter's more strenuous averaging requirements—a significant margin of improvement.

More attention needs to be given to the selection of noise exposure criteria. An L_{eq} or L_{dn} of 55 dB was discussed extensively as a criterion level, above which noise impacts would be unacceptably severe. The evidence and reasoning to support this choice, however, were not compelling. The so-called "normalization" corrections discussed in a limited fashion at the hearings may be helpful in establishing flexible, yet sensitive, guideline levels or criterion levels. The hearings did not adequately develop this important concept.

The characterization of AN levels in the presence of ambient noise and related questions occupied a significant portion of the hearings. Conflicting opinions were offered about the basic methodology of such measurements—two methods of measurement can yield average values that differ by 5-10 dB (A-weighted). Clearly, when a noise intrusion is about the same magnitude as existing ambient levels, and when the degree of intrusiveness is expected to affect the psychological impact of the intruding noise, it is important for predictive purposes to have valid and reliable ambient noise data. Because the hearings did not produce a consensus on this matter, the definition of a methodology for using ambient noise measurements should be a high priority research and development goal. This methodology should incorporate the recent National Bureau of Standards work for DOE on the annoyance of transmission line noise. The potential annoyance of transmission line noise is particularly important because it may mean that AN levels underestimate impacts when interpreted solely by dBA-based measurements.

Complaints about AN from transmission lines are likely to occur sporadically. However, the testimony suggests that some people may well be disturbed by transmission line noise. Thus, it is important to make provision for addressing these complaints.

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Sleep interference is discussed in some detail in:

- J. S. Lukas, "Measures of Noise Level: Their Relative Accuracy in Predicting Objective and Subjective Responses to Noise During Sleep," prepared for the Environmental Protection Agency, EPA-600/1-77-010 (February 1977).
- K. D. Kryter, *The Effects of Noise on Man* (Academic Press, 1970).

II ELECTROMAGNETIC FIELDS UNDER TRANSMISSION LINES AND BIOLOGICAL SYSTEMS: EFFECTS AND/OR HAZARDS

Scientists have investigated the biological effects of electromagnetic fields for many years and generally agree that electromagnetic fields at frequencies well below that of visible light present a hazard whenever they cause excessive tissue heating. They also agree that transmission line field strengths at ground level are too low to cause excessive heating. Current U.S. standards for allowable exposure to microwave and radio frequency radiation safely protect against harmful heating, but no U.S. standards exist in regard to exposure to fields at powerline frequencies (60 Hz).

Some scientists believe that biological effects, not dependent on heating, may result from exposure to transmission line fields; however, the majority of scientists working in this area believe nonthermal effects are highly unlikely. Such proposed—although not thoroughly demonstrated—behavioral and central nervous system effects have no explanation that is based on currently accepted biophysical theory. Many of the experiments reporting nonthermal effects were performed in the Soviet Union and other European countries and reports on them frequently fail to supply adequate documentation of the experimental procedures. Because of this failure, scientists in the United States are not fully confident of Soviet findings. Thus, the scientific community disagrees about whether or not electromagnetic fields of the strengths found under UHV systems cause biological effects and/or hazards.

The continuing disagreement in the scientific community apparently results in public fear about possible dangers from electromagnetic fields under UHV systems. It is unfortunate that the public may interpret disagreement among scientists, a valid and integral part of the scientific process, as providing proof that a hazard exists.

Given this background, the hearings focus on three central questions:

- What are the electric and magnetic fields under 60-Hz 765-kV transmission lines?
- Do the fields cause biological effects?
- If biological effects occur, do they constitute a hazard?

In approximately 10,000 pages of testimony, these primary questions are addressed by the following eight principal witnesses, who are expert in a variety of scientific disciplines:

- R. O. Becker, M.D., Chief of Orthopedic Surgery and Director of the Orthopedics-Biophysics Laboratory of the Veterans Administration Hospital, Syracuse, NY, has undertaken research in biological electric control systems.
- E. L. Carstensen, Ph.D., Professor of Electrical Engineering and Director of Bio-medical Engineering at the University of Rochester, Rochester, NY, has researched the acoustic and dielectric properties of biological materials.

- A. H. Frey, M.A., Technical Director of Randomline, Inc., has done research in biophysics, physiology, engineering, and medicine.
- M. H. Hess, M.Sc., Manager of Biostatistics and Computer Operations Sections of the NUS Corporation, Pittsburgh, PA, provides an independent statistical appraisal of certain of Dr. Marino's experiments.
- A. A. Marino, Ph.D., J.D., Research Biophysicist under Dr. Becker at the Veterans Administration Hospital, Syracuse, NY, has undertaken research in interactions of electricity and biological organisms.
- S. O. Michaelson, D.V.M., Professor of Radiation Biology and Biophysics and Associate Professor of Medicine and of Laboratory Animal Medicine, University of Rochester, Rochester, NY, has researched the biological effects of electromagnetic radiation.
- M. W. Miller, Ph.D., Associate Professor and Assistant Director of Radiation Biology and Biophysics, University of Rochester, Rochester, NY, has researched the effects of radiation on plants.
- H. D. Schwan, Ph.D., Professor of Electrical Engineering and of Physical Medicine, University of Pennsylvania, Philadelphia, PA, has undertaken research on the mechanisms of electricity conduction in tissues and cells, on the effects of low-frequency and radio-frequency electrical fields on cells and molecules, and on the effects of nonionizing radiation on biological systems.

Although these brief biographies describe the credentials and the research backgrounds of the witnesses, the aspects of potential biological effects about which each witness testifies are not necessarily restricted to their specific research interests, as can be seen in the section on Interpretation of the Hearings.

The testimony focuses on experiments that some scientists claim demonstrate biological effects from exposure to electric, magnetic, or combined electromagnetic fields. The claimed biological effects include:

- *In Humans and Primates*
  –Increased triglycerides in the blood
  –Accelerated bone fracture healing
  –Altered psychomotor reaction times
  –Shifts in the timing of normal daily rhythms
  –Lack of a feeling of well-being
  –Sensations of fatigue, depression and headache
  –Changes in the electrical activity patterns of the brain

- *In Rats, Mice, and Guinea Pigs*
  –Decreased weight gain
  –Altered enzyme levels in various organs
  –Altered levels of steroids in the blood
  –Increased bone growth
  –Bone tumor induction
  –Electrocardiogram phasing
  –Changes in blood cell counts
  –Alterations in the concentration of blood chemicals

–Perception of electromagnetic field
–Locomotor activity changes
–Lethality
–Weight loss in progeny
–Organ weight changes
–Water consumption changes
–Changes in milk production in nursing females
–Changes in litter size

- *In Miscellaneous Species and Organisms (dogs, cats, birds, invertebrates, and plants)*
  –Cell cycle alteration
  –Alterations in the cell division rate
  –Perception of electromagnetic fields
  –Leaf tip burning
  –Reduction in calcium release from brain tissue
  –Orientation to electromagnetic fields
  –Decreased compensation to stress induction

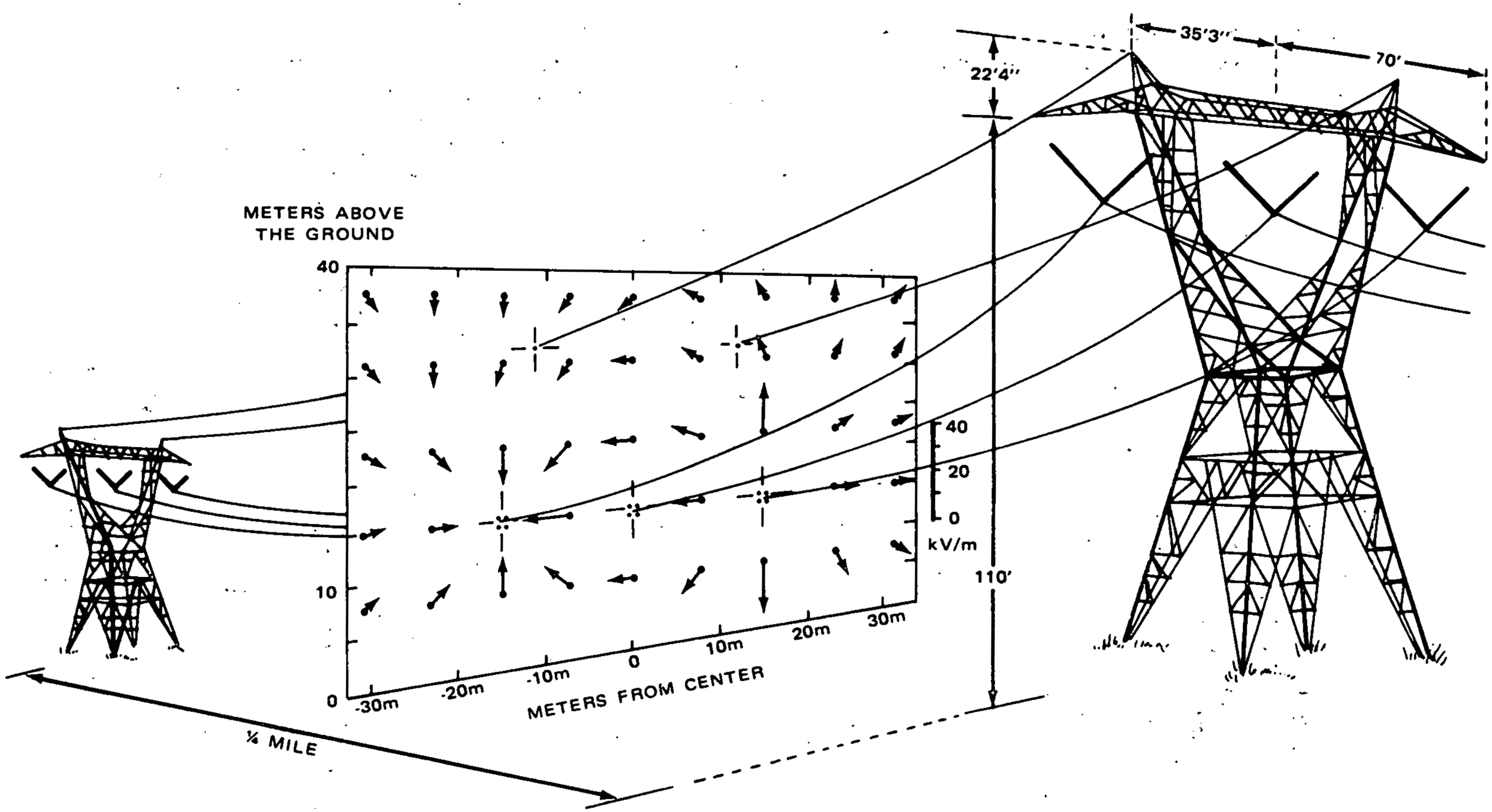
Testimony focuses on identifying experimental results that relate to these effects. The experts' views vary from claims that no effects exist (other than unimportant heating) to recommendations that the likelihood of hazards is sufficient to justify action by the NY Public Service Commission to halt construction of the proposed 765-kV lines. The witnesses express opinions about the likelihood of biological hazard and indicate their conclusions about whether the proposed lines should be constructed.

The Electric and Magnetic Fields Around UHV Lines

Complex patterns of electric and magnetic fields surround a transmission line. At each point in space around the lines, these fields change in magnitude and direction 60 times each second. For 60-Hz overhead lines, the electric and magnetic fields do not depend strongly on one another. For example, a line that is energized to its operating voltage will have very much the same electric field, whether or not current flows. The magnetic field increases in proportion to the current transmitted. Close to the conductor surface, the electric fields are nearly radial, whereas the magnetic fields are nearly concentric around the conductor. A complete description of the fields requires complex mathematics. The figures described below help portray the fields typical of 60-Hz 765-kV lines. Of primary interest at the hearings were the fields near ground level.

Figure II.1 illustrates the field pattern around a 765-kV line at one instant in time. Only the fields in a hypothetical plane between two towers are shown. A grid of points makes the display clearer. The arrows indicate the direction and magnitude of the electric field at each of the grid points. Because the voltage on each conductor varies sinusoidally 60 times per second, the total pattern is repeated many times per second. Figure II.2 shows the fields one-quarter cycle later. At the center of the span, the electric fields lie primarily in a plane perpendicular to the line. Away from midspan, the fields have a small horizontal component parallel to the line. Figure II.3 shows the peak value of the electric field measured at ground level along a hypothetical line at midspan perpendicular to the transmission

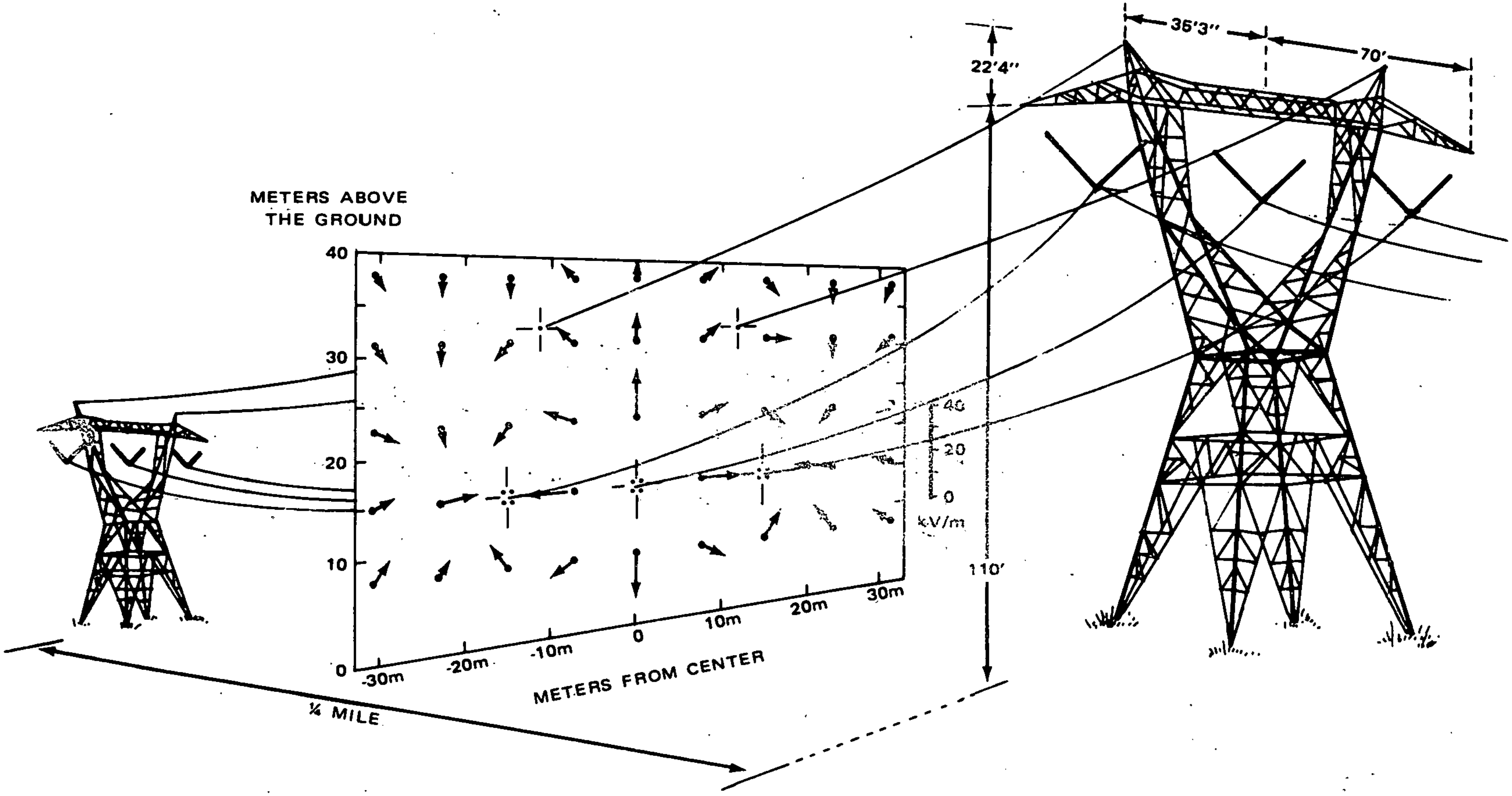
ELECTRIC FIELDS AROUND A 765-kV TRANSMISSION LINE



Source: D.W. Deno, "Transmission Line Fields," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-95, No. 5 (September/October 1976)

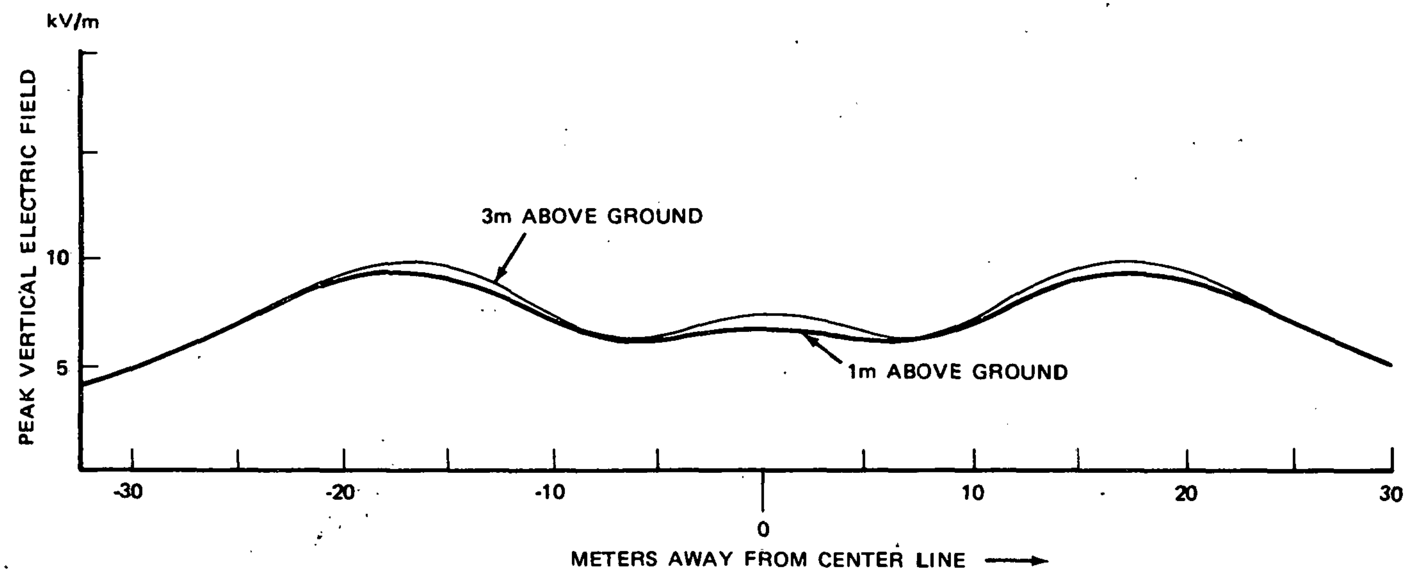
FIGURE II.1. ELECTRIC FIELDS AROUND A 765-kV TRANSMISSION LINE. (The fields are shown at the instant in time where the fields at ground level are at a maximum. Between two towers the fields are primarily in the plane perpendicular to the transmission line right-of-way.)

ELECTRIC FIELDS AROUND A 765-kV TRANSMISSION LINE 1/4 CYCLE LATER



Source: D.W. Deno, "Transmission Line Fields," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-95, No. 5 (September/October 1976).

FIGURE II.2. ELECTRIC FIELDS AROUND A 765-kV TRANSMISSION LINE ONE-QUARTER CYCLE LATER IN TIME (During each cycle, the electric fields change in direction and magnitude. The fields are maximum at the conductor surface where they approach the voltage at which air will break down and conduct electricity. That field is approximately 25 kV/cm.)



Source: D.W. DENO, "Transmission Line Fields," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-95, No. 5 (September/October 1976)

FIGURE II.3. PEAK ELECTRIC FIELDS UNDER A 765-kV TRANSMISSION LINE WITH A MINIMUM CONDUCTOR HEIGHT OF 14.6 m (58 ft). (The fields are symmetric on either side of the transmission line. The fields increase in strength as the distance to the conductors decreases.)

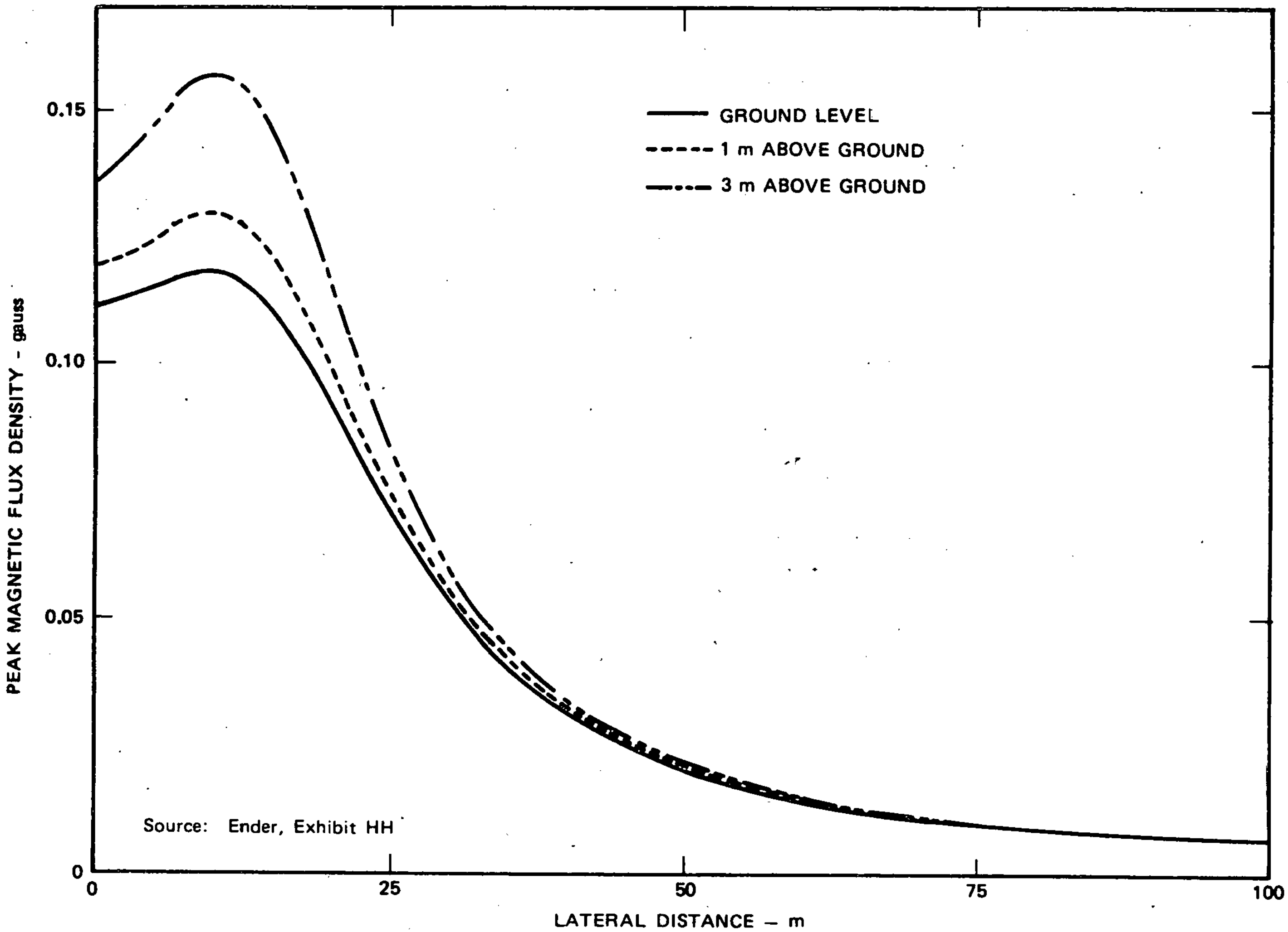


FIGURE II.4. MAGNETIC FLUX DENSITY UNDER A 765-kV TRANSMISSION LINE CARRYING 1,000 AMPERES PER PHASE. (The magnetic flux density is proportional to the current carried in the line. The figure shows the flux density at a conductor height of 14.6 m (48 ft). The earth's magnetic field is about 0.5 gauss.)

line, and the field measured along a hypothetical line about 1 m above the ground. The peak electric fields increase as one approaches the maximum at the conductor surface. Figure II.4 shows the peak value of the magnetic field measured along the same hypothetical line used in Figure II.3.

Hazard Definition and Assumptions

Societies differ strikingly in their approach to answering the questions of whether hazards exist. Differences in regulatory philosophy profoundly affect the exposure regulations that result from hazard assessment. The hearings discuss at some length the differences in the Soviet and the American philosophies of setting standards for exposure to electromagnetic fields. The following discussion highlights some of the overall differences in defining hazards—an undertaking that the SRI project team considers to be a social process, which uses the information gathered by the scientific community on biological effects as one of its many inputs.

The term "hazard" used in this text should be considered a legal or regulatory term that implies a judicial or quasijudicial determination that the biological effects of substances or forces introduced into the human environment are undesirable or unacceptable. Determining biological effects is a scientific and technical problem. Interpreting information on effects to arrive at a hazard evaluation involves assumptions and philosophical problems that lie outside the scope of science and, frequently, outside the scope of law: Which biological effects should be considered? What criteria should be used in categorizing an effect as unacceptable? Is there an intensity or concentration threshold for an effect? What consideration should be given to the rare individual who is exceptionally sensitive? And who should bear the burden of proof in determining that an effect or hazard exists?

Many of these questions were encountered in the development of air quality standards for industries and factories in the United States and the USSR between 1946 and 1970. In the United States, the American Conference of Governmental Industrial Hygienists developed the concept of the Threshold Limit Value (TLV), defined as the time-weighted average concentration of an airborne substance to which most workers could be exposed 8 hours a day, 5 days a week, for an indefinite period without adverse effect. In the USSR, the State Committee on Standards of the Council of Ministers developed the concept of Maximum Allowable Concentration (MAC), defined as that concentration of an airborne substance that will not produce in any of the persons exposed any disease or any deviation from normal. The assumptions underlying both viewpoints are clear: In the United States, harmful effects are emphasized, whereas in the USSR any effect out of the ordinary is considered undesirable. In the United States, the hypersensitive individual is excluded, whereas in the USSR all individuals are included. In both countries a threshold is recognized, below which no effects are induced.*

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*It should be noted, however, that every substance or force in the environment probably has biological effects at some concentration or intensity. Even the noble gases—helium, neon, argon, krypton, and xenon—have well-documented biological effects, although these effects are found at high partial pressures. It is not known whether these gases or other physical phenomena in nature, such as the natural magnetic and electric fields of the earth, have biological effects at the ordinary concentrations or intensities at which they are found; nevertheless, such a possibility cannot be excluded. Hence, it is meaningless to speak of the absence of effects of a particular substance or agent: the biological effects are either too subtle to be detected or cannot be produced at the concentrations or intensities of exposure characteristic of the natural environment. This concentration or intensity dependence is the basis of the concept of threshold.

The concept of threshold was central to the formulation of protection standards in both the United States and the USSR. This concept applies in principle not only to industrial air quality standards but also to safety standards for food additives and colorings, and to other conditions considered to have health significance (e.g., exposure to electric fields in the USSR). In recent years the concept of threshold as a defining limit of permissible exposure has been questioned in the United States with (1) the development of increasingly sensitive methods for determining biological effects; (2) disagreement about what constitutes a "harmless" effect, including concern about the additive effects on an individual of several environmental factors; and (3) public concern about the possibility that certain environmental pollutants may be carcinogenic or increase susceptibility to cancer. To meet these concerns, the concept of risk (or cost) benefit analysis has been developed. Carried to an extreme, risk/benefit analysis ignores the question of threshold, and attempts to establish a limit of permissible exposure by compromising among the social and personal advantages or detriments associated with an environmental pollutant or physical force.

Risk/benefit analysis is frequently used by government agencies to assist in decision making. For example, a current controversy in the U.S. Food and Drug Administration (FDA) concerns the question of whether or not the use of nitrites in the preparation of bacon, ham, and sausages should be permitted. Opposition to nitrites is based on the possibility that they may react with organic materials in food to produce nitrosamines, which are considered to be strong carcinogens. However, the FDA continues to permit nitrites because they inhibit the growth of the bacteria that cause botulism. The benefit in preventing botulism is considered to outweigh the still questionable (unquantified) hazard of cancer.

The chief disadvantages of risk/benefit analysis are that risk and benefit are more difficult to define and measure than threshold or injury and that definitions are contingent on personal viewpoints. In the example cited above, the risk and benefit occur in the same person, and that person can recognize this fact. In the hearings under review, the ordinary person living along the power line right-of-way probably perceives the risk as personal and the benefit as accruing to a remote and indifferent corporation. Benefit to "society" may well be perceived in the same way. Hence, risk/benefit analyses must consider the distribution of risks and benefits and how these factors are perceived by the persons affected.

Two assumptions occasionally exist—sometimes tacitly—in positions on environmental pollution. One assumption is that a substance or agent must be assumed harmful until proved otherwise ("guilty until proved innocent"). For at least 20 years the FDA has used this assumption as the basic guidelines for licensing food additives and colorings and new drugs. The extension of the assumption to everything in the environment is relatively recent, and advocates often do not consider the economic consequences.

A second approach that frequently underlies attitudes about environmental pollution is the black/white assumption: A substance or agent is or is not harmful or dangerous to human health. If it is harmful, it must be removed or at least reduced to the lowest possible level. With respect to some naturally occurring substances and phenomena, such an unrestricted assumption is scientifically unsound. A number of naturally occurring substances, including the oxygen in the atmosphere that we breathe, are essential or beneficial to life at one concentration and toxic or detrimental to life at higher concentrations. The key point is the dependence of the effect on concentration or intensity. Some substances or agents such as carcinogens may, in fact, be deleterious to some degree at any concentration ("zero threshold"), but failure to consider concentration or intensity (dose) dependence could lead to unrealistically low environmental concentration standards, with the attendant cost borne by the public.

Scientific Evidence in Hazard Determination

Scientific information about the biological effects of a substance or agent generally consists of an interrelated network of theoretical, experimental, circumstantial, and epidemiological evidence that must be assessed as a whole. In addition to the direct evidence about biological effects, it is sometimes also necessary to consider other evidence about the properties of the substance or agent that may contribute to its potential hazard (e.g., solubility, volatility, flammability, electrical conductivity under different conditions, and, in the case of chemical pollutants, the mechanism by which the substance is removed from the biosphere). For a given potential hazard, certain types of evidence may be absent or equivocal, and in some circumstances more weight may be given to one type of evidence than to the others. Nonetheless, all available evidence should be considered.

Theoretical evidence is concerned with mechanisms of interaction between the substance or agent and the biological tissues or system under consideration, and with the chemical or physical properties of the substance or agent that might cause a biological effect. In the hearings, the theoretical evidence is sometimes referred to as biophysical evidence or biophysical theory. It consists of testimony regarding the ability of the electric fields under the power lines to cause tissue heating or molecular polarization or deformity within tissues. The evidence is generally valid for what it states: that electric fields cannot produce sufficient heating or molecular polarization to cause significant biological effects. Note, however, that other as yet unknown biophysical mechanisms could exist by which a biological effect could be produced by electric fields, and these mechanisms are not covered by existing theory. Hence, the absence of theoretical explanation does not necessarily imply absence of effect.

Experimental evidence results from direct exposure and observation of experimental animals and sometimes of man. Experimental evidence is usually considered stronger than theoretical evidence, but it is subject to various limitations. One such limitation concerns the adequacy of experimental design and the validity of conclusions. Another limitation is that studies of biological responses to chemical and physical agents center on biological effect rather than hazard. In fact, the experimental evidence for an actual hazard may be inconclusive, even though the experiments have been conducted properly. In the hearing, the experimental results were largely obtained from studies unrelated to hazard determination. For instance, Marino states that his studies were intended to find ways to promote healing of bone fractures. By contrast, the original studies on hazards of ionizing radiation were designed to reveal potential hazard. The results of the studies showed that radiation levels above 0.1 R/day* reduces the life span of the animals, an effect that can be presumed to imply hazard.

Circumstantial evidence relies on the known effects of similar or related substances or agents, or similar effects in other animal species. Thus, if a chemical compound is known

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*R/day = Roentgen per day.

to cause cancer, another compound with a related chemical structure might also be suspected of causing cancer. In the broad sense, all experimental results in animals present circumstantial evidence for effects in humans. Circumstantial evidence about hazards to humans does not prove actual hazard, but regulatory agencies acting in the public interest frequently accept results from animal studies in deciding about human hazard.

Epidemiological evidence derives from monitoring health indices in a human population that is exposed to a substance or agent. Epidemiological studies are usually health-oriented, and provide direct evidence about potential human hazard under the conditions of exposure. These studies, however, are subject to a number of problems that limit the validity of their conclusions. They are usually retrospective; appropriate controls are difficult to obtain, and the results are often presented in the form of a correlation ("A is associated with B"), rather than a direct cause-and-effect relationship. For these reasons, epidemiological results are inherently weak, and should be supported by experimental evidence.

Other aspects of scientific evidence as well must be considered in evaluating hazards to humans:

Confirmation versus duplication. An experiment performed a sufficient number of independent times or on a sufficient number of animals with consistent results establishes beyond reasonable doubt that a true effect has occurred. Beyond that point it is not usually considered necessary to repeat the experiment unless one suspects an artifact or a flaw in the experimental design. Independent confirmation in several laboratories is particularly important in developing a scientific consensus. Ultimate acceptance of the experimental results depends on how they fit into the general body of scientific knowledge. When an experiment is repeated, the experiment is often redesigned to yield additional information. For instance, the original experiments on the hazard of chronic exposure to ionizing radiation were repeated, but the new experiments were redesigned to yield data from which a dose-rate/effect formula could be derived.

In the hearings, the validity of the experimental results presented by Marino were challenged in cross examination. Considering the points raised and the general nature of the results, the experiments should probably be repeated, with design modifications that would give more information about hazard.

The Extrapolation Problem. Testimony at the hearings was related to the question of whether or not a hazard exists, but this is not the question asked by a regulatory body involved in setting the permissible conditions of exposure of humans to avoid or minimize human hazard. For power lines, this might involve questions of width of right-of-way, height of power lines, or shielding. The extrapolation problem involves transferring data on biological effects from the circumstances in which they were acquired to conditions under which man might be exposed, and then judging what might happen to man. The problem includes transferring data from animals to man, predicting effects at a low concentration or intensity from results obtained at a high concentration or intensity, and predicting the effects for a particular kind of agent from results obtained in a physically or chemically related agent.

Predicting how biological effects in man depend on concentration, amount, or duration of exposure to a substance is difficult, particularly when the data are derived from other animal species. For effects that depend on the interaction of a substance with normal biochemical and physiological processes, equivalent effects in different species are produced when the amount or concentration of the substance is proportional to the body surface area of the animals. For other effects, the amount may be proportional to the body weight of the animals or to the rate of some physiological process such as respiratory exchange or urine excretion. When the biological effects of a substance are believed to be completely reversible, the usual practice is to estimate the level for human effects from animal data, reduce this level by some safety factor, and test the reduced level in human volunteers for absence of effect. The size of the safety factor varies: for industrial gases, atmospheric contaminants, and prescription drugs, the safety factor ranges from 2 to 20; for food additives, it is 100.

For exposure to microwaves the safety factor was originally chosen to be 10, but more recent work indicates that the allowed level implies a safety factor of between 4 and 6. For ionizing radiation, the safety factor excludes medical irradiation for diagnosis or therapy, which adds a variable amount to the radiation burden of each individual.

The most serious questions about extrapolation of biological effects to low dose or concentration involve irreversible effects (e.g., carcinogenesis). For carcinogenesis, the relationship between the amount or concentration of a cancer-producing substance and the degree of effect produced at low exposure levels is unknown. To deal with the data on cancer induction in rats and mice, several statistical procedures have been proposed. Using conservative assumptions, these procedures attempt to estimate the concentration or amount of the substance that will produce no more than some arbitrarilv low level of cancer cases in the human population—usually in 1 out of 1,000,000 people. The procedures extrapolate from cancer rates of 10 to 40% observed in mice down to a 0.0001% rate predicted in humans in the absence of any parametric model. This arbitrarily low rate of occurrence is adopted by regulatory boards for want of any better way to reach a decision.

Limitations

Aside from the problems discussed above, other constraints limit the contribution that science can make in resolving problems of environmental hazard to human health. These limitations are related to the nature of science as an intellectual pursuit, the special problems involved in biology and medicine, and the personalities of individual scientists.

Pragmatic Nature of Science. Scientific facts and theories should combine information currently thought to be relevant and true. Such synthesis is always subject to revision as new information becomes available or as the alternative significance of old information is recognized. As a result, scientists tend to so qualify evidence that its value is diminished in aiding legal decisions about hazard evaluation. Some scientists function better than others as witnesses, but competence as a witness is not the same as competence as a scientist.

Probabilistic Nature of Scientific Conclusions in Biology. The scientific philosophy generally assumes that nothing is known with absolute certainty; rather, facts are known to some level of probability. In biology, the margin of uncertainty is usually larger than in the physical sciences because of the complexity of biological systems. In many experiments it is common practice to accept a 95% probability of a correct scientific hypothesis calculated from statistical models as the dividing line between acceptance and rejection.

In expanding the field of knowledge, the 95% probability criterion is usually adequate. In hazard assessment, however, using conclusions based on 95% probability of correctness may involve serious problems, particularly when questions of serious human injury or considerable economic cost are involved. If the reliability of a result is questioned, it is possible to retest at a higher level of statistical certainty by using a larger number of animals.

Parametric Relationships in Biology. Biology has relatively few parametric (quantified) relationships among its variables, and many of those that exist are only approximate. Hence, problems in standard setting, when the level of a substance must be determined so that only a specified level of effect will occur, are often difficult to solve. For instance, the concept of a threshold concentration has been used regularly in hazard evaluation and standard setting for a number of years; yet no accepted formulation or set of formulations about the nature of definition of threshold exists. Thus, the determination of a threshold largely depends on empirical processes that rely on an evaluation of the probability that the effect will or will not occur in a randomly chosen human being.

Formulation of Scientific Hypotheses (the Null Hypothesis). In biological studies of the effect of a substance or agent on animals, the common experimental procedure divides the animals into two groups—one group exposed and the other unexposed. Then, for any effect observed or tested for in both groups, it is hypothesized that chance accounts for the differences in magnitude or frequency of occurrence of this effect between the exposed and unexposed groups and appropriate statistical methods are used to test this hypothesis. If the statistical probability indicates that the observed differences could not occur by chance more often than at some predetermined low frequency, the hypothesis is rejected. A residual observation is left: In the presence of substance or agent A, effect B is found. The assumption that agent A causes effect B is then made provisionally, subject to no other cause being found for effect B. When many related cause-effect conclusions of this type are linked by some rational theory of cause, it can be assumed for purposes of evidence that the conclusions are correct. However, when only the results of a single experiment are available, conclusions about cause and effect are generally weak and should be recognized as such in considering evidence.

Proving a Negative. In formulating scientific hypothesis about cause and effect, the basic hypothesis is to assume that there is no cause and effect relationship—in other words, form a negative statement about the effects; then all observed effects can be applied to disprove this negative statement. If the appropriate statistical tests applied to experimental data fail to disprove the statement, it does not thereby prove it. The only statement that can be made is that no effects were found. Hence, it is never possible to prove that no biological effects are produced by a given substance or agent. Regulatory agencies concerned with licensing, such as the FDA, sometimes resolve this dilemma by requiring the substance under consideration to demonstrate consistent negative results under a prescribed protocol of testing, but the agency recognizes that the results fall short of proving absolute safety of the substance.

Inconsistent Results. Not every individual is equally affected by substances or agents in the environment, and it is possible that only a few individuals will be affected by many substances or agents proposed as hazardous. Human beings differ, other factors contribute to effects, and pure chance intervenes. An example of the contribution of other factors is found among uranium miners, who are subject to a marginal increase in lung cancer that presumably results from their inhalation of radioactive material. However, miners who smoke cigarettes are subject to a much greater risk of lung cancer than either miners who do not smoke or smokers in the general population. In considering evidence on the potential hazard of a substance, it is thus necessary to inquire about how many people or what proportion of the population will be affected, what contribution individual behavior makes to the hazard, and whether it is possible to avoid hazardous consequences by identifying and protecting hypersensitive individuals.

Resource and Cost Problems in Biological Studies. Long-term biological testing is extremely expensive. It is estimated that currently each complete assay for carcinogenicity of a chemical under 1978-1979 National Cancer Institute protocols costs about $290,000 and takes about 3 years. Because of the requirements for tests on three or more animal species, long-term testing of drugs and food additives is probably more expensive. Costs aside, the nation's facilities and trained manpower are not and will not be adequate for complete and exhaustive testing of every substance or agent in the environment. Every biological test required for a possible hazard results in a diversion of manpower and facilities from other tests and scientific studies that might be more important for human welfare. For these reasons, decisions about what constitutes a hazard may have to be made in the absence of complete knowledge or test results, and the consequences of ordering additional testing should be weighed in analyzing the risks versus benefits to the general public.

Scientific Objectivity. Scientists, like others, have personal values, attitudes, beliefs, and goals that are incorporated in the work they report. Scientific "objectivity" applies to the scientists as a group, rather than to individuals. The maintenance of objectivity depends on the existence of numerous scientists who do not depend on political or partisan agencies for support. Fraud in reporting data is rare—and strongly condemned by scientists' ethics. Personal bias, on the other hand, can consciously or unconsciously affect how a scientists designs an experiment, what he observes and what he ignores in an experiment, how he interprets the data, and his belief about the significance of results. In adversary proceedings, the scientist has as much difficulty in maintaining objectivity as anyone else, and the possibility of bias in his testimony must be recognized.

Interpretation of the Hearings

All witnesses considered the same body of experimental information; thus, when their testimony differed, it reflected differences in their perceptions rather than differences in information. As a consequence, their evaluations are matters of interpretation. Given the variety of viewpoints among the witnesses, it is unlikely that they would agree on the probable biological consequences of constructing a power line according to the proposed design parameters. Nevertheless, all are willing to recommend whether or not construction should proceed on the basis of currently available information. Moreover, all call for further research on power line characteristics because little information exists from controlled and well-scrutinized studies. Indeed, the uncertainties associated with using information from studies not designed to bear directly on potential power line hazards appear to influence the differences among the witnesses significantly.

"For the believer, no more evidence is necessary; for the unbeliever, none will suffice."
—Anon

The inseparability of each witness's testimony from his conception of the biological effects of electromagnetic fields is illustrated by the summaries that follow. Five of the witnesses—Michaelson, Miller, Schwan, Carstensen, and Frey—recommend construction. Two of the witnesses—Marino and Becker—are opposed.

Solomon M. Michaelson, concludes that the proposed lines will not pose an electromagnetic hazard. He bases this conclusion on his review of the literature and his long association with experimental work in the biological effects of nonionizing radiation. He differentiates between effect and hazard, defining the latter as an effect that compromises function or overcomes recovery capability. He emphasizes evidence from studies on humans and mammals. He rejects, as not pertinent, evidence from studies in which the electromagnetic parameters widely depart from those projected for the proposed lines. He accepts a lack of statistically significant effect as the criterion of safety.

"The fact that a living organism responds to many stimuli is a part of the process of living; such responses are examples of effects . . . these effects may be well within the capability of the organism to maintain a normal equilibrium . . . if . . . an effect . . . compromises the individual's ability to function properly or overcomes the recovery capability of the individual . . . then this effect may be considered a hazard."
–Michaelson

Morton W. Miller, predicts no unreasonable risks to health or safety or harm to the environment from the electromagnetic fields resulting from the proposed lines. He bases his predictions on his review of the literature and his field observations of plant life under power lines. He differentiates between effects and hazard, viewing lack of a statistically significant effect as a criterion of no hazard. He admits that his experimental research has essentially been limited to plant studies, but believes that he can also evaluate the evidence from animal studies adequately.

"While continued research is always desirable to advance the state of technology, it is my considered professional opinion that the current state of the art with respect to the potential of adverse biological effects from the electric and magnetic fields associated with the proposed transmission line is adequate to assure the public that there will be no unreasonable risks to health or safety or harm to the environment, as a result of electric and magnetic fields resulting from the operation of these lines."
–Miller

Herman P. Schwan, represents the theoretical approach to hazard evaluation. Concerning himself only with irreversible effects, he concludes that only electromagnetic fields of sufficient magnitude to (1) produce volume heating, (2) change membrane permeability, or (3) result in excitation could be potentially hazardous. Because he calculates that electromagnetic fields from the proposed power line at ground level will be several orders of magnitude below the threshold values for producing any of these three phenomena, he concludes that no hazard will occur. He accepts experimental findings that do not fit with biophysical theory only if they are unequivocally free of artifacts or alternative causative interpretation and

". . . basic biophysical principles as applied to molecular consideration, what is known about tissue structure, biology, morphology of tissue, current density distributions, et cetera, permits [sic] us to make the statements which I have made in my testimony."
–Schwan

have been confirmed by other findings. It appears that he, like virtually all scientists, does not demand the same rigorous examination of findings that agree with biophysical theory.

Edwin L. Carstensen, concludes that the electromagnetic fields from the proposed power line will not constitute a significant risk to human health or safety, or to the environment. For him, the theoretical approach provides a sound basis for assessing results based on experimental evidence, and he believes that the theoretical and experimental approaches, taken together, allow for greater confidence in making conclusions. However, in the testimony, he relies heavily on the biophysical approach. He finds that information available about reported biological effects is either inapplicable because the physical characteristics differ from those predicted for the power line or because the effects are inconsistent with current theory and thus suspect in the absence of confirmation. He discusses two important concepts: (1) the differences between duplication and confirmation of results, and (2) the practical impossibility of proving a negative. He also emphasizes permanent change as a requirement before he considers an effect a potential hazard.

"My principal effort has been to estimate from electric and magnetic field and dielectric considerations the internal electric and magnetic fields induced in biological objects exposed to the external electric and magnetic fields generated by the proposed 765-kV transmission lines and to assess their potential for biological effects."
–Carstensen

Allen A. Frey, is equivocal in recommending that construction of the power line should proceed but does advocate placing right-of-way limits so that electromagnetic field strengths at the boundary would not exceed those for existing power lines. His is an experimentalist viewpoint that rejects the biophysical approach as useless for hazard evaluation. He finds its underlying assumptions oversimplified. At the same time he rejects experimental findings in which the electromagnetic field parameters, including frequency, are not close to those predicted for the proposed line. Addressing only the question of potential neural stimulation and behavioral effects in humans, he bases his belief on his consideration of the literature as a whole and not on specific experimental work.

"We have a situation in which there are weak indications that the 60-Hz power line fields could cause neural and behavioral effects. There is insufficient data to establish whether these possible effects are hazardous or not. Further, there is no way, through calculations and modeling, to determine if there are or are not hazardous effects. To establish whether these transmission lines represent a hazard from the neural or behavioral standpoint, multiple years of experimental investigation are necessary."
–Frey

Andrew A. Marino, bases his recommendation against construction of the power line on his interpretation of his and others' biological findings and rejects the theoretical biophysical approach as too simplistic. However, he takes a general experimental position and does not restrict his consideration to a specific set of electromagnetic parameters. He reasons that because biological effects are produced by electromagnetic fields, biological effects will probably be produced in humans exposed to the power line fields, and that these effects may be hazardous. Thus, he does not differentiate effects from hazards and holds that the proponents of the line must prove that the line's electromagnetic fields would be harmless. He recommends a safety standard of 0.15 kV/m, calculated by accepting that effects occur at 15 kV/m and above and by dividing this level by a safety factor of 100—the FDA factor for food additives rather than the less stringent ones for environmental contaminants.

Robert O. Becker, recommends against power line construction on the basis that literature reports, including his work, represent a solid body of data indicating that living organisms are influenced by extremely-low frequency (ELF; i.e., less than 100-Hz) fields. However, Becker bases his testimony about the medical consequences of exposure to electromagnetic fields almost entirely on Marino's interpretation of the literature, including the results of their joint experiments. Thus, his significance as an independent expert witness is questionable. He appears to believe that if effects could occur, the power line should not be constructed. This orientation does not distinguish between effect and hazard and fails to recognize the probabilistic nature of the effects.

"Doctor, are any of your opinions, assertions or conclusions contained in your testimony as to the physical occurrence of the biological effects which may occur as the result of exposure to the transmission line fields the result or consequences of any independent analysis by you of any of the studies identified as references 1 through 32, inclusive, of Dr. Marino's prefiled testimony?"

"The answer is no." – Becker

"As I pointed out, I think that if the Marino testimony falls, the Becker testimony falls right along with it." –Examiner

Major Considerations in the Experts' Testimony

Human Response. The major information on the effect on humans of exposure to ELF fields is contained in the reports of six groups of authors: Kouwenhoven et al. who reported no significant changes in power line workers subjected to extensive medical examinations; Krumpe and Tochman who conducted clinical evaluations of personnel working at a Project Sanguine test facility and reported no effects attributable to electromagnetic fields; Beischer et al. who studied human subjects exposed to 1 G* at 45 Hz using a battery of physiological and psychological tests and reported only a postexposure rise in serum triglycerides; Wever who reported that synchronization of circadian rhythm in humans depends on the presence of electromagnetic fields: and Hamer and Konig who reported that psychomotor reaction times in humans are inversely proportional to the frequency of electromagnetic fields of 1 to 12 Hz.

The witnesses who support construction, either specifically or by implication, accept these authors' negative findings; however, they do not regard positive findings as pertinent because the experimental characteristics differ from those for the proposed power line (Wever, Hamer and Konig) or because of inadequate matching of experimental and control subjects (Beischer et al.). Marino takes the opposite view: He criticizes negative conclusions either because the studies were inappropriate (e.g., linemen were not exposed 24 hours a day) or because even statistically nonsignificant effects should be of concern. He argues that studies reporting biological effects should be considered as indicating potential hazards from the power line even when the studies were done at other wave lengths or when potential artifacts that could affect the results have been identified.

*G = Gauss, which is the measure of magnetic field strength.

USSR and East European Reports. In addition to differences in Western and East European definitions of "hazard," the typical biases of Western scientists in interpreting information are likely to be accentuated by differences in experimental designs and in accepted standards of writing and publishing. By Western standards, the design of East European experiments is frequently inadequate, particularly with respect to selection of appropriate nonexposed controls. Moreover, the interpretations of Eastern European authors often appear biased toward central nervous system mediation, even when the reason for selecting this mechanism is obscure. Many East European reports, particularly epidemiological ones, are merely reviews of other reviews, and it is often difficult to discern whether new information is being presented or not. Exposure parameters are often lacking altogether or reported in nonspecific terms (e.g., "low frequency"). Finally, the East European preoccupation with the central nervous system is consistent with an acceptance of "nonthermal" effects. The heavy Soviet emphasis on nonthermal mediation of effects leads many Western scientists to interpret Soviet reports with skepticism–especially when Soviet experimental designs are frequently inadequate by Western standards.

"From this I would conclude that if there is any effect at all of ELF at 10 Hz, there are no implications with a 60 Hz [sic] or at least with regard to 50 Hz, necessarily."
–Schwan

Michaelson rejects the pertinence of East European reports because of the uncontrolled and/or unspecified variables resulting from their procedures. He notes that field strengths in experiments reporting biological effects range from 5 to 500 kV/m (average, 20 to 200 kV/m). Frey also judges some work to be of poor quality by Western standards; however, he describes several East European reports that indicate changes in auditory, visual, and olfactory sensitivity at microwave power densities of a few mW/cm^2.

Marino attaches great significance to the USSR standards and believes that they have been received skeptically in the United States. Because he believes that USSR standards are set on the basis of biological effects and because he is not aware of a compelling basis for the USSR standards in the Soviet literature, he infers that unpublished information may have been used by the Soviets. Because the ground level fields estimated for the proposed power line (below 10 kV/m) are less than the USSR standards (10 to 25 kV/m) discussed in the hearings, the reason for Marino's concern with the USSR standards as they relate to the power line is not clear.

"I therefore conclude that there is merit in the argument that there exists data and information within the Soviet Union which indicates [sic] that the presently proposed transmission lines might be a biological hazard."
–Marino

The proponents, especially Michaelson, believe that USSR standards represent objectives rather than enforced limits as in the West. He notes that fields as high as 27 kV/m occur in USSR substations and offers two quotations from USSR scientists to support this view of USSR standards:

"If a certain production is required then the [USSR] plant does not have to abide by that particular standard as long as it can get the work out. It is important to note that these (standards) are ideals, they are not operational standards as we have in the

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*kV/m = kilovolts per meter, which is the measure of electric field strength.

Why, in a Socialist country whose constitution explicitly says that public interest may not be ignored with impunity are industry executives permitted to break the laws protecting nature?
– N. Popov

United States. In the United States, our standards are operational and they are enforceable and they are enforced."
–Michaelson

What is it in our society with its consistent progress in all spheres of life that interferes with the rapid advance in such an extremely important field as the rational exploitation of nature? Soviet emphasis on the legal formalities has generated a form of self-deception. This appears to be an instance where some authorities have been lulled into believing that respect for Soviet authority is such that the mere passage of highly desirable laws is all that is necessary to induce compliance. The danger in such situations is that exaggerating the superiority of one system frequently leads to overreaching and overcommitments by setting unattainable goals . . . . – I. Gerasmivs

Animal Studies. Schwan and Carstensen concentrate almost exclusively on the biophysical approach; thus, neither makes much reference to specific experiments in mammals. When queried about specific experiments, they assume that artifacts may have been responsible for the results. Frey restricts his comments to neural/behavioral studies. Thus, only Michaelson, Miller, and Marino consider the findings of experiments with mammals principally in terms of their relevance to predicting human hazard. Although they refer to the same body of experimental information, their interpretations vary. Because Marino's recommendations stem entirely from his interpretation of experimental findings, he cites specific reports more than either Michaelson or Miller.

"Science proceeds equally by making measurements and observing the facts and then cataloging and describing them and ultimately deducing from the observations the laws that govern them."
–Marino

Marino cites experiments by McElhaney et al. that report that tumors were produced within 28 days in the legs of rats exposed to 7 kV/m fields at 3 and 30 Hz. Marino states that Russian experiments at 50 Hz 20 kV/m indicate an effect on cell division in liver and corneal epithelium. He states that Basset et al. found that at 1 Hz 0.2 kV/m and at 65 Hz 2 kV/m the rate of bone fracture healing in dogs increased. He notes that Bianchi et al. studied hematology and EKG phasing in mice exposed to 50 Hz 100 kV/m and found alterations, and that Lott and McCain reported increased hypothalmic activity but no increase in general brain activity in rats exposed to 40 kV/m 640 Hz. He reports that reduced lever pressing, avoidance of the electric field, and changes in locomotor activity in rats exposed to 50 Hz 50-70 kV/m were noted by Spittka et al. Marino also states that similar phenomena were observed by Altman in mice at much lower field strengths and cites a Soviet study in which mice were exposed to 500 kV/m at 50 Hz and died within several hours. The lethal effect was not related to artifacts such as ionization, corona, or spark discharge. He describes the work of Gavalas-Medici and her co-workers as indicating changes in interresponse times in trained monkeys exposed to 7-75 Hz 0.35-35 kV/m. He reports that hematologic and serologic changes occurred in guinea pigs (Altman and Soltau), and that body water content and hematologic changes were noted in mice (Long). Variations in these changes were related to electromagnetic fields, including experimental fields and natural fields, as compared to Faraday cage conditions (no electric field).

He notes that Moos reported increased activity in mice exposed to 60 Hz at 1 kV/m and that Knickerbocker found weight loss in the male progeny of animals exposed to 60 Hz 160 kV/m. Marino reported that in his experiments on rats exposed as juveniles to 60 Hz 15 kV/m body weight was depressed, serum corticoids depressed, and serum albumin elevated, with changes in the pituitary and adrenal weights. He does note that, except for water consumption changes, the results were inconsistent from one experiment to another. In a second set of studies involving mice exposed to horizontal or vertical fields of 60 Hz 10 kV/m for three generations he found increased infant mortality and depressed body weight, with greater effects in the animals exposed to the vertical field. Again, he notes that microampere short-circuit currents could have occurred during drinking or eating in the case of the vertical field exposed animals.

"I must say in true candor that Dr. Marino's references for the most part are either irrelevant, unsubstantiated, or have no basis for even scientific evaluation."
—Michaelson

Michaelson accepts as evidence of no appreciable biological effect the study by Knickerbocker et al. of mice exposed to 60 Hz at 160 kV/m for 1500 hours over 10.5 months, in which the only statistically significant finding was slightly reduced weight for male offspring. He notes that Gavalas-Medici et al., do not believe that studies of low frequency (< 60 Hz) exposure on electroencephalograms in monkeys indicate biological hazards from transmission lines, even though certain effects were noted, and points out that no effects were observed at 60 Hz. He describes monkey experiments (Grisset, de Lorge) in which no effects of alternating electric and magnetic fields on various characteristics, including blood chemistry, were observed, even though the magnetic field was 10 times that used by Beischer in human studies. He refers to a National Academy of Sciences site visit report about work by Noval, which Marino cited in support of his own findings, that states that Noval's procedures were so crude as to obviate any of his conclusions. Michaelson then points out that for corticosterone levels Noval reports an increase, whereas Marino reports a decrease.

Miller interprets Coate's study of lactation indices in rats as showing no effects at 45-75 Hz,10-20 kV/m and 1-2 G. The findings of Knickerbocker et al. that there were no effects on weight of mice, number of litters, first-generation progeny, sex ratio, pathology or growth curves of female offspring, with a suggestion of slightly reduced growth during the second generation, at 160 kV/m, indicate to Miller that power lines do not pose potential problems. Miller cites de Lorge et al. who reported no statistically significant behavioral changes in rhesus monkeys exposed to 75 Hz, 10 G, and 10 kV/m, and Grisset who found no effects in experiments in squirrel monkeys at 45 Hz, 3 or 10 G, and at 7 Hz, 3 G. Following redirect examination concerned with whether any experiments concerned with duplication or confirmation of any of the Marino experiments have been reported. Miller relates that he attempted to evaluate the Marino-type rat cages by making replicas and observing movies of rat behavior at various voltage fields. He found aversive behavior on the part of rats, and felt shocks when he placed his hand on the drinking spouts. He also notes that he received shocks when he placed his hand in Marino's cages. The implication is that electrical shocks might affect the results in certain of Marino's experiments.

Biostatistician Henry K. Hess appears only in the rebuttal phase to assess Marino's use of statistics, a matter previously raised in less detail by other witnesses. Of Marino's 10 rat experiments, Hess finds that errors in statistical design—multiple caging of controls in larger cages, single housing of experimentals in small cages, different cage tops, pooling of blood samples within groups—obviate statistical comparison of the effect of the electric field in 5 of the experiments. Errors in statistical procedures—trimming by deletion of extreme values, use of a statistical test that was inapplicable because the experiment failed to meet the criteria for valid use of the test—resulted in a reduction of comparisons among the remaining 5 experiments that Marino claimed to be statistically significant from 10 of 29 to only 4 of 29. Finally, he finds that Marino failed to account properly for pretreatment differences between control and experimental groups.

"It is my opinion that Dr. Marino's statistical analyses of the data gathered from these experiments cannot be used to support Dr. Marino's conclusion that biological changes were produced in the rats as a result of exposure to an electric field."
—Hess

However, no comparable rigorous analysis of the data from other reports, especially those claiming no effect of exposure to electromagnetic fields, was presented. Thus, Marino's complaint has validity that his information is being unfairly, or at least unequally, criticized.

"As I survey the record of this hearing, I find that possibly no other specific set of experiments in history have [sic] received the attention which the applicants have lavished on our work."
—Marino

Project Sanguine—Nonmammalian Studies. Project Sanguine (also called Project Seafarer), was a proposal to construct an extremely large underground antenna in the continental United States to serve as a communications device for the Navy. The proposal stimulated a series of investigations of the biological effects of ELF on a variety of species including the potential consequences to man and the environment. Most of the information available about ELF effects comes from the Project Sanguine studies.

Project Sanguine's information is interpreted differently according to the witnesses' views, especially with respect to the relationship between effect and hazard.

Marino cites the following authors and the effects that they reported as evidence that the nonmammalian species studied under Project Sanguine showed effects: Goodman, Marron, and Greenebaum reported that mitotic delay and retarded protoplasmic streaming occurred in exposed slime mold *(Physarum)* and that there was a frequency dependence for the latent period for retardation. Southern reported disruption of orientation in exposed gull chicks, and Graue reported alterations in the flight direction of homing pigeons. Durfee et al. found no effect on hatchability or growth rate of chicks but found inhibition or acceleration of growth in chick embryo cells exposed in vitro to electric fields. McCleave et al. reported that salmon and eels could perceive electric fields but that this perception did not imply an adverse effect. Because Marino equates effect with potential hazard, he regards these findings as pertinent to his recommendation that the lines should not be constructed.

"Subsequently, most of the [Sanguine] scientific experiments performed under contract have found biological effects due to either the electric field, or to both electric and magnetic fields in concert."
—Marino

"There are approximately 49 completed research projects, of which only 12 report effects from exposure to an electromagnetic environment. Of these 12 reports claiming effects, I believe only 5 contain valid conclusions. Thus, there is no basis for claiming that the majority of the S/S [Sanguine/Seafarer] projects have indicated effects." —Miller

Miller, because of his participation in Project Sanguine (growth, chromosome aberrations and cell kinetics of a plant root system), focuses on Sanguine information. For comparison, he assumes that a human standing on the ground under the power line would be exposed to an electromagnetic field of 10 kV/m and 1 G, and that the induced current in the torso would be 0.0001 A/m^2. He describes the proposed Sanguine alternating fields as 45-75 Hz, 0.0001 kV/m, 0.2 G, but points out that many of the Sanguine experiments were done at higher electromagnetic field intensities (e.g., 0.02 kV/m or greater than 2 G). He believes that the Sanguine studies are appropriate to the power line values, even though Sanguine electric fields are much lower. Finally, he believes that, given the broad scope of experimental designs and organisms tested, biological effects would have been detected had they been produced. He notes that no consistent effects were demonstrated and believes that the few effects produced (e.g., fish and bird perception) of electromagnetic fields are not hazardous.

Miller accepts Goodman's finding that the mitotic (cell division) cycle of a slime mold *(Physarum)* was delayed. However, he believes the delay does not suggest a potential hazard because the current density in Goodman's experiment was 350 times that which would occur in a man standing on the ground under the line and because no effect was observed at a current density 75 times that calculated for a man on the ground. He agrees that finding no effects at electric field intensities 500-1000 times less than the power line, as in some Sanguine experiments, does not preclude effects from higher intensity electric fields; however, he believes that Sanguine is relevant because of the high current densities. From his discussion with bird refuge personnel and his observations of geese and blackbirds feeding under and perched on power lines and towers, he concludes that birds do not avoid them. Miller summarizes his view of the Sanguine studies: Of the 49 experiments, only 5 provide acceptable data indicating effects (Goodman—*Physarum,* Friend—amoeba, Straub—marine animals, Coate—fish, and Riesen— organelles), all at current densities at least 100 times greater than those estimated for the human torso at ground level under the power line and at least 10,000 times greater than those estimated for the soil or water under the power line.

Michaelson concurs with Miller's interpretation of the Sanguine experiments. He accepts the work of Graue and of Southern as apparently indicating effects on bird orientation patterns but does not view the findings as conclusive or the level of effect as determined by the experimenters as indicating a hazard; he quotes Graue as saying the data are suggestive only.

Schwan regards the eel and salmon perception of ELF fields (Rommel and McCleave) as, at the most, indicating an effect but not a hazard because he does not believe eel or salmon behavior will be significantly affected, and cites a later study by McCleave in which no effects were noted. He finds the reports of bird orientation effects (Southern, Graue) lacking in controls (e.g., gray day vs. sunny day differences) and marred by statistical shortcomings. He cites the authors of the slime mold work (Goodman) as suggesting uncontrolled factors in the experiments when division delay was noted and indicates that the pertinence of the information to the human situation is remote.

After a survey of a variety of ELF studies Frey concludes that both those that indicate effects and those that indicate no effects have to be discounted mostly because of no or poor controls.

Biophysical Theory. Considerable time was devoted to biophysical theory in the testimony. Carstensen's testimony sets forth the theoretical method of hazard evaluation and the interaction of the theoretical with the biological approach. He assesses the potential biological effects of the proposed lines by estimating the internal (inside the body) electric and magnetic fields likely to be associated with the projected 10-kV/m and 1-G fields. He defines this as the biophysical approach, and notes that it is quantitative, permits broad general conclusions, and provides a sound basis on which to assess results derived from the biological approach. As the physical characteristics of interest in this approach he identifies dielectric and bioelectric properties of biological materials, perturbation of electromagnetic fields by exposed objects, and internal-external field relationships; and heating, intracellular effects, and membrane effects as the processes that mediate biological effects. He concludes that in terms of current theory the projected electric and magnetic fields are too low to elicit biological effects by any of the three processes. He concedes, however, that clearly established biological effects can take place without scientists' understanding why they occur.

> *". . . the biophysical approach has great strength in providing principles of understanding and planning. Its weakness lies in the debatable simplicity of its models, no matter how good the principal properties of the constituent part."*
> *–Michaelson*

In response to the following question formulation, "Is it theoretically impossible for an ELF electric field of 10 kV/m to cause . . . [bone tumors, altered mitotic rate (i.e., cell division), altered human reaction times, etc.]," Carstensen answers that these types of questions are inappropriate to the biophysical approach because scientists do not try to prove that things are impossible. Scientists try to find positive postulates to support or explain effects. He identifies the problem of resolving apparent contradictions between predictions from biophysical theory and observed biological effects, and explains the interaction of theory and experimental results. He notes that when positive experimental results conflict with theory, they are usually subjected to rigorous evaluation, but negative results that appear consistent with theory are usually tacitly accepted. He also points out that confirming results in other experiments, rather than duplicating experiments, is the usual way that experimental results become accepted for integration into theory. He indicates that models mathematically express the theoretical relationship between dosimetry and theoretical considerations. He contends that, based on theoretical grounds, biological effects noted in microwave studies have no value in estimating 60-Hz hazards. He also evaluates experimental data that other witnesses interpret as indicating that potential hazards to man will be associated with the power line. He concludes that those data either (1) involve field strengths that are an order of magnitude greater than that predicted at ground level for the power line, (2) are of questionable merit, or (3) report effects that appear innocuous.

Miller accepts the theoretical approach as useful when different experimenters use different exposure parameters (e.g., calculating internal current densities as a common parameter for comparison). For Michaelson, a biophysical principle when linked with experimental evidence provides a basis for elucidating a mechanism.

Although Marino rejects the theoretical approach completely for the biological approach, Frey grants theory a limited role. He notes that if information about effects is lacking, we should not try to bridge the gap with theoretical models and calculations. Frey indicates that, in fact, we do not understand nervous system functions well. Therefore, conclusions based on assumptions about information coding, transfer, storage, and the like are unacceptable to him. Frey points out the difficulties of using modeling to draw valid conclusions that support or deny the possibility or impossibility of an effect. He indicates that, depending on the assumptions on which the model is based, it is possible to come to any desired conclusion.

Conclusions

Data Gaps and Unresolved Questions. Review of the testimony reveals that scientists' knowledge of the potential hazards of low-frequency electromagnetic fields has a number of weaknesses and gaps, including:

- The experts (particularly those testifying at the hearings) disagree about whether biological effects result from low-frequency electromagnetic fields at low intensities and whether effects imply a potential hazard to humans.
- Experiments claimed to support the existence of effects are challenged, based on poor experimental design and inadequate statistical treatment of results.
- Experimental evidence for biological effects creating a hazard for man is, at best, dubious. Some of the results presented by Marino indicate that the fields may produce a stress response of the type described by Hans Selye. However, stress response is a difficult concept to define, and experimental studies on stress response require extraordinary care in experimental design and execution. Past experiments referred to in the hearings lack such care. Current and future experiments may be more revealing.
- The hearings offer little evidence that people are adversely affected at home or at work by electric fields at power line frequencies. This absence of evidence cannot be assumed to indicate that there are no adverse effects; however, it does imply that if effects occur, they are more subtle than common occupational diseases (e.g., silicosis) or diseases resulting from widespread environmental pollutants such as urban smog.
- With minor exceptions, the testimony revealed no systematic study of thresholds of intensity or duration of exposure required to produce alleged biological effects. In the absence of such studies, it is impossible to set meaningful permissible levels of exposure.

Research Credibility. The New York State Public Service Commission hearings strongly indicate that at issue is the credibility of interpretations of the results of biological research previously conducted and currently under way. However, the issues primarily arise from the adversary circumstances that prompted the hearing, and do not necessarily reflect adversely on the scientific studies that have been performed. Nevertheless, the scientific evidence presented before the Commission involved problems that are not widely recognized outside the scientific community.

First, by comparison with the multitude of chemical and physical environmental agents, both man-made and natural, the fields of UHV power transmission lines appear remarkably benign. Well-conceived, carefully planned, meticulously executed experiments are required to detect evidence of their effects (if any) in living organisms. If alterations are observed in the parameters of the biological system under study, the question of the cause-and-effect relationship between the imposed electromagnetic fields and the alterations must be carefully considered to ascertain whether or not some other uncontrolled variable of the experiment rather than the fields may have, in fact, caused the alteration. Unfortunately, as the hearings pointed out, most research conducted in this area can be criticized at all levels—from conception and execution through conclusions that failed to account for artifacts due to uncontrolled variables.

Second, the research literature is unevenly "weighted." Scientists do not like negative (perhaps more correctly "nonpositive") results. In the existing "publish-or perish" milieu of academic research, positive findings (e.g., an effect resulting from UHV field exposure) result in more publications, professional recognition, public visibility, and general acclaim than do negative ones. The research literature is therefore replete with "positive" results but is lacking in "negative" results. As a result, the lay reader is given the impression that effects occur, which even the simplest scientific experiment will display.

Finally, much of the evidence presented before the Commission came from scientific studies that were unrelated to determining human hazard. Those that were oriented toward human hazard came largely from the Project Sanguine investigation, whose primary concern was magnetic fields, and whose electric fields were small in comparison with those associated with power lines. Given the generally innocuous biological effects of the electric fields, the absence of systematic prior investigation of hazard, and competing viewpoints at the hearing, it is not surprising that the scientific knowledge available for consideration was not definitive.

DOE Research Activities

DOE, the Electric Power Research Institute, and others have research programs under way to examine biological effects, if any, of transmission line electromagnetic fields. DOE programs include:

- Basic biological studies
  - *Possible mutagenic effects of dc and 60-Hz fields.* Battelle Pacific Northwest Laboratories is studying *Drosophila* (the fruit fly) and microorganisms exposed to extremely high field strengths (much higher than those under transmission lines). If effects are found, Battelle will attempt to measure a relationship between field strength and effect, and to delineate the mechanism that relates observed effects to field strength.

- *Possible genetic changes or perturbations in cell replication rate or survival rate in mammalian cells exposed to 60-Hz electric fields in vitro (in a conducting medium).* Sandia Laboratories in Albuquerque and the Los Alamos Scientific Laboratory are undertaking these studies, and will also investigate effects on chromosome structure.
- *Possible effects of 60-Hz electromagnetic fields on the central nervous system.* The Jerry L. Pettis Memorial Veterans Hospital, Loma Linda, California, is attempting to determine the mechanisms underlying the interaction of electromagnetic fields with living tissue.

• Applied studies

- *Possible animal responses to 60-Hz electromagnetic fields.* Battelle Pacific Northwest Laboratories is examining the response of rats and mice to electromagnetic fields. A broad range of biological factors is being observed, including growth, reproduction, and development of offspring, as well as body weights, weights of endocrine organs, levels of various plasma components, cardiovascular function, and effects on the central nervous system.
- *Feasibility of using nonhuman primates to study the effects of 60-Hz electromagnetic fields.* Southwest Research Institute is establishing experimental protocols for determining the effects of high-intensity fields on biological factors and behavior. Once established, these protocols will be used in conducting a long-term study on primates and with the objective of relating those results to humans.
- *Possible effects of 60-Hz electromagnetic fields on circadian rhythms.* Argonne National Laboratory is measuring circadian regulatory mechanisms in mammals under controlled exposures to uniform fields.
- *Feasibility of using a battery of assay tests (which have been used to test central nervous system functions at microwave frequencies) to determine whether 60-Hz electric fields affect the central nervous system.* Randomline, Inc., of Philadelphia, is undertaking this work.
- *Perception of and aversion to 60-Hz electric fields.* The University of Rochester is determining thresholds for perception of, and aversion to, 60-Hz electric fields in rats.

• Ecosystem studies

- *Possible effects of 1200-kV transmission line operation on natural vegetation, crops, wildlife, cattle, and honey bees.* These studies started immediately after the Bonneville Power Administration test line at Lyons, Oregon, began operation.
- *Observation of bird nests on transmission lines.* Bonneville Power Administration is undertaking these observations to determine the number and types of birds nesting on EHV transmission lines. Nesting platforms have been constructed on towers to facilitate observation.

Note that these experiments cannot fully resolve the question of whether or not transmission lines are hazardous. Certainly, they will help elucidate the problem and possibly allay some concern about possible hazards. Current uncertainties associated with defining the biological effects of transmission line fields (as well as fields of different strengths and frequencies) make it difficult to formulate research programs aimed at hazard assessment. Furthermore, the results of research already under way may determine that the fields are not hazardous. Studies of threshold intensities, dependence of effect on intensity, and variability of response in humans will be valuable in attempting to assess hazard.

Recommendations

Although available evidence indicates that electric fields do not present a serious hazard to human health or well being, DOE should continue supporting its research programs aimed at allaying public concern about the possible hazard. This program should and as indicated above in many cases does:

- Include repetition of experiments showing "effects," with careful attention to experimental design, including exposure conditions and field characterization. This will ensure that experiments meet adequate statistical criteria and avoid results due to experimental artifacts.
- Include in the design of new experiments additional studies suggested by conclusions drawn from the earlier experiments (e.g., "stress").
- Include in the design of new experiments a systematic study of threshold intensities and the dependence of the magnitude of the effect on field strength.
- Consider in the experimental design, when proposed experiments involve human subjects, the variability of response among individuals, and the existence of the exceptionally sensitive or resistant individual.
- Prepare experimental designs that are useful for hazard determination as opposed to effect determination. Given the experimental uncertainties currently surrounding the effects research, it may be some time before such experiments are possible.
- Keep funding and review of the experiments independent to ensure credibility.
- Distribute research results widely to encourage broad comprehension of significant results.
- Review the advisability of setting edge of right-of-way standards that make the electromagnetic fields equivalent to those present at the edge of the right-of-way of current systems.*

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*This recommendation is also discussed in R. S. Banks et al., "Public Health and Safety Effects of High-Voltage Overhead Transmission Lines: An Analysis for the Minnesota Environmental Quality Board," Minnesota Department of Public Health (October 1977).

Careful repetition of controversial experiments would improve the credibility of the research data base. Such repetition, however, is likely to engender its own controversy, primarily becasue of the personalities of the many scientists involved. Scientists whose work is repeated may feel that their work has been "singled out."

Independent funding and review is clearly important in establishing the credibility of research results. DOE should therefore continue funding experiments, although review by an independent advisory body would enhance credibility.

Public interest in the environmental issues related to UHV transmission lines, particularly among groups actively involved in siting new facilities, warrants the broad distribution of new data and technical information. However, because this audience is primarily a lay one, the technical information arising from ongoing research must be readily understandable. Moreover, nontechnical reports should be easily available.

Bibliography

The most recent, all-encompassing review of literature on the biological effects of low-frequency electric and magnetic fields is:

- A. R. Sheppard and M. Eisenbud, *Biological Effects of Electric and Magnetic Fields of Extremely Low Frequency,* New York University Press (1977). This book lists and describes all of the papers referenced at the hearings and provides an excellent guide to the literature.

Another recent literature review is:

- J. E. Bridges, "Biological Effects of High Voltage Electric Fields: State-of-the-Art Review and Program Plan," prepared by the IIT Research Institute for the Electric Power Research Institute, EPRI Report No. 381-1 (November 1975).

Public safety aspects of transmission line operation are described in

- R. S. Banks et al., "Public Health and Safety Effects of High-Voltage Overhead Transmission Lines: An Analysis for the Minnesota Environmental Quality Board," Minnesota Department of Public Health (October 1977).

The electric and magnetic fields and devices to measure them are described in:

- D. W. Deno, "Electrostatic and Electromagnetic Effects of Ultrahigh-Voltage Transmission Lines," prepared by the General Electric Company for the Electric Power Research Institute, EPRI Report No. EL-802 (June 1978).

Potential biological effects of low-frequency electromagnetic fields are also reported and summarized in:

- National Academy of Sciences, "Biological Effects of Electric and Magnetic Fields Associated with Proposed Project Seafarer," Report of the Committee on Biosphere Effects of Extremely-Low-Frequency Radiation (1977). Available from the National Technical Information Service as Sigert Report ADA 042515.

Experiments on the potential biological effects of low-frequency electromagnetic fields will be reported in:

- *Proceedings of the 18th Annual Hanford Life Sciences Symposium on the Biological Effects of Extremely-Low-Frequency Electromagnetic Fields,* October 16-18, 1978, sponsored by the U.S. Department of Energy and Battelle, Pacific Northwest Laboratories. To be published.

III SPARKS AND CURRENTS FELT WHEN TOUCHING VEHICLES PARKED UNDER TRANSMISSION LINES

The electric fields around transmission lines can sometimes energize large ungrounded metal objects such as trucks and buses with voltages. The vehicle is capacitively coupled to the transmission line and stores a positive and then a negative charge in synchronization with the 60-Hz electric fields described in Section II. A person can discharge such a charged vehicle via an electrical spark by touching it—just as a person discharges himself by touching a doorknob after walking across a carpet. After the initial spark, the continuous 60-Hz field causes a 60-Hz steady-state current to flow through the person while he is in firm contact.

There were five implicit questions that were central to the hearings:

- What are the charges and voltages on conducting objects (primarily vehicles) under transmission lines?
- What spark energy or current is likely when a person first touches a charged object?
- What are the steady-state currents that continue to flow?
- How are people of different ages and sizes affected?
- What is the likelihood of injury from involuntary withdrawal after receiving a shock?

"There are two types of currents that flow into a person under these circumstances. One is a 60-Hz steady state current, and the other is a transient current . . ."

"The physical phenomenon is similar to that occurring when a person walks across a carpet on a dry day, and receives a spark discharge when he touches a doorknob. The difference is that under a transmission line the insulated vehicle is recharged by the electric field, and the sparks can be repetitive if the contact is not firm."

"Once the person has a good electrical contact with the vehicle, only a 60-Hz state current will flow into his body. When the contact is broken, spark discharges can occur again."
—Deno

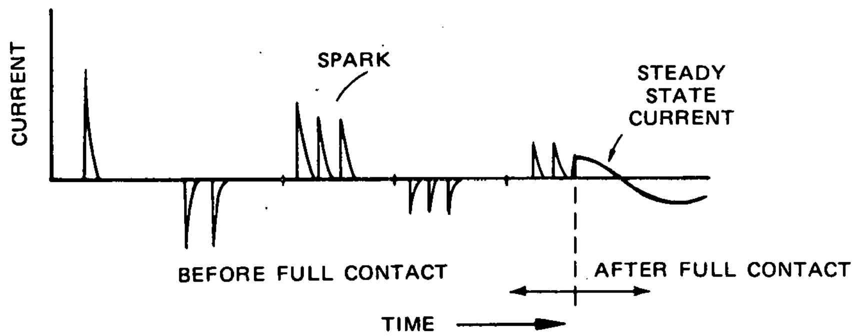
In several thousand pages of Testimony, D. W. Deno, Ph.D., of the General Electric Company, V. L. Chartier, B.S., of the Bonneville Power Administration, L. Cohen, B.S. E.E., of the Hydroelectric Commission of Quebec, D. A. Driscoll, Ph.D., of the Department of Environmental Conservation of the State of New York, S. O. Michaelson, D.V.M., of the School of Physicians and Surgeons of the University of Rochester, Rochester, NY, H. D. Schwan, Ph.D., of the University of Pennsylvania, and P. E. Stanley, Ph.D., of Purdue University address these questions.

Currents and Spark Discharges from Vehicles Under 765-kV Lines

The experts testifying on spark discharges from objects under lines focused primarily on the currents and voltages that could be anticipated from touching parked vehicles. The experts attempted to quantify those phenomena, and to establish values for the spark and steady-state current for different vehicle sizes under various conditions. Most of the data presented in the hearings were derived from experiments at the UHV test facility at Project UHV in Pittsfield, Massachusetts. Deno and Chartier discussed the data in some detail. Two distinct phenomena characterize the electrical discharge that occurs when a person touches a vehicle parked under the line:

- A spark or series of sparks is emitted when the person gets within a few millimeters of the vehicle.
- A steady-state or continuous current flows through the person after he has established firm contact with the vehicle.

Figure III.1 illustrates the two phenomena.



Source: EPRI, 1975

FIGURE III.1. CONCEPTUAL SKETCH OF THE CURRENT WAVEFORM FOR SPARK DISCHARGE THROUGH THE BODY OF A GROUNDED PERSON TOUCHING AN INSULATED OBJECT IN THE ELECTRIC FIELD OF A TRANSMISSION LINE (The peak current during the spark may be on the order of amperes for microseconds, whereas the peak current during full contact may be on the order of milliamperes.)

Each time the electric fields' direction changes, a vehicle sitting under a line is charged again by the fields. The magnitude of the electric field at the point where the vehicle is parked roughly determines the voltage a given vehicle will reach. Ground cover and the electrical resistivity of tires and road surfaces also determine the voltage. A well-grounded vehicle will not reach as high a voltage as a vehicle that is well-insulated

"Exhibit VLC-DD presents some of the data collected during my tests to determine the validity of the method used for the calculation of induced short-circuit current. You will note that I was the test subject. One would expect to experience a maximum of approximately 22% of the total calculated

from ground; for this reason, virtually all tires are manufactured to have relatively low electrical resistance.

Larger vehicles store more electric charge for a given voltage because they have higher capacitances. Hence a trailer, truck or bus is likely to furnish more current when parked under a line than a small car. Electrical grounding and road surface will affect the exact nature of the discharge current.

The hearings discussed two cases for the spark discharge and the steady-state currents:

- The theoretical worst case
- The likely actual case.

The theoretical worst case currents are determined by using mathematical models of the discharge process, based on electric field strength, vehicle capacitance, assumptions of maximum vehicle electrical isolation from the ground, and good electrical contact with the ground by the person touching the vehicle (e.g., as if he were holding onto a copper rod driven into the ground). Because many factors can reduce the current of the theoretical worst case, measured values for a number of different vehicles and situations were also presented.

short-circuit current under actual field conditions; generally, however, a person would expect to receive 4% or less of the calculated value. There are numerous factors which affect the current flowing through the person, including the person's weight, type of shoes worn, how dry the shoes are, the resistivity of the vehicle's tires, the weight of the vehicle, and the electrical continuity of the contact between the object and the person."
—Chartier

"Dr. Deno, have you taken any measurements on vehicles under actual field conditions in which the measured short-circuit current value was about equal to the worst-case value?"

"Yes. Recently at Project UHV, I measured short-circuit currents from a school bus parked on asphalt. Two people standing on wet earth received currents in excess of 90% of the measured worst-case currents."

"I might add that although the vehicle was on wet asphalt, it was still relatively well insulated because the level was 500 volts. The current level of the short-circuit situation was between 3-1/2 to 4 milliamperes."
—Deno

The witnesses did not fully characterize the reasons for the differences between the measured and theoretical values and disagreed about the mathematical model.

Figure III.2 shows the maximum steady-state current theoretically possible for the same vehicles. These values are calculated from mathematical models of the discharge process. Again, the largest vehicles have the largest steady-state currents. A vehicle's effective height above the earth also affects the current. Vehicles with the same capacitance that lie close to the ground will reach lower voltages, and hence currents, than vehicles that sit high off the ground or that have tall booms.

Figure III.3 shows the values measured for the same vehicles under experimental conditions. These currents are typically 10% of the theoretical values because the vehicles may be in good contact with the earth, but the person is in poor contact. However, Deno states that he has measured values that were about 90% of the theoretical maximum value when the vehicle was on pavement with poor electrical conductivity and the person touching the vehicle was off the pavement on wet or highly conductive earth. Many factors affect

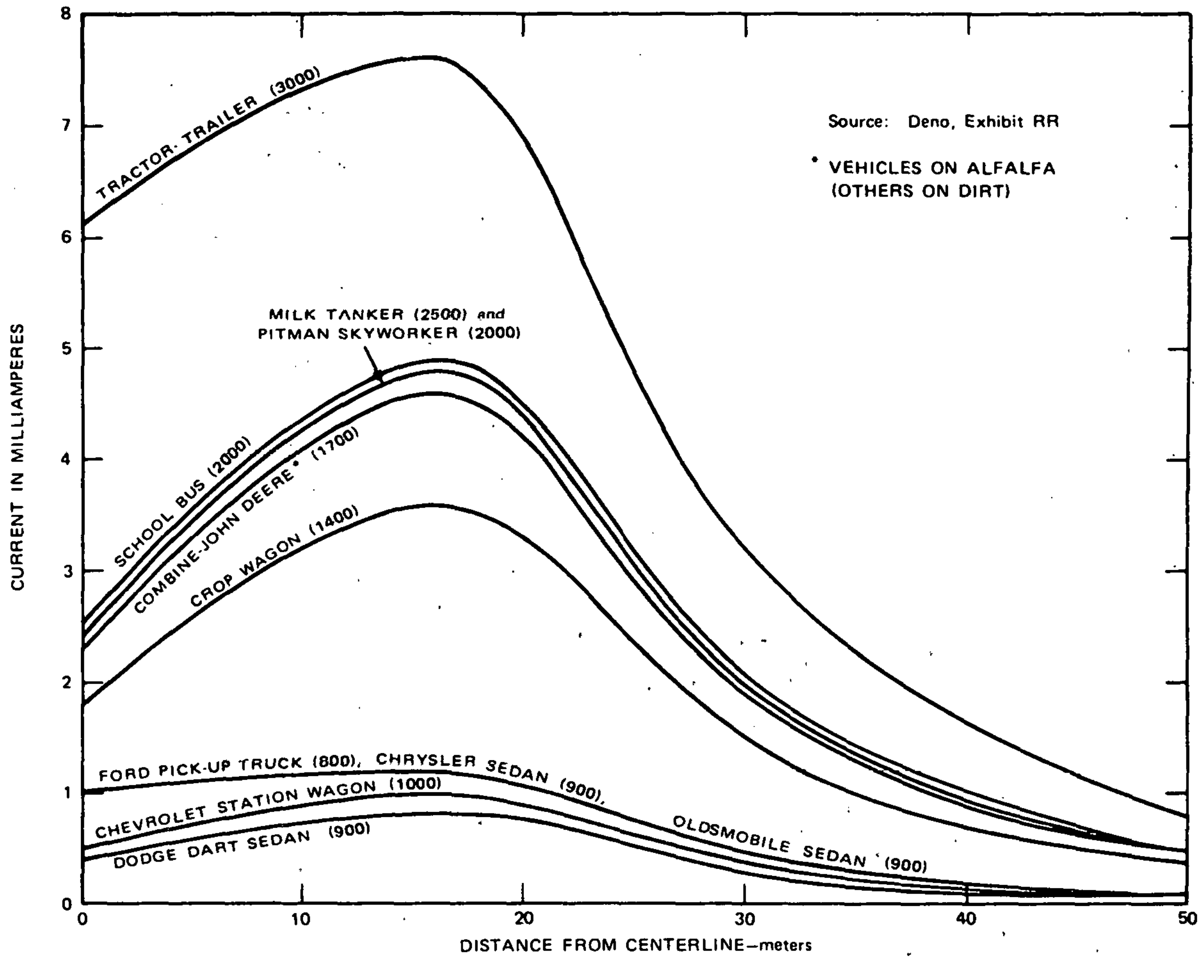
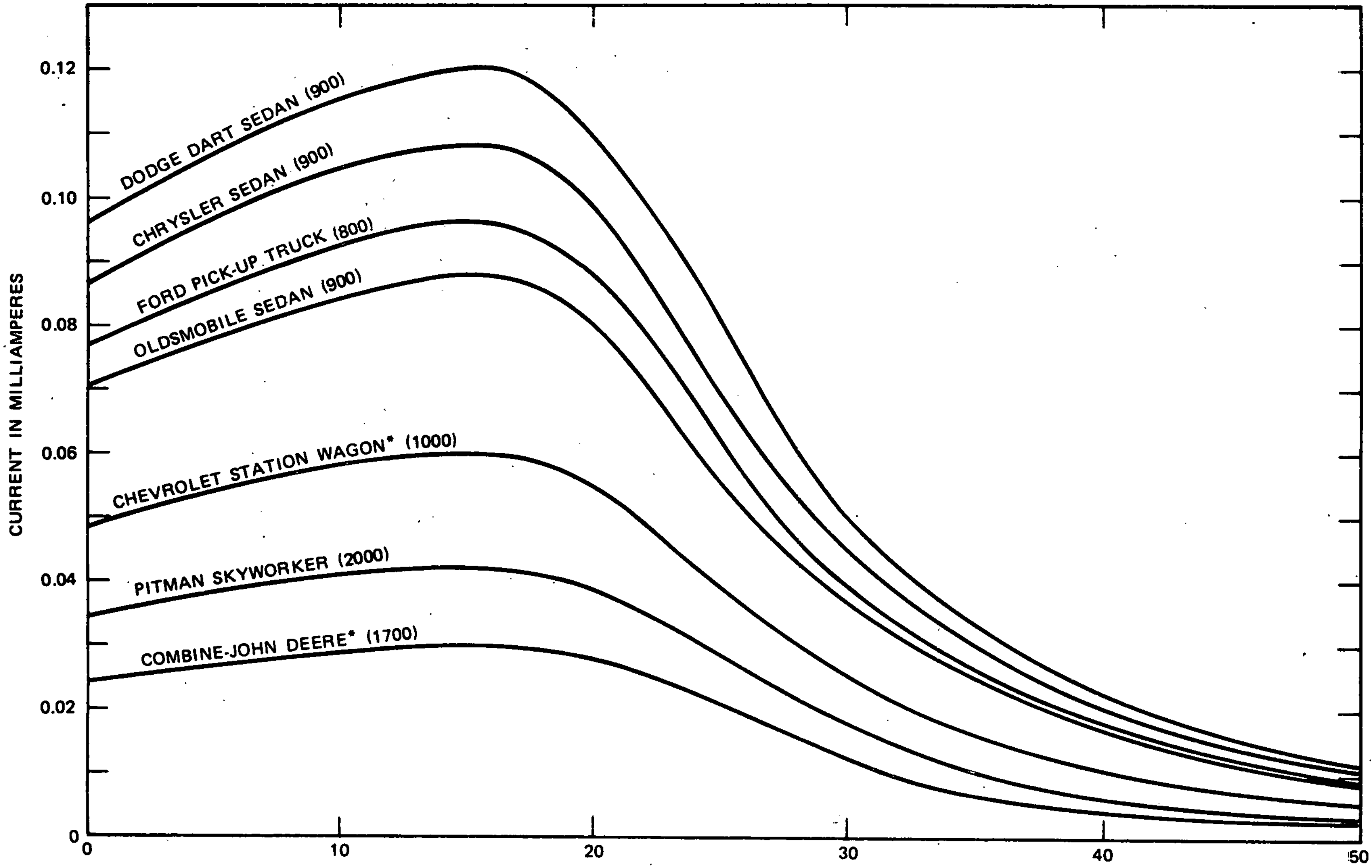


FIGURE III.2. THEORETICAL STEADY-STATE CURRENTS FOR A PERSON TOUCHING A VEHICLE UNDER "WORST-CASE" CONDITIONS

(These currents are calculated by assuming that the vehicle is positioned under the line at the point of minimum clearance of the line above ground, that the vehicle is well-insulated from the earth, and that the person is in good contact with the earth (touching a copper rod driven into the earth). The number in parentheses indicates the vehicle capacitance in picofarads. The calculations assume that the clearance between the line and ground is 12.8 m (42 ft).)



*Vehicles on alfalfa (others on dirt).

Source: Deno, Exhibit RR

FIGURE III.3. OBSERVED STEADY-STATE CURRENT FOR A PERSON TOUCHING A VEHICLE UNDER A 765-kV TRANSMISSION LINE (The data show actual experimental measurements. The number in parentheses indicates the vehicle capacitance in picofarads. The clearance between the line and ground is 12.8 m (42 ft).)

the measured values or the values likely to be experienced. A vehicle sitting on grass or cut alfalfa will effectively be close to the ground electrically and will therefore reach lower currents and voltages. A very heavy vehicle will make better electrical contact with the earth than a light vehicle. A person well-insulated from the ground by dry shoes or rubber boots will experience much smaller currents when touching a vehicle than a person whose shoes are wet.

Figure III.4 shows data for the maximum energy in the initial spark that is theoretically possible for a number of different vehicles under a 765-kV line with a 12.8-m (42 ft) ground clearance. Increasing the height of the line further reduces the spark energy because the fields at ground level are thus reduced. The largest vehicles show the highest spark energies because they have higher capacitances. Figure III.5 shows measured values for vehicles under experimental conditions. These values are typically 1% of the theoretical values for the same reasons discussed above for steady-state currents.

Effects of Steady-State Currents

The experts at the hearings discussed the full range of 60-Hz steady-state current effects:

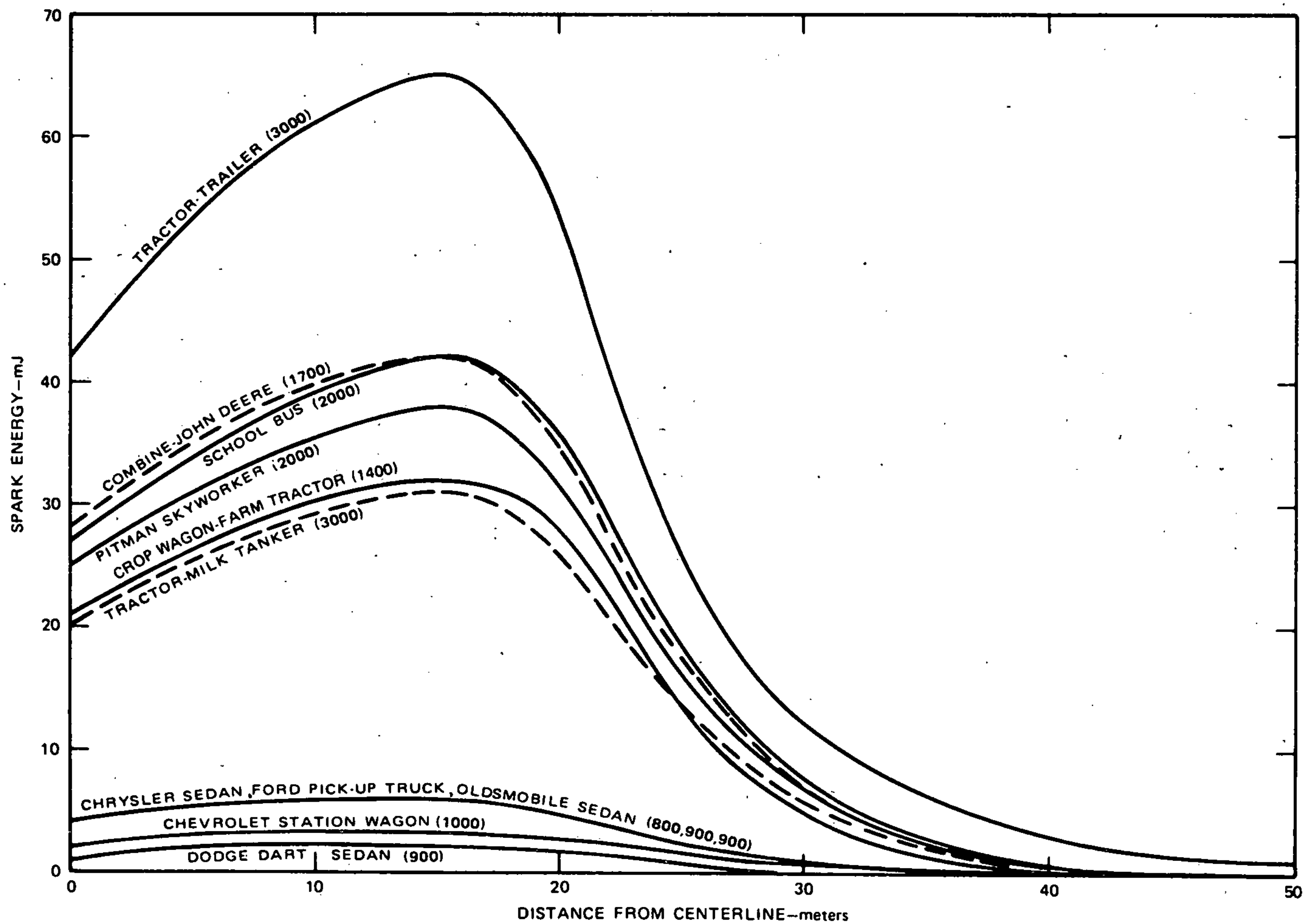
- Tingling sensation
- Startle reaction
- Involuntary muscle contraction without the ability to relax
- Respiratory paralysis
- Ventricular fibrillation
- Thermal burns.

Most of the effects likely to be experienced under UHV lines fall within the first two categories.

Most people cannot feel 60-Hz currents below 0.1 mA. As the current increases, a tingling sensation begins at the point of electrical contact (Barthold et al., 1972). This current level is defined as the threshold of perception. As with all other electrostatic shock effects, the threshold of perception differs slightly among individuals. Male adults appear to have a threshold of perception of steady-state currents that averages about 1 mA (Michaelson). The most sensitive people can perceive currents as low as 0.5 mA. According to Stanley, few people (less than 1%) can feel currents as small as 0.1 mA even if the point of contact is a particularly sensitive spot such as the underarm. More than 99% of the population can feel a current between 1.5 and 1.7 mA, although some cannot feel currents below 2 mA. Everyone perceives currents above 2 mA.

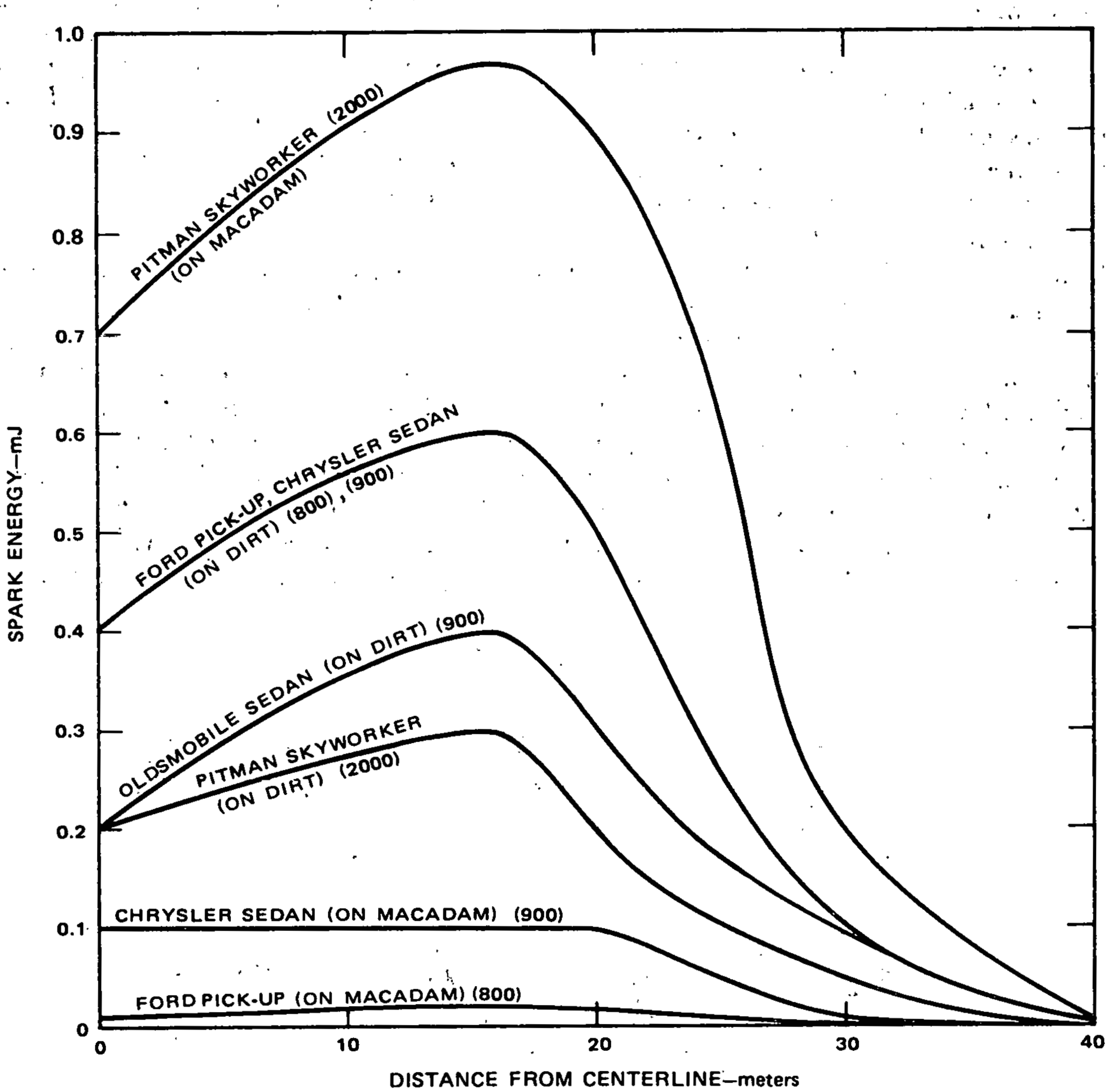
Most people will experience steady-state currents of 2 mA or more as painful or objectionable (Deno and Zaffanella, 1975). These sensations may cause a person to be startled enough to withdraw involuntarily from the current source—similar to withdrawing quickly after touching a hot object.

The range of current levels causing this reaction, termed the "startle reaction," is 1 to 5 mA. Although these currents are not in general considered to cause direct permanent damage, the involuntary reaction may constitute a potential secondary hazard. Experts



Source: Deno, Exhibit RR.

FIGURE III.4. THEORETICAL SPARK DISCHARGE ENERGY FOR A PERSON TOUCHING A VEHICLE UNDER WORST-CASE CONDITIONS UNDER A 765-kV TRANSMISSION LINE. (The calculations are shown for an assumed minimum line height of 12.8 m (42 ft). The number in parentheses indicates the vehicle capacitance in picofarads. To light a 1-W light bulb for 1 s, 1 J of energy is required.)



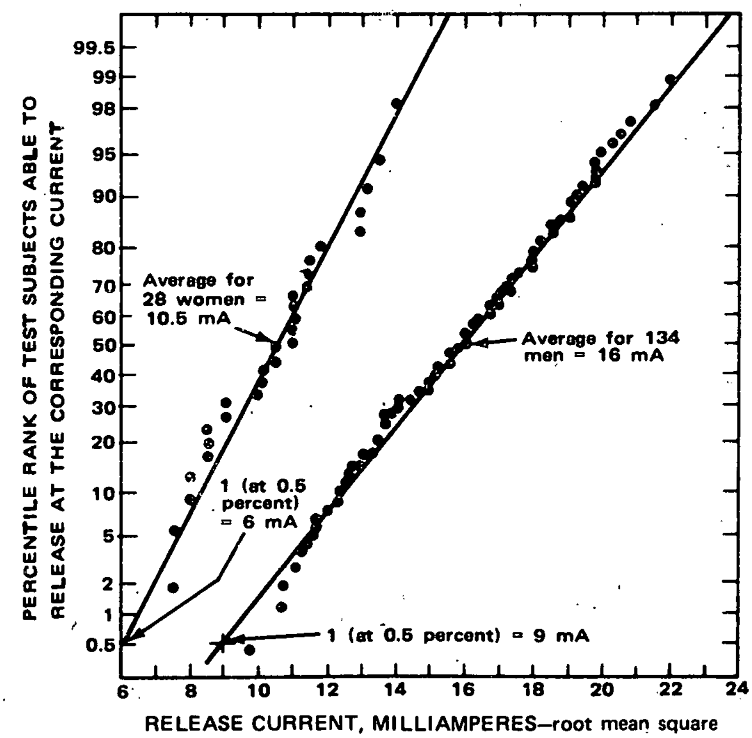
Source: Deno, Exhibit RR.

FIGURE III.5. OBSERVED SPARK DISCHARGE ENERGY FOR A PERSON TOUCHING A VEHICLE UNDER A 765-kV TRANSMISSION LINE
(The data show actual experimental measurements. The data are for a line height of 12.8 m (42 ft). The number in parentheses indicates the vehicle capacitance in picofarads.)

agree on the potential for secondary hazards; however, cases of such accidents have yet to be recorded.

"The involuntary sudden withdrawal of the hand from the point of contact with the current circuit and in fact with a larger reaction throughout the whole body may result in sufficiently violent movement to cause a fall from a ladder, or a hand to be thrust into moving machinery."
—Stanley

In small individuals, current levels around 5 mA will force contraction of the muscles through which the current is flowing. This contraction is severe enough that the person cannot escape the current source. The highest current level at which individuals can still voluntarily release their contact with the current source is called the "let-go threshold" or the "release current."* Release currents increase with forearm circumference and general strength (Keesey and Letcher, 1970). Dalziel's experiments with 134 men and 28 women are the classic source of data on release currents. (Indeed, few other original sources exist.) Dalziel's data, presented in Figure III.6, indicate that release current values for women are about two-thirds of those of the men studied. Dalziel et al. (1943) noted that the female subjects were more inclined than the male subjects to release themselves from high currents. Therefore, the values for women may be lower than their actual limits. The highest release currents Dalziel found were 22 mA for men and 14 mA for women, and the lowest were 9.5 mA for men and 7 mA for women.



Source: Dalziel and Lee, 1969

FIGURE III.6. DISTRIBUTION OF RELEASE CURRENTS FOR MEN AND WOMEN (The data for men and women primarily differ because of their different body size.)

*The standard terminology is "let-go threshold," but in the literature the distinction between the highest current from which the individual can release himself and the lowest current from which the person cannot release himself is not always clearly stated. For clarity, therefore, we will use the term "release current" in place of "let-go threshold."

Determining the threshold for children is difficult because, unlike adults, children respond by crying rather than by withdrawing from the painful stimuli (Dalziel, 1972). This makes it virtually impossible to determine the release current for children. [There are obvious ethical problems associated with experimenting on children.] Dalziel was able to determine a release current of 9 mA for an 11-year old boy and 7.6 mA for a 9-year old boy. He also reported that a 5-year old boy was unable to release at a current of 7 mA, but no release current was reported. Dalziel suggested establishing 4.5 mA as a safe current level for children by taking half of the minimum release current for adult males. He considered this to be a safe level for adults because 99.5% of adult men can release at that current.

Currents just above the release current are very painful, frightening, and exhausting (Keesey and Letcher, 1970). There seems to be very little evidence to determine how much higher than the release current are the levels for lethal, or potentially lethal, effects of respiratory paralysis, ventricular fibrillation (unsynchronized contractions of the heart muscle fibers), or burns, although it appears that the level of current that causes respiratory paralysis is less than the level causing ventricular fibrillation, which in turn is less than the level causing burns. The following quote is the best available indication that the lowest currents causing respiratory paralysis (produced by an uncontrollable contraction of the chest muscles that control breathing) may be at, or just above, the release current level for an individual:

> The muscular reactions caused by commercial-frequency [60-Hz] alternating currents in the upper ranges of let-go currents, typically 18 to 22 or more milliamperes, flowing across the chest stopped breathing during the period the current flowed, and in several instances caused temporary paralysis of the middle finger. However, normal respiration resumed upon interruption of the current, and no adverse after-effects were produced as a result of not breathing for short periods. – (Dalziel and Lee, 1969).

Because the release currents for the adults studied by Dalziel and Lee were not reported, no generalization can be made from their report about how much currents must exceed the release current to cause respiratory paralysis.

Stanley summarized effects of currents at the release current or a slightly higher current:

- Current at the release level flowing for a few seconds will cause soreness in the strained muscles for hours or days.
- Release current flowing for several minutes may cause burns at the point of contact with the conductor.
- Release current or slightly higher flowing through the chest muscles may cause respiratory arrest that can lead to death if the flow exceeds 3 to 5 minutes.
- Release current or slightly higher flowing through the head for at least 3 to 5 seconds may interfere with the respiratory control center in the brain. The resulting cessation in breathing will last for minutes or hours, during which time the individual will need artificial respiration to survive.

Hodgkin et al. (1973) describe a case of a man who received a 39-kV shock from both hands to both feet and who did not breathe when contact was broken. The man's life was maintained by artificial respiration until spontaneous respiration began several minutes later. The current was not recorded. This report demonstrates that respiratory arrest does not reverse immediately after current flow ceases; it also demonstrates that the current need not flow through the head to cause respiratory arrest.

Current levels above those causing respiratory paralysis can induce ventricular fibrillation that immediately makes the heart incapable of circulating blood through the body. Even if the current stops flowing, the heart will not resume normal beating by itself. Thus, unless promptly treated with electrical countershock, ventricular fibrillation can result in permanent brain damage within a very short period and in death within a few minutes.

Current levels causing ventricular fibrillation vary widely with different circumstances. Ventricular fibrillation occurs at lower levels if current flows from one arm to one leg than if it flows between the arms (Geddes, et al., 1973). Weight is also an important factor; the larger the person, the greater current that can be withstood before experiencing ventricular fibrillation. Ventricular fibrillation may possibly occur at currents around 50 mA and will definitely occur at currents of 100 mA and above. Very high currents, in the range of 1 A (1000 mA), produce sufficient heating to destroy tissue by thermal burns.

The safety of any current source must be judged against the safe levels for sensitive individuals exposed to it (e.g., children). Only limited data exist to aid in determining hazard levels for children. In 1940, a 4-year old boy was reported to have been killed by contacting, and being unable to release, an 8 mA current from an electric fence (Keesey and Letcher, 1970). Neither the mechanism of his death nor his release current were speculated on. A similar accident involving another child was reported (see quote from Stanley); however, the details of this accident were not described by the experts. Neither accident involved transmission lines.

". . . the serious hazard level for children must be considered as beginning at about 4.5 milliamperes since it is conceivable that the tetany [i.e., uncontrollable muscular contraction] may cause paralysis of the chest muscles and result in respiratory arrest."
–Stanley

"There are two cases on record of children having been killed by current levels of the order of 7 to 8 milliamperes [who were] being unable to release themselves."
–Stanley

Effects of Transient Currents

Transient currents are sparks that occur when a person touches a charged object; for this discussion the charging is caused by transmission line fields. The effects of sparks in general are:

- Threshold of perception
- Startle reaction
- Pain caused by microscopic burns.

These effects appear to be determined primarily by the energy in the spark.

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.

"While the effects of transient (or impulse) currents have been studied . . . since 1972, there is no agreement among experimenters as to the correct parameters to describe the threshold and painfulness of transient electric current flow through any part of the human body."
–Stanley

Most people have experienced transient currents from carpet shocks; a person walking across a rug on a dry day will accumulate a static charge.

> This can build up to surprisingly large values, sufficient to cause potential differences on the order of 10,000 volts between the body and nearby grounded objects. The static field intensity near the body surface will range between 10 and 15 kV/m. Near the finger tips just before arc-over, this field intensity obviously must surpass 2500 kV/m–the voltage [electric field] breakdown of air. The peak current flowing during arc-over may rise to a few tens of amperes. The energy content can be in excess of 10^{-3} J. – (Bridges and Formanek, 1976)

Deno and Schwan agree that the threshold of perception of transient current is about 0.1 mJ. As with steady-state currents, variability in the threshold of perception results from differences in the area of contact, size of the individual, and experience with shock currents. For transient currents, the capacitance of the object generating the spark and the number and duration of sparks also affect the sensation.

The energy levels at which transient currents become painful* are not totally agreed on. Project UHV staff reported objectionable experiences with transient currents from voltages of between 700 and 1200 V, a capacitance of the object of 100 pF, and, therefore, an energy in the discharge of between 0.5 and 1.5 mJ (Deno and Zaffanella, 1975). Dalziel reports a very different value of 250 mJ to be the threshold of "unpleasant" transient current received from a single discharge from a capacitor (Deno and Zaffanella, 1975). Deno and Zaffanella stated that this difference is not due to an extreme difference in subjective reaction, but that it is probably due to the "particular nature" of the transient current received under transmission lines (i.e., that they are repetitive and they involve a discharge through air, which has low electrical resistance during a spark).

"The combination of the repetitive nature of the spark generated transients and the nearly microscopic burns resulting from the high current densities cause the transient current to be an important problem."
–Stanley

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*Experience with transient currents above perception levels has been called "painful," "objectionable," and "unpleasant" by witnesses without further attempt to define these experiences. Therefore, it is not easy to determine the comparability of these experiences and the threshold levels associated with them.

Some investigators state that transient currents cause microscopic burns at the point of contact. This theory is based on the fact that some transient currents are experienced as painful, even though their duration is shorter than the 20 μs required to excite a nerve. Microscopic burns, however, would provide a long enough nerve stimulation to indicate pain.

Stanley states that transient currents at painful energy levels (250 mJ to 25 J) do not induce violent muscular contractions (as do steady-state currents), but they can also cause an involuntary reaction due to pain. It seems logical to assume, although not stated explicitly by the witnesses, that transient currents at levels inducing pain may also present the secondary hazard of involuntary motion leading to injury.

According to Schwan, transient currents can be fatal in the range of 25 to 50 J. At these energy levels, transient currents are believed to cause ventricular fibrillation (Bridges and Formanek, 1976).

Experts in the field of transient currents disagree on whether peak current or energy best determine human effects. The testimony emphasizes effects based on energy.

". . . a very considerable question exists between Dr. Deno, myself and some colleagues as to the exact nature of this spark discharge . . ."
—Stanley

". . . the proper way to evaluate an electrical shock, particularly a transient shock, is not understood."
—Stanley

"No satisfactory studies of peak currents in the ampere range with time constants below 10 microseconds, such as from 765-kV line, have been made."
—Stanley

Effects of Shock Currents Received Under 765-kV Lines

Magnitudes of steady-state and transient currents that might be received under the proposed 765-kV lines were predicted by Deno in Exhibit RR and are shown here in Figures III.2-III.5. Table III.1 summarizes those magnitudes, as well as current magnitudes producing the effects in humans.

Deno's maximum theoretical (worst-case) values for steady-state current range from perceptible to release currents for small adults and children. Worst-case values for transient currents range from below perceptible levels to generally painful levels. The only case in which the lines could cause direct and serious physiological harm (e.g., respiratory paralysis or ventricular fibrillation) is with small children. A small child touching a large vehicle (sitting at the point of maximum field under a 765-kV line at a ground clearance of 13 to 15 m) may under worst-case circumstances receive a current very close to the 8-mA current that

"Are there detrimental effects on nerve or other body tissues from exposure to these induced currents, both steady state and transient?"

"Very little data exists [sic] on which to base conclusions. At the levels measured and predicted by Dr. Deno even under 'worst conditions' there will be no detrimental effects on nerve or other body tissues. The only exception would be in the case of a child or small adult for whom the worst-case steady-state current level of 5.8 mA calculated from a tractor-trailer was above the let-go level for that person. Should such a current flow through the subject for several minutes, burns could occur."
—Stanley

Table III.1

COMPARISON OF SHOCK CURRENTS FROM 765-kV TRANSMISSION LINES 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 (theoretical):*		0.5-2.0 mA	Threshold of perception
	Lowest value	0.1 mA	1 mA	Threshold for startle reaction
	Highest value	7.5 mA**	2 mA	Objectionable (EPRI, 1975)
	Probable case:			Release currents:
	Lowest value	0.003 mA	5 mA	Suspected for small child
	Highest value	0.12 mA	10.5 mA	For average adult female
			16 mA	For average adult male
	Highest measured value:‡		18-22 mA	Respiratory paralysis
	Bus parked on asphalt	3.5-4 mA	50-100 mA	Ventricular fibrillation
			1,000 mA	Threshold for burns
Transient	Calculated worst case:§		0.1 mJ	Threshold of perception
	Lowest value	0.02 mJ	0.5-1.5 mJ	Threshold of annoyance
	Highest value	65 mJ	250-25,000 mJ	Involuntary reaction due to pain
	Probable case:§			
	Lowest value	0.0003 mJ	25,000-50,000 mJ	Ventricular fibrillation
	Highest value	1.0 mJ		

*Source: Dr. D. W. Deno, Exhibit RR.

†Source: Testimony by witnesses in the NYPSC hearings.

‡Source: Testimony by D. W. Deno

**For an exceptionally low clearance of 12.8 m (42 ft).

§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.

killed a 4-year old boy in 1940. Lack of data about how closely lethal currents lie above release currents, especially for children, makes it critical to understand the likelihood of receiving the maximum currents (7.6 mA and less) that Deno calculated for "worst-case" conditions.

The most likely hazard from currents in the range of Deno's "worst case" is that of being startled and falling off a ladder or thrusting an arm into moving machinery. Although almost every expert noted this possibility, no one was able to cite reported cases of such an accident under transmission lines. However, the future trend toward higher voltages may make secondary hazards due to involuntary reactions of greater public interest.

Deno's probable currents in Table III.1 indicate that steady-state currents will not be perceptible. Transient currents, on the other hand, may be annoying to some. The energy level is so low, however, that the startle reaction should not be severe.

"The worst case conditions reported by Dr. Deno in Table 3 of Exhibit RR . . . could undoubtedly cause rather serious pain-induced involuntary reaction for persons touching all vehicles, except possibly the smaller ones 50 meters [or more] from the center of the transmission line.

"In Table 4, 'probable' conditions . . . indicate some voltages and peak currents large enough to cause pain. However, most situations are not likely to create any hazards.

"There is no evidence that currents of such levels [to cause ventricular fibrillation or burns] will be induced by a 765-kV transmission line with 50-ft clearance."
–Stanley

"Based on the foregoing, I must repeat that spark discharge resulting from the lines proposed by the applicants may, on occasion, be unpleasant, but is not dangerous to life."
–Schwan

"If there is no possibility that a current of more than 1 mA would flow through the human being, I would say that is a reasonably safe line."
–Stanley

Major Data Gaps and Unresolved Questions

The hearings disclosed a number of data gaps and unresolved questions:

- Does the current in a spark discharge or the energy in the discharge determine physiological effects?
- Do the effects arise primarily from individual sparks or from the cumulative effects of multiple sparks?
- Does the energy per spark or the total energy for all sparks determine the physical effects?
- What is the best mathematical description with which to model the physics of the discharges?
- Are there errors in the labeling of data? The data are not always clearly labeled with respect to peak value and root mean square value. Hence, possible discrepancies by factors of $\sqrt{2}$ in the data could not be addressed by the SRI team.

- What is the relationship between human reactions and animal reactions to spark discharges and steady-state currents? This relationship must be determined in order to apply data from animal studies to humans.
- How can data on currents hazardous to adults be extrapolated to currents hazardous to children? Virtually no data are available on the electrical currents threshold levels of children. Clearly, numerous difficulties would occur in attempting to collect data.

Data and calculations presented by witnesses indicate that electrostatic shocks are likely to occur when humans touch large vehicles parked under UHV transmission lines. However, a complete statistical description of such occurrences is virtually impossible. A significant unknown brought out by witnesses is the question of whether or not the steady-state currents encountered under maximum current conditions could approach the value 5 mA, or perhaps less, at which small children could not release themselves from the vehicle. A second major unknown for children is how much above the release current is the current resulting in respiratory arrest or ventricular fibrillation.

Conclusions

People will sometimes experience uncomfortable sparks and currents if they touch a vehicle parked within about 50 m of the center of the right-of-way of a 765-kV transmission line. Under conditions of maximum current—when a well grounded person touches a large vehicle that is on dry pavement directly under the point of minimum ground clearance of the lines—the steady state current could approach 5 mA. People would find this current level startling and adults would probably withdraw involuntarily from the vehicle. Based upon extrapolated data, a very small child might be unable to voluntarily release hold of a vehicle if the current is 5 mA or greater.

Recommendations

- Resolve the data gaps with respect to shock thresholds of children by appropriate modeling or animal studies.
- Develop siting and routing procedures that account for electrical shocks from vehicles parked under lines.

The thresholds for children need to be determined. Further research could help determine whether respiratory paralysis can occur in children under worst-case, steady-state currents under the proposed transmission lines. It is clear that strong enough currents passed through the chest wall can cause respiratory paralysis. It is not clear, however, whether currents just above the release current or substantially stronger ones cause respiratory paralysis.

Experimenting on adult volunteers may be infeasible because of issues raised by research on humans and because of risks to volunteers. Stanley states that once the current is interrupted paralysis ceases and normal respiration resumes. Therefore, the current must promptly be turned off once the establishment of respiratory arrest is recognized. However, Hodgkin et al. show that artifical respiration may be needed until respiration spontaneously begins.

If the results of this research establish that respiratory paralysis can be induced by currents at, or only slightly above, the let-go threshold level passing through the chest wall, then research to establish a release current for children becomes important. If currents causing respiratory paralysis are substantially above the release current, this research is less urgent because the currents that cause respiratory paralysis in children presumably would not occur, even under worst-case conditions, with low 15-m (50-ft) clearance for a 765-kV line.

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*In this paper Dalziel uses the term "release current" to refer to the level of dc current that is so unpleasant that subjects involuntarily release the current source. That level is different from the level at which people can no longer voluntarily release the current source because of tetany.

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IV POTENTIAL EFFECTS OF TRANSMISSION LINE ELECTROMAGNETIC FIELDS ON CARDIAC PACEMAKERS

Approximately 100,000 to 300,000 people in the United States require electronic pacemakers to maintain healthy heart rhythms. Pacemakers electronically generate a signal strong enough to trigger the contraction of the entire heart muscle. Several types of pacemaker trigger the heart in response to the heart's natural electrical signals that are too weak. These pacemakers may sometimes respond (although not always adversely) to other electromagnetic signals such as those near radar installations or powerful radio and television transmitters. Occasionally, microwave ovens also affect pacemaker operation. In laboratory tests certain intensities of 60-Hz electric and/or magnetic fields have affected some types of pacemakers.

Given this type of background, the hearings focus on this central question:

> Can the electromagnetic environment under a 765-kV transmission line alter the performance of cardiac pacemakers and, if so, can any of the modes of altered performance affect the health of someone wearing the pacemaker?

In several hundred pages of direct testimony and cross examination, James C. Toler, M.S., of the Georgia Institute of Technology, Solomon Michaelson, Ph.D., of the University of Rochester, and Joseph T. Doyle, M.D., of the Albany Medical College of Union University, address this concern with testimony that centers on identifying:

- Types of pacemakers and the number of each type in use
- Evolution of pacemaker technology
- Normal pacemaker operation
- Research studies on pacemaker operation in the presence of 60-Hz electric and/or magnetic fields
- Likelihood of altered operation in the presence of transmission line electromagnetic fields
- Health implications of altered pacemaker operation*

Normal Heart Operation

The heart muscles contract because of electrical stimuli; an organized sequence of contractions of the muscle fibers constitutes a single heart beat. Although many muscles contract in response to electrical signals from the brain, the heart operates involuntarily. It spontaneously contracts, relaxes, and contracts every second or so with its own rhythm and without need of conscious control. Each bit of heart muscle fiber is independently capable of this repeated regular contraction. However, in a healthy heart, two regions of

*The hearings provided only four pages of prepared testimony by Dr. Doyle on the health implications of altered pacemaker operation.

heart tissue serve to trigger other heart tissue to create the smooth sequence of contractions necessary for the heart to pump effectively.

The first region is a small area, called the sinoatrial node, near where the major veins enter the top of the heart. It has a slightly faster natural sequence of contracting and relaxing than does either the rest of the heart muscle or the second triggering region, the atrioventricular node. Thus, its activity initiates activity in all other parts of the heart. The firing of the sinoatrial node first triggers the contraction of the atrial or upper chambers of the heart. The two nodes are shown in Figure IV.1.

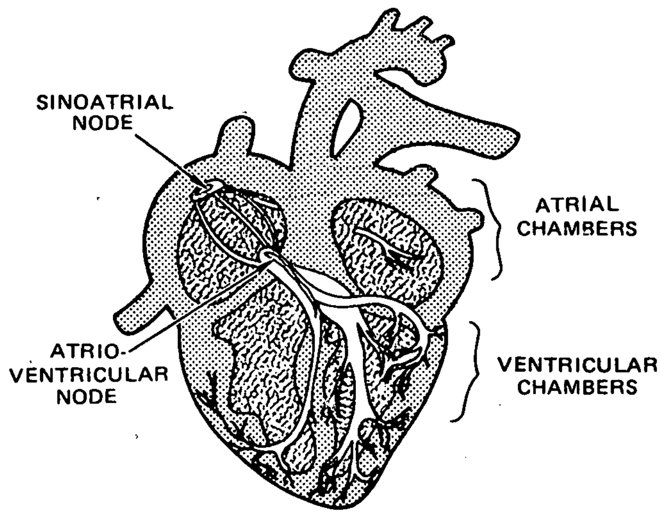


FIGURE IV.1. CUT-AWAY SKETCH OF THE HEART

Following atrial contraction, the atrioventricular node (located between the atrial and ventricular chambers) initiates an electrochemical reaction that progresses along conductive fibers throughout the ventricle section. Those chambers then contract, pumping blood to the body and to the lungs. The reaction's propagation rate throughout the heart is determined by the speed of the chemical reactions in the heart's conductive fibers—a speed far slower than that for signals in typical electrical circuits. The chemical reactions produce electrical signals that can be detected externally by an electrocardiograph or internally by a pacemaker's electronic circuitry. In a defective heart, these chemical reactions and the resulting fiber contractions can also be stimulated by a pacemaker's electrical signal.

An electrocardiograph monitors the electrical activity of the heart by measuring the voltage between an electrode placed on the chest and a common "ground" formed by electrodes connected to both arms and the left leg. Figure IV.2 presents a schematic representation of an electrocardiogram. Because various heart activities produce characteristic waveforms on the electrocardiogram, doctors use it to diagnose heart disease. The voltage maxima and minima on the electrocardiogram are identified by the letters P through U. The P-wave on Figure IV.2 corresponds to the firing of the sinoatrial node; the QRS complex or R-wave indicates the electrical action of the atrioventricular node's beginning the main pumping thrust of the heart. The T and U portions represent electrical activity preparatory to repeating the entire process.

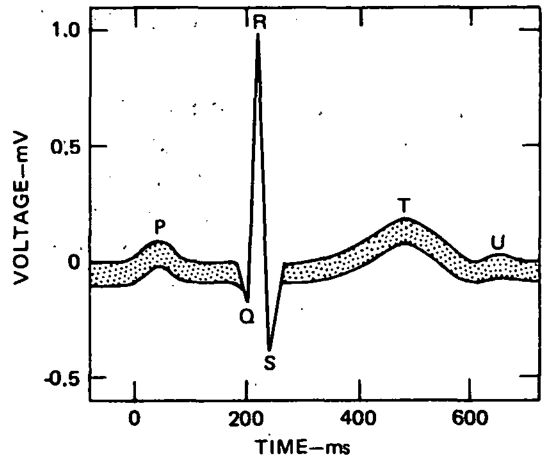


FIGURE IV.2. A TYPICAL ELECTROCARDIOGRAM

Pacemaker Types

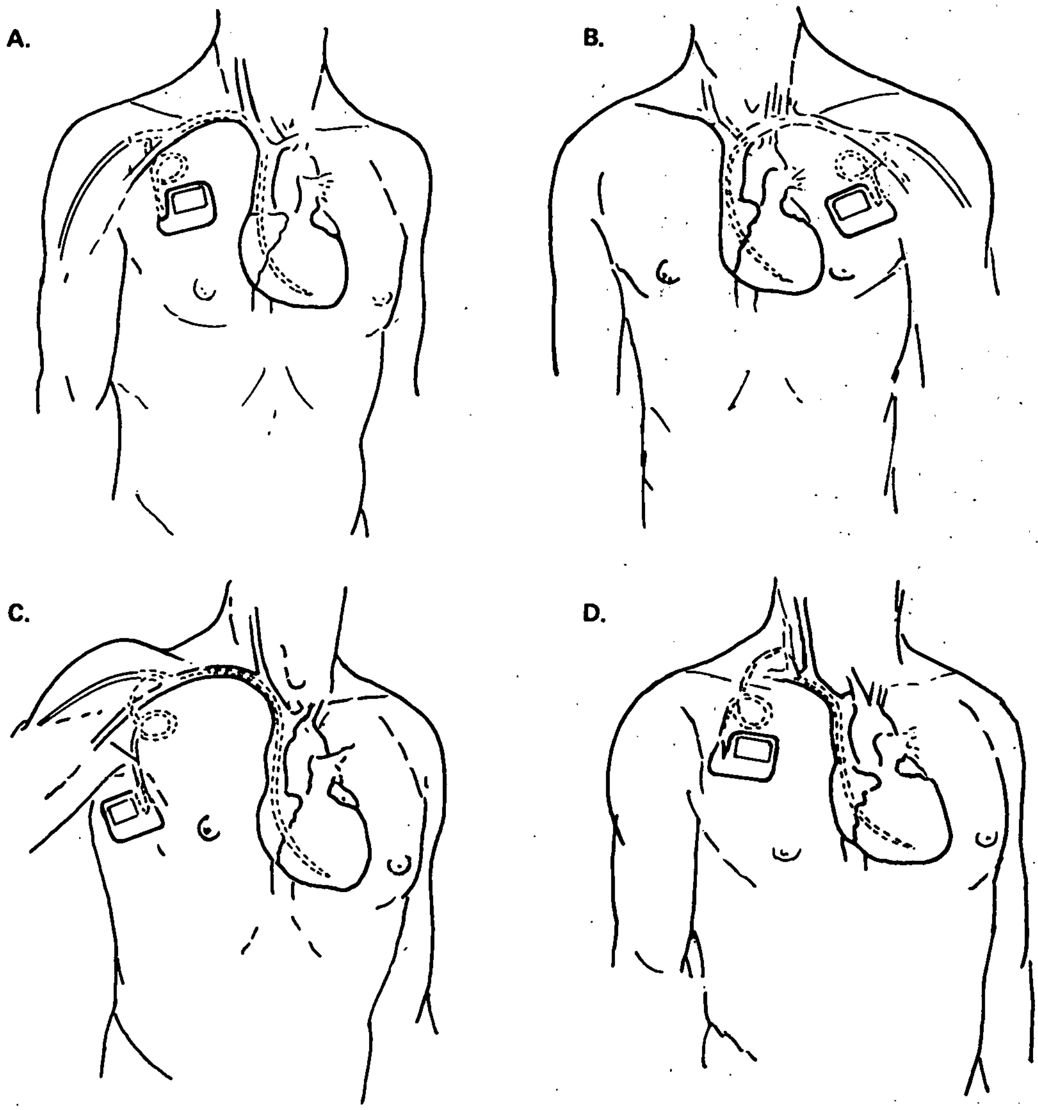
The pacemaker's electronic package is embedded under the skin; its size and typical locations (and its electric leads or catheter, which are discussed later in this section) are shown in Figure IV.3. The terminology for pacemakers relates to the electrical waveform on the electrocardiogram of the normal heartbeat. The four types of pacemakers are

- Asynchronous or fixed-rate
- P-wave synchronous
- R-wave synchronous
- R-wave inhibited.

The *asynchronous or fixed-rate pacemaker* stimulates the heart at a fixed rate, usually about 70 beats per minute. It is used for patients whose natural heart signals are weak or ineffective. This was the first pacemaker design, and Toler estimates that about 10% of the pacemakers being installed in 1976 were of this type.

The *P-wave synchronous pacemaker* (also called the atrial-synchronous pacemaker) has two electrical leads (catheters): One senses atrial electrical activity that normally initiates heartbeat; the other supplies an impulse to the ventricle, after a delay of approximately 120 milliseconds (ms) if the atrioventricular node fails to provide the R-wave, shown in Figure IV.2. If this pacemaker fails to sense electrical activity from the sinoatrial node, it changes to a fixed rate of operation (i.e., it reverts to an asynchronous rate). Toler estimates about 5% of the pacemakers implanted today are of this type, but Michaelson believes that the number is less then 1%.

The *R-wave snychronous pacemaker* (also called the ventricular-synchronous pacemaker) is used when the normally conductive fibers that lead from the atrioventricular node into the ventricles are defective. It senses the R-wave and immediately stimulates the ventricles. In the absence of an R-wave, this pacemaker also changes to a fixed rate of operation. Toler estimates that about 5% of the pacemakers are of this type.



Source: Toler, Exhibit OOO

FIGURE IV.3. TYPICAL IMPLANT SITES FOR A PACEMAKER AND CATHETER (Sketches A and B show the catheter placed through the cephalic vein and the pacemaker placed over the pectoralis major muscle. Sketch C shows the catheter placed through the cephalic vein and the pacemaker placed in the axillary [armpit]. Sketch D shows the catheter placed through the right external jugular vein and the pacemaker overlying the pectoralis major muscle.)

The *R-wave inhibited pacemaker* senses the relatively high-amplitude voltage of the R-wave (see Figure IV.2). After an R-wave occurs, the pacemaker is dormant for about 240 ms. It then becomes alert to sense the next R-wave. If that next R-wave does not occur within about 860 ms after the preceding one (the period of a 70 beat-per-minute rate), this pacemaker supplies the R-wave stimulus to the ventricle and becomes dormant again. An R-wave occurring within the pacemaker's alert period inhibits the pacemaker by keeping it from stimulating the heart. The pacemaker (pacer) then begins its dormant-alert sequence again, supplying a pulse only when the heart demands it. Toler says that about 80% of pacemakers today are of the R-wave inhibited type.

Toler applies the term "demand pacemaker" only to the R-wave inhibited pacemaker; Michaelson, however, indicates that term is also used for P-wave synchronous and R-wave synchronous pacemakers, and that it applies "to any pacer whose action is determined by the activity of the heart" or to any synchronous pacemaker. To further confuse matters, the R-wave inhibited pacemaker is sometimes also called a standby pacer. An IITRI research report (Zalewski, 1975) referred to extensively in the hearings states that both the R-wave synchronous and the R-wave inhibited pacemakers may be called demand or standby pacemakers.*

"I am beginning to wonder . . . whether the witness and counsel are talking about the same thing all the time. I do not know whether it is a semantic problem or understanding about the pacemakers, or what."
–Examiner

"Actually, there are no universally accepted definitions for these various pacemakers, although attempts are now being made to standardize this, so over the years the terms have varied."
–Michaelson

The History of Pacemaker Development

Artificial cardiac pacemakers have been implanted in heart patients since 1959, and many are now in use. Michaelson said there were about 90,000 individuals who were wearing pacemakers in the United States in 1972 and estimates that there are currently at least 100,000 to 120,000. Toler states that "estimates typically range from 100,000 to 300,000," but it is not clear whether he is referring to the United States or to the world. Given the U.S. population of approximately 217,000,000, perhaps as many as 1 in 2,000 uses a pacemaker. In 1972, 58% of the pacemaker users were males and 60% of the wearers were over 65. Michaelson says the average age of pacemaker users is 70 years. There are only about 25 manufacturers of pacemakers worldwide according to Toler. Medtronic Inc., the leading manufacturer of pacemakers, has about 50% of the world market. Some small firms consist only "of a couple of doctors who manufacture and implant their own design."

"The number of implanted pacemakers is almost impossible to determine precisely . . ."
–Toler

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*Yet another system of terminology has been suggested by some cardiologists. It involves three-letter codes such as VVT for R-wave synchronous, and VVI for ventricular inhibited.

Pacemakers have to be replaced periodically because their batteries wear out. Toler states that "conventional batteries might last 30 months before replacement." He also mentions new batteries under development–a lithium-iodine power source that may be good for 3 to 5 years and a nuclear-powered pacemaker with a lifetime of 8 to 20 years. However, the majority of current pacemakers use conventional batteries that will be replaced sometime within the next few years. Such replacement may benefit patients because they can thus receive pacemakers that incorporate technological improvements. Toler believes that the catheter which has already been implanted is generally left in the patient and connected to the new pacemaker electronic package.

Pacemaker development has been characterized by design "generations"; those now being implanted are considered third-generation. This distinction is important because some of the testimony cited instances of electromagnetic interference (EMI) in first- or second-generation pacemakers. These examples, however, were also claimed not to be relevant to today's improved products, which are designed to resist EMI.

The first generation of pacemakers, which were implanted from 1959 to about 1964, were asynchronous or fixed-rate pacemakers. They supplied a beat to the heart whether or not the heart could provide its own beat.

"What Mr. Toler recited yesterday, those case reports were all based on the first generation of pacemakers. We have two more generations since then and . . . we have to remember that these pacemakers are shielded now and have built-in filters."
–Michaelson

The second-generation, synchronous, pacemakers were introduced because doctors came to believe the heart should be permitted to develop its own pulse when possible rather than to have the pacemaker impose its rate. Because these synchronous pacemakers had to sense low-level electrical activity in the heart, it was soon learned that they might be susceptible to EMI from external sources. Steps to combat EMI problems resulted in the third-generation pacemaker.

The third-generation pacemakers, which have been made since 1970, are also synchronous. (Michaelson believes that because of the replacement rate, all synchronous pacemakers now in operation are third-generation.) Three measures to combat EMI were mentioned. By 1974, almost all manufacturers, as a first measure, had enclosed the electronic package in an hermetically sealed titanium or stainless-steel container to shield it. Michaelson believes that "it is doubtful that you will have an unshielded pacer today." As a second measure, filters were incorporated in the pacemaker to keep radio frequency (RF) signals picked up by the catheter from entering the shielded electronic package. The testimony contains little discussion of this filtering, except to note that it may have little influence on EMI at frequencies as low as 60 Hz (the power line frequency). As a third measure to combat EMI, the third-generation pacemaker can revert to asynchronous operation when it senses interference. Thus, in the presence of EMI the pacemaker assumes a fixed rate while interference continues. No specific information was given on how the third-generation pacemaker senses the presence of external electric or magnetic fields, although the asynchronous mode can apparently be deliberately induced with a magnetic field. In the asynchronous mode, the pacemaker and the heart compete because each supplies a pacing signal. Considering the improvements incorporated in the third-generation pacemaker, Michaelson believes that "in 1976 the chances are most likely that you would not have a pacemaker [from the first] or the second generation."

Pacemaker Response to EMI

The Association for the Advancement of Medical Instrumentation lists five principal ways in which a pacemaker may react to EMI:

- No effect
- Intermittent changes in rhythm or rate
- Ceasing to respond to the natural heart rate but continuing to pace the heart at an acceptable fixed rate (the reversion mode of asynchronous operation)
- Operation at an extreme rate, either fast or slow
- Failure to send a pacing signal to the heart for a significant length of time.

Obviously, only the latter two responses are clearly pacemaker dysfunctions, although testimony in the hearings covered all five. The reversion response to EMI is designed into the third-generation pacemaker, which *must* change rhythm and rate (the second response) in the transition from synchronous to asynchronous pacing.

A principal design feature determining pacemaker response to EMI is the lead, or catheter, that the pacemaker uses to sense the heart's electrical activity. Two major types of catheters are used—the bipolar and the unipolar. The bipolar catheter consists of two coiled wires in inert insulation. The ends of the wires in the heart are bare, and the pacemaker stimulates the heart with a voltage across those two ends. The unipolar catheter has a single coiled wire within the insulation. The electrical circuit is completed through the body tissue itself from the bare end of the wire within the heart to a metal disk on the side of the pacemaker's electronic package.

The catheter and the pacemaker type (including generation of pacemaker) appear to be the major determinants of response to EMI. Third-generation pacemakers sense EMI because they are designed to respond to electrical activity. On the other hand, third-generation pacemakers are also designed to minimize the potential for harmful effects from EMI. The hearings did not detail how pacemakers function as electronic circuits or the response of pacemaker types to differing electromagnetic environments. In addition, limited numbers and kinds of pacemakers were used in the research referred to in the hearings. No thorough, or statistically significant, publicly available assessment of the pacemaker response to EMI has been made. (Although pacemaker manufacturers obviously are aware of the response and sensitivity of their products, this information is proprietary and was not disclosed.)

As a result, the experts at the hearings often lacked sufficient data to allow them to reach definitive conclusions about the response of all pacemakers to electromagnetic fields in general and to electromagnetic fields under transmission lines in particular. However, certain conclusions and descriptions of the *likely* ranges of responses are possible and were made in the hearing.

Although reversion to asynchronous operation is an important ability of the pacemaker, the testimony reveals little about how this is done. Toler says that the pacemaker "in the presence of high electromagnetic fields, essentially switches its sensing circuitry off . . . By this means, a degree of immunity against interference fields is gained." The 1975 IITRI report demonstrates that the reversion switch can be activated by voltages injected into the catheter. However, the report devotes almost no discussion to which characteristics of the injected voltage tell the pacemaker that it is undergoing interference and therefore should shut down its sensing activity and switch to asynchronous operation. Some of Michaelson's testimony seems to indicate that the response is based on the amplitude of the interfering signal. However, in discussions of a procedure called "transtelephone monitoring," it becomes apparent that the reversion switch can also be activated by a magnet held over the pacemaker. Although testimony does not reveal whether this switching requires a permanent magnet or an electromagnet with a 60-Hz field, manufacturer's literature indicates that a permanent magnet is used with some systems.

In transtelephone monitoring, the pacemaker owner uses the telephone to transmit data, including the pacemaker's asynchronous rate, to indicate the condition of the battery to his physician. Weekly checks are made, and as battery depletion draws near, the rate decreases. The physician can thus determine when the unit should be replaced.

60-Hz Fields Necessary to Cause a Pacemaker to React. No solid data on the operation of implanted pacemakers appear available about the effect of 60-Hz electromagnetic fields at levels similar to the fields under very high voltage power lines. At best, the examples of data are for electric or magnetic fields alone (and these are generally bench tests). The work described in the 1975 IITRI report involves applying voltages directly to the pacemaker via the catheter; IITRI also undertook measurements and modeling to estimate voltages caused by the 60-Hz fields. Apparently, other data proprietary to pacemaker manufacturers exist about the effect of 60-Hz fields on operation; however, these data were not released to become part of the testimony. Confusion abounds in the testimony because the witnesses and attorneys often fail to clarify definitions of pacemaker types, catheter types, pacemaker generations, and other variables. Importantly, the testimony also fails to agree on whether some forms of pacemaker reactions to EMI (particularly reversion to asynchronous operation) constitute dysfunctions.

"Have there been any controlled investigations that you are aware of in which pacers have been exposed simultaneously to electric and magnetic fields from EHV power lines?"

"No." – Michaelson

"Is this data base [the 1971 and 1975 IITRI reports] in your opinion sufficient to permit determinations about the susceptibility of all types of pacers to electromagnetic interference?"

"No, it is not." – Toler

The Effect of Applied Voltages. One method of exploring the behavior of a pacemaker in an interference environment is to apply voltages directly to the unimplanted catheter and observe the pacemaker for changes in operation. These observations have shown that pacemakers can be affected by applied voltages. But the tests do not indicate effects, if any, on the pacemaker's owner from the resulting changes in the pacemaker's operation.

In IITRI tests extensively referenced in the hearings, a 60-Hz voltage was applied to the catheters of 10 unimplanted pacemakers—5 in the 1971 report and 5 in the 1975 report.* The 1975 report covers work done from mid-1972 through early November 1974. In the first type of test described—the "sensitivity test"—no simulated heart signal was applied to the pacemakers; thus, synchronous pacemakers operated at their design rate for asynchronous pacing in the absence of natural cardiac stimulation. The interpulse interval was monitored for changes as the applied voltage was increased from 0.1 to 100 mV.

IITRI noted no effects on either of the two asynchronous pacemakers or on three of the four synchronous pacemakers tested in 1975. Table IV.1 indicates this and also shows the threshold voltages at which effects were noted for the other five pacemakers. In the sensitivity tests described in 1971, the synchronous pacemakers, when subjected to "continuous (60-Hz) voltages above the threshold, exhibited effects which ranged from an occasional shortening of the time between pulses (sometimes less than 3%) to erratic pulse trains with a variation of as much as 50% in interpulse time." No mention was made in the 1971 test of a transition region—a voltage range marked by unstable operation as the pacemaker tries to decide between its synchronous mode and its interference mode with a fixed rate. The 1975 IITRI report showed, for example, that an American Optical pacemaker had such a transition voltage region (refer to Table IV.1). When the injected voltage was below the threshold, the pacemaker operated at about 74 pulses per minute; within the transition region the rate varied between 74 and 78 pulses per minute; and when the voltage was above the region a stable output was achieved of 78 pulses per minute.

It is not clear from the 1975 IITRI report, or from testimony on the sensitivity tests, whether the four affected 1971 pacemakers in Table IV.1 were second- or third-generation instruments. The third-generation American Optical pacemaker noted in the table can revert to asynchronous operation. Because the 1975 report says that the 1971 erratic operation occurred for "voltages above the threshold," SRI suspects that four of the five pacemakers that were affected by applied 60-Hz signals were second-generation instruments, now obsolete, that could not switch to asynchronous operation in response to interfering signals. The 1975 report indicates clearly that the General Electric pacemakers "were the ones being currently manufactured." However, Michaelson points out in April 1976 that this description applies to events "a year and a half ago." Pacemaker development may thus have also rendered those pacemakers obsolete by 1976.

". . . this question of the erratic rate is totally irrelevant today. It doesn't pertain to the situation and the point of fact is that it is not a hazard."
—Michaelson

The 1975 IITRI report describes a second test, called the interference test, which involved only 6 of the 10 pacemakers. The experimenter simulated a normal heart signal to the pacemaker. This signal was set at 100 pulses per minute for the American Optical pacemaker and at 72 per minute for the General Electric pacemakers; the 1975

*Many of the 1971 results were incorporated into the 1975 report, which became Exhibit UUU.

Table IV.1

RESULTS OF IITRI SENSITIVITY, INTERFERENCE, AND SLOW HEART TESTS—60-Hz INJECTED VOLTAGE

Pacemaker	Type	Threshold Voltages (and Threshold Ranges) Sensitivity Tests (mV)	Interference Tests (mV)	Slow Heart Tests (mV)	Source of Data
Medtronic	Asynchronous	None found†	No test	No test	IITRI 1971*
General Electric "A"	Asynchronous	None found†	No test	No test	IITRI 1975
Cordis Atricor	P-wave synchronous	0.57	0.79	No test	IITRI 1971*
Cordis Ectocor	R-wave synchronous	1.0	1.1	No test	IITRI 1971*
Medtronic	R-wave inhibited	0.43	No test	No test	IITRI 1971*
Cordis Stanicor	R-wave inhibited	0.82	No test	No test	IITRI 1971*
Americal Optical S/N 27056	R-wave inhibited	0.45-0.53	0.3-1.5	No test	IITRI 1975
General Electric "B"	R-wave inhibited	None found†	2.8-3.6	2.0-3.0	IITRI 1975
General Electric "C"	R-wave inhibited	None found†	1.0-1.25	1.3-1.5	IITRI 1975
General Electric "D"	R-wave inhibited	None found†	1.0-1.1	0.95-1.2	IITRI 1975

*Those 1971 data are from the 1975 report.

†If there is a threshold, it is greater than 100 mV.

report does not indicate the rate for the 1971 tests. Again, the 60-Hz voltage was increased and changes in operation were noted. In the 1971 tests (involving P-wave synchronous and R-wave synchronous pacemakers), a voltage threshold was found above which "the interpulse time interval was altered." However, the report does not reveal the nature of this alteration, and it may no longer have been relevant (see Table IV.1). In the more recent tests, which involved R-wave inhibited (or demand) pacemakers, thresholds and transition regions were noted. The voltage threshold is the level at which the pacemaker senses interference and thus begins to produce occasional pulses. This phenomenon continues throughout the transition region until its stable, asynchronous-mode pulse rate is firmly established.

The third test performed by IITRI involved three General Electric R-wave inhibited pacemakers sensing a simulated heart signal at a slow rate–about 43 beats per minute. At this slow rate, the pacemaker inserts a pulse between each pair of the simulated R-waves, which occur every 1400 ms. Again, voltage thresholds and transition ranges were found (see Table IV.1). Below the threshold, the pacemakers pulsed every 1400 ms. Within the transition region, the pacemaker's period varied between 1400 ms and its period designed for asynchronous operation. At the top of the transition region, the pacemaker reverted to its asynchronous mode–producing pulses at the steady rate it was designed for.

IITRI also contacted pacemaker manufacturers and obtained threshold voltages for pacemakers then being manufactured, including the General Electric product. IITRI points out that some of the manufacturer-supplied data pertain to pacemakers that have replaced those described in their tests. Table IV.2 (from IITRI's Table 10) shows the threshold data provided by the manufacturers. However, the IITRI report never states the type of test these data represent. Nor is the type of pacemaker mentioned, except that it was stated that Medtronic at that time also made some "special order atrial synchronous pacers" with a unipolar configuration that were said to have a threshold voltage of 0.5 mV. Considering that P-wave synchronous pacemakers constitute approximately 5% of the pacemakers (Toler) or perhaps less than 1% (Michaelson), it appears that this special order type is rare.

In the testimony, Toler states that he had just completed a series of sensitivity tests for a manufacturer who was unnamed (for proprietary reasons). He tested nine R-wave inhibited pacemakers–three each of three different models–and found that the sensitivities ranged from 0.27 to 0.34 mV; this is at the lower end of the voltages found by IITRI. He believes, however, he has also found threshold voltages (in other tests) as high as 2.8mV–at the upper end of the thresholds described by IITRI. Both Toler and the IITRI report acknowledge that sensitivites vary not only from manufacturer to manufacturer, but also from model to model. IITRI adds that different results may be found for individual pacemakers of the same model number. Thus, it is clear that the threshold of effect is a random value that cannot be completely characterized by a single voltage number.

In summary, then, it appears that knowledge presented at the hearings about the affects of 60-Hz fields on cardiac pacemakers is based on two sources: One is Toler's brief testimony on his recent work. The other is the IITRI study of 60-Hz voltages applied to 10 pacemakers, with incomplete manufacturer-supplied data. The 1975 IITRI report

Table IV.2

THRESHOLD DATA OBTAINED BY IITRI FROM MANUFACTURERS

Manufacturer	Heart Pacer Electrode Configuration	Threshold Voltage (mV)
Medtronic	Unipolar	1.24
	Bipolar	1.24
Cordis	Unipolar	1 to 2
	Bipolar	1 to 2
American Optical	Unipolar	3 to 4
	Bipolar	1 to 3
General Electric	Unipolar	0.95 to 2.8*
	Bipolar	0.95 to 2.8
Cardiac Pacemaker, Inc.	Unipolar	2.2
	Bipolar	2.2
Vitatron Medical, Inc.	Unipolar	1.0
	Bipolar	1.0

*Taken from IITRI's measurements in their 1975 report.

describes work done between mid-1972 and late 1974. Some of the data in that report were from measurements first reported in 1971. The applicability today of the latter data is questionable because pacemaker development has progressed and because implanted pacemakers are replaced with the newer models every 2 or 3 years as the battery becomes exhausted. Toler is not aware of any recent trends to make pacemakers more or less sensitive. Thus, sensitivities for R-wave synchronous pacemakers probably range from about 0.3 to almost 3 mV. Note that this is not the same as a transition range, which was described for only a few of the pacers.

The Catheter as a Sensor of Electromagnetic Fields

The catheter is the key to the pacemaker's susceptibility to EMI because it functions as a sensor, converting electromagnetic fields into voltages that are injected into the shielded electronic package. Of the two types of pacemaker catheters–bipolar or unipolar–the unipolar catheter can cause a pacemaker to be much more susceptible to EMI. The testimony did not consider the rationale for a physician's selection of one catheter type over the other. Nor were the relative numbers of implants of the two catheters discussed. Toler believes that the four basic pacemaker types can function with either type of catheter if designed to do so by the manufacturer. The 1975 IITRI report also mentions specific pacemakers that can use either unipolar or bipolar leads.

The catheter senses both electric and magnetic fields. With magnetic fields, the catheter functions as a one-turn transformer converting the 60-Hz magnetic field to a voltage in the pacemaker. The induced voltage is directly proportional to the effective area of the catheter's loop. A unipolar catheter's loop consists of the wire leading from the electronic package to the heart and the direct return path through body tissues. The 1971 IITRI report indicates that the area of this loop could be as large as 210 cm^2, but not what the more typical area might be. A bipolar catheter's loop is entirely within the heart; the area of the loop is circumscribed by the two catheter leads and by the heart tissue between their two ends. IITRI estimates this area to be about 5 cm^2. If the loops of both types of catheters are oriented for maximum pickup (with their plane perpendicular to the magnetic field), the pacemaker that uses the unipolar catheter, with its much greater area, could be subjected to induced voltages about 40 times as large as one using the bipolar catheter.

For electric fields, the important catheter characteristic is the distance between the ends of the wire. Because induced 60-Hz currents (as well as the pacemaker currents) flow along the path between the two ends of the wire, the 60-Hz voltage drop appears as EMI at the pacemaker's input terminals. The voltage will be directly proportional to the length of the path. The IITRI report states that the path length for a unipolar catheter could be as much as 19 cm (7.5 in.); for bipolar catheters the maximum path length would be about 2.5 cm (1 in.). Thus, considering optimum orientation to the field in both cases (with the current path parallel to the electric field), it appears that a pacemaker with a unipolar catheter could be subjected to induced voltages about 7 times as great as one equipped with a bipolar catheter.

Relating the Voltages Induced on the Catheter to the Electric and Magnetic Fields. All the 60-Hz tests noted have been bench tests, in which voltages were applied across the terminals of an unimplanted pacemaker as its pulse rate was observed for change. To deduce from these voltages how electric and magnetic fields affect the pacemaker's pulse rate requires information about how the external field and the internal catheter interact.

In measuring *electric fields,* IITRI attempted to measure indirectly the voltage induced within the chest by the electric fields under high-voltage power lines. The potential induced would appear across the ends of the catheter and be applied to the circuitry of the pacemaker by the catheter wires. The applied voltage is

$$V = E \cdot d \cdot K \quad , \qquad \text{(IV.1)}$$

Where E is the electric field strength and d is the vector component of the current path within the body (between bipolar catheter end points or between the unipolar catheter end point and the electronic package) parallel to the E field. K is a coupling constant (induced volts per unit length of current path per unit of field strength, which is also expressed in volts per unit length).* Because IITRI could not measure voltages within the chest, they developed this constant by measuring the potential between electrodes attached to the chests of individuals (apparently, seven). Electrodes were positioned to measure vertical and horizontal voltage drops in mV/ft across the chest. The individuals

*This coupling is potentially dimensionless (volts per meter per volt per meter). To avoid confusion, however, we will conform to IITRI's form, expressing K in the dimensions mV/ft/kV/m.

stood on styrofoam pedestals—sometimes with arms raised and sometimes with arms at their sides—under power lines and in a parallel-plate *E*-field generator; the fields were also measured. IITRI assumed that "the voltage between the leads of an implanted heart pacer is the same as the voltage measured between correspondingly placed electrodes on the surface of the chest."

In general, the vertical component of the electric field measured on the chest was considerably higher than the horizontal component, and the field was higher when the arms were raised. The values for *K* ranged from 0.241 mV/ft/kV/m, for an individual with arms raised, to 0.87 mV/ft/kV/m for one with arms at the sides. Average values were about half the maximum.

The IITRI values for *K* are consistently too small, according to rebuttal testimony prepared by Daniel A. Driscoll, a biomedical engineer of the New York Department of Environmental Conservation. He claims that "had the IITRI test subjects been in contact with the ground, the current flowing in the chest area and, therefore, the potentials measured on the chest would have been about 40% greater." Driscoll bases this claim on measurements he made using a styrofoam pedestal on which was placed a cylindrical model 1.7 m high and 25 cm in diameter that simulated a human.

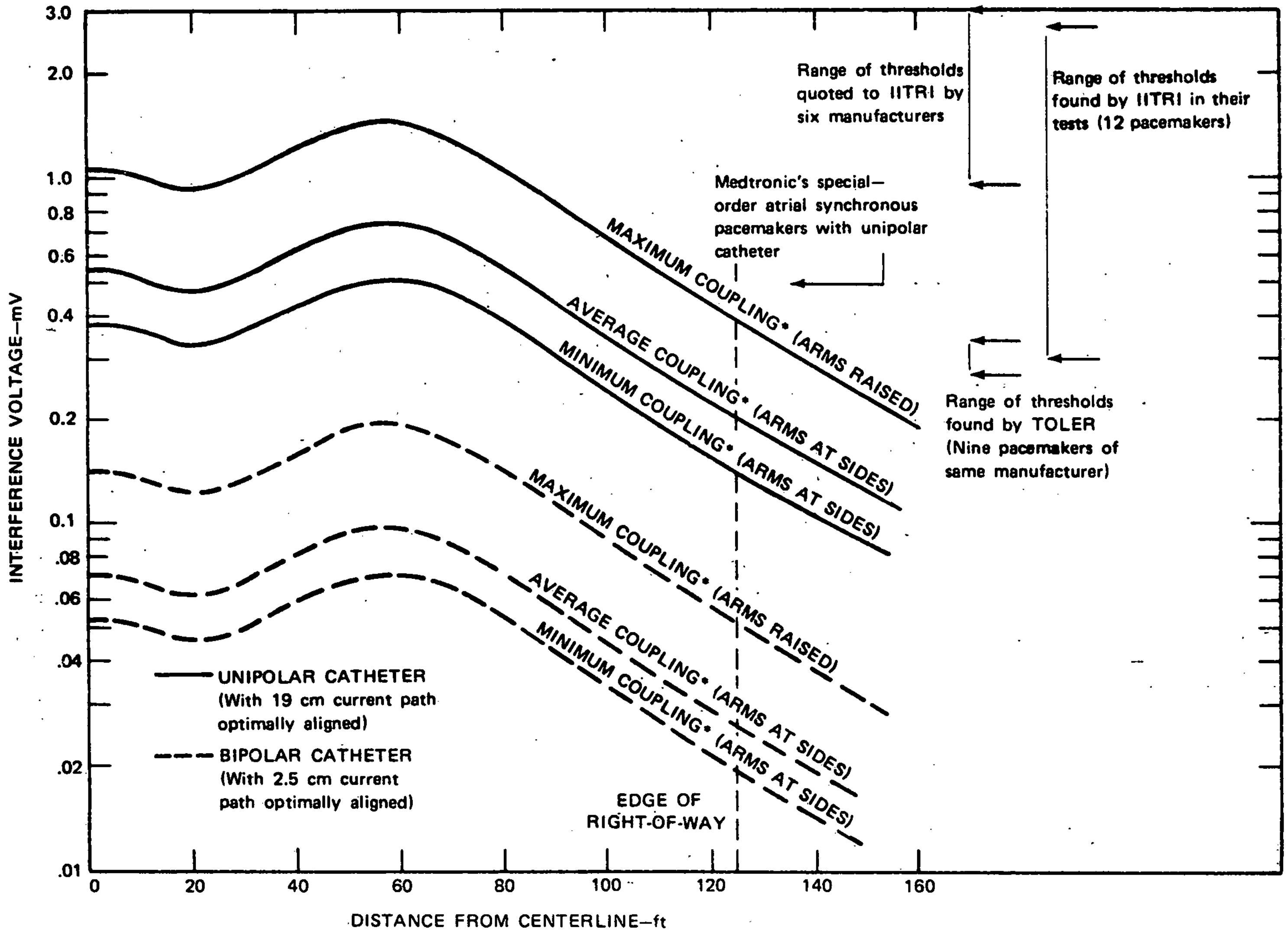
IITRI measured the vertical component of the transmission electric fields at a height of 1.5 m (5 ft) in the vicinity of a 765-kV power line and estimated that a maximum of about 10.7 kV/m would occur about 20 m (60 ft) off the centerline when the line drooped to a height of about 15 m (45 ft). This finding substantially agrees with data (Exhibit VLC-S) submitted by Chartier of "calculated ground level voltage gradients for proposed 765-kV lines" that shows about 10 kV/m about 20 m (60 ft) off the centerline and about 3 kV/m at the edge of the right-of-way 40 m (125 ft) off the centerline. Data submitted by Barnes (Exhibit HCB-2) indicate 9.9 kV/m directly under the lines.

IITRI chose to use Equation (IV.1) to solve for the field strength *E*, given some applied voltage *V* that they had observed to cause some effect on a pacemaker. This is a matter of preference, but it seems more straightforward to begin with some field strength and calculate the applied voltage. Figure IV.4 shows the results of example calculations. To obtain the applied voltage, SRI assumes that the pacemaker wearer stands where the *E*-field is at a maximum (about 50 to 60 ft from the centerline), that his arms are upraised, and that his body is in an attitude that places the current path exactly parallel to the 10-kV/m *E*-field. SRI also assumes the maximum current path length* and that the voltage inside the chest is the same as that measured on the surface of the chest. The 60-Hz interference voltage applied to the pacer, according to Equation (IV.1) will be about

$$V = 10 \cdot \frac{7.5}{12} \cdot 0.241 = 1.5\ mV \qquad \text{(IV.2)}$$

(Note that the pacemaker owner could also assume a position in which the current path is perpendicular to the field; in this case, the applied voltage would be zero). If the pacemaker owner moves to the edge of the right-of-way where the *E*-field is about 3 kV/m, the voltage applied to the pacemaker will be about

*According to an IITRI reference, the maximum observed path length for a unipolar catheter is "slightly less than 7.5 inches" (19 cm). SRI used the 7.5-in. figure to estimate maximum effects.



*Those are for the maximum, minimum, and average coupling factors found by IITRI.

FIGURE IV.4. MAXIMUM INTERFERENCE VOLTAGES FROM A 765-kV TRANSMISSION LINE FOR A PACEMAKER WEARER STANDING NEAR THE POINT OF MINIMUM LINE HEIGHT

(The minimum line height is assumed to be 14 m (48 ft). Unipolar catheters make pacemakers more sensitive to interference.)

$$V = 3 \cdot \frac{7.5}{12} \cdot 0.241 = 0.45 \; mV \qquad \text{(IV.3)}$$

If the pacemaker owner is in the high *E*-field position, with the most effective body attitude, but has a bipolar catheter, with a 2.5 cm (1 in.) current path, the pacemaker is subjected to a 60-Hz voltage of about

$$V = 10 \cdot \frac{1}{12} \cdot 0.241 = 0.20 \; mV \qquad \text{(IV.4)}$$

The chest is essentially transparent to *magnetic fields* (i.e., the magnetic field inside is about the same as that outside). Thus, IITRI used a simple equation to estimate the 60-Hz voltage induced in the one-turn transformer winding formed by the pacemaker catheter:

$$V = 2\pi \cdot f \cdot A \cdot B \cdot 10^{-8} \; V \qquad \text{(IV.5)}$$

where f is the frequency (60 Hz), B is the root mean square value of the magnetic flux density in gauss, and A is the effective area, in square centimeters, of a current loop within the magnetic field. The actual current loop consists of the catheter and the portion of the current path within the tissue; its effective area is the loop's projection on a plane perpendicular to the magnetic field. If the plane of the loop is parallel to the magnetic field, no voltage is induced. Although the use of the simple transformer equation was not challenged in the testimony, it implies an assumption never articulated: The equation describes the total voltage induced in the one-turn loop. However, only part of this voltage will be dropped across the current path within the tissue. Only if the impedance of the current path through the tissue is very small relative to the input impedance of the pacemaker will the equation apply. This may well be the case, considering the salinity of the blood and other factors, but the point was never discussed. Thus, the voltage induced at the pacemaker terminals may be smaller than that indicated by the equation.

The magnetic field near the lines is directly proportional to the magnitude of the current flow in the transmission line. Based on their measurements under a 765-kV line, IITRI estimates maximum fields, at a height of about 1.5 m (5 ft) above the ground, of 0.1555 G/1000 A per phase where the line droops to a height of about 14 m (45 ft). They state that the peak current seldom exceeds 2000 A and at that current produces a maximum field of about 0.31 G. Exhibit KK* suggests that a current of 1000 A per phase produces a field of about 0.28 G at a 1-m height. Therefore, these two documents generally agree on the strength of the magnetic field. However, Toler mentions that Exhibit PP indicates a maximum magnetic field strength of 0.56 G in the vicinity of the 765-kV lines–implying a current of about 4000 A per phase.

If it is assumed that a pacemaker owner with a unipolar catheter stands in the maximum magnetic field, that the current loop is perpendicular to the field, and that

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*This is a single sheet plot entitled "Maximum Magnetic Flux Density Calculated 1 Meter Above Ground." Its origin is not indicated.

the area of this loop is about 210 cm^2 (i.e., "the largest loop area found for a human endocardial implantation"), the induced voltage (for 2000 A per phase) is about

$$V = 2 \cdot \pi \cdot 60 \cdot 210 \cdot 0.31 \cdot 10^{-8} = 0.25\ mV \qquad \text{(IV.6)}$$

This voltage becomes much less for lower currents, greater distances from the line, less favorable pacemaker orientations, and smaller loop areas. In general, it appears that the magnetic field effects are considerably smaller than the electric field effects.

The testimony indicates that a pacemaker, in the vicinity of a line, will be simultaneously subjected to electric and magnetic fields. The voltages resulting from the two fields will add. Voltages caused by the magnetic field will apparently be much smaller than those from the electric field, and because the two fields are not in phase (i.e., do not reach their maxima at the same time), the maximum voltage will be essentially determined by the electric field alone. It is uncertain whether the pacemaker owner and his catheter could be positioned so that both fields become maximally effective. Consideration of both fields in action simultaneously is a complex problem and would require more effort than was expended in the development of the IITRI report.

Induced Voltage as a Function of Position Near a Line. In this subsection SRI uses predictions of the electric field in the vicinity of the high-voltage lines to estimate the 60-Hz voltage appearing at an implanted pacemaker's terminals. The electric field (voltage gradient) predictions are those of Exhibit VLC-S* applicable at the ground below a center-span height of 14.6 m (48 ft). The equation determining the voltage is:

$$V = E \cdot d \cdot K \quad . \qquad \text{(IV.7)}$$

This gives the voltage induced on the pacemaker when the plane of the catheter loop is aligned parallel with the voltage gradient for maximum effect. In Figure IV.4, curves of the injected voltage are presented for the maximum, minimum, and average couplings (chest potentials) measured by IITRI and for maximum-length, optimally oriented pacemaker current paths for both unipolar and bipolar catheters. The figure also shows some of the voltage thresholds above which pacemaker effects have been noted.

The figure shows that, given the assumptions of this model, pacemakers with bipolar catheters are unlikely to be affected by the electric field from the 765-kV lines. However, pacemakers which have bipolar catheters with a long current path may well be affected, even at the edge of the right-of-way or outside it. The only difference in the two sets of curves (bipolar and unipolar) results from the assumptions on current path length; the interference voltage is directly proportional to that length.

Driscoll would raise these curves by 40% because he claims that IITRI's values for K are too small. He concludes that "the proposed transmission lines can interfere with the operation of many (about 40% or more) of currently implanted pacers."

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*This is a single-sheet plot entitled "Calculated Ground Level Voltage Gradiant, Proposed 765-kV Lines at Varying CTR Span Line Heights"; its origin is unstated. In addition, see Figure II.3.

Need for Considering Likelihood of Occurrence. The combination of (1) EHV power-line *E*-field measurements and predictions and (2) the measurements of thresholds of effect on pacemakers for applied voltages suggests that some pacemakers may be affected when close to the lines. However, this circumstance requires coincident occurrence of several unlikely, and worst-case situations. In addition to a pacemaker owner's coming quite close to an EHV power line, the following conditions must also apply:

The pacemaker must have a unipolar catheter with a long through-the-tissue current path.

That path must be essentially parallel with the *E*-field.

The voltage induced in the chest must be approximately the same as that measurable on the chest.

The pacemaker must be as sensitive as the more sensitive of those tested by IITRI or by Toler.

Unfortunately, neither the testimony nor the available reports discussed the likelihood of occurrence of the worst-case situation. An accumulation of coincident worst-possible cases can in total represent a very unlikely situation. In fact, some EMI effects on pacemakers described in the testimony were later revealed either not to have been caused by 60-Hz fields or not to have involved implanted pacemakers or ambulatory patients. Some were instances recorded in the literature of the mid- to late-1960s, written before the third-generation pacemakers were in use, and they did not always involve otherwise healthy individuals, such as those that might be moving about in the vicinity of EHV power lines.

"You can always build a worst case situation, certainly, but you have to have certain perspective here. If you give me a statistical probability. . ."
—Michaelson

"My questions are not trying to prove that these pacemakers fail frequently, but my questions are getting to the point, Doctor, that they do in certain cases fail."
—Lawyer

"We cannot just list a whole lot of incidences, many of which are quite speculative, by the way, and put them all into one big frame . . ."
—Michaelson

EMI Effects on a Pacemaker's Owner

EMI Response Modes. Three conditions must occur simultaneously to affect the health or comfort of the pacemaker owner. First, the normal operation of the pacemaker must be disturbed. Second, the owner must react adversely to the disturbed operation. Third, the disturbed operation must continue long enough for it to be hazardous to the health of the pacemaker wearer.

Five pacemaker responses are possible, ranging from no change in operation to complete shutdown, which is not to say that all of these responses are equally likely with the modern third-generation pacemaker. Although pacemakers apparently can be affected by power lines, no testimony indicated that this has ever occurred to the harm of a pacemaker owner.

The first response is "no effect"; obviously, if the pacemaker is unaffected it will not adversely affect its owner. Asynchronous pacemakers, which are not designed to sense the heart's electrical activity, are relatively insensitive to EMI.

The second response mode, intermittent change in rhythm and rate, apparently can take place as the synchronous pacemaker's circuitry is determining whether to revert to asynchronous pacing–the third generation pacemaker's anti-EMI mode of operation. During this time, the pacemaker's pulse may be in competition with the naturally occurring pacing activity; the results of this are discussed later. There is a range of 60-Hz voltages at the pacemaker's terminals within which this uncertain operation may take place. Because the voltage range appears relatively narrow, a person's motion in the field may take him through it in a short time. Also, it does not appear, from testimony, that third-generation pacemakers exhibit erratic operation; the synchronous rate and the asynchronous rate are not widely different.

The third response mode, reversion to a benign fixed rate, has been carefully designed into the newer pacemakers to safeguard against the pacemaker being misled into functioning at rates detrimen- to the owner. The pacemaker turns off its sensing circuitry in this instance. Opinions differ, however, about whether the resulting competition is harmful to the wearer.

"Would you agree, Doctor, that there is a substantial lack of knowledge regarding the effects of 60-Hz electric and magnetic fields on pacemakers?"

"No, I disagree . . . People with pacemakers have lived in our society, they have carried on their normal functions and there have been no problems at all, and you can't ask for a better study than that."
–Michaelson

". . . there is no case on record where anyone has died from a pacemaker that has been interfered with from electromagnetic radiation."

". . . things of an instantaneous or short-term duration are not going to have any clinical consequences. The important point is that in requisite time, it will revert to a fixed mode and the short-time interval will not affect the patient."

". . . with the tremendous number of lines, tremendous number of miles of lines, and the large number of pacer wearers, if anything were developing [in terms of harm to pacer wearers], I think we would have been aware of it by now."
–Michaelson,

". . . once it reverts to an asynchronous mode, it is insensitive, and I think that has to be kept in mind."
–Michaelson

The fourth response, operation at an extreme fixed rate (either very fast or very slow), was not discussed at great length in the testimony because experts believed that the third-generation pacemakers do not exhibit this response.

The fifth response mode, cutoff or inhibition of the pacemaker for a significant interval, could harm the pacemaker-dependent individual. Such a response could occur when the pacemaker interprets an impulsive electromagnetic signal as the heart's own signal. The power line fields are smooth 60-Hz signals and do not have that impulsive characteristic.

". . . total inhibition would not occur from the transmission line field since these fields would give rise to a smooth sine-wave signal rather than a pulse, and in this case the pacer would not mistake this for a normal heart signal."
–Michaelson

Competition. Cardiologists reason that because the heart muscle has an intrinsic beat, in cases where this beat can still operate at least part of the time, it is wise to let the heart control its own activity rather than forcing it to compete with the pacemaker's rate. This reasoning led to the development of second-generation (synchronous) pacemakers that sense and react to the heart's electrical activity. The sensing feature opens the synchronous pacemaker to the possibility of sensing electrical signals other than the heartbeat. To avoid that, they have been designed to revert to asynchronous operation while they sense an interfering signal. Then, the pacemaker pulse and the natural pacing rhythm are in competition. The severity of this competition is a controversial point within the testimony.

"It is my professional opinion that competitive cardiac rhythms resulting in the injection of an artificial stimulus during the supernormal period of excitability may occasionally precipitate a lethal cardiac dysrhythmia; in my judgment this mechanism explains some of the sudden and unexpected deaths which have occurred in individuals with permanently implanted artificial pacemakers."
–Doyle,

A cardiologist, Joseph T. Doyle, M.D., testified about possible effects. Doyle claims, without citing specific studies, that there is ample experimental evidence and clinical experience to show that if a pacemaker stimulus happens to occur during a brief period of hyperexcitability in the heart's electrical cycle, serious disturbances of heart rhythm may be induced. Among these are two major effects: the first, ventricular tachycardia (rapid heart beat) is a serious medical problem requiring prompt treatment, especially in damaged hearts, as Doyle points out. Ventricular tachycardia may change into the second major effect–ventricular fibrillation–in which state the heart cannot contract efficiently; thus, no blood supply reaches vital organs, including the heart and the brain. If normal circulation is not restored within minutes by restarting the heart's cycle with an electrical countershock, death ensues. If normal circulation is denied for a shorter period, death may be avoided, but irreversible brain damage will occur because the brain cells will die from lack of oxygen.* Doyle also points out that these serious consequences from repeated stimulation during the brief period of hyperexcitability are more likely to occur in damaged hearts because of their sensitivity. He also points out that the competing stimulus can occur naturally from a ventricular premature beat (i.e., a single electrical impulse originating in the ventricle or from the artificial pacemaker, when the refractory period from the previous electrical impulse is over but before the normal impulse can start from the heart's natural pacemaker).† Doyle notes that relatively healthy hearts are much less likely to suffer serious consequences, such as ventricular tachycardia and/or fibrillation, from this stimulus than are diseased hearts. He cautions, however, that the transition from a "relatively resistant heart to one which is vulnerable to malignant dysrhythmias" can be so gradual that the pacemaker owner may not be aware of it.

"In our combined experience, comprising some 2,200 patients and some three times as many pacemakers, there have been only ten documented cases of implanted pacemakers affected by EMI. None of these was serious and none fatal." – Cardiologists Smyth, Parsonnel, Escher, and Furman quoted in the 1975 IITRI report.

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*This is general background information. Doyle states that ventricular fibrillation is fatal and must be treated promptly by electric countershock.

†This is also general background information.

Toler provides detail on the mechanics of competition by identifying the brief period of hyperexcitability—the vulnerable time—as coincident with the *T*-wave (see Figure IV.2). At that time, the ventricles are just becoming capable of reacting to another electrical stimulation. Toler's information, obtained from conversations with medical doctors, is that the magnitude of the pacemaker pulse is several hundred times less than that usually required to induce ventricular fibrillation. However, the stimulation level necessary to cause fibrillation can apparently be lowered by other conditions, including "enhanced excitability, certain cardiac drugs, electrolyte disorders, [and the] heart muscle receiving an inadequate blood flow." Toler states that deaths of patients who had competitive rhythms have been documented. He cites an addendum to the 1975 IITRI report that states:

> ". . . noncompetitive pacemakers that are caused to operate in an asynchronous interference mode for more than 15 to 60 seconds are regarded as potentially hazardous for the majority of patients with intermittent atrioventricular conduction and potentially catastrophic for patients who, in addition, have coronary artery disease, serious electrolyte imbalance, drug toxicity, or any other reason or condition which may cause the threshold of ventricular fibrillation to be low."

Toler's testimony on the effects on patients was struck from the record because the testimony was considered to be too much in the area of medical expertise, even though the quote above is in an addendum to the IITRI report.

The IITRI report itself (not the addendum) says that "continuous asynchronous interference-mode pacing is regarded by physicians as undesirable in the majority of pacemaker patients." But, the report goes on to say that as a response to interference, "reversion is obviously more preferable than total inhibition, which is potentially catastrophic."

It appears that the physical condition of the pacemaker owner and the duration that his pacemaker may be in competition with his heart's intrinsic pacing activity are important variables in judging whether competition would be harmful. The testimony suggest that individuals for whom periods of competition would be dangerous would be unlikely to be moving about in the vicinity of the EHV lines.

The many individuals who use transtelephone monitoring find their pacemaker in competition with the intrinsic heart activity once a week. They place a magnet over the pacemaker to cause it to revert to asynchronous operation and then use an external device to sense and send pacemaker rate information from their home over the telephone lines to a collection point. Battery life varies widely, and the pacemaker's asynchronous rate is an indication of battery condition; the rate begins to decrease as the battery wears out, and scheduled replacement is obviously important. Toler's struck testimony includes a cardiologist's information

". . . pacemaker induced ventricular fibrillation caused by transtelephonic monitoring would not be expected to occur."
—Toler (struck testimony)

"In more than 99.9 percent of transmissions the induction of a competitive magnet-produced rhythm to detect pacemaker rate is without meaningful effect. Pacemaker-produced premature ventricular contractions (PVC) [or premature ventricular beat] occur but are not sustained, and only very rarely do multiple PVCs require cessation of

that he would advise against transtelephonic monitoring for patients with electrolyte disorders, with heart muscles that receive inadequate blood flow, or that use certain cardiac drugs.

Apparently, patients who monitor their pacemaker battery condition via the telephone are healthy enough that their doctors do not anticipate that competition will prove harmful.

use of the magnet. No episode of ventricular fibrillation or sustained tachycardia competitively induced has occurred." – Cardiologists Furman and Escher in 'Transtelephone Pacemaker Monitoring Five Years Later', Annals of Thoracic Surgery, Vol. 20, No. 3, September 1975.

Testimony Suggesting Ways to Minimize Problems

Several of those testifying suggested that, because of the possibility of the EHV lines affecting pacemaker operation (and maybe also affecting the pacemaker owner), steps should be taken to keep the pacemaker owner away from the lines. Various approaches were mentioned.

Toler suggested that the transmission line be routed to minimize the number of people exposed to the fields. He also suggested that additional information could better define the problems associated with 60-Hz fields so that improved interference characteristics could be designed into pacemakers.

Driscoll suggested that the power companies should be responsible for posting the right-of-way to warn of shock and pacemaker problems. He also said that they should fund a "candid, comprehensive, and continuing educational and warning program directed at informing pacemaker owners that fields within the right-of-way can interfere with pacemaker function." David C. Momrow of the New York State Department of Health described a health education program that could be employed along the right-of-way.

Asked to assume that the 765-kV lines can interfere with the pacemaker of an individual standing under the lines, Doyle's opinion was sought on actions or warnings to avoid medical problems. He stated that pacemaker owners are now routinely appraised of "possible hazards of electromagnetic fields encountered in their ordinary routines of living" and suggested warning signs at points of access to the right-of-way. He did not recommend restricting the use of artificial pacemakers.

". . . since the number of pacemaker-dependent individuals is small, and since those individuals are, in general, restricted in their ability to travel, the introduction of 765-kV transmission lines into the state would not cause me to recommend restricted use of artificial pacemakers."
–Doyle

It is not certain that pacemaker owners are actually as well informed on EMI by their doctors as Doyle suggests. The accompanying quotes, from a panel discussion on Interference with Pacemaker Function in *Modern Cardiac Pacing*, show no medical consensus about how much to tell the pacemaker owner. This hesitancy was also referred to in the testimony. There, the term "biopolitics" was

"I never know whether to frighten my patients by telling them about the hazards of interference."
–A Physician

used, with a suggestion that some would favor restricting the flow of information on interference that appears in the lay literature "since it invariably produced 'patient pacemaker panic'." Toler was also aware of this possibility and stated that the doctor considers the mental state of the patient in deciding how well informed the patient should be on the potential effects of EMI. He said that he believed "from discussions with cardiologists that there are patients you don't mention this [EMI problems] to because of the mental concern itcauses them and their tendency to withdraw from so many activities."

Thus, we see that even if the pacemaker owners are placed in jeopardy, there is controversy about whether to warn the individuals about that possibility.

"If they do not ask a question, I usually do not bring it up."
–A Physician

"Most of my patients . . . are elderly people. Most of them are retired. The question of coming close to anything that might cause trouble simply does not arise, and I do not bring the subject up. It is important not to scare them."
–A Physician

". . . in general, it is best not to raise the question with the patient unless you have reason to feel that he will end up in a high-risk situation . . . I do not think that you should talk to the patient most of the time."
–A Physician

"We usually tell the patients to read the company booklet that comes with the pacemaker. It explains all these problems."
–A Physician

Data Gaps and Unresolved Questions

No definitive or satisfactory resolution to the question of danger to pacemaker wearers from EHV power lines emerged from the testimony. According to the testimony, only a very few pacemakers were tested against 60-Hz voltages with no indication about how this small sample related to the entire population of pacemakers. Nor were we presented with a clear understanding of whether a pacemaker that entered into competition with the intrinsic heartbeat would generally constitute a danger to the owner.

It seems that the attorneys were seeking to address the question of effects rather than hazards. The first appropriate question is: "Can a pacemaker be affected under these EHV power lines?" It is then reasonable to ask the question: "At each of various distances from the lines, what percent of implanted pacemakers is likely to be affected and how?" Once the effects are understood, the clinical implications of these effects can be evaluated by cardiologists. An engineering approach to determine the likelihood of occurrence of effects would avoid the need to perform costly and potentially dangerous experiments using pacemaker wearers in the vicinity of the power lines. This approach would assist in determining whether the fields are indeed hazardous to pacemaker wearers.

Conclusions

Pacemakers that could sense the electromagnetic fields under 765-kV transmission lines are designed to revert to asynchronous or fixed-rate pacing for as long as they sense interference. If maximum coupling of the transmission line fields to a pacemaker's sensing circuit occurs, pacemakers with unipolar catheters could sense interference within about 45 m (150 ft) of the center of the right-of-way. Pacemakers with bipolar catheters are unlikely to sense interference. Reversion to asynchronous operation appears to have no health effects, except for persons sensitive to competition between the heart's own rate and the pacemaker's reversion rate. Although little testimony was presented about the health implications of competition, it was indicated that those who would be harmed by such competition are generally hospitalized and unlikely to be in the vicinity of a 765-kV transmission line. The testimony also indicated that no cases of transmission line fields interfering with pacemaker operation have been recorded.

Recommendations

- Collect better data on pacemaker sensitivity to 60-Hz electromagnetic interference.
- Define better the relationship between the electromagnetic fields under transmission lines and the voltages and currents likely to be induced on the leads of an implanted pacemaker.
- Estimate the future population of the various types of catheters and pacemakers.
- Understand the probability of a pacemaker being affected by transmission line fields at various distances from the center of the right-of-way.

Work should be undertaken to better define the relationships between external electric and magnetic fields and the voltages induced at the pacemaker electronic package. Then, the effects of voltages applied directly to the pacemaker on the bench could be discussed as if they had resulted from actual fields. With that knowledge, measurements of electromagnetic fields will reveal the voltages that these fields would induce in an implanted pacemaker.

Defining the interaction of the pacemaker and the EHV fields demands a statistical approach because of the many variables that must be recognized in evaluating the effect of the power line's fields on a pacemaker. It is not enough to know that effects would occur under given situations. Instead, the probability of the pacemaker's being affected at various distances from the lines should be known.

A major factor involved in power line-pacemaker interaction is the through-the-tissue current path. The IITRI modeling work assumed a 19-cm (7.5-in.) current path oriented parallel to the electric field, but this path must actually be described by two variables: its length and its orientation in relation to the electric field. Pacemaker implanting methods should be surveyed to answer the following questions:

- What is the statistical distribution of current-path lengths for pacemakers in use?
- How is the current path likely to be oriented during a person's normal movements?

- Induced voltage is proportional to the cosine of the angle between the voltage gradient and the current path. For a person near or under a power line what is the distribution of the cosine of that angle?

Another unknown is the coupling factor between the external *E*-field and the voltage drop inside the chest. IITRI assumed that the voltage drop inside would be the same as that outside. However, a 3-to-1 range in voltage drop was observed among several individuals, and another expert claims that the IITRI figures should be increased by 40%. Thus, through measurements and/or modeling, more needs to be determined about this coupling constant. For example:

- How does this coupling constant vary from individual to individual?
- Is it a function of body attitude?
- Are there other important variables?

Thresholds of effect were noted as voltages were applied to the catheters of a few pacemakers and a wide range was found. Pacemakers currently being implanted should be surveyed to determine the characteristics of the pacemaker population in the near future. Measurements should also be conducted to answer questions such as:

- Are the low thresholds of effect described by Toler (see Figure IV.4) more representative of the population than are the thresholds measured by IITRI?
- Why are the thresholds of effect furnished to IITRI by the manufacturers almost an order of magnitude above those of Toler?
- What is the threshold of effect over the actual and the projected population of implanted pacemakers?
- What is the effect of EMI on each of the pacemaker types and what proportion of the pacer population is (and will be) represented by each type?

Bibliography

Few reports have been published on pacemaker sensitivity to electromagnetic interference by transmission lines. One report is referenced extensively in the hearings:

- R. A. Zalewski, "Effect of EHV Lines on Heart Pacemakers," IIT Research Institute, Final Report E8128 (June 1975), sponsored by the American Electric Power Service Corporation. This report became Exhibit UUU at the hearings.

Two other recent IITRI publications not described in the hearings include:

- J. E. Bridges, M. J. Frazier, and R. G. Hauser, "The Effect of 60-Hz Electric Fields and Currents on Implanted Cardiac Pacemakers," IEEE 1978 International Symposium on Electromagnetic Compatibility, IEEE Catalogue 78-H-1304-5-EMC, pp. 258-265 (June 1978).
- J. E. Bridges and M. J. Frazier, "The Effects of 60-Hz Electric and Magnetic Fields on Patients with Implanted Cardiac Pacemakers," IIT Research Institute Project No. E8167, Draft Report, EPRI Contract No. RP679-1 (November 1976).

V OZONE

Relatively little ozone is produced from UHV lines,* and its effects are restricted to the immediate vicinity of the right-of-way by atmospheric diffusion, mixing, and decay by oxidation. About one-tenth as many nitrogen oxides as ozones are produced—so few that the witnesses easily agreed that no effects would be seen. Because ozone emission peaks during heavy rain and snow at about 30 times the fair weather rate, witnesses concentrated on potential ozone effects during foul weather.

The hearings focused on three central questions:

- What are the local increases in ozone concentrations due to 765-kV lines?
- How do these increases compare with the local background concentrations in ozone?
- Are there potentially important biological effects?

In several hundred pages of direct testimony and cross examination, R. K. Stevens, of the National Environmental Research Center of the Environmental Protection Agency; W. N. Stasiuk, Ph.D., of the Department of Environmental Conservation of the State of New York; J. F. Roach, Ph.D., of Westinghouse Electric Corporation; N. E. Bowne, B.S., of The Research Corporation of New England; I. A. Leone, M.S., of the Department of Plant Biology, Cook College, Rutgers--the State University of New Jersey; R. E. Carroll, M.D., of the Albany Medical College; and D. A. Driscoll, Ph.D., of the Department of Environmental Conservation of the State of New York address these questions with testimony that centers on identifying:

- The rates of ozone production from 765-kV lines under various weather conditions.

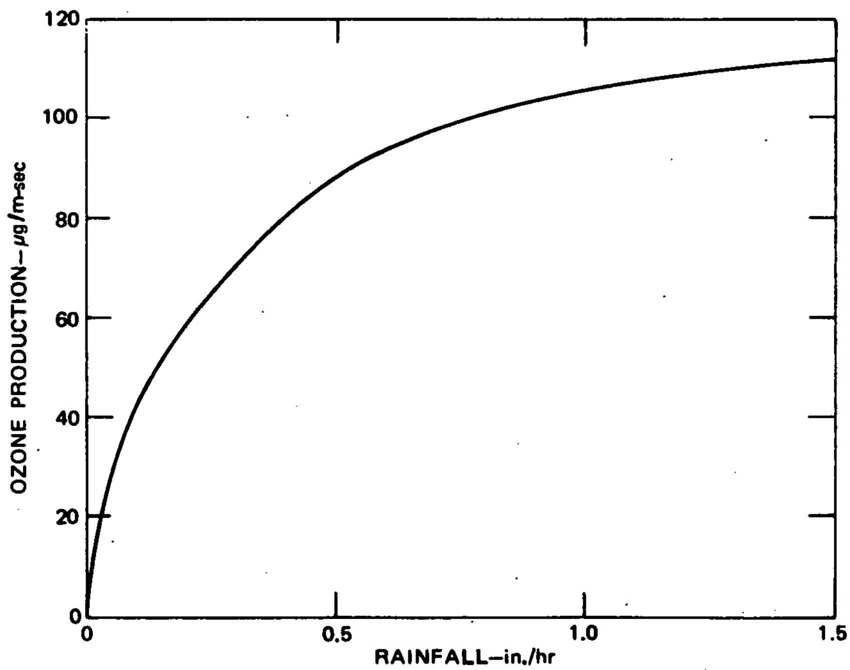
"I must assume that the ozone figures presented for 765-kV transmission lines will prevail during the plant growing season, roughly May through September. In light of these data:
(1) The general consensus seems to be that 765-kV transmission lines will add 5 to 9.2 ppb ozone to the atmosphere at ground level and this during the worst conditions of 'foul weather,' fair weather predictions being 0.03 x foul weather predictions.
(2) This concentration range (5-9.2 ppb) per se is considerably below that required to injure the most sensitive plants (5 pphm or 50 ppb).
(3) During 'foul weather' conducive to elevated ground level concentrations from this source, the contribution from photochemically produced ozone would be at a minimum.
(4) During these 'foul weather' conditions, plants would be unlikely to absorb any gas in appreciable quantities since their stomata, being light dependent, would be in relatively closed position."
—Leone

*The peak levels of ozone emitted from a 765-kV transmission line are comparable to the level of hydrocarbons (a primary contributor to high levels of ozone in urban areas) emitted by autos spaced 60 m apart and traveling at 50 km/hr on a two-lane road. Hydrocarbons from large numbers of automobiles driven upon many roads are a primary cause of high ozone levels in urban regions. (This comparison was not made at the hearings.)

- The ozone background conditions present along the right-of-way in the absence of the lines.
- The additional ozone concentrations present at ground level during periods of peak production from the lines.
- The frequency of concentration increases during natural variations in the ozone background.
- The significance of the increases.

Ozone Production Rates

Corona discharge from overhead power lines ionizes the air and produces ozone. During rain, fog, and snow, water droplets form on the surface of the conductors and distort and raise the local electric field above the voltage required to break down air. In dry air, an electric field of about 25 kV/cm will cause arcing. In moist air, even lower fields will cause electrical breakdown. Fields of this strength occur only near the conductor surface and decrease approximately inversely with distance (Figures II.1 and II.2), thereby keeping corona and ozone generation close to the surface of the conductors. Figure V.1 shows the rate of ozone production for a typical 765-kV line design as a function of rainfall rate (Roach submitted this data). Bowne indicates that the maximum expected ozone production rate is about 50 μg/s per meter of transmission line (50 μg/m-s) and occurs during heavy rain, whereas the minimum rate is about 1.7 X 10^{-3} μg/m-s and occurs during fair weather. (Roach's data indicate a higher rate of emission equal to 116 μg/m-s during extremely heavy rain).



Source: Roach, Exhibit ZZ

FIGURE V.1. CALCULATED OZONE PRODUCTION AS A FUNCTION OF RAINFALL FOR A 765-kV LINE

Ozone Concentrations and Ozone Background

Two general approaches can be taken in determining ozone concentrations. The first approach, on which experts at the hearings relied heavily, is to calculate the concentrations by using atmospheric dispersion models. The second approach relies on data collected during line operation under various weather conditions. Some data have been gathered at the Apple Grove Test Facility.

Two primary cases of wind direction were considered in the hearings:

- Wind parallel to the lines, which produces the maximum ground level ozone increases during stable atmospheric conditions when wind speed is low and rain heavy.
- Wind perpendicular to the lines, which produces the minimum ground level ozone increases during fair weather, strong winds, and turbulence.

The increase in ozone concentrations that results depends strongly on wind and weather conditions. A light wind blowing parallel to the transmission line causes a buildup of ozone concentrations that peak downwind of a long straight section of line. A heavy wind, or a wind that does not parallel the line, causes much lower concentrations.

Parallel Winds. Figure V.2 shows the calculated ground level concentrations downwind of a line in parallel wind, when a 1-hr decay rate is assumed for ozone. (Ozone decays in 15 to 20 hr in rural areas characterized by clean air; in areas where nitrogen dioxides are high or, when atmospheric moisture content is high, decay requires only a few minutes.) The data show that the concentration is greatest when:

- The wind speed is low (less than 1 m/s)
- The wind is parallel to the line
- It is raining or snowing heavily
- The air is clean.

"The wind speed term appears in the denominator of the equation (the Gaussian diffusion model). As the wind speed approaches zero, the concentrations become extremely large. However, perfectly calm conditions do not occur in nature." *
–Bowne

The witnesses generally agreed after cross examination that the calculated concentrations under these conditions are between 7 and 9 ppb at ground level (not shown in Figure V.2). The peak is limited to center of the right-of-way, downwind of several miles of straight line, and concentrations decrease away from the line to 2.5 ppb at 100 m and to 0.5 ppb at 150 m. Thus, effects on air quality are confined to a narrow corridor along the lines.

"The worst conditions are: foul weather (rain, snow, or fog), light (less than 1 m/s) winds blowing parallel to the lines, and a stable . . . atmosphere. We are fairly confident that the actual measured value would be greater than 5 ppb but less than about 7 ppb . . ."
–Bowne

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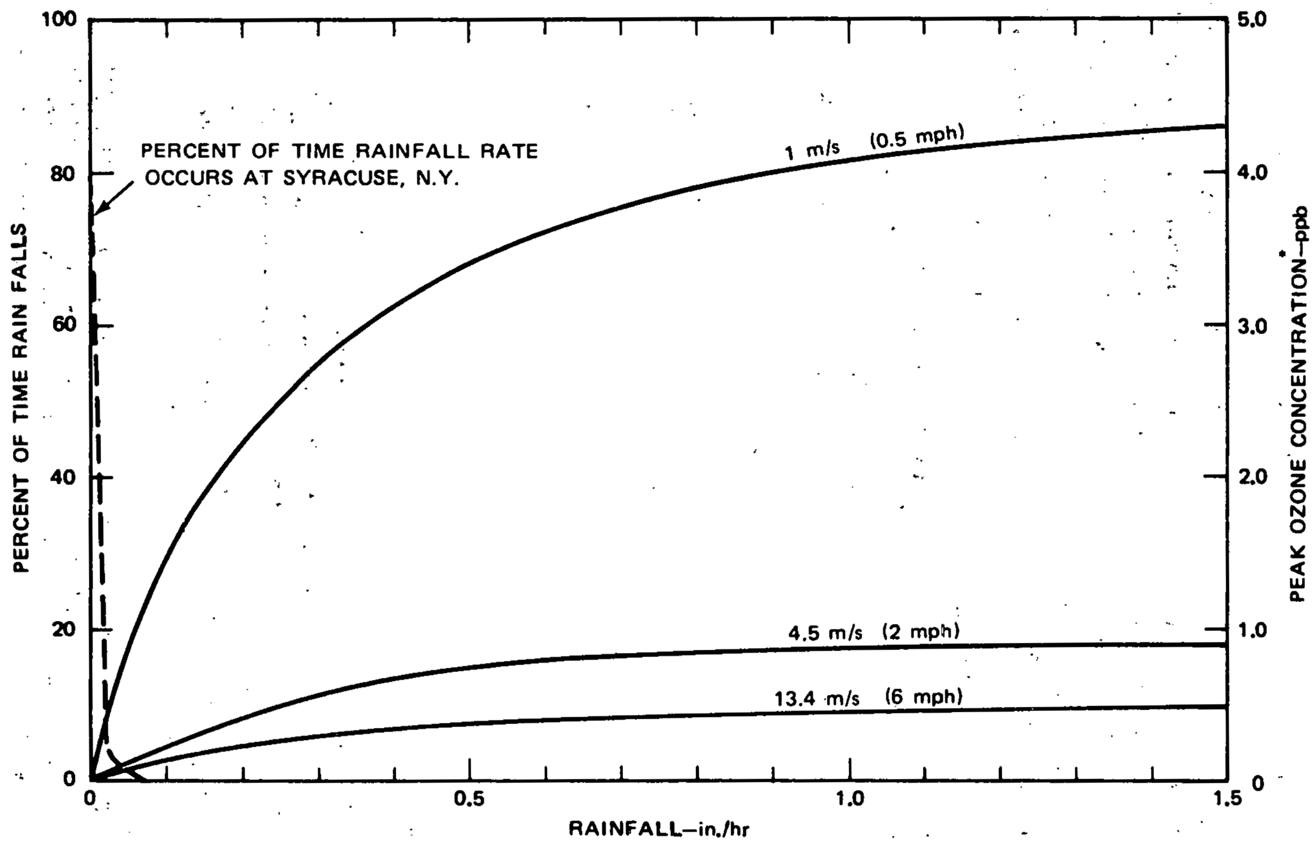
*Diffusion models can be used to calculate concentrations at zero wind velocity (Snow, 1976).



* Assuming a 1-hr decay rate for the ozone produced.

Source: Roach, Exhibit ZZ

FIGURE V.2 ESTIMATED MAXIMUM OZONE CONCENTRATION UNDER A 765-kV TRANSMISSION LINE IN PARALLEL WIND AS A FUNCTION OF RAINFALL RATE
(The figure also shows the percent of time during the year that the rain falls at the indicated rate. After accounting for the fraction of the time that rain falls, the annual average concentration would be 0.1 ppb in a 1 m/s wind, 0.02 ppb in a 4.5 m/s wind, and 0.01 ppb in a 13 m/s wind. These data indicate ground level concentration at the center of the right-of-way downwind of a long, very straight section of line.)

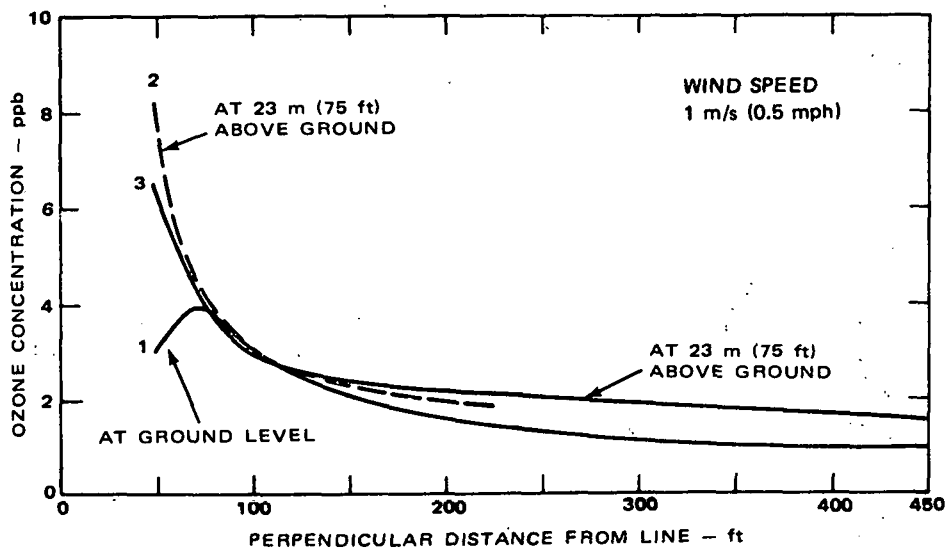
As shown in Figure V.2, downwind ozone concentrations decrease considerably in higher winds and when the rainfall is lighter. The Gaussian diffusion model predicts that concentrations increase rapidly as windspeed decreases. Much testimony was concerned with the likelihood of occurrence of such low wind speed conditions combined with little turbulence and heavy rainfall.

"At a distance for a line length of approximately 5 miles under these hypothetical conditions (stable wind of 0.5 mph), I would calculate approximately a concentration of 8 ppb . . ."
–Roach

Perpendicular Winds. The descriptions of ozone concentrations in perpendicular winds in the hearings were largely contained in the exhibits. Exhibits for this part of the testimony were not assessed by the SRI team in detail, and several were not available to the team. Exhibit YY, prepared by J. F. Roach, described dispersion model results for the Apple Grove Test Facility that are generally applicable to the proposed 765-kV lines.* Figure V.3, taken from that exhibit, shows results for perpendicular winds at 1 m/s. The concentrations shown would decrease approximately inversely with the wind speed, so that a 10 m/s wind produces a concentration one-tenth of that shown. Turbulence and atmospheric instability rapidly reduce the concentrations with distance.

"What would the fair weather incremental contribution to ambient ozone concentrations be . . .?"

"Approximately 0.03 times the foul weather values . . . this amounts to 0.5 ppb for the longitudinal 1 m/s wind and to 0.015 ppb for the transverse situation."
–Bowne



Source: Roach, Exhibit YY

FIGURE V.3. THEORETICAL ESTIMATES OF INCREASED OZONE CONCENTRATIONS DUE TO 765-kV TRANSMISSION LINE OPERATION. (Curve 1, which depicts ground level concentrations at Apple Grove (for the A line, which compares to the New York 765-kV transmission line) in an unstable wind blowing perpendicular to the line for mean rainy weather corona loss. Curve 2 depicts concentrations 23 m (75 ft) above the ground in the same conditions as for Curve 1. Curve 3 depicts concentrations 23 m (75 ft) above the ground in a stable wind blowing perpendicular to the line for mean fair weather corona loss.)

*The Apple Grove Test Facility in West Virginia is similar in design but not identical to the New York 765-kV transmission lines.

Other Wind Directions. Results for other wind directions were not discussed in detail. It was agreed that the concentrations would lie between the maximum for parallel winds and the minimum for perpendicular winds, and that the concentration increases would still be confined to the vicinity of the right-of-way. However, few supporting data were presented.

Weather Effects and Ozone Background. Ozone concentrations vary widely with time, season, and region. Figure V.4 shows peak hourly concentration for 3 years at an air quality monitoring station near Schenectady, New York.* During winter, the monthly peak 1-hr average concentration varied from about 30 to more than 150 ppb.

". . . stable conditions do not tend to occur during daylight hours when photochemical ozone production will occur . . . The ozone contribution from the proposed lines is a maximum during the light wind/stable conditions, especially so if there is also foul weather. But such conditions when the power lines have their maximum contribution—occur when the ozone contributed by other sources, such as a motor vehicle, is likely to be low."
—Bowne

During rain and fog, when transmission lines contributions of ozone would be highest, background concentrations of ozone fall considerably below those that occur in fair weather (refer to Figures V.4 and V.5). For example, the average concentrations during rain and fog of about 6 ppb and 13 ppb were well below the annual averages, which ranged from 18.5 to 21.6 ppb over 3 years. Data from rural air monitoring stations in New York at Glen Falls and Elmira differed little from data gathered at Schenectady. Testimony indicated that some rural stations showed little diurnal variation in the ozone background, which ranged from 51 to 60 ppb at Whiteface, New York, and 60 to 68 ppb at Mt. Utsayantha, New York. Some urban regions showed diurnal ranges of 50 to 60 ppb from 2:00 to 5:00 p.m. to 3 to 8 ppb from 6:00 to 8:00 a.m. at Glen Falls, New York City, and Kingston.

The concentrations produced by the lines add to the highly variable background conditions:

- During fair weather, the maximum concentration increase due to 765-kV lines would be only about 0.25 ppb. Background concentrations range from 8 to more than 150 ppb during these periods.
- During rain, snow, or hail, the maximum concentration increase would be 8 ppb. Background concentrations would peak at about 90 ppb.
- During fog, the maximum concentration increase would be 8 ppb. Background concentrations would peak at about 50 ppb.

Also important is the statistical occurrence of rain and fog. Figure V.2 shows the annual percentage occurrence of rainfall at Syracuse. Clearly, rain occurs a small fraction of the time in New York.

*Exhibit HHH, Data from Continuous Air Monitoring Stations, supplied by the New York State Department of Environmental Conservation.

Wind speed and constancy of direction are also highly variable. J. F. Roach states that, for the maximum estimated concentration of about 8 ppb to occur in a wind parallel to the lines with a speed of 1 m/s, it would take 10 hr for the concentration to reach this value. It seemed highly unlikely to the witnesses and to the SRI team that such stable conditions would occur for sufficient time to establish the peak concentrations predicted by the models. The variations in ozone concentrations due to the lines are currently difficult to measure; before statistically significant variations can be recorded, extensive data must be collected.

In only about 30 hrs out of the year, or 0.34% of the time, could the worst case maximum ozone increase occur. During these periods, the background concentrations of ozone would be considerably below the annual average concentrations because of atmospheric moisture content and cloud cover (which considerably reduces photochemically produced ozone).

"The mean foul weather ground level concentration of ozone produced by the proposed lines is predicted to be 1 ppb, which would occur less than 10 percent of the time, whereas ambient mean hourly average ground level ozone concentrations in excess of 50 ppb are common. It is not surprising, therefore, that field investigations conducted adjacent to actual power lines have not detected concentrations above ambient levels."
–Roach

"In reviewing data on ozone variability in the vicinity of power lines, it is important to keep in mind the fact that because of normal variability in ozone concentration, differences . . . of 5 ppb or less cannot be considered significant unless supported by extensive meteorological data, as well as simultaneous measurements by other ozone monitors."
–Stevens

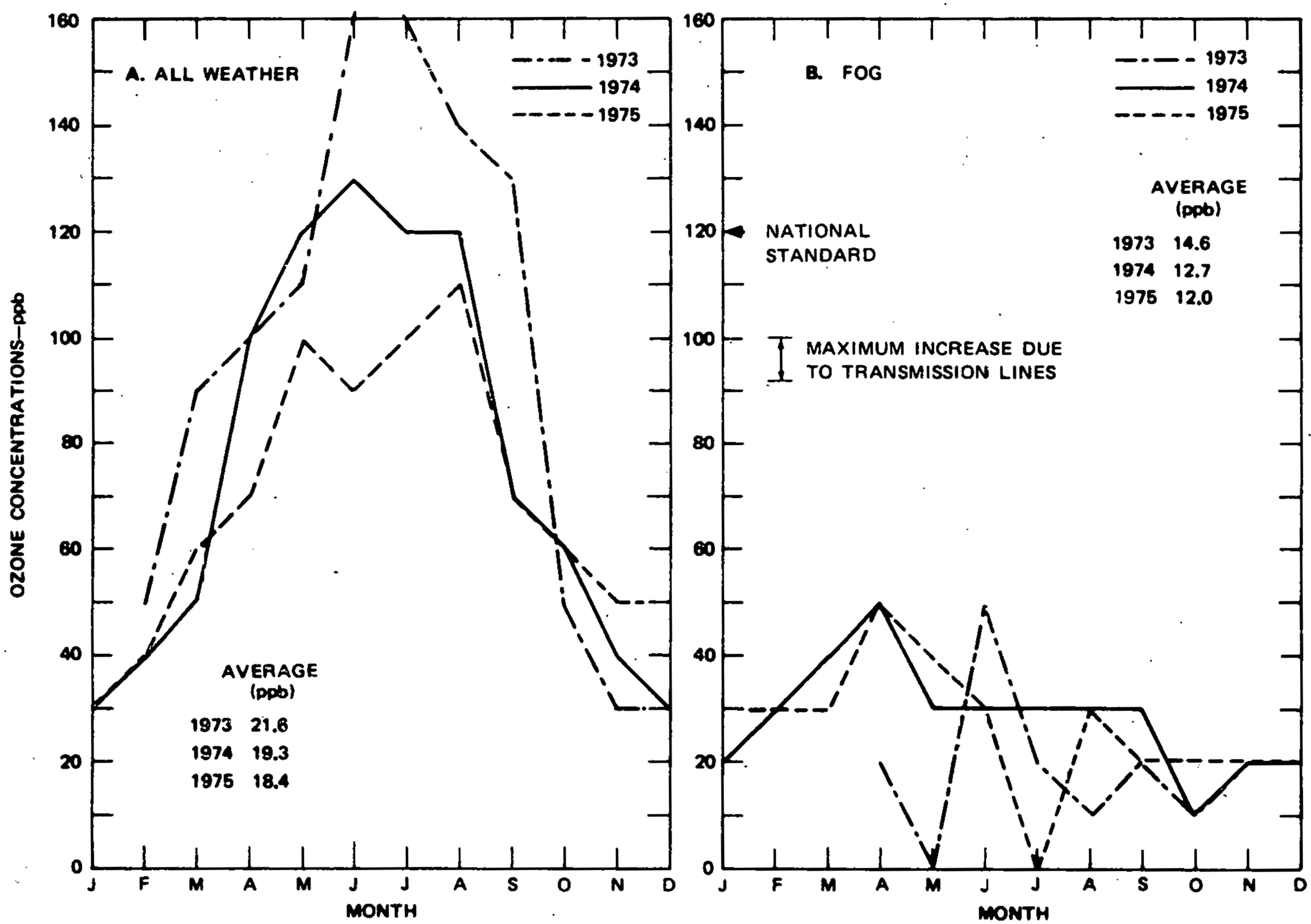
"How frequently do such conditions of F stability [little mixing] and very light 1 meter per second, winds occur in the vicinity of the proposed lines?"

". . . I would expect these conditions to occur about 3.8 percent of the time, which is 333 hours per year. Approximately one-third of these [conditions] would exhibit foul weather."
–Bowne

Biological Effects of Ozone Produced by Transmission Lines

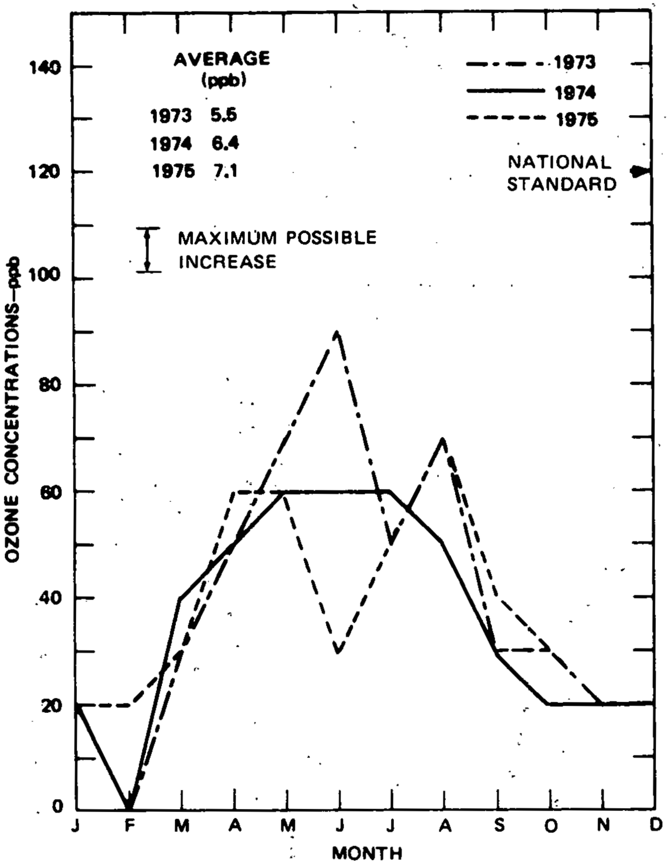
Experts at the hearings concluded that no biological effects would be attributable to increased ozone levels along the transmission line right-of-way. Leone testified that visible injury to plants occurs at concentrations of 50 ppb and above, although there are a few plant species sensitive to 30 ppb (e.g., an extensively cultivated variety of tobacco called Bel W-3). Carroll testified that "effects" on man and other mammals are not

"After considering all submitted testimony [with] respect to prevailing ozone concentrations from photochemical sources, together with concentrations likely to be emitted from 765-kV transmission lines, my position is that any effects of transmission line-emitting ozone on ozone-sensitive plant species would be minimal at best."
–Leone



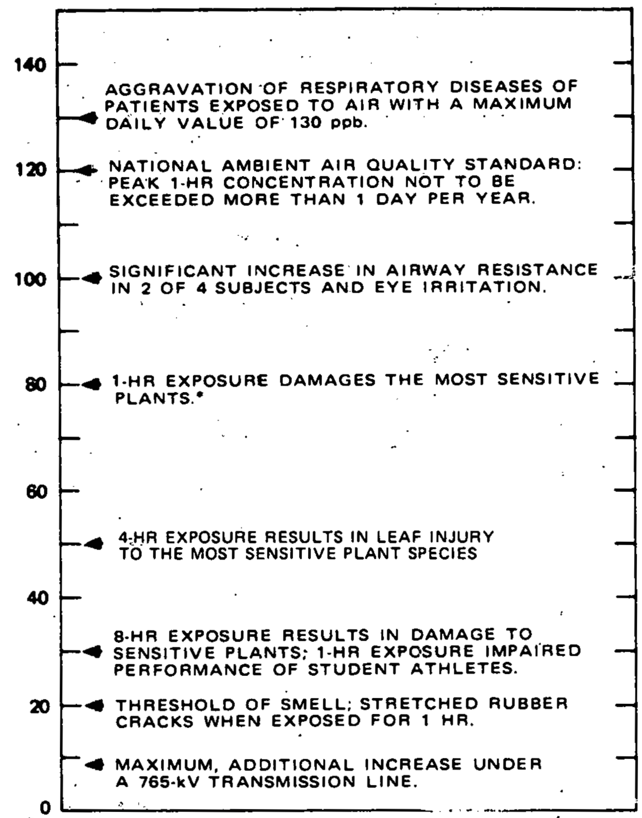
Source: Driscoll, Exhibit HHH

FIGURE V.4 ONE-HOUR PEAK OZONE CONCENTRATIONS AT SCHENECTADY, NEW YORK, UNDER ALL WEATHER CONDITIONS AND DURING FOG
(The annual average concentrations are considerably less than the peak concentrations. The concentrations are considerably reduced during fog because atmospheric moisture increases the decay time of ozone. The average concentrations during fog are less than half the average concentrations during all weather. The mean increase due to transmission line operation during foul weather is 1 ppb—too small to be seen in these figures.)



Source: Driscoll, Exhibit HHH

FIGURE V.5 ONE-HOUR PEAK OZONE CONCENTRATIONS DURING RAIN AT SCHENECTADY, NEW YORK
(Ozone concentrations during rain are higher than during fog)



* National Research Council, 1977

Source: National Air Polution Control Administration, 1970

FIGURE V.6 EFFECTS OF DIFFERENT LEVELS OF EXPOSURE TO OZONE AND MAXIMUM INCREASE IN OZONE CONCENTRATION DUE TO TRANSMISSION LINE OPERATION
(The average increase due to transmission line operation is too small to be seen on these plots)

known to occur at ozone concentrations less than 100 ppb, and indeed, that definitive effects begin at 210 ppb. Figure V.6 shows the range of effects of ozone at various exposure times. The figure is placed adjacent to the transmission line data for a better comparison with the data discussed in the previous section. The present air quality standard for ozone concentrations is 120 ppb as a daily maximum 1-hr concentration not to be exceeded on more than 1 day during the year *(Federal Register*, 1979). Dr. Driscoll concludes that no additional violations of the state and federal air quality standards are likely to occur because of the operation of the proposed lines.

"I do not believe that these levels will have any demonstrable effect on human health. During the worst foul weather period, when levels would be highest, the additional ozone from the lines is estimated at levels below 8 ppb. These levels are at least 10 times less than the government standard of 80 ppb. They are 25 times below the level of 200 ppb where demonstrable human effects would be expected. They are about one-half the level where man would be expected to notice the distinctive odor of ozone."*
—Carroll

"In summary, based on an analysis of three years of data at two continuous air monitoring stations having ozone data representative of conditions along the proposed lines, the proposed transmission lines would not cause any additional violations of the state and federal ozone standards."
—Driscoll

There are no demonstrated effects at low levels of exposure (below 30 ppb). The witnesses were asked about studies in this range and the potential for effects. Three major points were raised:

- Little is known about how to look for ozone damage at levels below 30 ppb. Most studies look for visible leaf damage as an indicator of plant damage.
- Ozone (a free radical) damage is analogous to damage by free radicals induced by ionizing radiation. Therefore, a linear dose response relationship for ozone damage is possible.
- Ozone damage in animals is enhanced by the presence of other air pollutants such as sulfur oxides or nitrogen oxides, but the data for plants are inconclusive.

Dr. Carroll notes that because of the variability in sensitivity of biological populations, he would expect some groups of plants to be very sensitive; hence, by implication, thresholds lower than have been definitely demonstrated may exist for certain species. He indicates that effects at low levels are poorly known and states that he has little idea of what effects to look for. Each species has a range of variation in its ozone sensitivity, although damage consistently occurs in the spongy parenchyma cells (i.e., the leaf tissue characterized by large voids between adjacent cells), causing stippling as the cells around the stomata die.

"I would not know what effects to look for. I think that is another way of answering that I would not consider it worthwhile because I would not know what parameters to measure to study effects at levels in the 10 to 20 ppm range. I would be almost certain that we could not find anything—we do not know what to measure that would have any results at all."
—Driscoll

*The standard is now 120 ppb.

Ms. Leone addressed the possibility of a biochemical mechanism of ozone damage similar to, if not identical with, that by which ionizing radiation damages tissue. Ms. Leone acknowledges that free radicals might damage plants but states that little evidence is available.

Dr. Carroll does not discuss in detail evidence for chromosomal damage in response to ozone, but noted that one study reported that the chromosomal breaks in human cell cultures exposed to 8000 ppb ozone corresponded to those produced by 200 roentgens of (ionizing) radiation; a second study noted chromosomal damage to hamster lymph cells following exposure to 200 ppb of ozone for 5 hr. Dr. Carroll considered the parallels between ozone and ionizing to be speculative.

Dr. Carroll differentiates between effects due to ozone alone and the oxidant mixtures. However, he notes, for example, that the combined effects of ozone and sulfur dioxide, when each is at a concentration of 370 ppb, were much stronger than either chemical alone would produce.

Ms. Leone testified that synergism with both sulfur dioxide and nitrogen dioxide is reported in the literature, but that the data are still inconclusive. Experiments with ozone-sulfur dioxide and ozone-nitrogen dioxide pairs available at the time of testimony showed that at least 50 ppb of each chemical was necessary for effects to be seen. In addition, the concentrations of ozone required to cause effects in greenhouse tests are consistently higher than those required under natural conditions. The magnitude of this difference was not given.

"The effect of ozone is to produce free radicals in a manner similar to ionizing radiation and that if this is the case, it is possible that no minimum threshold may exist with respect to ozone impact."
–Leone

"Is this an appropriate concept for damaged plants as well?"

"This is a hypothesis that is considered with respect to plants as well."
–Leone

"If ozone acts in a manner similar to ionizing radiation, then one might extrapolate that no minimum threshold exists for genetic damage, and that any additional exposure of a potential child-bearing population should be kept as low as possible. This theory, however, and the implications for exposure standards is still speculative. To my knowledge it has not resulted in changing the recommendation for exposure limits by any scientific groups."
–Carroll

"Are you saying then, Professor Leone, that even if synergism of ozone with other gases did occur, it is your expert opinion that [at] levels of ozone lower than 50 ppb, no injury to plants would occur?"

"I would not say that. It is possible that effects at lower combinations of ozone with SO_2 might occur, but I have no way of knowing that at this time. This is work that is going on at the present time, and there are pros and cons. There is evidence for synergism and there is evidence against synergism, and until we have a burden of proof, we cannot make a conclusive statement."
–Leone

Data Gaps and Unresolved Questions

None of the witnesses described ozone concentrations very close to the transmission lines. This could be important for determining whether or not linemen working on energized lines during periods of high corona discharge might possibly be exposed to harmful ozone levels. Also, little attention was paid to concentration increases at heights above ground level. This is important for determining whether or not trees along the right-of-way are exposed to harmful levels of ozone.

Conclusions

The worst case increase in ozone concentration, which occur only during rain and fog, of about 8 ppb could occur only about 0.3% to 0.4% of the time. During these periods, the ozone background along the New York right-of-way is limited to about 100 ppb. Thus, ozone produced by 765-kV transmission lines would probably not contribute to violations of the National Ambient Air Quality Standard for ozone of 120 ppb, which is not to be exceeded as a 1-hour peak concentration on more than 1 day during the year. According to the EPA *(Federal Register,* 1979), "... the Administrator has determined that a standard of 0.12 ppm [120 ppb] is necessary and is sufficiently prudent unless and until further studies demonstrate reason to doubt that it adequately protects public health."

Recommendations

- Measure ozone concentration increases from 765-kV lines to confirm model calculations. DOE recently undertook these measurements.

The model calculations discussed in the testimony predict little or no additional ozone damage to plants or animals from the operation of UHV systems as high as 765 kV. At the same time, however, the testimony indicates that few data exist on whether ozone concentrations around operating systems increase. To check the model results, data from line operations has been gathered by DOE.

Because ozone and other oxidants are widespread pollutants in the atmosphere, considerable research on the biological effects of these pollutants has been under way for some time. Transmission lines contribute to minor localized ozone increases, and ozone background concentrations vary widely by hour, day and season at virtually all potential transmission line sites; therefore, additional biological studies in conjunction with line operation are unwarranted, unless new data indicate considerably higher ground level concentration increases than those cited at the hearings.

"Contrary to statements of a few of the authors of papers we have reviewed, it is not possible to state that 'no problems exist' with respect to ozone production by high voltage power lines. Studies of this type can only conclude that significantly increased levels of ozone have not been demonstrated to exist in spite of efforts to measure such increases."
—Stevens

"If further studies of this type (ozone measurements) are undertaken, long path measurements . . . might prove to be a very useful tool . . . since such measurements would reduce the 'noise' caused by spatial variation of the ozone levels."
—Stevens."

Bibliography

An excellent overview of ozone production by transmission lines is presented in:

- The Electric Power Research Institute, *The Transmission Line Reference Book/ 345-kV and Above* (1975).

An overview of recent literature on ozone production by transmission lines is provided in:

- IIT Research Institute, "Evaluation of Health and Environmental Effects of Extra High Voltage (EHV) Transmission," draft report prepared for the Environmental Protection Agency (May 1978).

Ozone concentrations at zero wind speed are described in:

- R. H. Snow, Y. Shau, and J. E. Bridges, "Ozone Concentrations Near Transmission Lines Under Conditions of Zero Wind Velocity," IIT Research Institute, Final Report E9640, sponsored by Commonwealth Associates, Jackson, Michigan (October 1976).

Ozone concentrations at low wind speed are described in:

- J. F. Roach, V. L. Chartier, and F. M. Dietrich, "Experimental Oxidant Production Rates for EHV Transmission Lines and Theoretical Estimates of Ozone Concentrations Near Operating Lines," *IEEE Transactions on Power Apparatus and Systems,* Vol. PAS-93, No. 2 (March/April 1974). This article was used as Exhibit YY.

Data on ozone production by transmission lines in the Proceedings of the 18th Hanford Life Sciences Symposium, "Biological Effects of Extremely Low-Frequency Electromagnetic Fields," Richland, Washington, October 16-18, 1978.

Major literature sources on the biological effects of ozone are:

- National Academy of Sciences, "Medical and Biological Effects of Environmental Pollutants: Ozone and Other Photochemical Oxidants" (National Academy of Sciences, Washington, D.C., 1977).
- National Air Pollution Control Administration, "Air Quality Criteria for Photochemical Oxidants," EPA Publication AP-63 (March 1970).
- National Research Council, "Ozone and Other Photochemical Oxidants" (1977).

The Environmental Protection Agency recently revised the National Ambient Air Quality Standard for Oxidants. A review of the literature on biological effects of ozone is described in:

- "Revisions to the National Ambient Air Quality Standards for Photochemical Oxidants," *Federal Register,* Vol. 44, No. 28 (February 8, 1979).

Other important exhibits include:

- Exhibit ZZ, "Predicted Maximum Ground Level Ozone Concentrations for the Proposed Transmission Lines," submitted by J. F. Roach.
- Exhibit HHH, "Data from Continuous Air Monitoring Stations," submitted by D. A. Driscoll.

Appendix

A BRIEF HISTORY, INCLUDING A LIST OF THE LEGAL FIRMS AND WITNESSES THAT APPEARED, OF THE NEW YORK STATE PUBLIC SERVICE COMMISSION COMMON RECORD HEARINGS IN CASES 26529 AND 26559 AS EXERPTED FROM THE FINAL JUDGMENT*

"BY THE COMMISSION:

In 1973, the Power Authority of the State of New York applied for a certificate of environmental compatibility and public need, under Article VII of the Public Service Law, for a proposed 765-kV transmission line from the Canadian border, near Massena, to Marcy, a distance of about 155 miles. Early in 1974, Rochester Gas and Electric Corporation and Niagara Mohawk Power Corporation applied for a certificate for a 765-kV line from the Pannell Road Substation in Monroe County to Volney, a distance of about 66 miles.[1] The hearings in each of those cases disclosed the existence of questions about the health and safety aspects of 765-kV lines generally, and, on a motion made by staff, the Administrative Law Judges in the two cases jointly ordered common record hearings on those issues. Routing and other remaining issues in each case continued to be treated separately; the RG&E case (26559), which involves a line not planned to be in service before 1983, has been dormant since the common record hearings began, but the PASNY case (26529) has proceeded to its conclusion in all respects save health and safety. Pursuant to Opinions 76-2, 76-12 and several subsequent orders, certification of the route is now complete, construction is authorized and under way, but operation is precluded pending completion of the health and safety inquiry.[2] The premise for authorizing construction was our determination, in Opinion No. 76-12, that even the worst-case health and safety findings would not preclude operation of a transmission line at a nominal voltage in the 765-kV range; we felt that any adverse health and safety effects could be adequately treated through various operating conditions or protective measures. . . ."

[1]PASNY, RG&E, and Niagara Mohawk are collectively referred to as applicants.

[2]Case 26529, Opinion No. 76-2, issued February 6, 1976; Order Amending and Clarifying Opinion No. 76-2, April 1, 1976; Opinion No. 76-12, issued June 30, 1976; Order Granting Further Partial Certificate of Environmental Compatibility and Public Need, issued December 29, 1976; Order Granting Partial Certificate of Environmental Compatibility and Public Need for Certain Route Segments and Denying Motion for Certification of Other Route Segments, issued June 21, 1977; and Order Granting Certificate of Environmental Compatibility and Public Need for Remaining Route Segments, issued January 12, 1978.

*New York Public Service Commission, "Opinion No. 78-13: Case 26529–Power Authority of the State of New York (Moses-Massena 230-kV Transmission Line, Massena-Moses 765-kV Transmission Line, and Massena-Quebec 765-kV Transmission Line; and Cases 26529 and 26559–Common Record Hearings on Health and Safety of Extra High Voltage Transmission Lines. Opinion and Order Determining Health and Safety Issues, Imposing Operating Conditions, and Authorizing, in Case 26529, Operation Pursuant to Those Conditions" (June 19, 1978).

CONCLUSION

"We find, on the basis of the record in the common record hearings and in Case 26529, that the operation of the facilities proposed by PASNY in Case 26529, the construction of which we have previously approved, is needed to serve the public interest, convenience and necessity, and will have, if conducted in accordance with the conditions described in this Opinion and specified in its ordering paragraphs, the minimum adverse environmental impact considering the state of available technology and the nature and economics of the various alternatives. We also find that the standards and conditions here adopted should also be applied to the transmission line proposed by Rochester Gas and Electric Corporation and Niagara Mohawk Power Corporation in Case 26559. We shall issue presently an order requiring Niagara Mohawk Power Corporation to show cause why these standards and conditions should not be applied to its Volney-Edic 765-kV transmission line, which we certificated in 1974[3] but which has not yet been built. It is also our intention to apply these standards and conditions, to the extent pertinent, to the operation at 345 kV of the transmission lines already certified in Cases 26462 and 26758[4] and Case 26717[5] and to all future proceedings pursuant to Article VII of the Public Service Law.

The Commission orders:

1. Subject to the conditions set forth in this Opinion and Order and in all previous applicable orders, the certificate of environmental compatibility and public need previously granted, in Case 26529, to the Power Authority of the State of New York is extended to authorize the operation of the transmission facilities to which it applies.

2. The operation of the 765-kV transmission lines here authorized is conditioned upon the following:

(a) PASNY is to acquire a right-of-way sufficient to exclude existing residences in an area extending 175 feet on each side of the centerline of the certified route.

(b) PASNY must acquire permanent rights to bar future residential development within a zone extending 125 feet on each side of the centerline of the certified route; it must also acquire rights to preclude, for a period not less than seven years, future residential development within a zone extending an additional 50 feet on each side of the centerline. The Commission reserves the right to require those additional rights to be made permanent or to permit earlier development if warranted by the result of the program of studies described in Ordering Paragraph 5.

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[3]Case 26251, Niagara Mohawk Power Corp. (Oswego-DeWitt, Oswego-Volney, and Volney-Edic), 14 NY PSC 266 (1974).

[4]Cases 26462 and 26758, Long Island Lighting Company (Holbrook-Ruland, Holbrook-Newbridge, and Holbrook-Pilgrim-Ruland-Bethpage), 16 NY PSC 627 (1976).

[5]Case 26717, Long Island Lighting Company (Riverhead-Brookhaven), 16 NY PSC 737 (1976).

(c) PASNY shall report to the Commission and attempt to resolve all complaints concerning audible noise produced by the lines. In the event such a complaint is made by the owner of a house located within a zone extending from the edge of the right-of-way to a point 600 feet from the centerline of the certified route and cannot be satisfactorily resolved by other means, the Commission may require PASNY to offer to purchase or move that house. This option shall exist for a period of 18 months from the date on which the 765-kV transmission line is made fully operational. The resale by PASNY of any such house shall be on notice to the buyer of the events that resulted in PASNY's having acquired it.

(d) PASNY shall contribute an amount, to be determined by the Commission but not to exceed 2% of the total cost of constructing the facilities here certified, toward the funding of the program of studies described in Ordering Paragraph 5.

(e) PASNY shall undertake a suitable program, consistent with this Opinion, for grounding and bonding fixed metal objects on the right-of-way and large movable metal objects likely to be brought on the right-of-way. It shall also undertake a suitable program for informing persons living near the right-of-way of the possibility of induced shocks from the lines and the best methods for avoiding them.

(f) PASNY shall serve a copy of this Opinion and Order, together with a cover letter to be composed by the Commission's staff, upon every manufacturer of cardiac pacemakers in the United States and upon every association of cardiologists in New York State.

(g) PASNY shall establish a procedure for receiving, responding to, and reporting to the Commission every complaint concerning the operation of the transmission lines here certified.

3. PASNY shall not energize the transmission lines here authorized until it has agreed to comply with the conditions here imposed and has submitted to the Commission two copies of, and the Commission has approved, a detailed supplemental environmental management and construction plan (EM&CP) setting forth in detail its proposals for complying with the terms of conditions (c), (e) and (g) in Ordering Paragraph 2, above. Contemporaneous with its submission of the supplemental EM&CP, PASNY shall serve the Department of Environmental Conservation and the St. Lawrence-Eastern Ontario Commission, as well as any party to this proceeding who had previously requested copies of the EM&CP filed pursuant to Opinion No. 76-2, with a copy of its supplemental EM&CP and shall notify every other person included on the service list in this proceeding that it has submitted its supplemental EM&CP, indicating the location of the places where the supplemental EM&CP is available for inspection, that any person desiring additional information may receive it by written request to PASNY indicating the information of concern, and that any person wishing to comment on the supplemental EM&CP should do so by filing comments with the Commission and serving them on the applicant within 20 days of the submission of the supplemental EM&CP. PASNY shall report any proposed changes in the supplemental EM&CP to the staff, which shall refer them to the Commission for approval.

4. The Commission reserves the right, at any time during the existence of the certified facilities, to impose such reasonable restrictions on the operation of the line—including but not limited to its operating voltage and loading—as may be necessary to protect the health or safety of the public and any other protective measures, as a condition to the line's continued operation, that the Commission determines, after hearing, necessary as a result of the further research it is requiring or which may otherwise be brought to its attention.

5. The staff of the Commission is directed to submit, within 60 days, a proposal for a program of studies into the biological effects of the electric and magnetic fields generated by extra-high voltage transmission lines.

6. The staff of the Commission is directed to serve a copy of this Opinion on the United States Occupational Safety and Health Administration.

7. The standards and conditions here adopted shall apply, to the extent pertinent, to the transmission facilities for which certification is sought in Case 26559.

8. Except as here modified, the recommended decision of Administrative Law Judges Thomas R. Matias and Harold L. Colbeth is adopted as the Opinion of the Commission.

9. Except as here granted, all exceptions to the recommended decision of the Administrative Law Judges, and all outstanding motions, are denied.

10. These proceedings are continued."

APPEARANCES BEFORE THE COMMISSION

Howard A. Jack, Robert A. Simpson, Arthur D. Rheingold, Cornelius J. Milmoe, Michael Flynn, Stanley Klimberg and John Dax (Legal Assistant), Esqs., Empire State Plaza, Albany, New York 12223, for the Staff of the Public Service Commission.

Scott B. Lilly, John R. Davison, Robert Zagier, and James Woods, Esqs., 10 Columbus Circle, New York, New York, and Francis X. Wallace, Esq., 80 New Scotland Avenue, Albany, New York, for the Power Authority of the State of New York.

C. H. Moore, Jr., Assistant Attorney General, Two World Trade Center, New York, New York, for the New York State Department of Law.

Edward R. Patrick, Norman Willard and Richard Feirstein, Esqs., 50 Wolf Road, Albany, New York, for the New York State Department of Environmental Conservation.

Julius Braun, Esq., New York State Campus, Washington Avenue, Albany, New York, for the New York State Department of Agriculture and Markets.

Nixon, Hargrave, Devans & Doyle (by Robert G. Harvey, Ernest J. Ierardi and Ragna O. Henrichs, Esqs.), Lincoln First Tower, Rochester, New York, for the Rochester Gas and Electric Corporation.

Huber, Magill, Larence & Farrell (by Edgar K. Byham and Roderick Schutt, Esqs.) 99 Park Avenue, New York, New York, for the New York State Electric & Gas Corporation.

Richard Freedman, Esq., 250 Old Country Road, Mineola, New York, for the Long Island Lighting Company.

Michael J. Whitelaw, Gerald F. Thompson and Robert E. Carberry, P.O. Box 270, Hartford, Connecticut, for Northeast Utilities.

John N. DiPlacido, 2 Broadway, New York, New York, for American Electric Power.

B. R. Isbister, 620 University Avenue, Toronto, Ontario, for Ontario Hydro.

Robert D. Swanson, P.O. Box 960, Cincinnati, Ohio, for Cincinnati Gas and Electric.

LeBoeuf, Lamb, Leiby & MacRae (by Jacob Friedlander and David R. Poe, Esqs.), 140 Broadway, New York, New York, for the Aluminum Company of America.

James J. Kaufman and William F. Matthes, Esqs., 627 South Main Street, Neward, New York, Wayne County Citizens and Citizens for a Quieter Environment.

John L. Debes, 303 Erie Street Road, Macedon, New York, for the Power Line Committee for Environmental Protection.

Allan E. McAllester and Robert J. Sassone, Esqs., 2 Judson Street, Canton, New York, for UPSET, Inc.

Michael M. Platzman, Esq., 40 Grove Street, Middletown, New York, for the Chester Packing Corporation.

John Smigel, Medusa, New York, for the Albany County, Greene County Power Committee.

WITNESSES APPEARING IN COMMON HEARING[6]

Barnes, Howard C., B.S.E.E., Rose Polytechnic Institute; P.E., New York, Ohio, and Kentucky. Vice President of the Power and Environmental Systems Division of Chas. T. Main, Inc. . . . Sponsored by applicants; testified as to operating experience with extra-high voltage lines.

Bowne, Norman E., B.S. (meteorology), Pennsylvania State University, 1953; certified consulting meteorologist, the American Meteorological Society. Director, Division of Environmental Sciences, TRC – The Research Corporation of New England. . . . Sponsored by DEC; testified as to the line's contribution to ambient ozone concentrations. Testimony was prepared with the assistance of George F. Collins, P.E., certified consulting meteorologist, and Dr. Leslie G. Polgar.

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[6]This portion of the Appendix contains biographical data excerpted from the testimony of the various witnesses. It does not set forth in full each witness' description of his qualifications. Note: "DEC" refers to the Department of Environmental Conservation. "Staff" refers to the staff of the Public Service Commission.

Becker, Dr. Robert O., M.D., New York College of Medicine, 1948; Diplomate, American Board of Orthopedic Surgery, 1959. Chief of Orthopedic Surgery, Veterans Administration Hospital, Syracuse; Professor of Orthopedic Surgery, Upstate Medical Center; Director of the Orthopedic-Biophysics Laboratory at Syracuse Veterans Administration Hospital—Upstate Medical Center. Sponsored by staff; testified as to biological effects of exposure to electric and magnetic fields.

Carroll, Dr. Robert E., M.D., Albany Medical College, 1961; M.P.H., Harvard, 1964. Professor and Chairman of the Department of Preventive and Community Medicine, Albany Medical College. . . . Sponsored by the New York State Attorney General; testified as to the effects of the ozone concentrations expected to be produced by the proposed lines.

Carstensen, Dr. Edwin L., B.S. (physics), Nebraska State Teacher's College, 1938; M.S. (physics), Case Institute of Technology, 1947; Ph.D. (physics), University of Pennsylvania, 1955. Professor of Electrical Engineering and Director of Biomedical Engineering, University of Rochester. . . . Sponsored by applicants; testified as to biological effects of electric and magnetic fields.

Chartier, Vernon L., B.S. (electrical engineering) and B.S. (business), University of Colorado, 1963; P.E., Pennsylvania. Employed by Bonneville Power Administration, Branch of Laboratories. . . . Sponsored by applicants; testified as to anticipated levels of audible noise, magnitudes of anticipated electric fields, magnitudes of anticipated induced voltages and currents, magnitudes of discharge currents resulting from induced voltages, effectiveness of grounding procedures with respect to discharge currents, and fuel ignition.

Cohen, Louis, B.E. (electrical engineering), McGill, 1946. Consultant-Automation and Communications Division, Production and Transmission, Hydro-Electric Commission of Quebec. . . . Sponsored by applicants; testified as to Hydro-Quebec's experience with 735-kV lines.

Comber, Michael G., B.S. (1st class, honors) (electrical engineering), University of Aston, Birmingham, England, 1966; M.S. (power systems engineering), University of Aston, 1967; M.E. (electric power engineering), Rensselaer Polytechnic Institute, 1973. Employed by General Electric Company at Project UHV as electrical research engineer in charge of research on the effects of corona from ultra-high voltage transmission lines. . . . Sponsored by staff; testified as to anticipated levels of audible noise.

Deno, Dr. Don W., Bachelor's degree (electrical engineering), Cornell, 1949; master's degree (electrical system engineering), University of Pennsylvania, 1968; doctorate (electrical system engineering), University of Pennsylvania, 1974; P.E., New York and Pennsylvania. Employed by General Electric Company at Project UHV. . . . Sponsored by staff; testified as to strength of electric and magnetic fields; induced currents; and gasoline ignition.

Driscoll, Dr. Daniel A., Bachelor's degree (electrical engineering), University of Cincinnati, 1961; master's degree (electrical engineering), Rensselaer Polytechnic Institute, 1964; Ph.D. (electrical engineering), University of Vermont, 1970; P.E., New York. Energy Generation and Transmission Specialist with the New York State Department of Environmental Conservation, Office of Environmental Analysis. . . . Sponsored by DEC; testified as to effects of audible noise, ozone, induced currents and voltages, and electric and magnetic fields.

Doyle, Dr. Joseph T., A.B., Harvard; M.D. Harvard. Professor of Medicine and Head of the Division of Cardiology in the Department of Medicine of Albany Medical College, and Head of the Clinical Division, Director of the Cardiovascular Health Center and Director of the Private Diagnostic Clinic of the Albany Medical Center Hospital. Testified on the medical implications of cardiac pacemaker interference.

Ender, Robert C., B.S. (electrical engineering), Union College; M.S., University of Maryland; P.E., New York and Pennsylvania. Manager, System Planning and Analysis, Uhl, Hall and Rich, a Division of Chas. T. Main of New York, Inc. . . . Sponsored by applicants; testified as to anticipated magnitude of magnetic fields.

Fletcher, Dr. John L., B.A., University of Arkansas, 1951; Ph.D., University of Kentucky, 1955. Professor and Director of Research of the Department of Otolaryngology and Maxillofacial Surgery, University of Tennessee Center of the Health Sciences. . . Sponsored by the Attorney General; testified as to effects of audible noise on animals.

Frey, Allan H., B.A., Temple University, 1956; M.A. (physiological psychology), Temple University. Technical Director of Randomline, Inc., a consulting firm specializing in Engineering as applied to the life sciences. . . . Sponsored by staff; testified as to effects on the nervous system and behavior of electromagnetic fields.

Hess, Henry K., B.A., 1970; M.Sc. (statistics), 1972, West Virginia University. Manager Biostatistics and Computer Operations, NUS Corporation. Testified for the applicants on the statistical methods used by various experimenters whose work was cited in the testimony on biological effects of electromagnetic fields.

Fullerton, Francis M., Certificate Structural Design, Franklin Technical Institute, 1952; Associate Degree Civil Engineering, Lincoln Technical Institute, 1953; Bachelor of Business Administration in Engineering and Management, Northeastern University, 1956. Associate member of Chas T. Main organization. Sponsored by applicants; testified on transmission line right-of-way costs.

Kryter, Dr. Karl D., B.A., Butler University; Ph.D. (psychology and physiology), University of Rochester. Director, Sensory Sciences Research Center, Stanford Research Institute (now SRI International). . . . Sponsored by staff; testified as to effects of audible noise on humans.

Leone, Ida A., B.S., New Jersey College for Women (Rutgers University), 1944; M.S. (plant physiology), College of Agriculture (Rutgers University), 1946. Employed by the Department of Plant Biology, Cook College, Rutgers University. . . . Sponsored by the Attorney General; testified as to the effects of anticipated levels of ozone on New York State vegetation.

Marino, Dr. Andrew A., Bachelor's degree, St. Joseph's College, Philadelphia, 1962; master's degree, Syracuse University, 1965; Ph.D. (physics), Syracuse University, 1968; J.D., Syracuse University, 1974. Employed as a Research Biophysicist at the Syracuse Veterans Administration Hospital. Sponsored by staff; testified as to biological effects of electric and magnetic fields.

Michaelson, Solomon, B.S., College of the City of New York, 1942; D.V.M., Middlesex, University, 1946. Professor of Radiation Biology and Biophysics and Associate Professor of Medicine and Laboratory Animal Medicine, School of Medicine and Dentistry, University of Rochester. . . . Sponsored by applicants; testified as to biological effects of an anticipated electric and magnetic fields and potential electric shock hazards.

Miller, Dr. Morton W., B.A., Drew University, 1958; M.S., University of Chicago, 1960; Ph.D. (botany), University of Chicago, 1962. Associate Professor of Radiation Biology and Biophysics and Assistant Director of the Department of Radiation Biology and Biophysics, University of Rochester. . . . Sponsored by applicants; testified as to biological effects of electric and magnetic fields.

Momrow, David C., B.S., Manhattan College, 1968; Master of Public Health, University of North Carolina, 1970. Director of the Public Health Education Unit of the New York State Department of Public Health. Testified on public health and safety educational programs.

Nowak, Henry, P.E.; Systems Standards Engineer with Niagara Mohawk Power Corporation. Sponsored by applicants; testified, briefly, as to minimum ground clearances of the proposed line.

Pearsons, Karl S., B.S. (electrical engineering), Massachusetts Institute of Technology, 1956; master's degree (electrical engineering), Massachusetts Institute of Technology, 1959. Supervisory scientist and manager, Psychoacoustics Department, Bolt, Beranek and Newman, Inc. . . . Sponsored by applicants; testified as to effects of audible noise on humans.

Roach, Dr. J. Frank, B.S., College of William and Mary, 1959; M.A., College of William and Mary, 1962; Ph.D. (physics), Lehigh University, 1969. Senior Scientist, High Voltage and Gas Physics, Westinghouse Electric Corporation. Sponsored by applicants; testified as to anticipated production and ground level concentrations of ozone and nitrogen oxides.

Schwan, Dr. Herman P., Dr. Phil. Nat. (biophysics), University of Frankfurt, Germany, 1940; Dr. Habil. (biophysics and physics), University of Frankfurt, 1946. Professor in the College of Engineering and Applied Science and in the School of Medicine, University of Pennsylvania. . . . Sponsored by applicants; testified as to biological effects of electric and magnetic fields.

Stanley, Dr. Paul E., B.A., Manchester College, Indiana; M.A., Ph.D. (physics), Ohio State University, 1937; Certified Clinical Engineer. Professor of Aeronautical and Astronautical Engineering, Professor of Electrical Engineering, and Associate Director of the Biomedical Engineering Center, Purdue University. . . . Sponsored by staff; testified as to effects of electric shocks.

Stasiuk, Dr. William N., B.S. (civil engineering), Manhattan College, 1965; M.E., Manhattan College, 1966; Ph.D. (environmental engineering), Rensselaer Polytechnic Institute, 1974; P.E., New York. Staff Assistant to the Deputy Commissioner for Programs and Research, New York State Department of Environmental Conservation; Senior Research Associate, Atmospheric Sciences Research Center, State University of New York at Albany. . . . Sponsored by DEC; testified as to distribution and sources of ozone in urban and rural areas in New York State.

Stevens, Robert K., B.S., Virginia Polytechnic Institute, 1956; M.S. (chemistry), Virginia Polytechnic Institute, 1957. Chief, Field Methods Development Section, Chemistry and Physics Laboratory, National Environmental Research Center–Environmental Protection Agency. . . . Sponsored by DEC; testified as to adequacy of instrumentation used to measure ozone production.

Savedoff, Malcolm P., A.B., Harvard, 1948; M.A. and Ph.D. (astronomy), Princeton, 1950, 1951, respectively. Professor at University of Rochester, Rochester, New York. Sponsored by the applicants? testified briefly on Dr. Moreno's allegation that there may be an increase in ultraviolet radiation and changes in global weather patterns caused by power line radiation from the proposed 765-kV transmission lines.

Toler, James C., B.S. (electrical engineering), University of Arkansas, 1958; M.S. (electrical engineering), Georgia Institute of Technology, 1970. Employed at the Georgia Institute of Technology Engineering Experiment Station. . . . Sponsored by staff; testified as to anticipated effects of the proposed lines on cardiac pacemakers.

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