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Interim Report
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AC Field Exposure Study: Human Exposure to 60-Hz Electric Fields

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R E P O R T S U M M A R Y

SUBJECTS Transmission line effects / Human health studies

TOPICS Electric fields; Transmission lines; Human exposure

AUDIENCE R&D scientists / Environmental managers

AC Field Exposure Study: Human Exposure to 60-Hz Electric Fields

A method is now available for quantifying public exposure to electric fields during a variety of outdoor and indoor activities. Estimates produced by this method indicate that people thought to have the highest exposure, such as farmers, experience less than 1% of the exposure levels used in laboratory experiments.

BACKGROUND Laboratory research has been probing the possible health effects of high-level exposure to electric fields for years. But data about human exposures in normal daily activities have been lacking.

OBJECTIVE To develop ways to measure and model human exposure to 60-Hz electric fields.

APPROACH Researchers first designed a data collection system in the form of a vest made of conductive cloth. Wearing the vests, they took measurements at locations across the United States near transmission lines ranging from 115 to 1200 kV. The measurements were to serve in calibrating an exposure model. In developing the model, analysts combined activity data with calculated field strength values to simulate human exposures in a variety of situations. They prepared annual estimates of time spent in electric fields of different strengths during various outdoor and indoor activities.

RESULTS For farmers whose property is crossed by 345-kV transmission lines, the annual exposure estimates ranged from 10 to 120 kV/m/h, with an average of 60. A 765-kV line appears to produce approximately four times the exposure of the 345-kV line. Time spent above the perception threshold, where people are aware of the field, ranges from none to a few hours annually. In comparison, exposure in the home is approximately 70 kV/m/h per year, with electric blankets accounting for roughly half that total.

People are normally exposed to low-level electric fields, according to this study. But most people spend little or no time above thresholds of perception, whereas many laboratory animals experience prolonged exposure to perceptible fields. As a result, laboratory experiments typically indicate cumulative exposures two to four orders of magnitude greater than the annual cumulative exposure of a farmer who works near a transmission line.

The report provides annual exposure estimates for human activities near transmission lines and in the home, which it compares with data obtained in laboratory animal experiments.

EPRI PERSPECTIVE

This is a first effort to characterize human exposure to electric fields by means of measured and modeled data. Such characterization is important for placing general human exposures into perspective against studies involving laboratory animals. It may also be valuable for use in epidemiological studies of human health as the exposure patterns of different subgroups in the population are identified. The vest measurement system for collecting data on electric field exposure proved itself as a relatively simple, reliable means of data collection. EPRI is continuing to develop further data on human exposure to electric fields in this project while beginning a similar study of exposure to magnetic fields in project RP799-21.

PROJECT

RP799-16
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Research Project 799-16

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ABSTRACT

The objective of this study was to develop a method of estimating human exposure to the 60 Hz electric fields created by transmission lines. The method--the Activity Systems Model--simulates human activities in a variety of situations where exposure to electric fields is possible. The model combines maps of electric field, activity maps, and experimentally determined activity factors to produce histograms of time spent in electric fields of various strengths in the course of agricultural, recreational, and domestic activities. For corroboration, the study team measured actual human exposure at locations across the United States near transmission lines ranging in voltage from 115 to 1200 kV. The data were collected with a specially designed vest that measures exposure. These data demonstrate the accuracy of the exposure model presented in this report and revealed that most exposure time is spent in fields of magnitudes similar to many household situations. The report provides annual exposure estimates for human activities near transmission lines and in the home and compares them with exposure data from typical laboratory animal experiments. For one exposure index, the cumulative product of time and electric field, exposure during some of the laboratory animal experiments is two to four orders of magnitude greater than cumulative exposure for a human during one year of outdoor work on a farm crossed by a transmission line.

ACKNOWLEDGMENTS

Over the past year we have collected a large body of unique data during visits to electric utility systems around the United States. The success of this measurement program is due largely to the cooperation, support, and guidance of the electric utilities, farmers, and property owners who participated in the investigation. The project team gratefully acknowledges the assistance of the following utilities:

Allegheny Power System
American Electric Power
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Central Illinois Public Service
Detroit Edison
Duquesne Light
Georgia Power
Hawaiian Electric
Kansas Gas & Electric
Los Angeles Department of Water & Power
Nebraska Public Power District
Pacific Gas and Electric
United Power Association

The assistance and guidance of the Farm Sector Economics Branch, USDA--in both Washington, D.C., and Oklahoma -- and of the many agricultural economists at a number of this country's land grant universities were greatly appreciated.

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SUMMARY

This study developed a method for quantifying public exposure to electric fields for a variety of human activities. The study focused on electric fields generated by high voltage transmission lines, but also examined domestic exposure. When this study was undertaken, the existing literature addressed exposure to 60 Hz electric fields in only the most nominal terms, sometimes using anecdotal evidence alone. Engineering evaluations of exposure were often based on very conservative assumptions and the most limited data. The exposure assessment methodology and experimental data presented in this report have helped to rectify this situation.

The purpose of the study was to develop ways to measure and model human exposure. The results of this study will be useful to: (1) laboratory investigators studying animal exposure, who will be better equipped to design future experiments or compare research findings with human exposure estimates; (2) risk analysts, who can improve assessments of exposure; and (3) utility executives, public service commissioners, and individuals in similar positions of responsibility who must address public concerns.

Of necessity, the term <u>exposure</u> is broadly defined in this study. Because no physiological indicator or mechanism for measuring the effects of exposure has yet been identified, the following formats were used to present exposure estimates: time spent at various levels of electric field, in hours; cumulative exposure, expressed as the time integral of time spent in electric fields, in kilovolt-per-meter hours; and time spent above some threshold electric field level, in hours.

To estimate human exposure occurring in the course agricultural, recreational, and domestic activities, a framework, the Activity Systems Model, was developed. The model simulates human activities in situations where exposure to electric fields is possible. In this framework, the electrical environment is calculated and estimates of exposure are produced by using activity time spent in various levels of electric fields. The electric field values are reduced by using experimentally determined activity factors to reflect relative grounding and shielding during an activity. The instrument for collecting experimental exposure data was a vest made of conductive cloth, worn like a hunting vest. The vest and its associated data collec-

tion instrumentation were developed specifically for this study. The vest measures an induced current which is proportional to the electric field surrounding a person. The vest electronics can store exposure information in five different ranges of electric field. With the exposure vest system, a large number of measurements were made at locations across the United States near transmission lines ranging from 115 to 1200 kV, and in household or domestic environments. The following paragraphs summarize the main findings of this study:

- Human exposure to 60 Hz electric fields cannot be evaluated on the basis of the unperturbed or calculated electric field alone. Often the exposure calculated with the unperturbed field is much greater than that actually measured. Rather, it is necessary to include the mitigating effects of body position and the degree of grounding, as well as the shielding afforded by any objects or equipment used in an activity. These factors can combine to significantly reduce the electrical quantities applied to the body, such as induced current. Therefore, instead of experiencing the full value of the unperturbed electric field, the human body may in fact be subject to a significantly lower "equivalent" electric field. (Equivalent in the sense that it is the lower value of electric field that would cause the same induced electrical quantities to be applied to the body as those applied and measured in a reference situation.) Equivalent fields reflect the effects of grounding and shielding and are generally only a fraction of unperturbed fields.

- The ratio of a person's actual exposure during a given activity to their theoretical exposure while grounded and standing erect in an unperturbed electric field is called the activity factor. (The product of activity factor and unperturbed field is the equivalent field). Activity factors can range from less than 5% for a person in a cabbed farm vehicle, to more than 90%, for a person standing in damp grass. Exposure is significantly reduced by the shielding provided by vehicles, farm machinery, and vegetation and by deviations of body posture from the erect position. Electrical insulation of the body from the ground, which may be provided by shoes and by the surface underfoot, reduces exposure also.

- The relative evaluation of exposure depends on the quantity selected to characterize human exposure to electric fields. Two formats for presenting and characterizing exposure are particularly useful: the time spent in different ranges of equivalent electric field (presented in time histograms) and cumulative exposure (presented as the total time integral of equivalent field in (kV/m)*h). Data presented in the time histogram format (hours spent in various field levels) can be converted to any number of exposure quantities of interest.

- The annual exposure of farmers to the electric fields of high voltage transmission lines crossing farms was estimated for eighteen typical farms (as defined by USDA). The average time a farmer spends above the threshold of perception is estimated to be zero for transmission voltages up to 345 kV, about one hour per year for 500 kV, and a few hours per year for 765 kV. The annual exposure of operators (principal workers) on farms crossed by a 345 kV line ranges from 10 (kV/m)*h to 120 (kV/m)*h. Differences in voltage class make an important difference in farm exposure level: a 765 kV line could produce about four times the exposure of a 345 kV line.

- Annual exposure of farmers to transmission line fields was compared with annual exposure to 60 Hz electric fields in the home. No equivalent field above the threshold of perception is present in the home or domestic environment. Equivalent electric fields are generally a few volts per meter and probably do not exceed about 60 V/m. Because people spent a considerable amount of time at home, however, total cumulative domestic exposure is comparable to exposure for farmers near power lines. Average annual domestic exposure is estimated to be about 70 (kV/m)*h; about half of that exposure is related to the use of electric blankets.

- For recreational activities (jogging, bicycling, horseback riding, skiing) along rights-of-way, exposure depends on activity path position and orientation with respect to a transmission line, on line voltage class, and on duration and frequency of the activity. No systematic data on recreational activities along rights-of-way are available. Recreational activities must therefore be examined on a case-by-case basis. Cumulative exposures were evaluated for a few examples and found them to be generally lower than estimated agricultural and domestic exposures. There is always the possibility that a person might occasionally be in peak fields for longer periods of time than a farmer would be (even though the farmer spends more time outdoors). Locations near higher voltage lines, where equivalent electric fields may be above the threshold of perception, are not commonly suitable for recreational activities.

- Comparison of human exposure to the exposure of laboratory animals will be governed by any number of physical and biological assumptions. Two important factors in any exposure comparison are: (1) Human exposure is spread out over long periods of time rather than being concentrated. Whereas farmers and most other people spend little or no time above their threshold of electric field perception, laboratory animals are generally exposed to electric fields above perception for the entire duration of an experiment (the animals are chronically stimulated). (2) Cumulative exposure during some of the typical laboratory animal experiments is two to four orders of magnitude greater than cumulative equivalent exposure for a human during one year of outdoor work on a farm crossed by a transmission line.

Section 1

INTRODUCTION

How much exposure do people receive from the electric fields of transmission lines? This simple question begs a simple answer--but it is unlikely to get one. People's activities are as complex as people themselves, and estimates of human exposure must be based on human activities.

For the past several years, we have been collecting experimental data by exposing rats, pigs, and other animals to high levels of electric field. The transition from the laboratory to the human health arena is dependent on a sound methodology for determining how much electric field exposure people really do get in their day-to-day living.

The objective of this study was to close the information gap between laboratory studies and actual human exposure. The goal was not to perform a detailed evaluation of the health effects of electric fields but simply to quantify exposure. This report provides three basic products:

- A model that will estimate human exposure to 60 Hz electric fields
- A system that will physically measure the electric field exposure a person receives while performing a given activity
- Actual measurements of human exposure for a variety of real-life situations--farming, horseback riding, and so on--near power lines.

Conducting the research for this report required some knowledge of electrical engineering, biology, agriculture, sociology, recreation, computer science, and mathematics. One of our intentions in assembling the report was to standardize terminology, unify concepts, and present the study in a clear, logical manner. This report provides exposure estimates for specific groups of people, but the methods presented can be applied to any number of situations of interest.

This report focuses on exposure resulting from three types of human activity in the United States. These sectors were chosen on the basis of their likelihood for higher exposure than other sectors. Farming activity was chosen because there are 4 million farm workers and because these people still spend a considerable amount of time outdoors, unlike most of the remainder of the population. Recreational activity was chosen because it represents a large cross section of the population and because transmission line rights-of-way may be attractive for use as recreation sites. Finally, exposure in the home was studied because this sector includes almost everybody, even though the source of the electric fields is not transmission lines. The data on domestic exposure may be valuable for comparison with data on other kinds of exposure.

One of the underlying philosophies established early in the study was that of modeling human exposure and corroborating the results with field studies, rather than collecting extensive sets of field data and interpreting the results. The modeling concept used here has been proved to be acceptable when applied to other types of studies (such as air quality) and it is certainly more versatile and cost-effective.

Future use of the methodology and results generated by this study could take at least three simultaneous directions. First, now that laboratory studies have been provided with a badly needed interface, their relationship to human exposure can be put into perspective. For example, future experiments could be designed to model human exposure more realistically. Second, risk assessment investigators, always looking for a better way to navigate their "order-of-magnitude" world, should find the methodology surprisingly accurate. Third, if human exposure becomes more of a public issue, the individuals in authority who must address people's concerns about high voltage lines will be better equipped to understand and discuss these issues.

A note on "soft" versus "hard" numbers: Engineers generally work with hard numbers--numbers of multidigit accuracy, in which they have a lot of confidence. On the other hand, risk assessors and sociologists must use soft numbers in instances where hard data are not available. Expert opinions and results of informal surveys are examples of numbers that could be called soft. In this report, we have attempted to use the hardest numbers possible; where soft numbers are used, they are always tilted to the conservative side.

The next ten sections are presented in a fairly natural order, each section building upon previous sections. Section 2 explains the concept of exposure to electric fields. The issue is relatively new and is still being debated and the material of this section may help to clarify some basic concepts. Section 3 introduces the Activity Systems Model, the tool that was used to calculate exposure for many conceivable situations. The concept of the model was borrowed from studies of transportation and air pollution, but its application to the problem of exposure to electric fields is unique. Section 4 describes the system for measuring exposure. The system uses an accurate, reliable instrument, worn like a vest, developed specifically for this study. An example problem is given in Section 5, where both the model and the measuring system are used in an actual case study.

The detailed program of exposure data collection near operating transmission lines using the measuring vest is described in Section 6. Section 7 is a discussion of exposure in the farming sector highlighted by an application of the model to 18 typical farms. Section 8 applies the model to a sampling of recreational activities. Domestic exposure is the topic of Section 9; the measurement and evaluation of household levels of electric field are discussed. In Section 10, some sample applications of the exposure estimates are presented to demonstrate the utility of the data. Section 11 summarizes the conclusions made from this exposure assessment study.

Section 2

ELECTRIC FIELD EXPOSURE

CHARACTERISTICS OF ELECTRIC FIELDS

In physics, the term field denotes a region in which something exerts an influence. The concept is useful whenever an influence extends into the region surrounding its source. An electric field exists in the region around an object that has electric charge and can exert an influence on other objects placed in this region. The intensity of an electric field is the force exerted on a unit electric charge placed in the field. The unit of measurement is the volt per meter (V/m). Electric fields are present in most environments. They may be constant or may vary slowly (as in the case of natural electric fields) or they may vary at different frequencies. Electric fields at power frequency (60 Hz in the United States) are evident around overhead power lines operating at high voltage but are also present around household appliances in a domestic environment. A detailed treatment of electric fields from transmission lines is given in References 1 through 3. The electric field in a domestic environment, which has different spatial and temporal characteristics, is described in Section 9 of this report.

The characterization of electric field for the purpose of defining the effects on a person is quite complex. In the course of this project it was found that some of the quantities previously used were not well suited to a study of human exposure. One such quantity is unperturbed electric field, that is, the field measured without the perturbing effect of an object or a person.

The perturbed electric fields on the surface of a person are significantly dependent on many factors, including body posture and electrical insulation from ground. Electric fields and currents in the body of a person in the region of an electric field are completely defined if the perturbed fields over the entire surface of the body are known. Therefore, the perturbed rather than the unperturbed field should be used. The evaluation of the electric field on the surface of the body is difficult, however, and not sufficiently accurate. This project took a simpler approach by defining equivalent electric field.

Equivalent electric field is the unperturbed electric field that would cause the same electrical quantities to be applied to the body as those that would be applied in a well-defined reference condition. The reference condition chosen is a person standing erect, with arms at sides, on a flat surface, electrically grounded, and in a uniform electric field.

In the following sections it is shown that the value of the equivalent electric field depends on which electrical quantity applied to the body is considered. For instance, the equivalent electric field that causes a given field on the forehead may be different from the equivalent field that causes a given current density in the thorax. Thus, defining the electrical quantities applied to all parts of the body for a given situation can be very complex and may require a number of equivalent fields. This issue has been resolved in a practical way by focusing on a number of electrical quantities of possible interest applied to the upper part of the body (for example, forehead field, current in the neck or thorax). This portion of the body was chosen because of its biological significance. The equivalent fields corresponding to these upper-body quantities are not much different from each other in most common situations. Therefore, it was possible to have the practical definition of equivalent field on a measuring system (described in Section 4) that is well-correlated to the upper-body electrical quantities.

EXPOSURE TO ELECTRIC FIELDS

The concept of exposure may imply an effect or response. No adverse effect on humans has been clearly demonstrated for the electric fields normally encountered near power lines. The effect, if any, of electric fields on humans remains unknown. If a mechanism for effects exists, it is probably dependent on such parameters as frequency of occurrence, intensity, and duration of exposure. In recognition of the difficulty of defining exposure to electric fields, it was decided that exposure must be defined in the broadest terms possible.

In this report, exposure is presented as a histogram of time spent at different intensities of equivalent electric field. The electric fields that may be encountered have been divided into practical ranges (called bins or windows) that correspond to typical situations, as shown in Table 2-1.

Table 2-1

EQUIVALENT ELECTRIC FIELD RANGES USED TO PRESENT EXPOSURE DATA

Range V/m	Situation Described
0 - 50	Domestic or household electric fields
50 - 250	Electric fields near typical distribution lines or near houses adjacent to transmission lines
250 - 1000	Typical electric fields next to rights-of-way
1000 - 3000	Common values within rights-of-way
3000 - 6000	Lowest range values of field perception (1)*
6000 - 10000	Mid-range values of field perception (1)*
> 10000	Maximum electric fields found under transmission lines of the highest voltage class

* Range reflects different perception indicators and subject variability.

The method of estimating exposure outlined in this report is amenable to any set of electric field ranges of interest to the reader. An example of a time histogram of exposure in slightly different ranges is given later, in Table 2-2.

Several quantities that can be used to describe electric field exposure may be derived from time histograms. Two quantities were found to be particularly simple to use: (1) the time spent above a given equivalent field (for example, threshold of perception) and (2) the total time integral of equivalent field. The latter, quantity, which has been called cumulative exposure is measured in (KV/m)*h (the product of field and time). In addition, the cumulative exposure in each range (or bin) of equivalent field has been defined. (It has also been measured with the system described in Section 4).

The exposure process may have characteristics that cannot be completely described by time histograms alone. Consider the example of Figure 2.1, which is for a farming operation near a 345 kV transmission line. The figure represents the unperturbed electric field traversed by a farmer while riding on a tractor during a disc harrow operation. Each peak of the plot represents one 335m (1100 ft.) pass with the tractor. (Because of shielding and relative grounding, the farmer would not experience these unperturbed fields, but instead experiences an equivalent electric field which is significantly lower). Even while working near a transmission line, the farmer does not remain stationary for very long in the region of peak fields. Large spatial variations in electric field intensities are encountered in this example. It presents an exposure situation that is markedly different, for instance, from the exposure during laboratory experiments, in which laboratory animals may be continuously exposed to electric fields of constant intensity.

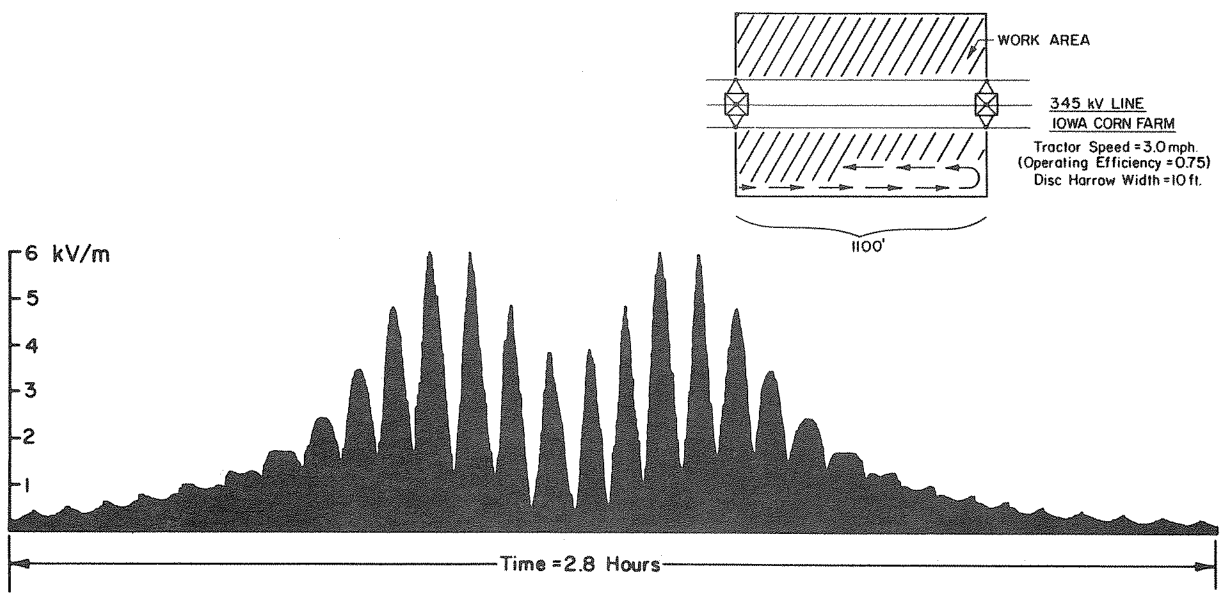


Figure 2.1. Unperturbed Electric Field Traversed during Typical Farming Operation

METHODS OF PRESENTATION OF EXPOSURE DATA

There are a number of ways to present data on human exposure to 60 Hz electric fields. The data that will be presented and discussed in the following sections have been obtained by calculation and by measurement. In either case the concept of exposure is related to the temporal variation of the equivalent electric field experienced during an activity. The equivalent field is related to the electrical quantities applied to the body. Thus, exposure data presented in terms of equivalent field can easily be converted into terms of any electrical quantity of interest. Consider as an illustration of the methods of presentation of exposure data, the hypothetical example of an activity with a duration of 1 hour, performed in the right-of-way of a 765 kV line. The data for such an activity are shown in Table 2-2.

Table 2-2

EXAMPLE OF EXPOSURE DATA

Range (V/m)	Time (h)	Time (%)	Average Field in Each Range (V/m)	Exposure ((V/m)*h)	Exposure (%)
0 - 50	0.850	85.0	16	13.6	9.3
50 - 250	0.095	9.5	120	11.4	7.8
250 - 1000	0.026	2.6	600	15.6	10.7
1000 - 2000	0.010	1.0	1400	14.0	9.6
2000 - 6000	0.012	1.2	3000	36.0	24.6
6000 - 10000	0.006	0.6	7500	45.0	30.8
> 10000	0.001	0.1	10500	10.5	7.2
	1.000	100.0		146.1	100.0

The exposure can be graphically expressed by bars with heights proportional to the time in each field range (see the second column of Table 2-2). The exposure also can be graphically expressed in either of the two forms shown in Figures 2.2 and 2.3. The cumulative time, T, shown in Figure 2.2 is the time during which the equivalent field was greater than the value given on the horizontal axis. This time can be expressed either in hours or as a percentage of the total time. In the latter case, the value of the total exposure time T_{tot} is needed to complete the data.

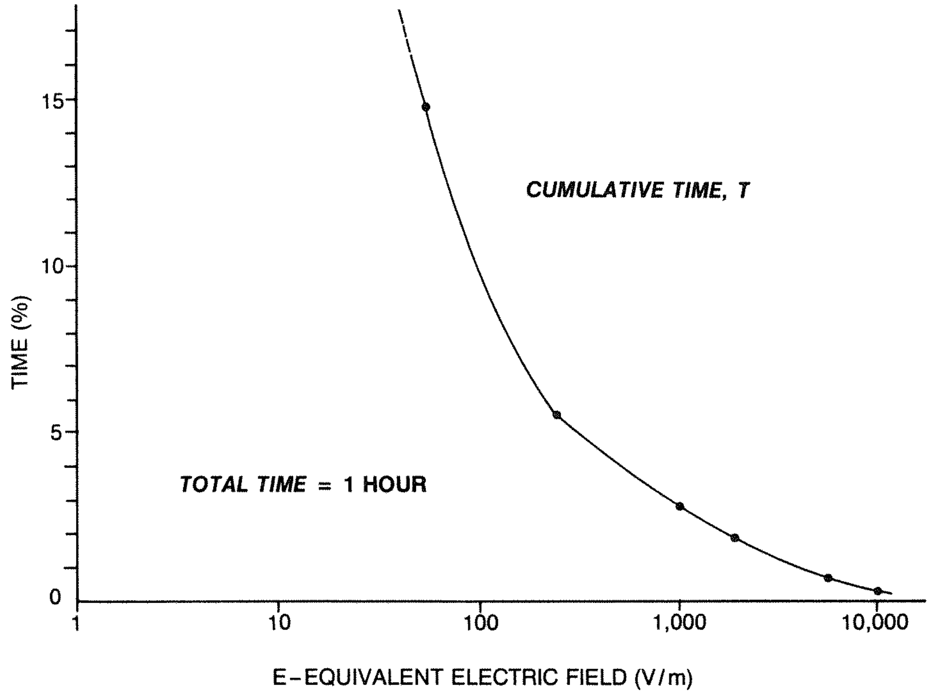


Figure 2.2. Distribution of cumulative exposure time, T, above the field E.

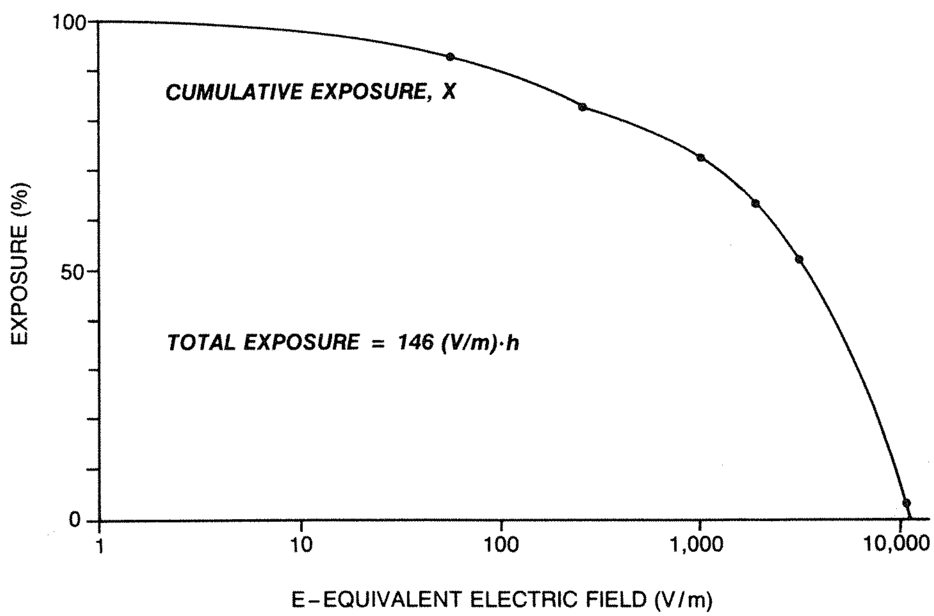


Figure 2.3. Distribution of cumulative exposure value, X, above the field E.

The cumulative exposure, X, shown in Figure 2.3 is the exposure that has occurred at equivalent fields above the value given on the horizontal axis. This exposure can be expressed in (V/m)*h or as a percentage of the total exposure. In this last case the value of the total cumulative exposure X_{tot} is needed to complete the data.

Both types of data were used during this project. The electric field exposure measuring system described in Section 4 measures exposure in (V/m)*h in five different ranges of equivalent electric field. Thus, measurements made with this system lend themselves to a representation such as that of Figure 2.3. On the other hand, the activity system model described in Section 3 was used to simultaneously calculate both the cumulative time curve and the cumulative exposure curve.

It is possible to pass from one form of representation to the other. In fact, the functions T and X are related by Equations 2-1 and 2-2.

$$X = \int_0^\infty - (dT/dE)*E*dE \qquad (2\text{-}1)$$

$$T = \int_0^\infty - (dX/dE)*dE/E \qquad (2\text{-}2)$$

Passing from one form to the other is not simple, however, when the data are expressed as time (or exposure) values corresponding to a small number of ranges of equivalent field. When the conversion is required, it is necessary to estimate either the average field or the average time for each range. For example, in Table 2-2 the time column can be translated into the exposure column only if the average field for each field range is known.

It is often convenient to plot, instead of the time T or the exposure X above a given field, the time (T_{tot} - T) and the exposure (X_{tot} - X) below a given field. This method of data presentation is used in Appendix D.

The curves of Figures 2.2 and 2.3 may be used to represent the average exposure for a given activity. However, if a statistical view of the exposure of all people participating in that activity is desired, curves for a hypothetical population such as those in Figures 2.4 and 2.5 can be constructed.

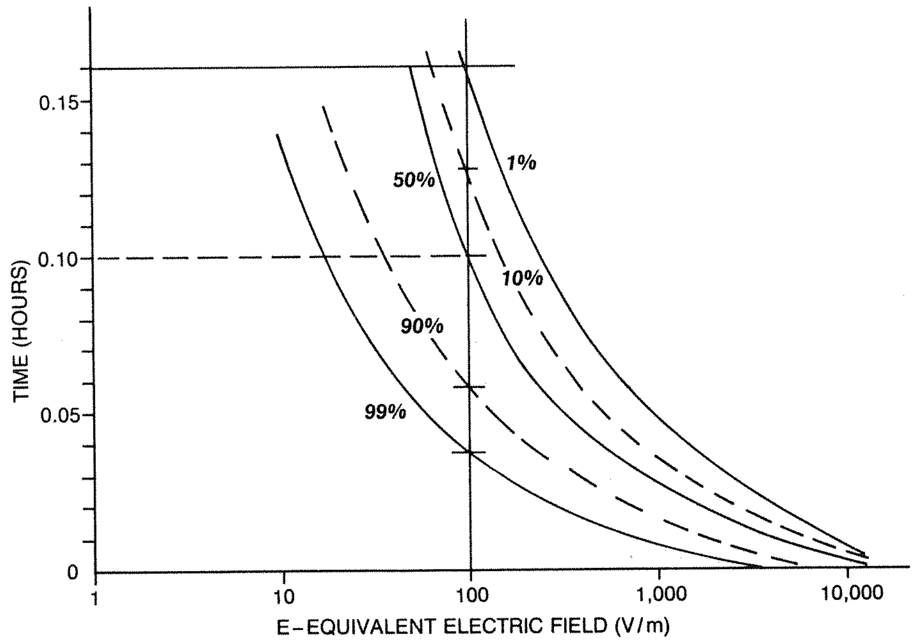


Figure 2.4. Cumulative exposure time, T, above the field E exceeded by 99%, 90%, 50%, 10%, and 1% of the population.

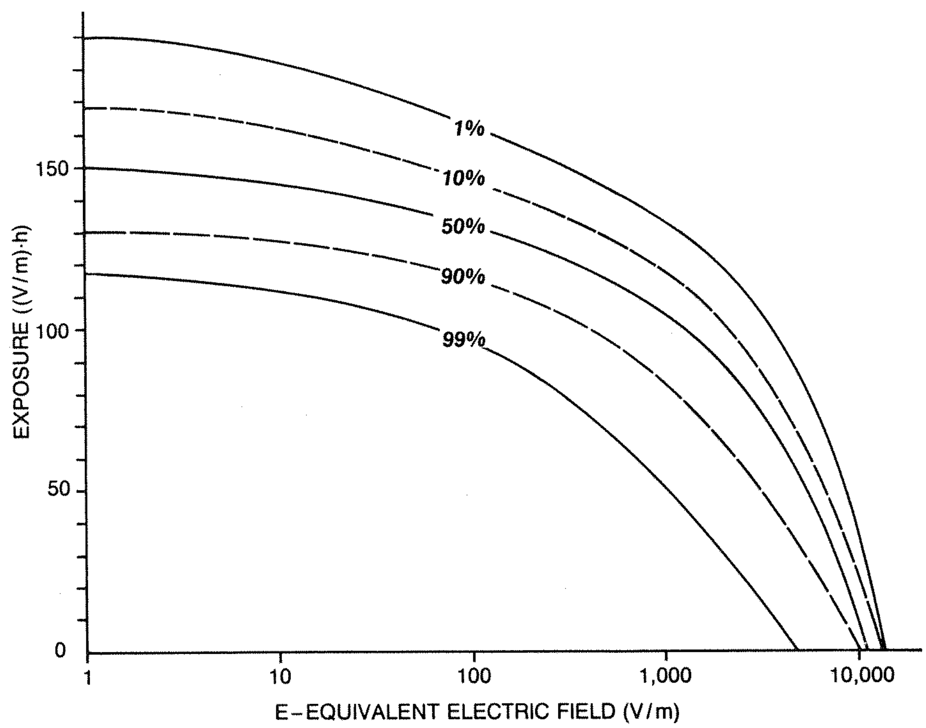


Figure 2.5. Cumulative exposure value, X, above the field E exceeded by 99%, 90%, 50%, 10%, and 1% of the population.

Assume we want to know how much time a person spends above 1000 V/m performing the example activity. Figure 2.4 gives the statistical answer: 50% of the people would spend more than 0.10 hours, and 1% of the people would spend more than 0.16 hours, at fields exceeding 1000 V/m. If we want to know a person's total exposure, Figure 2.5 gives the answer: 50% of the people would have an exposure greater than 150 (V/m)*h, and 1% of the people would have an exposure greater than 190 (V/m)*h. Most of the results of this study are expressed in terms of the average person--the person represented by the 50% curves of Figures 2.4 and 2.5.

DISCUSSION

Exposure estimates are presented in various formats, including time spent in electric fields over a range of intensities--histograms--and cumulative exposure--for example,(kV/m)*h or μA*h for some part of the body. The reason is that multiple exposure criteria will make the results more flexible and therefore more valuable.

Combining experimental data on laboratory animals with the exposure assessment data of this report must be undertaken with great caution and with due concern for the complexity of the task. The exposure parameters for the laboratory animals must be clearly understood. Also, human exposure might best be considered in a statistical framework. For example, a statistical description of exposure and possible biological responses could be combined to determine the probability of some response of a given magnitude.

A final issue for consideration is whether exposure to electric fields is cumulative. In this report, cumulative annual exposure is one of the formats used to present results, and a methodology is outlined for calculating lifetime values. As stated earlier, it can be debated whether the results of continuous testing of exposed laboratory animals can be applied directly to humans, whose exposure may be spread over time (4). This issue relates to the cumulative versus temporary effects of exposure and also to the biological recovery mechanisms. To date there is no scientific evidence to support a cumulative lifetime exposure process in humans for the electric field intensities produced by 115-765 kV transmission lines.

REFERENCES

1. Transmission Line Reference Book--345 kV and Above. 2d ed. Palo Alto, Calif.: Electric Power Research Institute, 1982, p. 367.

2. D. W. Deno. "Transmission Line Fields." IEEE-PAS, Vol. 95, September/October 1976, pp. 1600-1611.

3. Electrostatic and Electromagnetic Effects of UHV Transmission Lines. Palo Alto, Calif.: Electric Power Research Institute, EL-802, June 1978.

4. R. Kavet. "Biological Effects of Electric Fields: EPRI's Role." IEEE-PAS, Vol. 101, July 1982, pp. 2115-2121.

Section 3

ACTIVITY SYSTEMS MODEL

OVERVIEW

Activity systems models are used to study the relations between the activities of human populations and their physical environments. Activities are characterized in terms of their space and time patterns, and these patterns are related to environmental conditions.

Activity systems models have been used for more than a decade to study human activity patterns and their results. Models of this type have been used to study human activity patterns in urban areas (1). Other models have been used to analyze transportation behavior (2,3) and exposure to indoor and outdoor air pollution (4). In all these studies the locations in which peoples' activities place them for periods of time are associated with social or physical conditions of interest.

In one commonly used theoretical framework, human activities are conceptualized as trajectories through space-time prisms (5). The prism is the standard Cartesian coordinate system with the base plane described by x and y, representing geographic space and the vertical dimension, z, representing time. Trajectories of human activities describe both mobile and stationary activities. Projection of the trajectory onto the time axis describes the schedule of activities, and projection onto the geographic space plane describes geographic mobility.

The activity systems approach will be used to estimate two possible exposure modes: time spent (in hours) above or crossing various electric field threshold levels, and a cumulative estimate consisting of the product of time and electric field, in (kV/m)*h. The time spent at locations in geographic space is the primary focus. Each location on the geographic plane can be described in terms of an electric field, and time spent in such electrical environments is the conceptual kernel of modeling both types of exposure mode.

MODEL DESCRIPTION

An activity systems model of human exposure to 60 Hz electric fields has several components. First, the physical geography must be characterized. Next, the trajectory of human activities must be mapped onto this geography to represent the time spent at particular locations. The process is outlined in the flowchart presented in Figure 3.1.

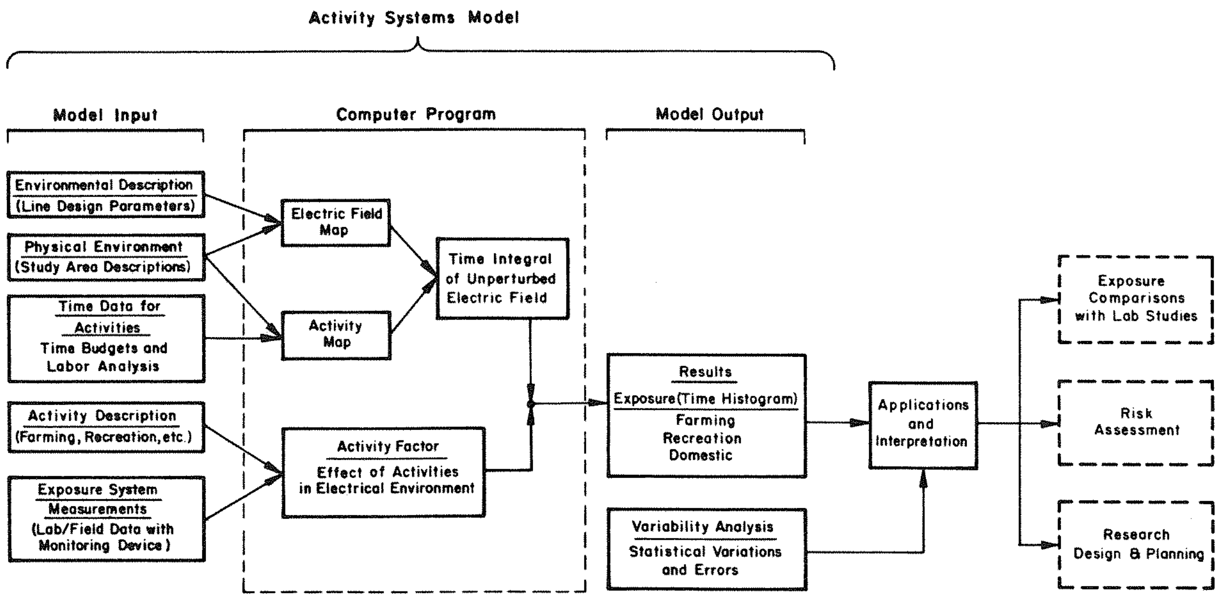


Figure 3.1. Activity Systems Model of Electric Field Exposure

For example, an activity systems model for estimating electric field exposure on farms must describe the geographic layout of the farm, the boundaries of the farmstead and agricultural fields, and various land uses. The activity trajectories are represented by time values (hours per acre), the second component of the model. These values have been calculated by the U.S. Department of Agriculture and others on the basis of the speed, size, and efficiency of agricultural equipment. These calculations transform the properties of a farmer's activity trajectory into time based summaries of each type of activity.

The third component of the activity systems model is the electrical environment of 60 Hz electric fields. Once a transmission line location has been fixed, a map of the electric field is calculated over the same geography used to reference activities. The fourth component is labeled the activity factor. It describes the electrical relation between a reference condition (standing erect, with arms at sides, perfectly grounded) and a specific activity, which may involve movement, use of equipment, and varying degrees of grounding. (The activity factor, for example, is the actual body current as a percentage of the theoretical, reference body current.) The activity factor is used to modify the calculated unperturbed field, in which the activity occurs, to an equivalent field under the reference condition.

The final component of the activity systems model computes exposure: the integral (or sum) over physical space of the product of time spent at a location and the equivalent field strength at that location.

The results of this exercise are estimates of exposure to electric fields for a variety of human activities. It was recognized that the spatial and temporal aspects of human activity can vary dramatically for most people, including the study subjects. The following three general activity categories have been identified:

- Distributed: Activity spread out in an approximately even fashion over a surface--for example, farming
- Linear: Activity extending along a path or route--for example, hiking, cross-country skiing
- Point: Activity confined to specific location or position--for example, playing at a playground, picnicking

In this study, exposure was characterized in terms of these three categories. Some human activities may be a combination of the three.

A mathematical formulation of the model is presented in Equation 3-1. This version calculates cumulative exposure over a study area that is divided into subareas; time within each subarea is assumed to be uniformly distributed (in the sense of the Distributed category described above). Implementing the model requires superimposing a rectangular grid system on the study area and calculating the electric field and time spent at each grid point.

$$\text{Exp} = A \sum_{i=1}^{N} \sum_{j=1}^{G_i} \sum_{k=1}^{L_i} E_{ij} T_{ik} F_{ik} \qquad (3\text{-}1)$$

where:

- Exp = total exposure in (kV/m)*h
- A = area represented by each grid point in acres
- N = number of subareas
- G_i = number of grid points in subarea i
- L_i = number of labor activity types in subarea i
- E_{ij} = unperturbed electric field at grid point j within subarea i, in kV/m
- T_{ik} = time spent at labor activity k in subarea i, in hours/acre
- F_{ik} = activity factor for labor activity k in subarea i, expressed as a fraction

The model can be applied to the Linear and Point categories, as well, by simplifications of Equation 3-1. In addition, the model can tabulate concurrently with accumulating exposure, the time spent in different ranges or bins of electric field. For example, to accumulate the time spent in the range 0 to 0.05 kV/m, the model would look like this:

$$T_{0-0.05} = A \sum_{i=1}^{N} \sum_{j=1}^{G_i} \sum_{k=1}^{L_i} T_{ik} \qquad \text{if } 0 < E_{ij}F_{ik} < 0.05 \text{ kV/m} \qquad (3\text{-}2)$$

In the case of transmission line electric fields, the exposure predictions can be presented in time histograms of annual hours spent in various intensities of electric field.

The results of the activity systems model lend themselves to three broad applications (the dashed boxes in Figure 3.1). The exposure of a general population or subpopulation (farmers, for example) can be compared with available laboratory studies of electric field exposure. A second application is risk assessment. The model can supply fundamental exposure calculations that can be extrapolated to global risk assessment problems. Finally, the exposure estimates can be used in the design and planning of future research projects. The model results can help investigators more accurately model the magnitude and temporal aspects of actual human exposure.

ESTIMATING LIFETIME EXPOSURE

Participation in human activities that lead to exposure is generally age-dependent. The important phenomenon of age-related behavior patterns has often been studied. One investigation of urban activity patterns (7) focused on age as a factor in various human activities. The information in Table 3-1 has been adapted from this 1966-1969 study (not all of the activity categories are reported) and is presented here to demonstrate the correlation with age.

Table 3-1

DURATION OF SELECTED ACTIVITIES IN MEAN HOURS PER DAY PER PERSON

	Age Group of Respondent		
Activity	Under 35 Years (n = 324)	35-64 Years (n = 619)	Over 64 Years (n = 153)
Income-related work*	4.46	4.75	0.80
Watching TV	1.64	1.84	3.33
Participation in church activities	0.11	0.19	0.12
Socializing	0.74	0.53	0.50
Recreation and other diversions	0.53	0.46	1.15
Rest and relaxation	0.86	1.09	1.90
All discretionary activities	4.37	4.62	7.50

* Study includes students, the unemployed, and so on.

Source: Adapted from Reference 7.

Any estimate of electric field exposure accumulated during one or another activity must account for this age-dependence. One technique for including age-dependence in estimates of lifetime exposure from participation in a given activity is called synthetic cohort analysis (6). In this technique, data for a given activity are sampled for all age groups in a single calendar year. The data might, for example, include information such as the time spent participating in the activity, or the electric field exposure accumulated during an hour's participation in the activity. This age-dependent information can be used to define a synthetic cohort, an imaginary age-homogeneous group that is assumed, as it ages, to behave according to the measured data. Lifetime exposures can be estimated for each member of the cohort by summing annual exposures received throughout the individual's synthetic lifetime. The validity of synthetic cohort analysis rests on the assumption that age-dependent rates are in steady state, that is, that data for a given activity across all ages do not change from calendar year to calendar year. One would have to assume, for instance, that a person lived and worked near the same transmission line his or her entire life--a boldly conservative assumption.

Lifetime electric field exposures accumulated while participating in some activity can be modeled by considering, for each successive class, the age, the probability distributions of the number of hours of participation per year in the activity, and the exposure per hour of participation. Since activities and exposures for a person of a given age class may have some predictive value for activities and exposures at the next age class, one needs to consider also the age-to-age correlations among the probability functions for activity per year and exposure per unit activity time. In the model presented in Appendix E, age-to-age correlation is assumed to exist only among adjacent ages.

These age-specific probabilities taken from the male population in 1977 were used to drive a Monte Carlo simulation that, in combination with a standard statistical package, generates a cumulative density function of lifetime person-years in the workforce. The resulting distribution is shown in Figure 3.2. Multiplying this estimate of work life with the estimated exposure per year of work, E', we obtain the desired result, a cumulative density function of lifetime exposure to EHV fields due to the activity of work. This distribution is shown in Figure 3.3.

DISCUSSION

Activity systems modeling provides a very useful framework for improving our understanding of the human exposure process. This methodology can be implemented into a computer program that can analyze a broad range of human activities. The process is more effective than attempting to put instruments on a large population and collect data for many years. It is also very flexible: a similar approach can be utilized in the study of a number of environmental factors. The model offers the basis for providing more accurate estimates of exposure. Results of this method can now be used to put the issue of electric field exposure in proper perspective.

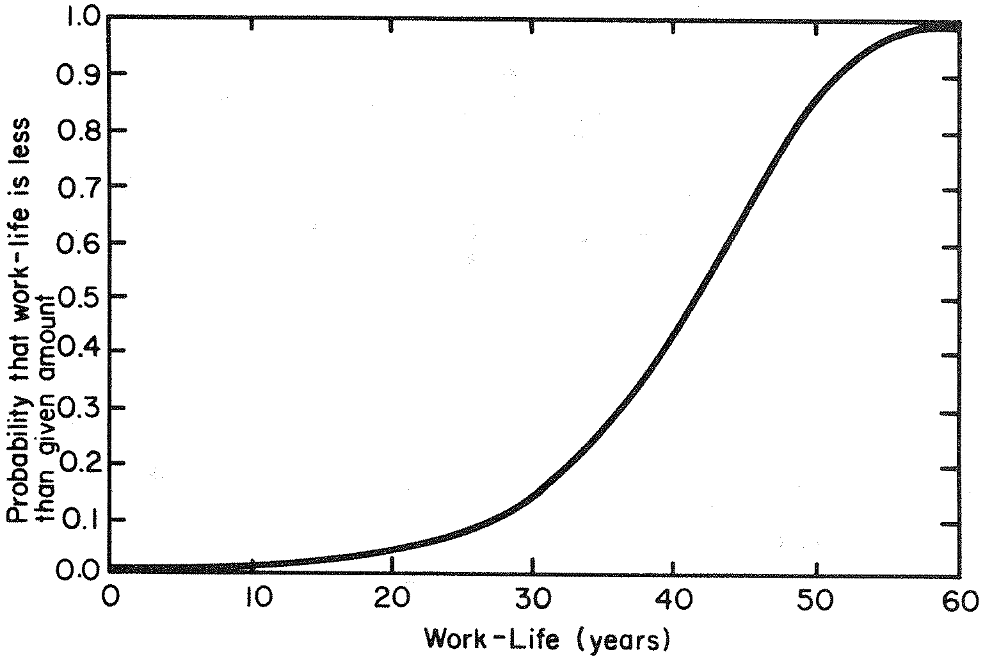


Figure 3.2. Cumulative distribution function of lifetime person-years in the work force.

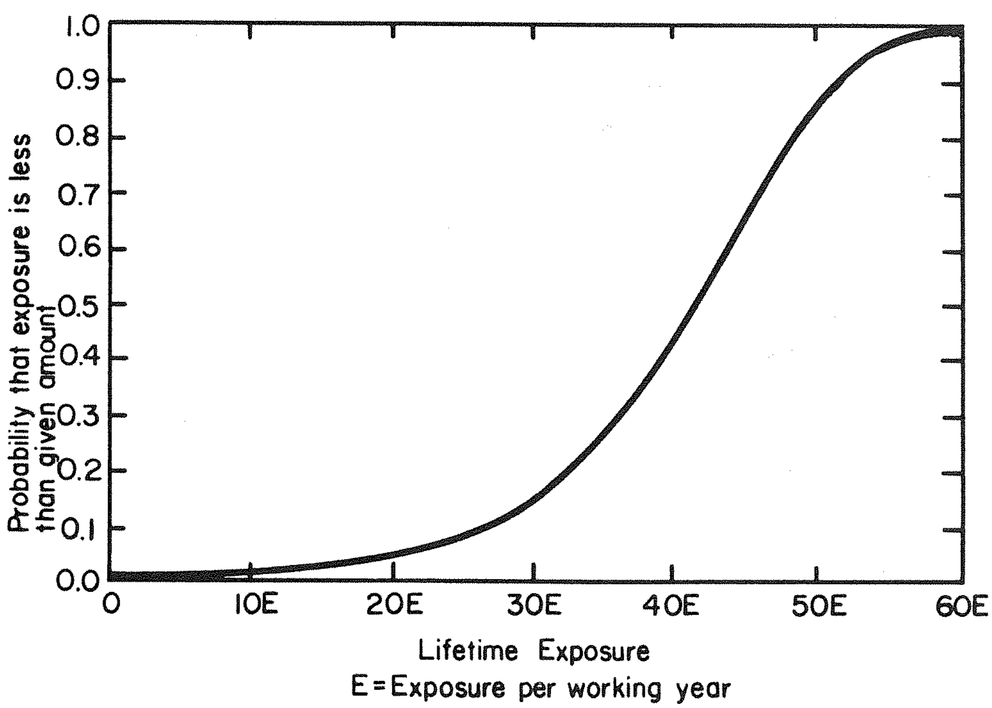


Figure 3.3. Cumulative distribution function of an individual's lifetime electric field exposure.

REFERENCES

1. F. Stuart Chapin. Human Activity Patterns in the City. New York: Wiley, 1974.

2. N. P. Hummon, R. Baker, and L. Zemotel. "An Analysis of Time Budgets of U.S. Households: Transportation Energy Conservation Implications." University of Pittsburgh, September 1979.

3. N. P. Hummon and L. Burns. Automobile Tours: How We Use Our Cars. General Motors Research Laboratories, June 22, 1981, GMR-3771.

4. D. J. Moshcandreas, J. Zabransky and D. J. Pelton. Comparison of Indoor and Outdoor Air Quality. Geomet Incorporated, March 1981, EA-1733, Research Project 1309.

5. T. Hagerstrand. "What About People in Regional Science?". Presidential address to the Eighth European Congress of the Regional Science Association, Copenhagen, 1969.

6. N. Keyfitz. Applied Mathematical Demography. New York: Wiley 1977.

7. R. K. Brail and F. S. Chapin. "Activity Patterns of Urban Residents". Journal of Environment and Behavior. Vol.5, No. 2, June 1973, p. 176.

Section 4

EXPOSURE MEASURING SYSTEM

INTRODUCTION

There have been few published attempts to quantify human exposure to 60 Hz electric fields from high voltage transmission lines. One reason for this paucity has been the lack of a good exposure measuring system.

A simple device to record the time histogram of unperturbed electric field exposure has been previously described (1,2,3). The device measures the time integral of the current on a small portion of the body and stores this information in an ion-transfer electrolytic cell for later readout. It has been used in Sweden to compare measured exposures of substation workers with those based on field-strength surveys of the work area (1). In Canada, estimates of household and occupational exposures of electrical workers based on average field strength and time spent in various locations were compared with measured exposures (4). In the United States a pilot study is being conducted to determine the feasibility of a large scale monitoring program for electrical workers (5). For this effort, a small electric field exposure meter is used to sense various levels of the perturbed local field on the body and record exposure in a digital memory.

To provide the reliable data for the development of exposure system models, this study has developed a new measuring system. It is suitable for power line, substation, household, and general public exposure measurements. The exposure measuring system, which is described in this section, uses a sensor vest and pocket-size data collection instrumentation. This system has been thoroughly tested in the laboratory and in the field. It was used extensively to obtain electric field exposure data for domestic activities and for a wide range of farming and recreational activities in proximity to transmission lines.

DESCRIPTION OF THE MEASURING SYSTEM

Principle of Operation

The exposure measuring system is shown schematically in Figure 4.1. A sensor made of conductive material intercepts the current, I_v, which enters the part of the body covered by the sensor. The current flows through the data collection instrumentation before entering the body through a medical electrode tab. The sensor is otherwise electrically insulated from the body. The data collection instrumentation contains ion transfer integrators, which accumulate electrical charges proportional to the exposure. The ion transfer integrators are discharged by a separate readout device, and the value of the accumulated charge is read at the end of the period of exposure. The exposure measuring system is shown in use in Figures 4.2 and 4.3.

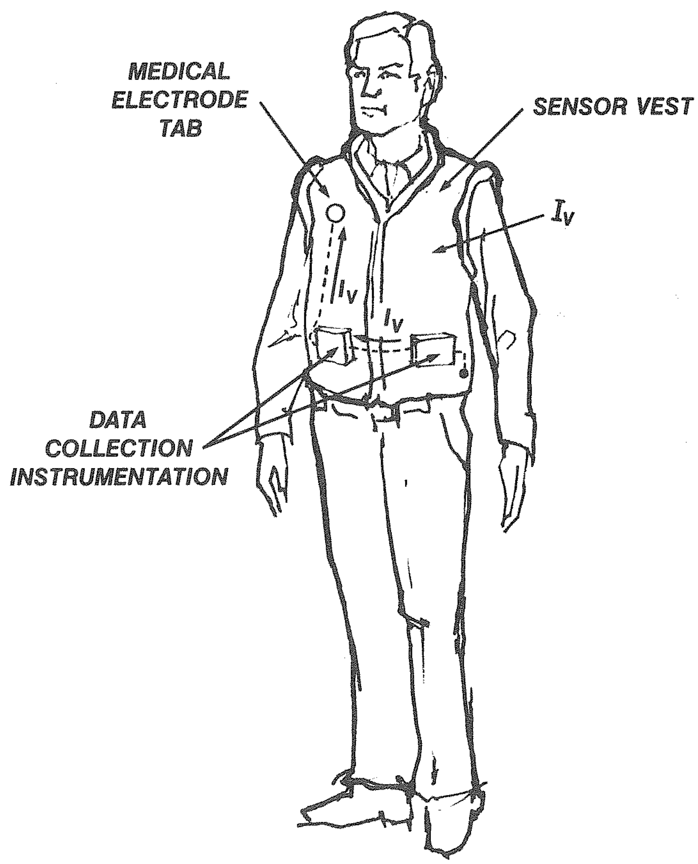


Figure 4.1. Electric Field Exposure Measurement System

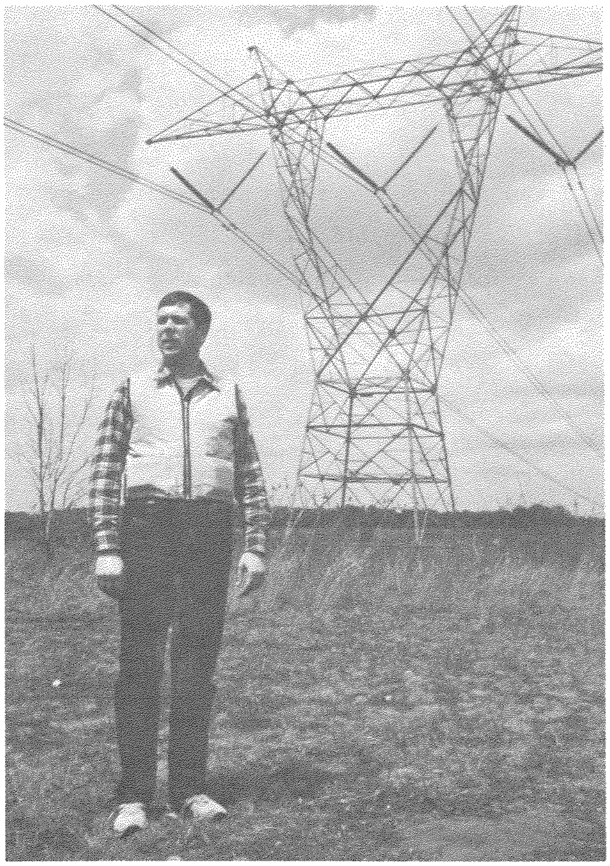


Figure 4.2. Exposure Measuring System in Use under 500 kV Line

Figure 4.3. Instrumentation for Data Collection

Sensor Characteristics

The sensor material consists of lineman's conductive suit cloth, made of 25% stainless steel yarn, sewn over commercially available (typically nylon) vests or jackets. The nylon vest material provides suitable insulation between the conductive cloth and the body. Multiple connections between the conductive cloth and an electric wire harness leading to the data collection instruments minimize the series resistance between sensor and body through the instruments. The resistive, rather than perfectly conductive, cloth provides more comfort. It also works well in another respect. If the surface of the sensor cloth were to come in contact accidentally with a person's hand, an electrical ground, or any other conductive object, an error could result. The resistive cloth minimizes the currents flowing through these low voltage contacts, yet, because of the distributed connections, practically all of the field-induced currents in the area covered by the cloth flow through the instruments. In other words, very little information can be lost. Sensors of this type are characterized by the area of the body covered and by the sensitivity in a reference condition. The sensor vest used in this study covers the shoulders and upper torso but does not cover any portion of the arms. The sensitivity of the vest is expressed in terms of induced current in the vest per unit of electric field, μA/(kV/m).

The reference position chosen for the vest calibration is the following:

- Body erect, with arms at sides
- Person well grounded
- Uniform electric field (the field caused by a high voltage transmission line close to ground, for example, is uniform; the value of the unperturbed electric field is taken as reference)

Vests of four sizes were used in this study; they can be characterized by sensitivities ranging from 5.6 to 7.9 μA/(kV/m). The sensor calibration can be made independently of the data collection instrumentation. The calibration consists of determining the vest sensitivity in the reference conditions. Ideally, the calibration should be made with the particular person who will be wearing the vest. Calibrations performed with the same vest but with 23 different people resulted in a standard deviation of the sensitivity equal to about 5%. The vest sensitivity was found independent of a person's height (1.65 to 1.93 m) and weight (60 to 93 kg). The variations depended mainly on body posture and arm position. Therefore, it was possible to assign a nominal sensitivity to each vest used for situations where individual calibration information was not available. The lack of significant effect of a person's height on the current collected by the vest is in sharp contrast with the proportionality of total body current to ground and the square of a person's height, as illustrated in Figure 4.4 for two adults and two children. The vest used to obtain the data in this figure did not fit small people well. In the normal range of adult heights, the current is practically constant.

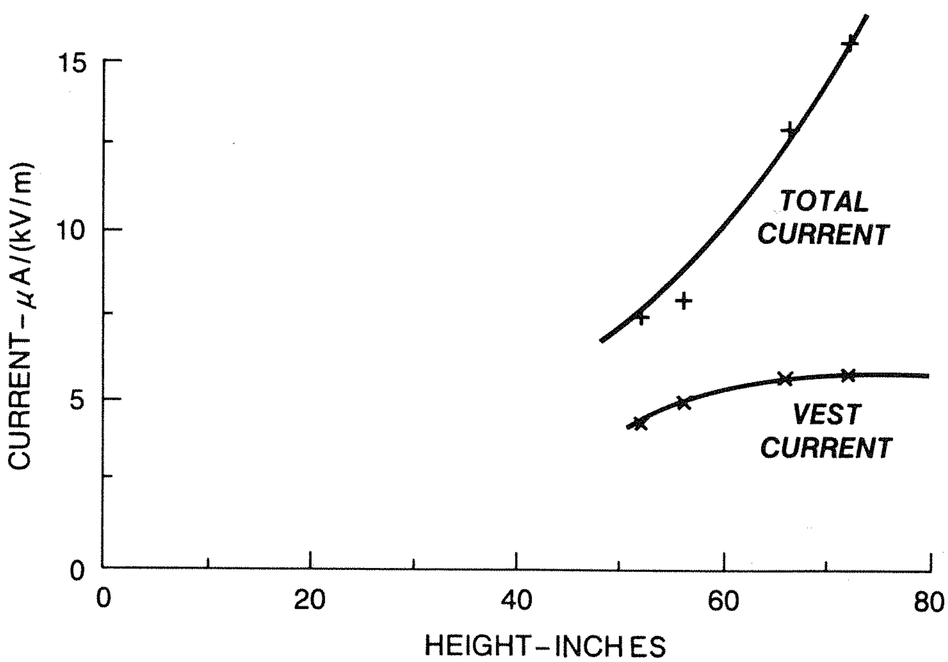


Figure 4.4. Effect of person's height on normalized total body current to ground and vest current. All persons are in the reference position and wearing the same vest.

DATA COLLECTION INSTRUMENTATION

The data collection instrumentation is a modification of that developed by EPRI in 1977 (2). The use of existing equipment provided easy access to instrumentation with proven performance. It was desirable, however, to have a larger number of storage bins, or windows, (electric field intensity ranges) than the original three bins. Two of the existing units were combined to provide five new bin values.

The conceptual schematics of the instrumentation are shown in Figure 4.5. The instruments are contained in two packages, which are carried in the two pockets of the vest. Figure 4.6 is a block diagram of the system.

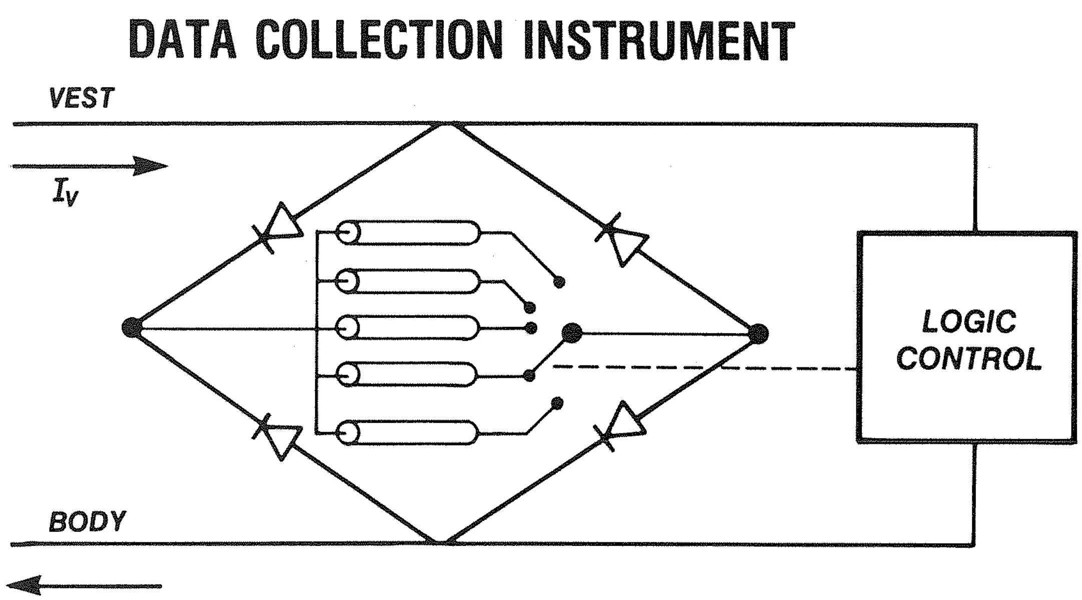


Figure 4.5. Conceptual schematic of data collection instrument. The current collected by the sensor vest is rectified and flows into one of five ion transfer integrators.

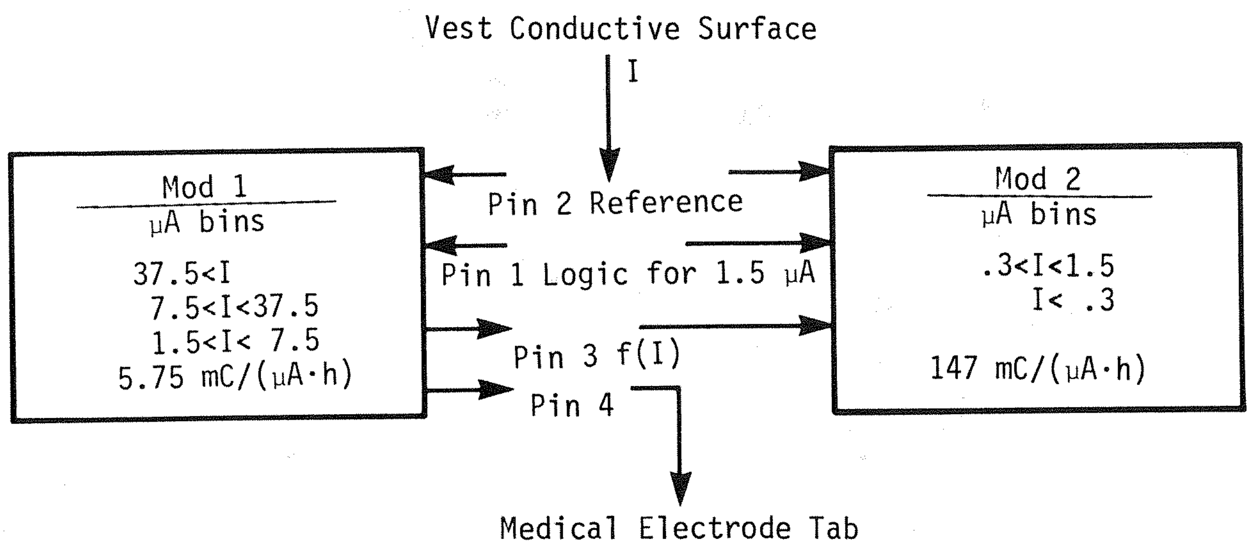


Figure 4.6. System Block Diagram with Bins Shown for Mod 1 and Mod 2

Each bin is characterized by (1) a range of currents, that is, a lower and an upper value for current that can be switched by the logic circuit into the corresponding ion transfer integrator, and (2) the sensitivity of the integrator, which results from amplifier and circuit characteristics and is expressed by the ratio between the tranferred charge and the product of vest current and exposure time, mC/(μA*h). Three types of electronic package were built; the packages are characterized by different exposure bins. The choice of package depends on the expected range of electric field. Mod 1-2 packages are intended for a wide range of fields, from 0 to about 10 kV/m; Mod 3-4 packages are intended for fields in the 0-1 kV/m range; and Mod 5-6 packages are intended for fields in the 0.2-2 kV/m range.

A complete description of the bins and sensitivities of the three electronic packages used is shown in Table 4-1. Each bin is defined by a lower and an upper current limit. The four lowest bins are characterized by a sensitivity expressed as charge/(current*time), mC/(μA*h). The charge in this expression is that stored in the integrators as a result of the exposure. The uppermost bin is characterized by a sensitivity expressed in charge over time, mC/h.

Table 4-1

INTEGRATOR BINS USED

			Electric Field Equivalent to Standing Erect with a 5.6 A/(kV/m) Sensor Vest	
Unit Pairs	Bin Definition(A)	Sensitivity (mC/(A*h))	Bin Definition (kV/m)	Sensitivity (mC/(kV/m*h))
Mod 1	37.5 < I	260†	6.70 < E	260†
	7.5 < I < 37.5	5.75	1.34 < E < 6.70	32.2
	1.5 < I < 7.5	5.75	0.27 < E < 1.34	32.2
Mod 2	0.3 < I < 1.5	147	0.054 < E < 0.27	823
	I < 0.3	147	E < 0.054	823
Mod 3	1.5 < I	260†	0.27 < E	260†
	0.876 < I < 1.5	147	0.16 < E < 0.27	823
	0.51 < I < 0.876	147	0.09 < E < 0.16	823
Mod 4	0.30 < I < 0.51	430	0.054 < E < 0.09	2410
	I < 0.30	430	E < 0.054	2410
Mod 5	7.5 < I	260†	1.34 < E	260†
	4.38 < I < 7.5	28.5	0.78 < E < 1.34	160
	2.56 < I < 4.38	28.5	0.46 < E < 0.78	160
Mod 6	1.5 < I < 2.56	86.2	0.27 < E < 0.46	483
	I < 1.5	86.2	E < 0.27	483

†Expressed as mC/h.

The principal characteristics of the data collection instrumentation can be summarized as follows:

- Battery power
- Long battery life (more than 3 months)
- Low weight (about 1/2 lb)
- Integrator error less than 3%
- Residual charge in cells corresponding to few seconds of exposure
- Linear response down to 0.001 μA (about 0.1 V/m)
- Insensitivity to high frequencies ($>$1000 Hz)
- Resistance to dust, vibration, temperature extremes, electric fields

A more detailed description of the performance of the electronics is given later, when accuracy of measurements is discussed.

Readout Device

The charge stored in the ion transfer integrators is measured by separate readout devices. Two types were made available, one an instrument with automatic digital readout of charge (mC) and requiring a 110 V power supply, and the other a portable (5 cm by 5 cm by 2.5 cm) battery powered device to be used in conjunction with a stopwatch for field use. Both readout devices are shown in Figure 4.7. The schematic of the portable readout device is shown in Figure 4.8. When the switch is closed, current will flow through the integrator and will discharge it. When the discharge is completed, the impedance of the integrator will rise rapidly and cause the current to flow in a light-emitting diode (LED). The time elapsed from the closing of the switch until the appearance of the light, multiplied by the current, equals the charge that was stored. From this value, exposure in the individual bins can be calculated using the calibration factors of Table 4-1. The portable device was found to be very reliable and convenient for field use.

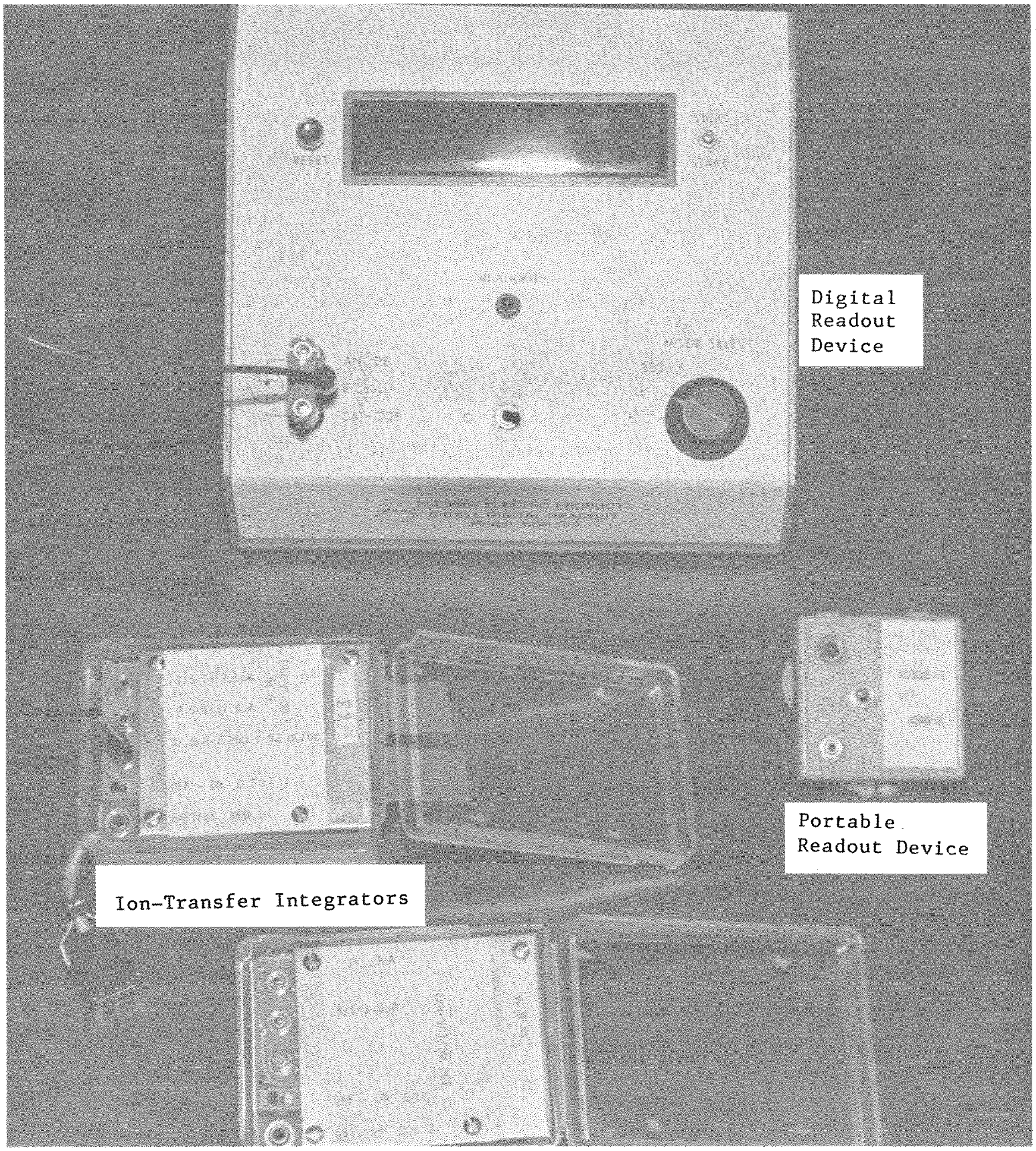


Figure 4.7. Digital and Portable Readout Devices with Ion Transfer Integrators

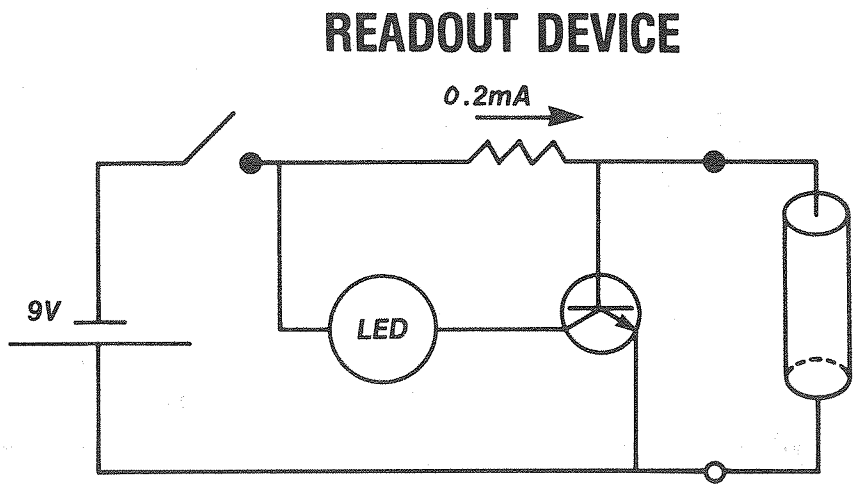


Figure 4.8. Schematics of Portable Readout Device

Measurement Accuracy

Because of the sensitive nature of the applications of human exposure measurements, a considerable effort was made to define and reduce to a minimum the potential errors. Three types of error can be incurred in the evaluation of human exposure: the first is in measuring technique, the second is in definition of an exposure situation, and the third is in interpretation of the results in terms of electrical quantities applied to the body. Measurement technique errors are discussed below, but they are generally negligible in comparison with the other two types of error.

Sensor Calibration Factor. The vest sensor calibration made in a uniform field with a number of different people showed a standard deviation of the calibration factor (μA/(kV/m)) equal to 5%. Variations were caused by differences in body posture and arm position and not to any significant degree by height and size of the person.

Errors in Switching Levels. The switching level from one integrator to the next is very accurate and does not change with use except for the upper bin level, which is a function of battery voltage. The battery voltage should be checked periodically, and the battery should be changed if the voltage is below 8 V. With proper battery conditions, the error in the switching level is less than 6%.

Upper Bin Saturation. All integrator bins have a linear performance (that is, a charge proportional to the injected current) except for the upper integrator bin, which has a response that saturates at a level about 40% higher than the lowest field--bottom-range bin level (see Figure 4.9). Therefore, the upper window cannot be calibrated in terms of charge/(current*time), mC/(μA*h). The preferred course was to choose a mid-level current for that bin and express the sensitivity in mC/h. The error involved in this procedure can be as much as 20%. Therefore, it is advisable to avoid the use of the upper bin, if possible. This can be done by choosing the appropriate electronic package. If the field exceeds the minimum switching level by no more than 30%, a linear response can be assumed and the sensitivity of the adjacent bin should be used. As a practical matter, this problem was almost never encountered during the measurement program of Section 6.

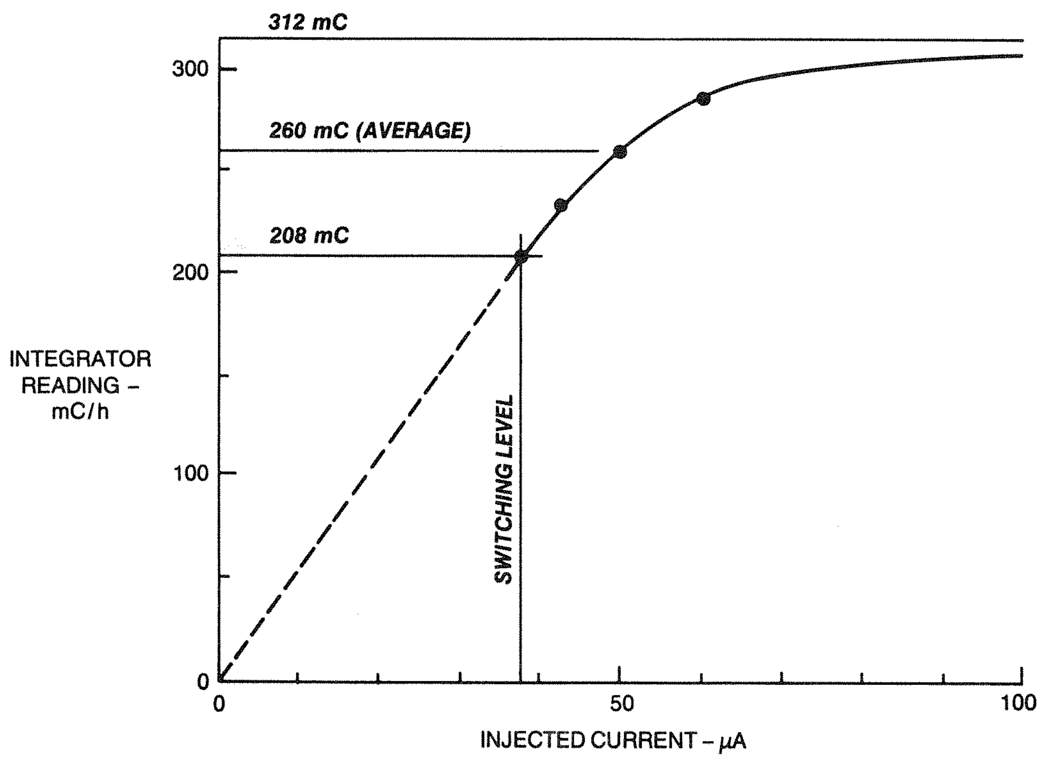


Figure 4.9. Response of upper integrator bin to injected currents. (Mods 1 and 2: upper window level equal to 37.5 μA.)

Integrator Error. Integrator errors have been evaluated by injecting known currents through the instruments. This process was part of the regular calibration procedure before field use. The measured integrated values were systematically compared with the expected values. The errors were found to be equal to 1.5%, with a standard deviation of the error equal to 1.1%. Adjustments were required only when some electronic component had failed, causing gross and easily detectable malfunctions. Another type of error is introduced by a small charge that can remain on the integrators even when the system is not exposed to electric fields. This residual charge amounted to no more than about 0.2 mC. This value is equivalent to an exposure of a few seconds at most. To virtually eliminate errors due to residual charges, we measured the residual charge of the inactive bins and subtracted it from the values recorded by the active bins.

Response of Lower Bin. The response of the lower bin is relatively accurate even for exposure to extremely low electric fields (see Figure 4.10). Even at a current of 0.001 μA, which corresponds to a field of about 0.13 V/m, with a medium size vest, the errors are about 20%. These errors are quite negligible when exposure to such low fields is added to exposure to much higher fields.

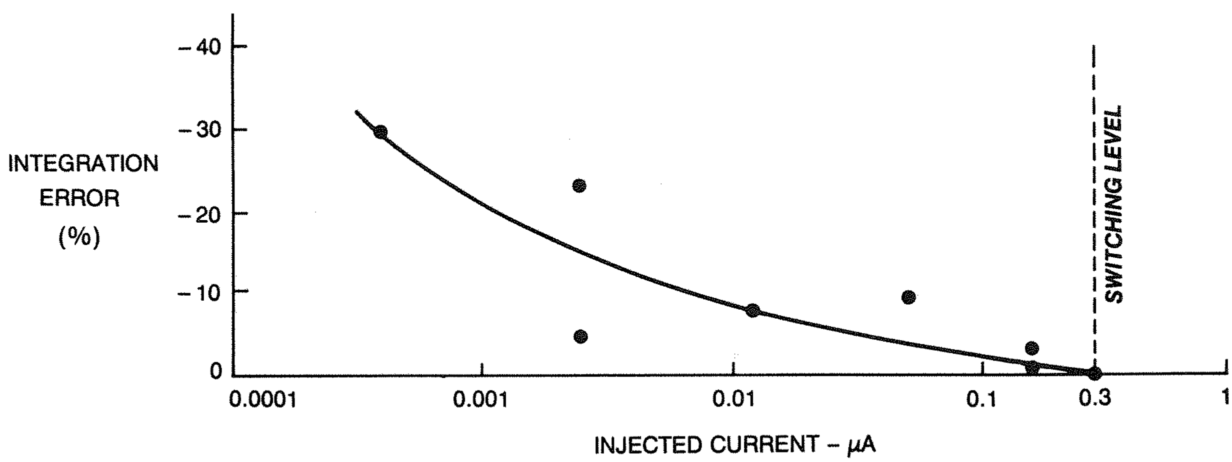
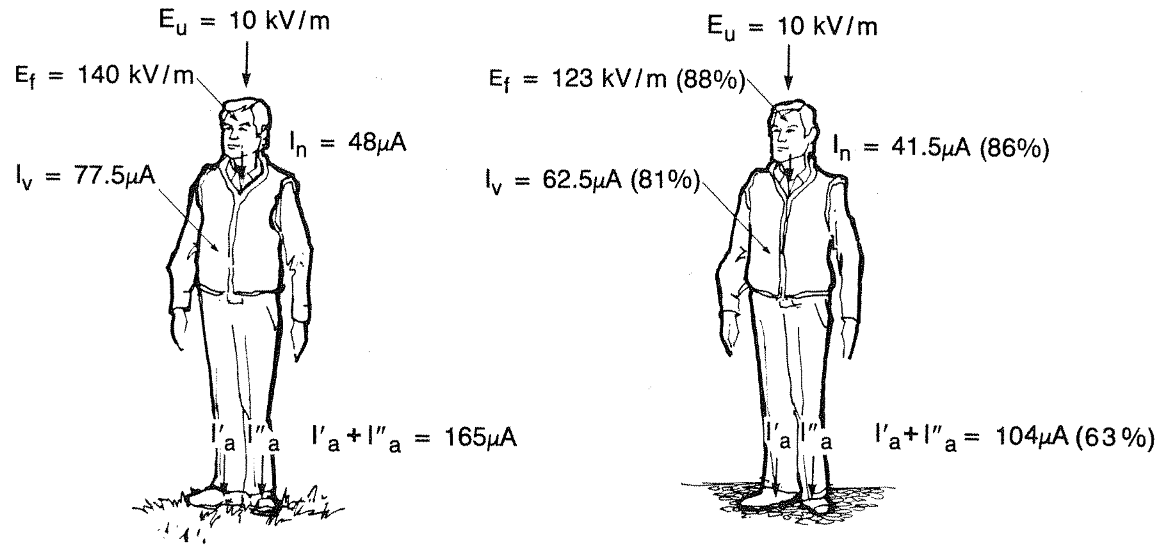


Figure 4.10. Integrator Error for the Lowest Window

Effect of Body Position. The choice of the sensor with which to take exposure measurements was made on the basis of experience obtained with other, smaller, sensors situated at specific places on the body (on the hat, arm, belt, shirt pocket, and so on). It was found that a small area sensor is critically sensitive to body position, type of clothing (or hat), and humidity conditions. The sensor vest has been selected because of its large area, which makes it relatively insensitive to specific positions of the arms and to whether or not the person is facing the source of the electric field. The vest measurements--although not perfectly correlated with a specific electrical quantity--are correlated with all electrical quantities applied to the upper part of the body. For example, consider the field on the forehead and the field on the back of the head. As the head is bowed, the field at the forehead will decrease and the field at the back of the head will increase significantly, whereas the vest current will increase only slightly. The average exposure (specific electrical quantity applied to the body) estimated through vest measurements is accurate within about 10%, even for complex activities.

ACTIVITY FACTOR

Investigators have found that actual measured exposure to electric fields is considerably lower than predicted exposure (4). Many factors combine to produce lower exposures, and some of the most important are effect of body position, relative grounding during an activity, and shielding caused by objects or equipment that may be used in that activity. To illustrate the effect of grounding, consider a person standing in an unperturbed 10 kV/m electric field. If the person wears regular shoes on dry pavement, the electric fields on the surface of the body and the body currents induced by the external electric field are significantly lower than the surface fields and body currents induced when the person is electrically grounded (for example, standing with wet shoes on wet grass). The differences between these two situations are shown in Figure 4.11. When the person is insulated, each electrical quantity applied to the body is reduced as if the unperturbed electric field were less than 10 kV/m (that is, the body does not experience the 10 kV/m field but instead experiences an "equivalent" electric field, which is significantly lower). This effect is described by the activity factor (shown in parentheses in Figure 4.11).



ON WET GRASS WITH WET SHOES (PERSON ELECTRICALLY GROUNDED)

ON DRY PAVEMENT WITH REGULAR SHOES (PERSON INSULATED)

Figure 4.11. Electric field on forehead (E_f), current in neck (I_n), vest current (I_v), and current in ankles (I_a) for a person grounded and a person insulated in unperturbed field (E_u). The activity factor for each quantity is shown in parentheses.

Definitions

Activity factor is the ratio of exposure during an activity to the exposure that would have been measured in a reference condition for the same exposure time and the same unperturbed electric field. (For example, activity factor could be the actual body current expressed as a percentage of the theoretical, reference body current.)

The reference condition is as follows:

- Body erect, arms at sides
- Person well grounded on conductive, flat ground
- Uniform electric field

Exposure of a person to 60 Hz electric fields can be expressed in several ways. Cumulative exposure is expressed by time integrals of electrical quantities applied to the body. For instance, if the 60 Hz current flowing through a specific area of the body is of concern, the cumulative exposure can be defined in terms of the product of current and time: ampere-hours (A*h). The cumulative exposure can be expressed also by the time integral of the equivalent unperturbed field, that is, the unperturbed field that would result in the same electrical quantity applied to the body placed in the reference condition. The use of this equivalent cumulative exposure is preferable because the resulting values, expressed in (kV/m)*h, can be interpreted directly.

To visualize the relation between an electrical quantity applied to the body and the equivalent unperturbed field, imagine a person loading and unloading a wheelbarrow in a place in which the unperturbed field is 1 kV/m for 1 hour. Although the unperturbed field remains constant during this activity, the electrical quantities applied to the body vary according to (1) body movements from one position to another, (2) changes in impedance to ground due to changes in pressure on the shoes, and (3) varying partial shielding by the wheelbarrow. Measurements revealed that the current entering the portion of the body covered by a vest varied from 3.8 to 5.3 μA, with an average value of 4.55 μA during the activity period. In contrast, the same person standing erect in a uniform 1 kV/m field without the wheelbarrow and electrically grounded, received a vest current of 5.6 μA. The situation is equivalent to the reference condition, but the field varied from 3.8/5.6 = 0.68 kV/m to 5.3/5.6 = 0.95 kV/m, with an average value of 4.54/5.6 = 0.81 kV/m. The total equivalent cumulative exposure was 0.81 (kV/m)*h. The concept of cumulative exposure is of use here only if there is a linear relation between (kV/m)*h and the presumed effect of the field exposure. When such a relation cannot be presumed, the exposure is better expressed by the equivalent field-time histogram, which gives the time spent in different ranges of equivalent fields. Alternatively, exposure to different equivalent fields can be expressed by cumulative exposure in different ranges of equivalent fields.

For the example of wheelbarrow loading or unloading, measurements provided have the following data:

- Equivalent cumulative exposure: $P = 0.81$ (kV/m)*h

- Equivalent field-time histogram:

$E < 0.46$ kV/m	$t = 0$
$0.46 < E < 0.78$ kV/m	$t = 18$ min
$0.78 < E < 1.34$ kV/m	$t = 42$ min
$1.34 < E$	$t = 0$

- Cumulative exposure in different ranges of equivalent field:

$E < 0.46$ kV/m	$P = 0$
$0.46 < E < 0.78$ kV/m	$P = 0.19$ (kV/m)*h
$0.78 < E < 01.34$ kV/m	$P = 0.62$ (kV/m)*h
$1.34 < E$	$P = 0$
	$P_{total} = 0.81$ (kV/m)*h

The last two sets of data (equivalent field-time histogram and cumulative exposure in different ranges) are equivalent. It is possible to pass from one to the other if the average equivalent field in each range is estimated.

<u>Measurements of Activity Factors</u>. Static measurements of activity factors can be taken when a person is in fixed positions that are characteristic of the activity being considered. These measurements may consist of measurements of current induced in a specific surface of the body or of the equivalent cumulative exposure. The current measurements must be referenced to those made in reference conditions. For instance, vest currents during loading and unloading of a wheelbarrow were made for two positions: standing in work boots (5.3 μA) and bending 90 degrees at the waist (3.8 μA). In the reference condition the current was 5.6 μA. Therefore the activity factor corresponding to the two positions were 0.95 and 0.68 respectively. Static equivalent cumulative exposure was measured with a person remaining for a known period of time in the same position. The measured cumulative exposure in A*h divided by exposure time resulted in the same values for current as those measured directly. When an activity involved a combination of different positions, dynamic measurements of activity factors were made using the measuring system developed for this study.

Depending on the type of instrumentation and on the method of elaborating the data, the dynamic activity factor can be expressed in terms of average activity factor, histogram of activity factors, or activity exposure factors in different ranges of activity factor. For instance, the activity factors for the wheelbarrow example previously illustrated are:

- Average activity factor: $AF = 0.81$

- Activity factor histogram:

$AF < 0.46$	$t = 0$
$0.46 < AF < 0.78$	$t = 30\%$
$0.78 < AF < 1.34$	$t = 70\%$
$1.34 < AF$	$t = 0$

- Average Activity Factor in different ranges:

$AF < 0.46$	$EF = 0$
$0.46 < AF < 0.78$	$EF = 0.19$
$0.78 < AF < 1.34$	$EF = 0.62$
$1.34 < AF$	$EF = 0$
	$AF = 0.81$

The activity exposure factor, EF, is the time integral of the activity factor divided by the total exposure time. The sum of all the EFs is the average activity factor. The last two sets of data (activity factor histogram and average activity factor in different ranges) are equivalent. It is possible to pass from one to the other if the average activity factor in each range is estimated.

Activity Factor for Children. The sensor vests used during the exposure measurement program were constructed for adults and were not used for systematic measurement of activity factors for children. The currents induced by 60 Hz electric fields in the body of a person are proportional to the square of a person's height (see Figure 4.4). Therefore, induced currents in children are much smaller than those in adults. The activity factors, however, do not change appreciably because the currents are also reduced in similar proportions to the reference condition. A significant reduction of the activity factor for children may be caused by shielding from nearby objects, which becomes more effective because of the smaller size of the body being shielded.

CORRELATION BETWEEN VEST READINGS AND BODY ELECTRICAL QUANTITIES

The choice of a vest or a jacket as a sensor for exposure measurements was dictated by a number of practical reason. A vest or jacket is:

- Convenient to wear
- Insensitive to small changes in body position
- Nondisruptive of the induced currents entering the body
- Responsive to the electrical quantities applied to the upper part of the body

To demonstrate and evaluate the last statement, several measurements of electrical quantities applied to the body were taken simultaneously and compared with vest current measurements.

The following quantities may be of interest:

- Surface electric fields (V/m)
- Current densities at the surface (A/m**2)
- Currents entering given surfaces of the body (A)
- Currents in given sections of the body (A)
- Current densities in given sections (A/m**2)
- Internal electric fields (V/m)
- Potential differences between different points (V)

The first four quantities in the above list can, in some cases, be determined through measurements external to the body. The amount of current that enters the surface of the body of a person in a 60 Hz electric field and the total current flowing in sections of the body are known for the erect position (3).

In Reference 2, a special mannequin was used to measure induced currents and fields. In the current study a large number of body positions related to various activities was considered. Since a mannequin did not provide sufficient flexibility to cover all the body positions of interest, special techniques were used to measure the following three quantities:

- Electric field on the forehead
- Current flowing in the neck
- Total body current

The electric field on the forehead, E_f , was measured with a small surface electrode (2.2 by 8.7 cm) inserted in a headband placed on the forehead. The current between sensor and body, I_f, measured with an ammeter with shielded leads, is related to the field by the following equation:

$$E_f = I_f/(\omega * \epsilon * A) = 175 \times 10^9 I_f \qquad (4.1)$$

where:

A = area of the sensor (small/medium/large)

f = 60 Hz

$\omega = 2 \pi f$

ϵ = the dielectric constant of air = 8.85×10^{-12} F/m

The current flowing in the neck was measured by covering the head with a hood taken from a conductive suit used by linemen for maintenance of live lines. Since the hood would collect more current than the head without hood, the hood was calibrated versus the neck current using a mannequin, and it was found that $I_{hood} = 1.16\ I_{neck}$.

The total body current was measured by insulating the body from ground and connecting it to ground through an ammeter. The total body current describes an electrical quantity when the body is grounded through a contact. When the body is insulated, however, this quantity becomes difficult to define. Figures 4.12 and 4.13 illustrate techniques for measuring forehead field and neck current.

Figure 4.12. Sensor Used to Measure Forehead Field

Figure 4.13. Hood Sensor Used to Measure Neck Current

The comparison of vest current and body electrical quantities measured for different body positions related to working with and around farm vehicles is reported in detail in Table 4-2.

An examination of the data of Table 4-2 reveals that the electric field on the forehead has very large variations. The forehead field becomes extremely small when a person's face is shielded by a grounded object and becomes high, relative to the vest readings, when the head is the least shielded part of the body. This latter condition occurs, for instance, when a person is standing in high vegetation. Similar but smaller variations occur for the neck current.

If the ratio between body electrical quantities and vest current measured in the reference position (body erect and grounded) are taken as nominal, and if all the positions listed in Table 4-2 are given equal weight, the deviations between nominal and measured values can be calculated. They are presented in Table 4-3.

The values of Table 4-3 indicate that, on the average, the vest current is a good indicator of the electrical quantities applied to the upper part of the body. For other portions of the body, additional measurements would have to be made to correlate vest current to the desired quantity. Deviations from the nominal values can be quite large. Vest readings can, however, be correlated with almost any body electrical quantity through further calibration.

Therefore, the values of average activity factor obtained with the vest can be applied to body electrical quantities with sufficient accuracy for practical estimates of exposures. On the other hand, when the activity factor for vest currents is determined as a statistical quantity (as it is in dynamic exposure measurements), the determination of activity factor must take into account also the variability shown in Tables 4-2 and 4-3.

Table 4-2

RELATION BETWEEN VEST CURRENT AND MEASUREMENTS OF BODY ELECTRICAL QUANTITIES

(Vest Sensitivity was 7.75 A/kV/m)

Position	Grounded E_f/I_v (kV/m)/μA	Grounded I_n/I_v	Grounded I_t/I_v	Insulated E_f/I_v (kV/m)/μA	Insulated I_n/I_v
Reference: erect, grounded	1.81	0.65	2.22	1.82	0.68
Inside tractor with cab	0.95	0.42	1.97	0.81	--
Standing in back of tractor	0.97	0.62	2.17	0.95	0.65
Bending in back of tractor	0.82	0.56	1.47	0.82	0.67
Climbing into cab	0.30	0.20	1.86	--	--
Standing on side of cab	0.77	0.53	1.88	0.76	0.52
Bending in front of tractor	0.39	0.31	1.80	0.33	0.31
Sitting in open tractor	3.47	1.37	4.48	--	--
Sitting not touching wheel	3.87	1.53	3.31	--	--
Various positions--tractor	0.95-4.04	1.22-1.25	4-4.55	--	--
Standing in back of tractor	1.14	0.84	2.17	1.12	0.88
Bending in back of tractor	0.14	0.10	1.65	0.05	0.05
Climbing into tractor	1.35	0.64	2.3	1.4	0.73
Bending: front of tractor	0.24	0.16	1.78	0.04	0.09
Standing: front of tractor	2.85	1.06	2.15	3.37	1.24
Standing near hay wagon	1.69	0.71	2.21	2.22	0.75
Facing away from tractor	2.48	0.89	2.42	2.8	0.95
Standing: back of hay wagon	1.83	0.72	2.26	2.8	0.76
Sitting on hay wagon	2.6	0.79	5.78	3.86	1.27
Standing on hay wagon	1.85	0.64	3.24	2.33	0.79
Standing: 2' vegetation	2.16	--	2.21	2.25	--
Bending	0.54	--	2.27	0.52	--
Bending: 2' vegetation	0.04	--	1.42	0.04	--
Sitting in Jeep	1.75	--	3.33	4.90	--
Standing beside Jeep	2.23	--	2.55	2.85	--
Standing: 6' vegetation	5.38	--	3.21	8.95	--

Table 4-3

NOMINAL AND MEASURED VALUES OF THE RATIO BETWEEN BODY ELECTRICAL QUANTITIES AND VEST CURRENT

Parameter		Reference Condition	Measured Values: Average	Measured Values: Standard Deviation
$\frac{E\text{-forehead}}{I_{vest}}$:	(kV/m)/μA	1.81	1.85	1.67
$\frac{I\text{-neck}}{I_{vest}}$:	μA/μA	0.65	0.71	0.38

The correlation between activity factors determined from vest current measurements and activity factors determined from neck current and forehead field measurements is shown in Figure 4.14. For the example of Figure 4.14, and in most other practical cases, the average activity factor with the vest can be used also to estimate the activity factor applicable to other upper body electrical quantities.

VARIATION OF ACTIVITY FACTOR WITH BODY POSITION AND PROXIMITY TO OBJECTS

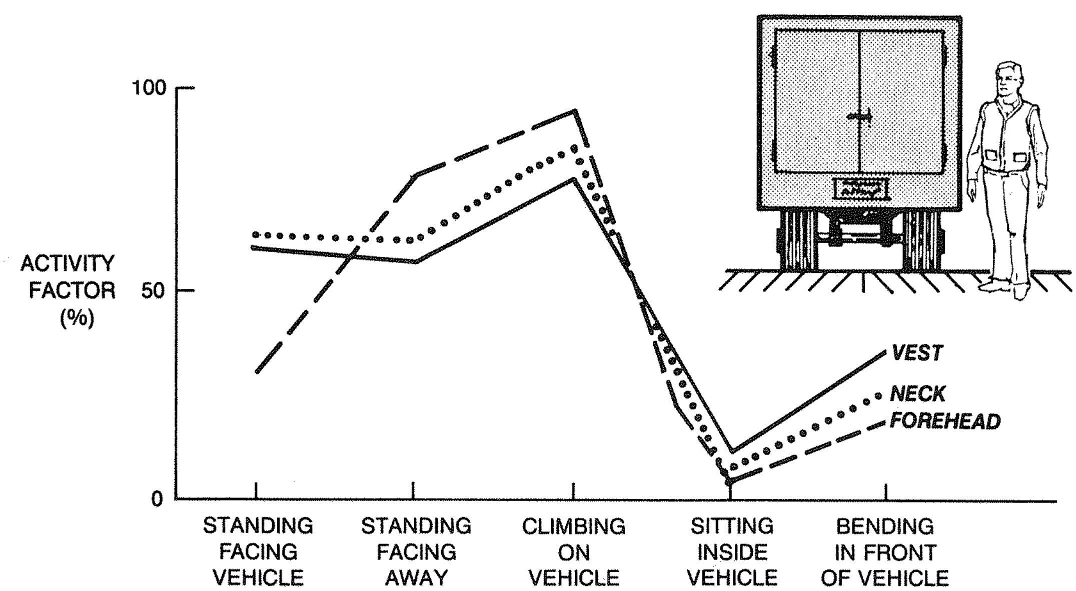


Figure 4.14. Variation of activity factor with body position for work around and beside a vehicle.

REFERENCES

1. "Biological Effects of Extremely Low Frequency Electromagnetic Fields". Proceedings of the 18th Annual Hanford Life Sciences Symposium (Richland, Washington), October 16-18, 1978, pp. 85-108.

2. Electrostatic and Electromagnetic Effects of Ultra High Voltage Transmission Lines. Palo Alto, Calif.: Electric Power Research Institute, 1978. EL-802

3. Transmission Line Reference Book--345 kV and Above. 2d ed. Palo Alto, Calif.: Electric Power Research Institute, 1982.

4. G. J. Stopps, W. Janischewskyj. Epidemiological Study of Workers Maintaining HV Equipment and Transmission Lines in Ontario. Canadian Electrical Association, 1979.

5. Analysis of BPA Occupational Electric Field Exposure Data. Bonneville Power Administration, 1983 Interim Report.

Section 5

EXAMPLE PROBLEM

Perhaps the best way to describe how all the parts of the exposure model fit together is through an example problem based on a set of actual measurements. The example problem utilizes exposure data gathered during a farming operation in southwest Georgia (see Section 6). Because the actual exposure was known, calculating the corresponding theoretical exposure was an opportunity to exercise the Activity Systems Model. This process was used for all the experimental data gathered during the measurement program described in Section 6. The course of this example problem will follow the model flowchart described in Section 3 and reproduced here as Figure 5.1.

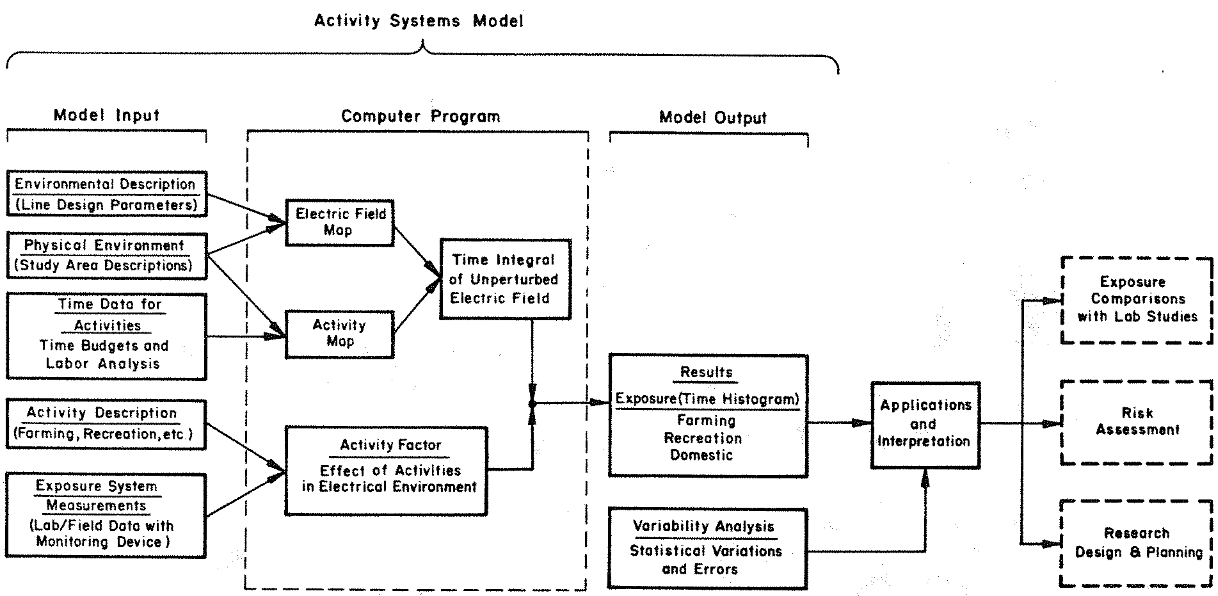


Figure 5.1. Activity Systems Model for Electric Field Exposure

PROBLEM DESCRIPTION

In this example case, a Georgia farmer performed a disc harrow operation under and adjacent to a 500 kV transmission line. His exposure, in (kV/m)*h, was measured using the exposure vest system described in Section 4. The task at hand for the model was to simulate the disc operation in terms of time and electric field and provide an estimate of the theoretical exposure for the reference condition (described in Section 4).

The farmer worked for about 1/2 day in a 9 acre study area. The farmer is shown performing the work with his tractor in Figure 5.2. The study area is shown in Figure 5.3. The area was divided into three subareas that would each take about 1 hour to disc, and exposure readings were taken using the vest measurement system for the work in each of the three areas. Also shown in Figure 5.3 is the location of the 500 kV transmission line. The line operating voltage was 518 kV throughout the measurement period. The design details of this line are presented in Figure 5.4.

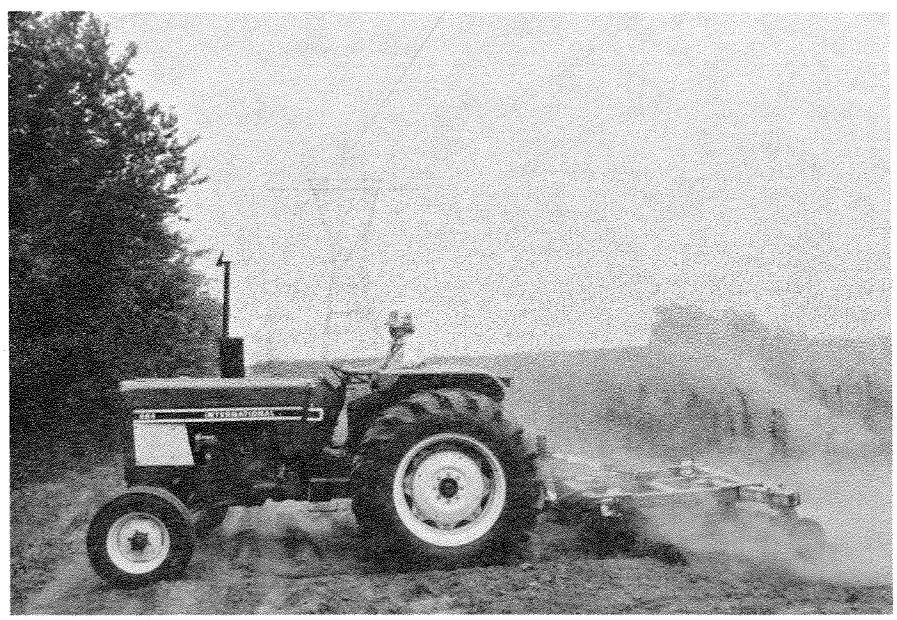


Figure 5.2. Farmer Conducting Disc Harrow Operation Under 500 kV Line

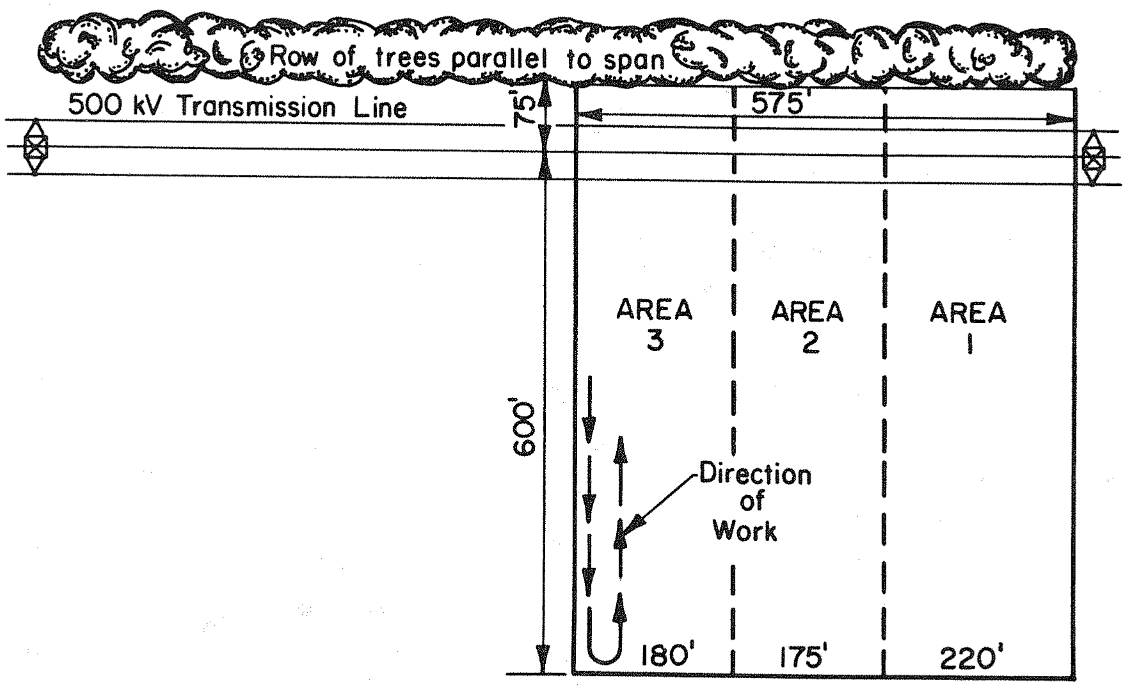


Figure 5.3. Geographical Layout of Study Area on the Georgia Farm

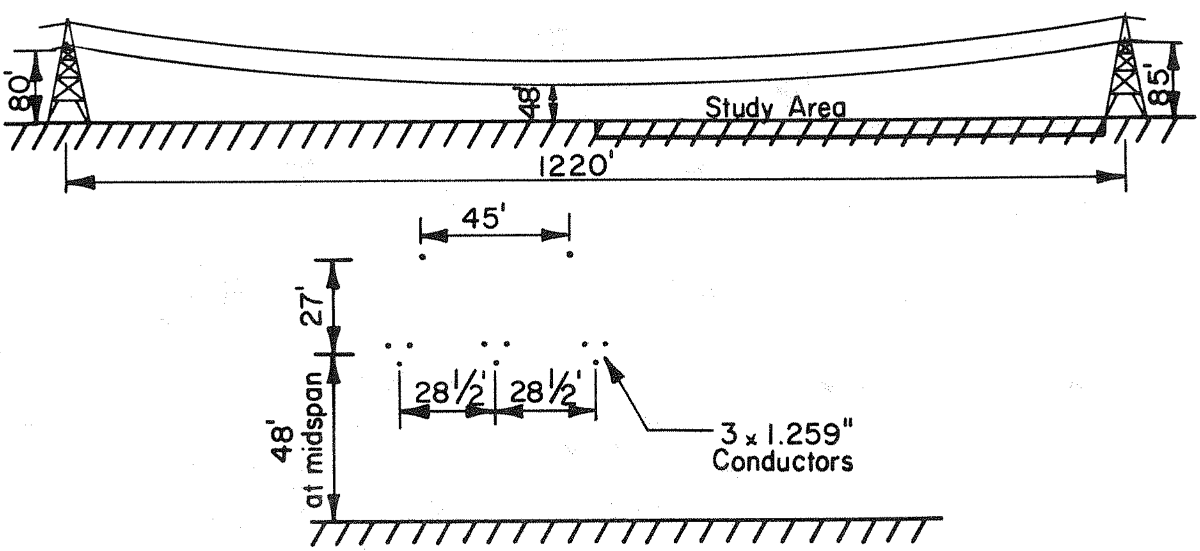


Figure 5.4. Design Details of the 500 kV Transmission Line

The first step in the use of the Activity Systems Model was to generate an environmental description in the form of an electric field map, calculated using the line design parameters already described. This map is a regular grid of sampling points spaced 10 feet apart and superimposed on the study area for this example. The electric field was calculated at each grid point by using the distance from the grid point to the transmission line and the height of the conductors. The electric field program used for this calculation was a version of the method presented in Reference 1. Results compared well with three electric field profiles measured at the study site in accordance with IEEE recommended practice (2). Another check was performed using a computer program developed at the Bonneville Power Administration.

This particular study area required an adjustment to a small portion of the electric field map because of the shielding effect from the row of trees at the right-of-way edge, 75 feet from the transmission line center. A shielding correction factor, derived from measured electric field profiles on the day of the study, was applied to calculated values. The electric field was essentially zero near the base of the tree line (distance = 0). The shielding effect extended out to about 50 feet, where negligible electric field reduction occurred, and the effect was approximately linear for all points in between. The correction factor was therefore applied to the electric field map as a linear function of the distance from the grid point to the tree line, for distances less than 50 feet. This correction factor for the trees, as it turned out, helped to avoid overestimating total exposure for the work area by 10%.

The physical environment was described simply by the boundaries of the study area itself and the boundaries of the three subareas within. The "Time Data for Activities" input category used the actual recorded time that the farmer took to disc each area. The model assumes that the time spent in each subarea is uniformly distributed throughout the subarea (field observations confirm this assumption).

The electric fields, area boundaries, and time data are all, of course, referenced to a single coordinate system so that an electric field and amount of time are calculated for each grid point falling within the subarea boundaries. The exposure at each point is the product of the electric field, in kV/m, and the time, in hours. The total exposure in each area is simply the sum of the exposures calculated for all points. An additional feature of the model is that it is easy to tabulate other results such as the peak electric field encountered and the time spent in various electric field ranges. This feature is not illustrated in this example. The exposure results and activity factor calculations are listed in Table

5-1. In this table measured exposure is the data obtained using the vest, reference exposure (for the reference condition) is calculated using the Activity System Model (with activity factor set at unity) and activity factor is the ratio of measured to reference. In this manner activity factors were determined that can be applied to other exposure estimates.

Table 5-1

MEASURED AND REFERENCE EXPOSURE RESULTS

	Area 1	Area 2	Area 3	Total Area
Measured exposure ((kV/m)*h)	0.13	0.19	0.24	0.56
Reference exposure ((kV/m)*h)	0.51	0.63	0.79	1.93
Activity factor (%)	25	30	30	29

It can be seen that the Activity Systems Model was consistent in estimating activity factors for each of the three areas. In addition, the model correctly predicted that the exposure in Area 3 should be the highest because it is situated at midspan.

In addition to the disc harrow (dynamic) tests with the tractor, a static evaluation of the activity factor also was conducted. Here the farmer sat on his tractor in a known electric field of 3 kV/m for 10 minutes, yielding a theoretical reference exposure of 0.5 (kV/m)*h. The actual vest reading showed 0.151 (kV/m)*h. Therefore, the static activity factor was equal to 0.151/0.500 = 30%, a good comparison with the 29% measured in the dynamic tests. This activity factor was lower than the average value for typical tractors (about 42%) because of the presence of 1 m tall vegetation (see discussion of the Georgia testing site in Section 6). However, this activity factor would be the appropriate value to use for similar operations in low vegetation.

SUMMARY

The following discussion is a brief summary of the data and processing required to start from scratch with a particular farm and transmission line in mind. First, the geography of the farm is referenced to a coordinate system, and the farm is divided into subareas representing different crops, the farmstead, and so on. The locations of the transmission line towers are referenced to the same coordinate system. Second, the details of the transmission line design are used to generate an electric field map (1) based on the coordinate system, which is superimposed on the map of the farm. Third, time values, in terms of hours per acre, are assigned to the subareas for the work tasks to be performed. Sources for this type of data are listed in Appendix B. Fourth, activity factors are assigned for the various activities in each subarea. A list of activity factors may be found in Appendix A. Finally, data are input to the model formulated in Equation 3-1.

As a tool for the exposure study, the Activity Systems Model was implemented as a computer program on a popular microcomputer. The program was set up so that a very fine resolution (large number of grid points) would be possible. The program has been used to simulate large farms with 5000 to 30,000 grid points. Computation times range from about 15 to 30 minutes.

In summary, the Activity Systems Model has proved to be an effective approach to the problem of estimating exposure. The accuracy of the model is reflected in the comparison with actual field measurements.

REFERENCES

1. Transmission Line Reference Book--345 kV and Above. 2ed. Palo Alto, Calif.: Electric Power Research Institute, 1982.

2. IEEE Recommended Practices for Measurement of Electric and Magnetic Fields from AC Power Lines. Transmission and Distribution Committee of the IEEE Power Engineering Society, 1979. IEEE Standard No. 644-1979.

Section 6

EXPOSURE MEASUREMENT PROGRAM

INTRODUCTION

An important aspect of this study was the exposure measurement program. It involved a number of measurements of actual exposure during typical farming and recreation activities near operating transmission lines. The vest exposure measuring system previously described was used in this program at several sites across the United States (see Figure 6.1). Farmers and other individuals participated in this effort. The measurement program was conducted during actual farming and other tasks under a variety of conditions. The program had two main goals:

- To collect exposure data and measure activity factors under realistic conditions near energized transmission lines

- To validate exposure methodology based on activity systems modeling

Measurements included a number of electrical quantities such as induced current, body potential, surface and external fields for numerous situations and weather conditions. Typical exposure program measurements lasted from 1 hour to about 1/2 day of activity. A wide variety of transmission lines) were included in the measurement program. Various structure types and some single and double circuit designs were included. Approximately 725 individual and replicated measurements of various electric exposure parameters were made during this project by ENERTECH and General Electric High Voltage Transmission Research Facility. At the end of this section, a partial listing of some of the measured activity factors is provided. A much more detailed summary of activity factors for 74 activities, based on about 250 measurements, is provided in Appendix A. First, the measurement activities at each of the locations visited during this program are presented in approximate chronological order. Detailed results at each site are not presented here due to space limitations, but the brief descriptions are provided to give perspective on the breath of the measurement program. Essentially, the data were used to produce the activity factors of Appendix A and validate exposure model predictions.

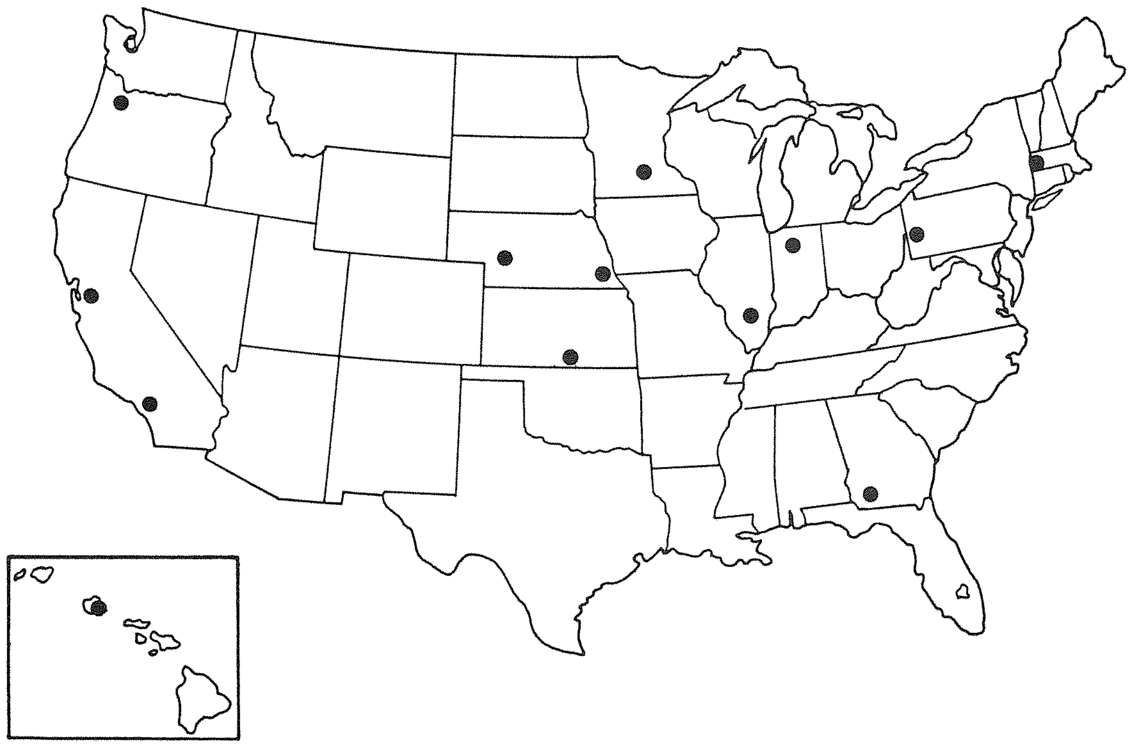


Figure 6.1. Exposure Measurement Program Sites

MEASUREMENT PROGRAM SITE DESCRIPTIONS

Pennsylvania - 1

Some of the first measurements were made during several visits to a site under an energized 500 kV line near Pittsburgh (see Figure 6.2). Activities studied include many types of recreational activities, such as playing tennis, hunting, playing softball and sitting in a lawn chair. The electric field shielding offered by a Jeep with a fiberglass top and shielding afforded by proximity to vehicles and other people were also studied. Various types of footgear (8 types of shoes and boots) and outerwear (various coats and sweaters) were investigated to determine the effect on exposure readings as measured by the vest. Outer garments worn over the vest were found to have little or no effect on vest current. Different types of footgear do affect activity factor by changing grounding conditions (see Appendix A).

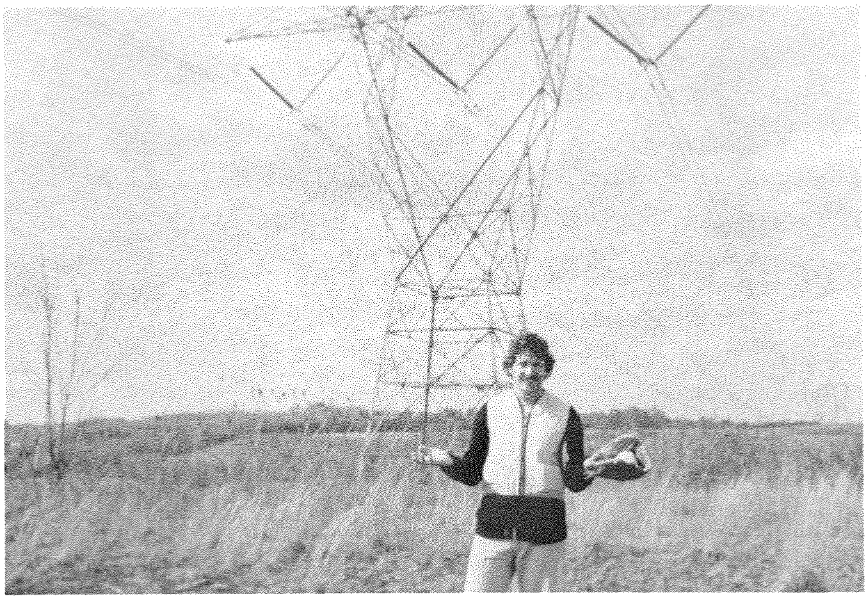


Figure 6.2. Recreation Measurements near 500 kV Line in Pennsylvania

Massachusetts

A number of activities were studied at the General Electric High Voltage Transmission Research Facility near Pittsfield. This research facility has the capability of studying a wide range of electrical parameters of transmission lines. Work was conducted by project staff at this outdoor test line to complement the detailed measurement program at farms and other locations throughout the United States. Activities studied include standing and walking in various situations, tasks near farm equipment, and numerous outdoor recreational activities. Various body electrical quantities were compared with data collected with the vest measurement system. Much of the basic instrumentation calibration was also performed at this site.

Georgia

Two activities were studied in this set of measurements: the clearing of brush near Atlanta and a disc harrow operation in the southwest corner of the state. The brush cutting was conducted on a right-of-way with both a 500 kV and a 230 kV transmission line in parallel orientation. Work was in an area with tall brush and small saplings (3-5 m tall) and with very damp soil conditions. About three-fourths of the exposure time was near brush and trees, and the rest was near clearings.

The disc harrow operation (see Figure 6.3) was conducted by a farmer in an open top tractor approximately 1 meter tall. The work area was situated directly under a 500 kV line between midspan and a tower and extended to 180 meters to one side (see Section 5). The measured activity factor for this work was 30%, a value lower than the average value for this type of tractor (about 42%, as reported in Appendix A). The two probable causes for this lower activity factor are that the soil conditions were somewhat dry and that the vegetation effectively raised the ground plane, causing a lower than average activity factor. A reduction effect of approximately the same magnitude is seen for a person standing in vegetation (see Appendix A) and results directly apply to similar activity in low vegetation.

Figure 6.3. Disc Harrow Operation near 500 kV Line in Georgia

Pennsylvania - 2

Hay cutting activities were studied near a 500 kV line in western Pennsylvania (see Figure 6.4). A farmer used an open top tractor to cut hay on a parcel of land near the midspan of the transmission line. The trapezoidal work area was on a gently sloping hay field that extended about 80 m to one side of the line and about 250 m to the other side. The farmer used a hay cutting attachment for the operation.

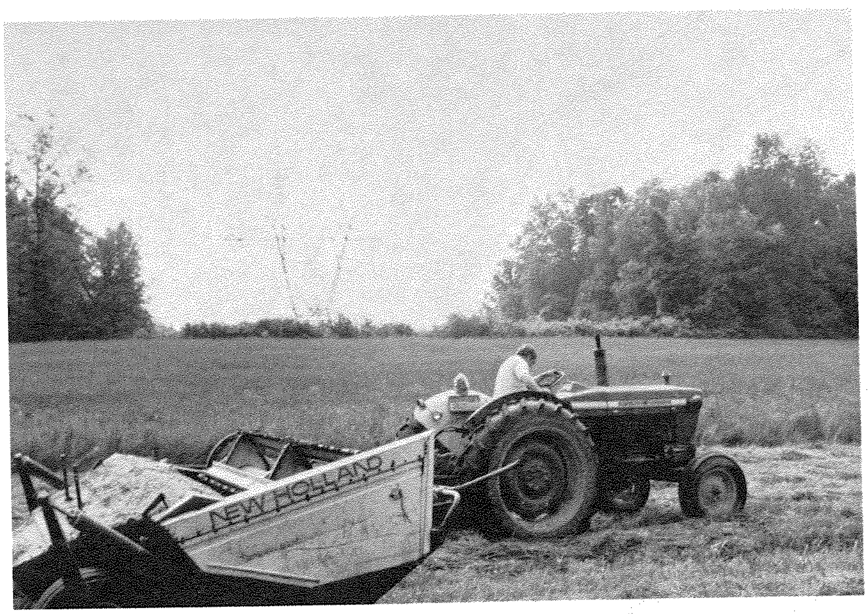


Figure 6.4. Hay Cutting Operation under 500 kV Line in Pennsylvania

Indiana

Measurements were made during the planting of a cover crop on a farm in northern Indiana near a 765 kV transmission line(see Figure 6.5). The work area was in a very large field- - centered on the transmission line at midspan and extending approximately 350 m to each side of the line. The day was very hot and dry. The farmer used an open top tractor and pulled a combination disc and grain drill in tandem. This study site yielded some of the lowest exposure data (and activity factors) for working with open top tractors. Several factors combined to give this result: speed of operation, dry soil, and the large metal fenders and radio antenna of the tractor. These last two items provided shielding to the operator. (The thin, 1 meter tall antenna reduced the space potential near the tractor seat by about 10%.) In some modern tractors, farmers tend to ride "low in the seat" and are shielded by the exhaust stack, steering wheel, and metal fenders that can sometimes extend to about elbow level (or higher). This shielding can also be seen in Figures 6.3, 6.4, and 6.6.

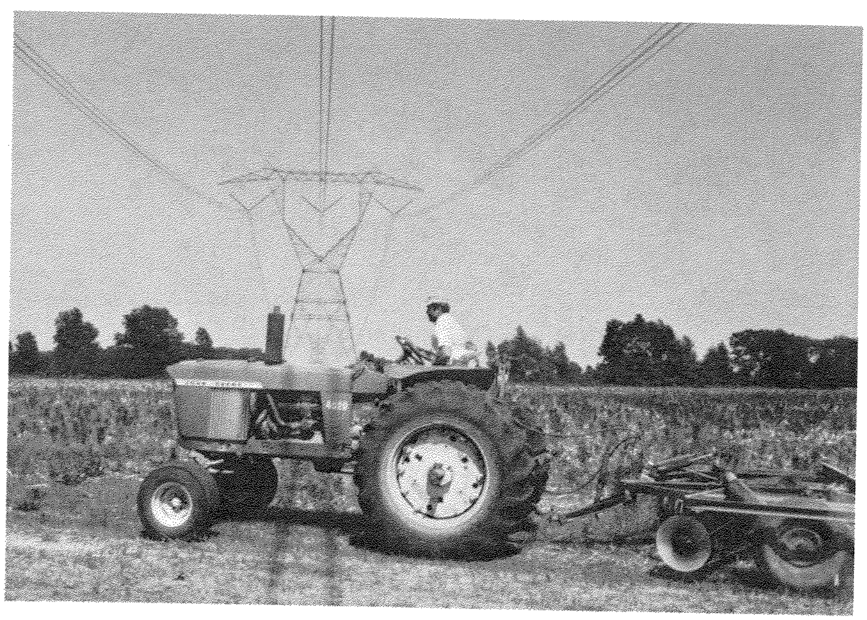


Figure 6.5. Planting Grain near a 765 kV Line in Indiana

Illinois

Exposure data were collected while a farmer was performing a grass cutting operation in a field under a 345 kV line in south-central Illinois (see Figure 6.6). The work area was rectangular in shape and centered on the line at midspan. The farmer used an open top tractor and cutting attachment. These measurements, like those for the Indiana farm, resulted in a lower than average activity factor. The weather was not particularly dry; in fact, a heavy dew covered the ground at the start of the day. In this case, vegetation 0.5 m tall and tractor geometry (that is, a low seat and tall metal fenders) are the probable reasons for the lower value. (These low values were also recorded during static measurements--with the farmer sitting in place on the tractor.) Longitudinal electric field measurements were taken to determine attenuation of the field in the region near the metal H-frame structures at the pasture fencerow.

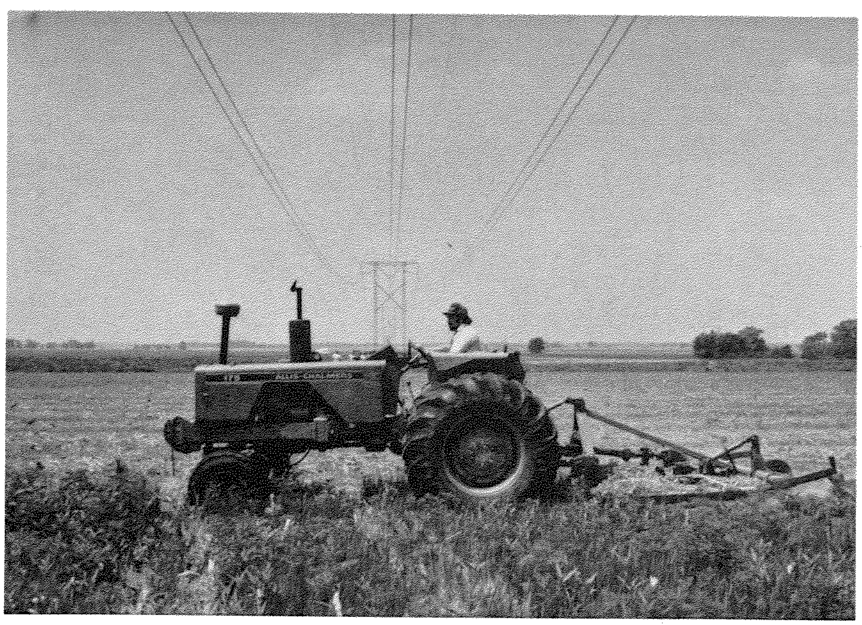


Figure 6.6. Farming Operation near 345 kV Line in Illinois

Nebraska - 1

This study site is situated in central Nebraska. Measurements were made of electrical exposure parameters for open and closed cab tractors on a very wet day. An assortment of tractors and farm implements were studied. The farmer moved the vehicles to a dirt road that crossed under a 345 kV line with 115 kV underbuild (see Figure 6.7). Another individual took a short hike (about 2-1/2 km) along a small field road on the right-of-way to provide additional data. The route along this dirt road passed through adjacent fields of 1 m tall wheat and 0.75 m tall corn. A light, misty rain fell during about half of the measurement period.

Figure 6.7. Closed Cab Tractor Measurements near 345 kV/115 kV Line in Nebraska

Nebraska - 2

Measurements were taken on a 2500 acre farm in southeast Nebraska. The farmer positioned various pieces of equipment on a damp field road under a 345 kV line for a series of exposure measurements (see Figure 6.8 through 6.10). The farmer provided the machinery routinely used in the various phases of his farm operation. Equipment included a large combine with 6-row corn header, open top tractors with and without metal umbrellas, and a half-ton pickup truck. Several sets of data were collected for each exposure configuration.

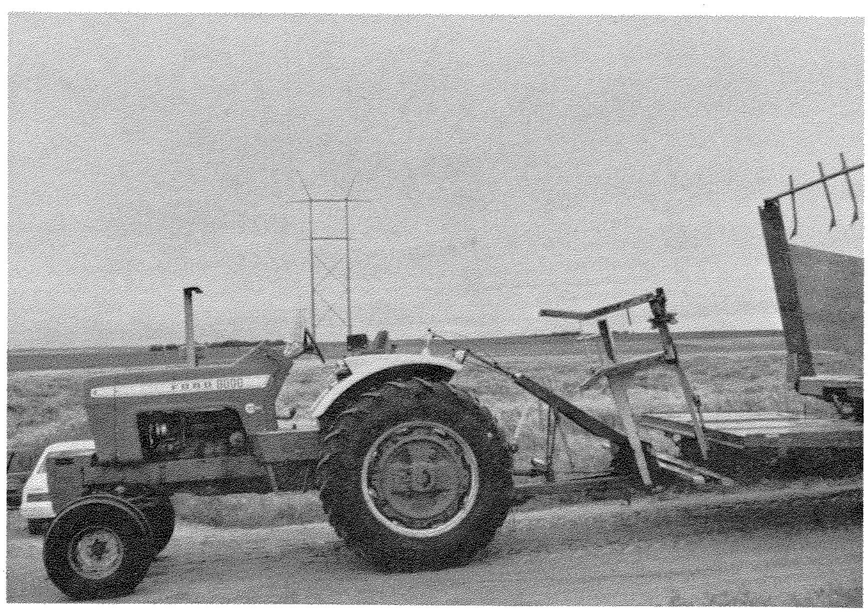


Figure 6.8. Tractor and Hay Wagon under 345 kV Line in Nebraska

Figure 6.9. Combine with 6-row Corn Header Used in Exposure Measurements in Nebraska

Figure 6.10. Farmer on Combine in Corn Field under 345 kV Line in Nebraska

Kansas

The exposure study was conducted on an 800 acre farm and cattle operation in south-central Kansas (see Figure 6.11). The study involved measurements of exposure during an actual wheat harvesting operation. A 345 kV and a 138 kV line are situated in the wheat field that was to be harvested. The farmer used a combine and grain trucks in the harvest operation (he routinely drove the combine through the legs of the H-frame structure without stopping the operation). Measurements were taken also on an open top tractor with a canvas and metallic frame sun top to determine the degree of shielding afforded by the sun top. Data were collected also for standing and moving through wheat 1 meter tall. (Note: During the harvest operation, we noticed that a length of chain was attached to the combine frame and allowed to drag behind the vehicle on the ground. When asked about its purpose, the farmer said, "It's an old farmer's tale that the chain drag helps grain harvesting." He said he has always used it and that it has nothing to do with the transmission lines. He uses it in all his fields, even those with no power lines.)

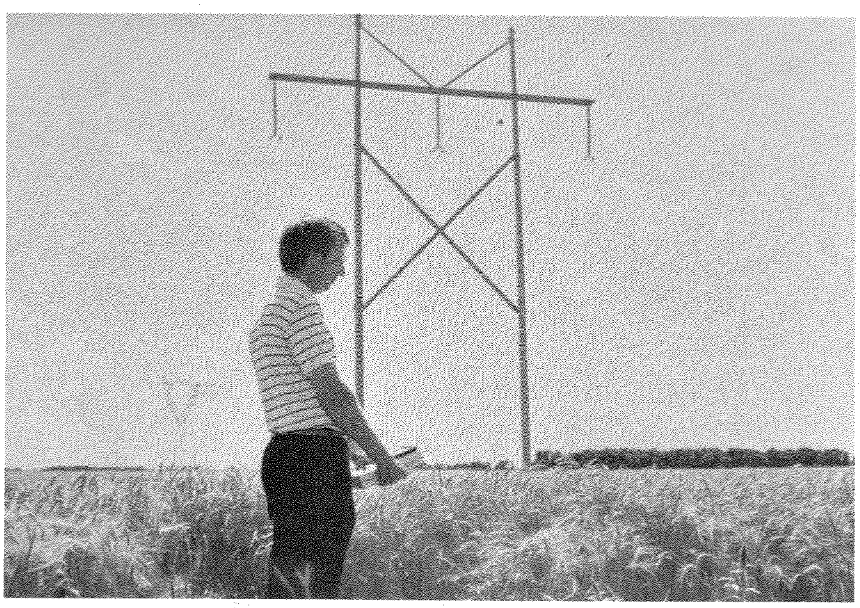


Figure 6.11. Measurements in Wheat Field under 345 kV Line in Kansas

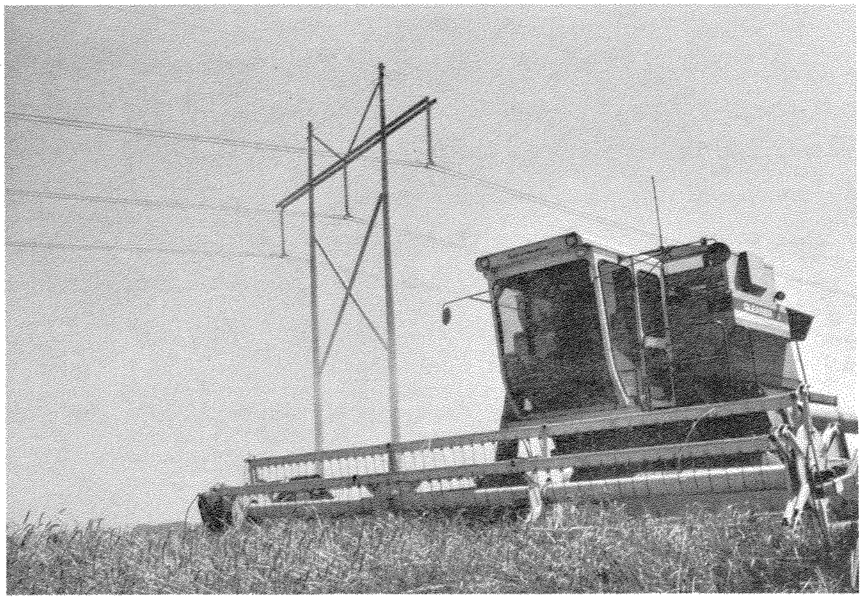


Figure 6.12. Harvesting Wheat under 345 kV Line in Kansas

Figure 6.13. Tractor with Sun Top under 345 kV Line in Kansas

Nebraska - 3

A disc operation was conducted on a large (1160 acre) farming operation in central Nebraska. The work involved a 1/2 mile stretch of field directly under and parallel to a 230 kV transmission line (see Figure 6.14). The farmer used a dual-wheel, air-conditioned cab tractor and 6-1/2 meter wide disc harrow. The operation started under the center phase (or middle) of the transmission line and continued in a longitudinal direction until the work was finished. Results from this location compared well with previous data for similar enclosed cab equipment (Nebraska 1, Nebraska 2, Kansas).

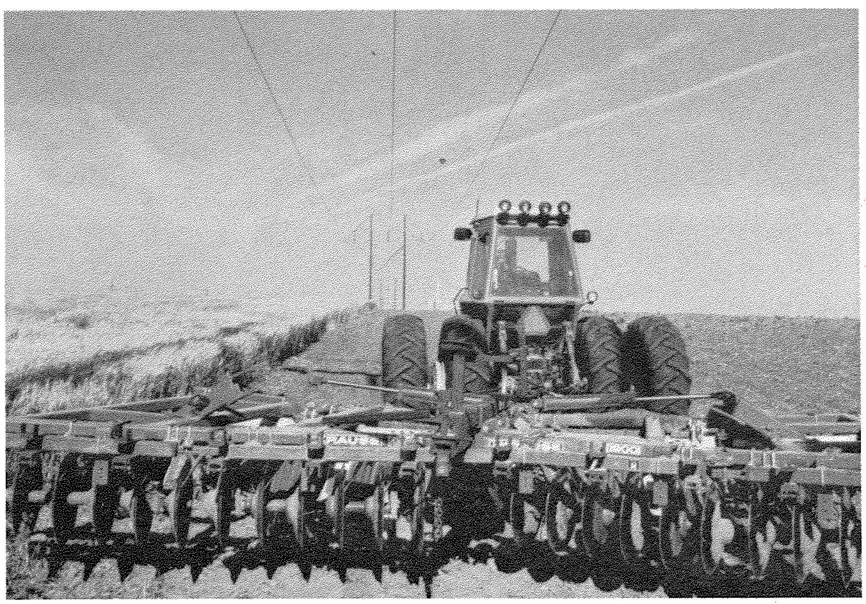


Figure 6.14. Disc Operation under 230 kV Line in Nebraska

California - 1

Measurements of a series of recreational activities were made on the right-of-way of a 500 kV transmission line (with very dry, rocky soil conditions) in southern California (see Figures 6.15 and 6.16). The studies were conducted along a 1/2 mile section of right-of-way directly under the outside phase of the line. A local property owner took a horseback ride over the study path under the 500 kV line. Data were also collected for a person riding an off-road type motorcycle and for two joggers along the right-of-way. For each exposure measurement, the participant completed several trips back and forth along the study path under the transmission line.

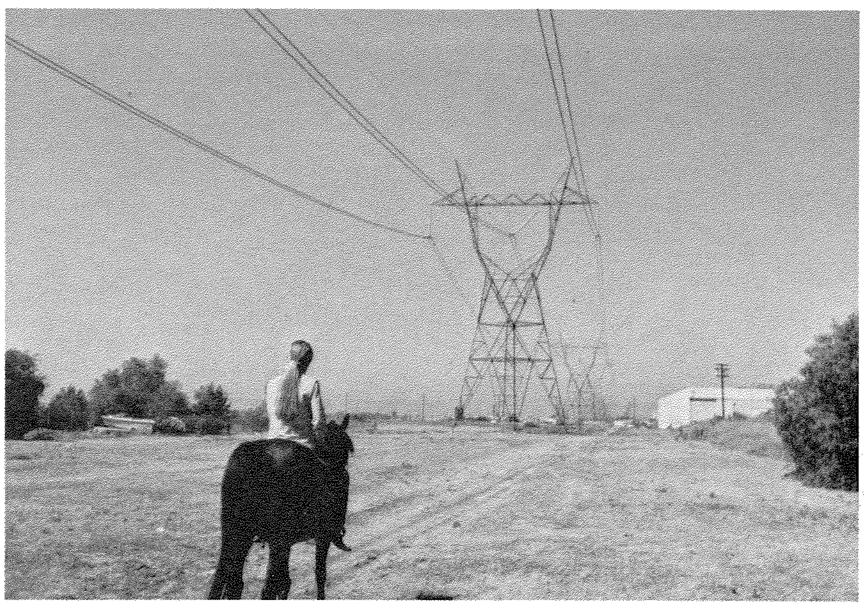


Figure 6.15. Horseback Riding under 500 kV Line in California

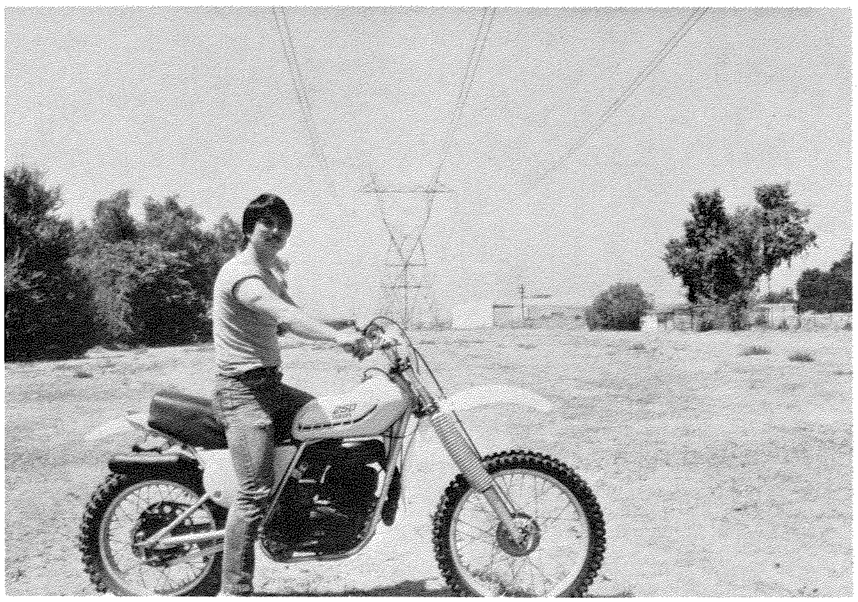


Figure 6.16. Motorcycle Riding under 500 kV Line in California

Minnesota - 1

A series of measurements were taken on a playground located directly under a 230 kV transmission line and adjacent to a double circuit 345 kV line in east-central Minnesota (see Figure 6.17). This study site involved an assortment of wood construction playground equipment and a variety of activities, ranging from swinging to sliding and climbing.

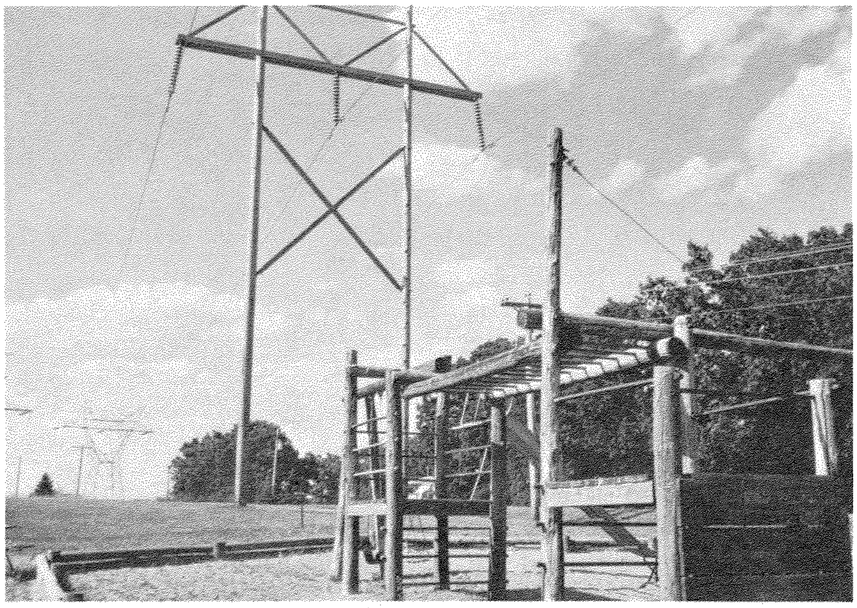


Figure 6.17. Playground near 230 kV Line in Minnesota

Minnesota - 2

A hay cutting operation was conducted on a 600 acre farm and dairy operation under a double circuit 345 kV transmission line in eastern Minnesota (see Figure 6.18). The farmer used a self-propelled swather to cut the hay. The work area was centered on the 345 kV transmission line right-of-way at midspan. The experimentally determined activity factor for the swather was similar to the results for open top tractors (it was a little low--probably because of a 1 m tall radio antenna).

Figure 6.18. Self-propelled Swather under 345 kV Lines in Minnesota

Oregon - 1

A number of measurements were made with a small open top farm tractor in northwest Oregon. The study was conducted at an experimental 1200 kV transmission line research facility (see Figure 6.19). The study involved different operating conditions under the line. A horseback riding study was conducted at this site also. The rider traveled directly under the 1200 kV line (see Figure 6.20). (Additional data were collected at a nearby 230 kV substation for walking on gravel and concrete.) One important observation from previous measurement sites was studied in detail at this site and verified: Activity factors were always lower for movement as opposed to stationary conditions (possibly because of changes in grounding contact pressure). This effect was observed for all situations--walking for instance, as well as riding on a tractor. It is clearly demonstrated in the detailed summary of activity factors in Appendix A. (The only mitigating factor was for operating a tractor during misty rain conditions. In such a case, the tires remain wet, and dynamic values are about the same as values for static conditions.)

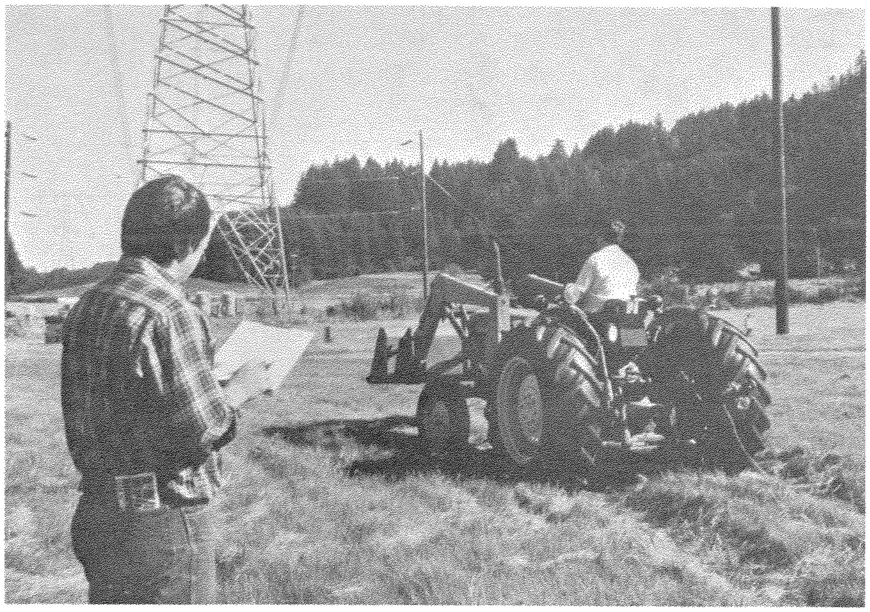


Figure 6.19. Small Farm Tractor under 1200 kV Research Line in Oregon

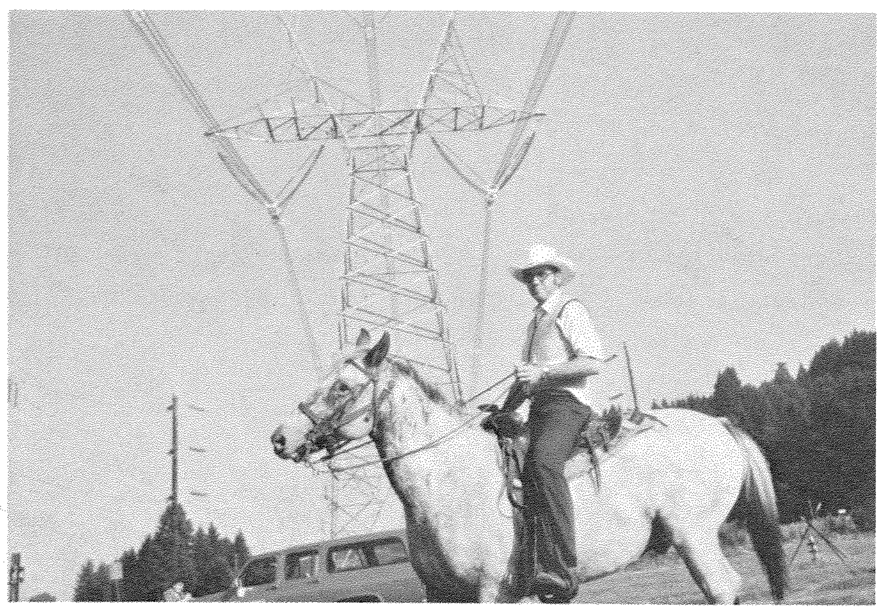


Figure 6.20. Horseback Riding under 1200 kV Research Line in Oregon

Oregon - 2

A series of measurements were made under a 500 kV transmission line in northwest Oregon. The property owner operated a small farm tractor and drove an off-road type motorcycle on a dirt road at the edge of the right-of-way (see Figure 6.21 and 6.22). Various measurements were taken for about 6 hours under very wet conditions. This series of measurements revealed one of the highest activity factors for a tractor. This result was obtained because operators are not as well shielded on these small tractors as on larger ones and because in this case the ground was muddy. A set of static measurements for the operator sitting on the tractor (with and without the engine running) confirmed that vehicle electronics did not affect exposure results. This finding was confirmed at other sites also. The other exposure measurements at this site compared well with results from other sites. The data from these wet (sometimes muddy) conditions helped to complement data from sites with dry conditions.

Figure 6.21. Small Farm Tractor near 500 kV Line in Oregon

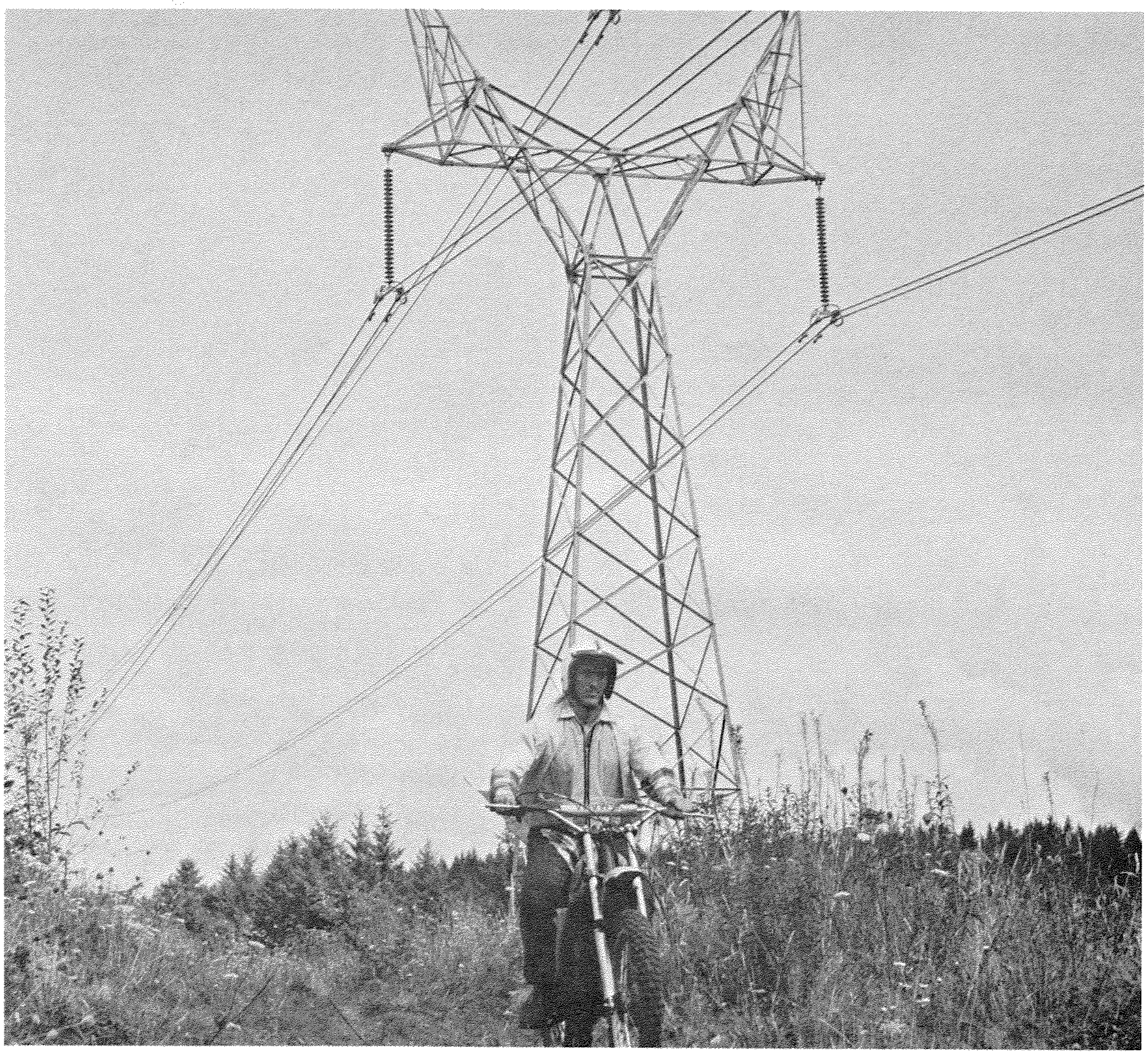


Figure 6.22. Motorcycle Riding near 500 kV Line in Oregon

California - 2

A series of exposure measurements were made for walking and jogging in a public park along a double circuit 230 kV line in northern California (see Figure 6.23). The right-of-way was incorporated into a park with walking paths, picnic benches, and small playgrounds. The path winds back and forth across the right-of-way for a distance of about 1/2 mile. The study was conducted in grassy areas under the line with wet and damp soil conditions. The effect of standing, walking, and running was also studied here. Movement reduces the activity factor; exposure while running in a constant field region was about 20% less than standing still in the same location. This is primarily caused by reduced grounding contact during running.

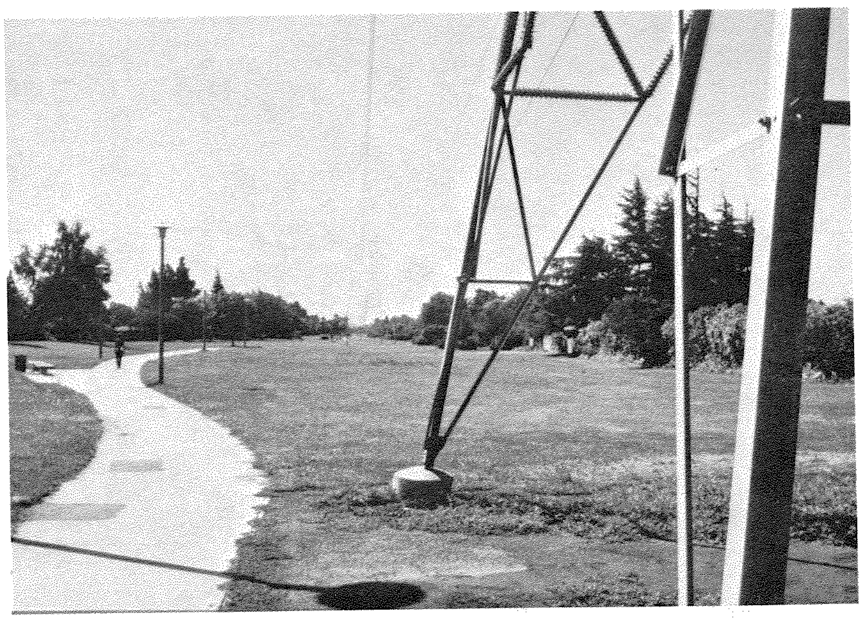


Figure 6.23. Park Situated on 230 kV Right-of-Way in California

Hawaii

Measurements were taken in a residential area in Honolulu near a 138 kV transmission line. The study involved subjects walking down a typical sidewalk in a suburban area (see Figure 6.24). The route for the walk was a little less than 1/2 mile. Path conditions varied; about two-thirds of the route was a concrete sidewalk, and the remainder was asphalt and gravel. The data compared well with exposure data taken for walking on gravel in a 230 kV substation in Oregon. An investigation was made also of shielding by shrubbery and other nearby residential objects.

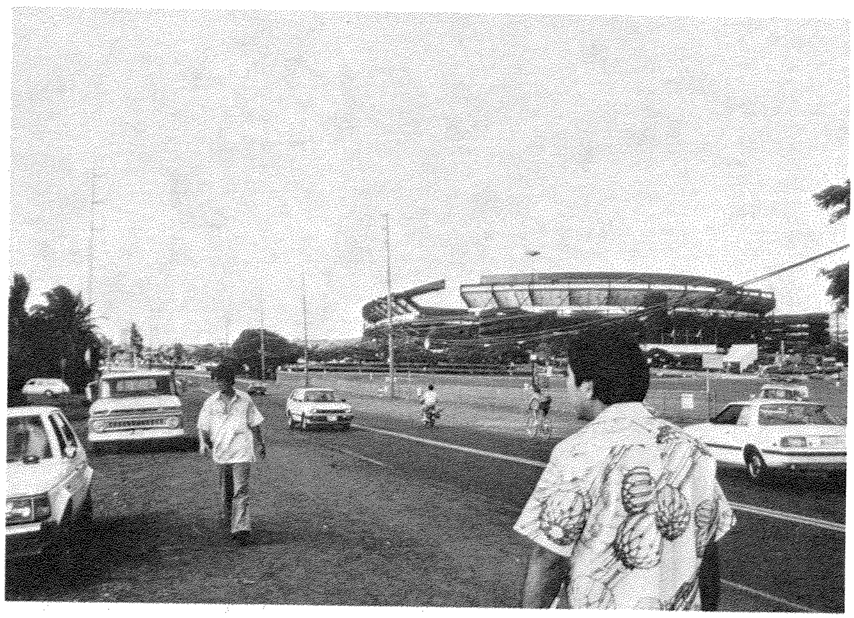


Figure 6.24. Residential Measurements near 138 kV Line in Hawaii

DISCUSSION

The exposure measurements program was able to secure the cooperation of a number of farmers and property owners, some of whom have lived and worked near transmission lines for a number of years. The key element in this program was the study of people near operating lines under actual exposure circumstances.

These measurements covered a wide range of farming and recreational activities and a wide range of conditions that might occur near transmission lines. (For example, the difference between dynamic and stationary activities was addressed in the Oregon - 1 study.) These measurements provided valuable experimental data and validation for the exposure prediction model. This work is the basis on which we developed the large number of activity factors presented in this report (see Table 6-1 for a partial list). A detailed summary is presented in Appendix A. These measurements are evidence that the methodology presented in this report is technically sound and can be applied to a broad range of human activities.

Table 6-1

PARTIAL LISTING OF ACTIVITY FACTORS

Activity Description	Number of Measurements	Activity Factor -(%) Range	Average
Standing in Workboots	20	68-96	89
Standing in various regular shoes	36	60-96	79
Standing barefoot on rocky soil	1	--	95
Standing in jogging shoes	5	67-79	73
Walking on residential sidewalk	1	--	78
Moving through heavy brush, saplings	1	--	21
Working bent over in regular shoes	3	52-76	65
Sitting in jeep with metal top	3	2-4	3
Sitting in jeep with fiberglass top	5	2-9	6
Sitting in half ton pickup truck	2	--	0.7
Driving open top tractor (all sizes)	25	11-63	42
Driving open top tractor with umbrella	2	18-20	19
Driving closed cab tractor	5	1-5	2
Driving self-propelled swather	3	20-43	30
Driving combine	5	0.3-0.4	0.4
Riding trail motorcycle	2	--	59
Riding horseback	4	80-87	84
Sitting in lawn chair	2	43-53	48
Swinging on swingset	2	57-63	60
Playing on playground equipment	5	18-38	28
Sitting at picnic table	8	42-69	53
Standing at picnic table	3	76-86	80
Playing tennis with metal racket	9	50-72	61
Playing tennis with wood racket	4	63-70	67
Riding bicycle	2	78-86	81
Sitting in aluminum boat	3	28-33	30
Fishing (seated)	2	7-12	10
Fishing (standing, moving about)	9	44-74	60
Hiking with backpack	13	73-104	90
Hunting with shotgun	3	57-61	58
Cross country skiing	1	--	78
Snowshoeing	1	--	86

Section 7

EXPOSURE ON THE FARM

AN OVERVIEW OF FARMING IN THE UNITED STATES

American agriculture is one of the most important components of the world economy. Its worth, in terms of dollars, is greater than that of most countries. In terms of land use in the United States, agriculture--at 55%--is the largest of all categories: rangeland comprises 25%, and cropland comprises 21% (1). One reason to study farmers' exposure to electric fields is that the total amount of time spent outdoors by the farming sector is probably more than that spent by any other group. Latest estimates show that 3.7 million people spend 4.3 billion hours a year on farm work. Historical trends of some farm labor indicators are shown in Figure 7.1 (2, 3).

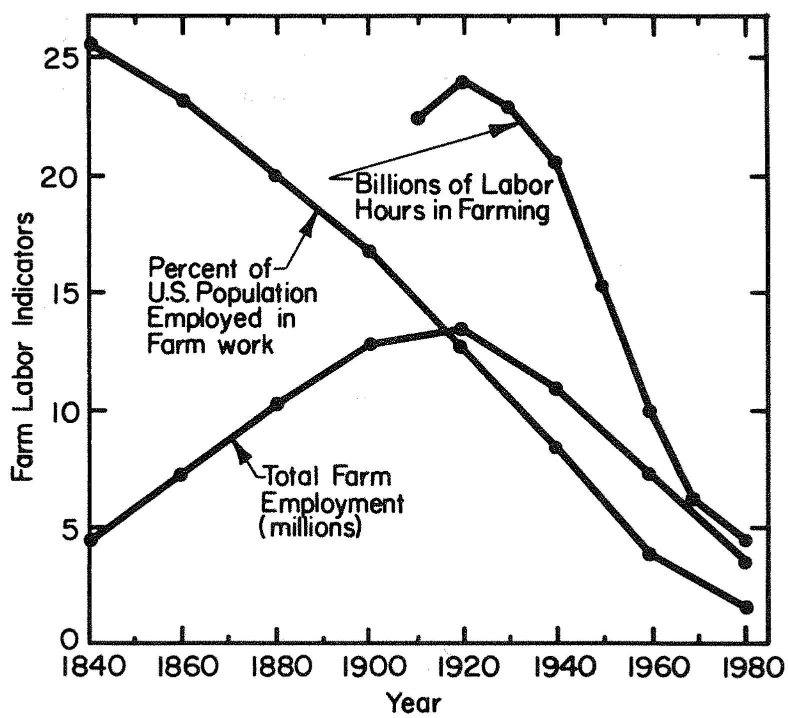


Figure 7.1. Historical Trends of Three Farm Labor Indicators

For the purposes of this study, it is fortunate that the federal government has compiled probably more data per capita on American farmers than on any other population segment. The United States Department of Agriculture (USDA) conducts research and compiles statistics in all areas of agriculture. The Census Bureau in the Department of Commerce conducts a very thorough Census of Agriculture every five years. On the local level, each state maintains its own agriculture department, with support from county extension agencies. In addition, the network of land grant universities was founded for purposes of agricultural research and information gathering. Sources of agricultural data are listed in Appendix B.

American agriculture is diverse: grain and livestock in the Midwest; dairy and general farming in the Northeast; cotton and soybeans in the South; and fruit, nut, and vegetable farming on the West Coast and in Florida. Associated with this diversity of crops is an even greater diversity of labor requirements and practices, even within the same geographical region or within the same crop. For example, cotton grown in Alabama requires no irrigation and little hand labor, whereas cotton grown in Arizona requires irrigation and a lot of hand labor. However, yield per acre in Arizona is about twice that in Alabama (4). Even the same farm may have several different crops or varieties of livestock, which may require different types of machinery and labor.

The basic unit agricultural economists use in farm labor analysis is hours per acre. This is the average amount of field labor spent in one year on an acre of cropland. It does not include overhead labor, such as farm management and machinery repair. It does include all machinery time in the field, with factors accounting for non-productive time such as travel time to and from the field, turning at the end of a row, field machinery adjustments, and so on. Field labor varies widely by crop--from about 2 hours per acre for highly mechanized wheat operations to about 500 hours per acre for very labor intensive crops such as irrigated strawberries and celery. The following values are representative:

- 2-6 hours per acre for most grain crops
- 10-20 hours per acre for cotton
- 50-500 hours per acre for fruit and vegetable crops

Livestock labor hours are estimated by head rather than by acre. However, much of this labor is performed indoors or on the immediate farmstead, a fact that simplifies the modeling of electric field exposure.

A gross ranking of different crops by total labor hours was compiled by multiplying the total acreage of each crop in the United States by the typical hours per acre for the crop. The result is the total hours spent on each crop (5). This ranking is provided in Table 7-1 for most of the important crops in this country. The purpose of this table is to indicate which crops may be the most important in overall exposure assessment.

The most significant sources of data on labor requirements for crops are firm enterprise budgets, or crop budgets, compiled by the USDA and by the Agricultural Economics departments of most land grant universities. The Firm Enterprise Data System (FEDS) is administered by the National Economics Division of the USDA. In this system, each state is divided into one to ten agricultural areas; the nationwide total is nearly 200 areas. Based on annual national surveys of about 10,000 farmers, statistics are compiled on field machinery use, operating expenses, and crop production within each study area. One of the direct results of these budgets is an estimate by month of the hours per acre spent on the most important crops in each area. These hours may be further separated, if desired, by time spent per operation, such as plowing or harvesting. In addition, other field labor such as hand and irrigation labor are compiled.

The FEDS provides approximately 680 standardized budgets for grains, hay, soybeans, cotton, and a few other crops but does not include data for vegetables or fruit, which account for approximately half the total labor hours in Table 7-1. Labor analysis for fruits and vegetables presents three major problems: (1) the budgets are compiled locally at universities and are not standardized from state to state or from crop to crop; (2) harvest labor is usually paid for by the unit rather than by the hour, so that extracting actual hours per acre is not as accurate as it is with the FEDS budgets; and (3) there is no central clearinghouse that collects fruit and vegetable data on a national scale. These factors account for the sometimes extreme range of values in the Hours/Acre Range column in the table. Moreover, irrigation and processing practices tend to spread the ranges as well.

Table 7-1

RANKING OF MAJOR CROPS IN THE UNITED STATES BY TOTAL ANNUAL LABOR HOURS

Crop	Leading States, 50% of Acreage	Total Acres (thousands)	Hours/Acre Range	Hours/Acre Typical	Total Hours (millions)
Tobacco	NC,KY	1,005	99 - 254	248.0	249.2
Corn	IA,IL,NE,IN	70,734	2.7 - 3.6	3.5	247.6
Soybeans	IL,IA,MO,AR,IN	61,833	2.9 - 4.0	3.6	222.6
Hay	WI,SD,NE,MO,TX	61,757	2.0 - 4.7	3.4	210.0
Wheat	KS,ND,OK,MT	54,458	1.1 - 4.2	2.8	152.5
Oranges	FL	914	70 - 200	135.0	123.4
Apples	WA,NY,MI,PA	578	127 - 240	186.0	107.5
Lettuce	CA	253	265 - 576	396.0	100.2
Cotton	TX	12,737	6 - 14	7.0	89.2
Tomatoes	CA	425	42 - 393	205.0	87.1
Peaches	CA,SC,GA	263	110 - 564	277.0	72.9
Corn/silage	WI,MN,NY,IA,MI	8,344	7.9 - 9.5	8.7	72.6
Grapes	CA	763	56 - 164	91.0	69.4
Potatoes	ID,ND,ME,WA	1,395	30 - 330	37.0	51.6
Sorghum	TX,KS	12,962	2.4 - 6.2	3.8	49.3
Onions	CA,TX,NY	128	70 - 550	268.0	34.3
Plums	CA	141	129 - 360	230.0	32.4
Sugar beets	MN,CA,ND,ID	1,249	13 - 30	25.0	31.2
Oats	SD,MN,WI,ND	10,241	1.5 - 3.8	2.6	26.6
Cantaloupes	CA,TX	111	64 - 354	239.0	26.5
Cucumbers	MI,FL,NC,TX	126	83 - 570	208.0	26.2
Grapefruit	FL	245	106	106.0	26.0
Carrots	CA,TX	89	32 - 510	280.0	24.9
Sweet corn	WI,MN,FL,IL	674	24 - 63	36.0	24.3
Rice	AR,LA,TX	3,003	7.3 - 8.3	7.8	23.4
Strawberries	CA,OR,MI,WA	46	243 - 718	480.0	22.1
Blueberries	ME,MI	48	74 - 530	454.0	21.8
Celery	CA	38	196 - 800	555.0	21.1
Broccoli	CA	68	65 - 426	283.0	19.2
Cabbage	TX,FL,NY	102	25 - 426	186.0	19.0
Cherries	MI,OR	130	48 - 219	142.0	18.5

Another significant factor in farm labor analysis as it relates to public exposure is the distribution of the labor among various types of workers--chiefly, the principal operator, other family members, and hired labor. Labor distribution varies widely over the country. Some of the main factors affecting labor requirements are farm size, crop type, presence of livestock, degree of mechanization, and irrigation requirements. Farms in the Northeast, for example, tend to be just small enough to be handled by one family, and there is little need for hired labor. In California, on the other hand, farms are large and specialized, and a very large proportion of the labor is hired. Average farm sizes may vary from about 200 acres in the Northeast to over 1000 acres in the West (5).

Agricultural economists generally divide labor into three categories: that performed by the operator (one person), that performed by the family (the remaining family members--one or more persons), and that performed by hired laborers (zero or more persons). Labor requirements are usually fulfilled first by the operator. Family members provide assistance if the workload becomes too heavy. Finally, hired labor is used, either year round (if there is enough work) or only during the harvest.

FARM MACHINERY

The amount of exposure that a farm worker receives has a great deal to do with the equipment he is using. Farm activities can vary widely, and the type of equipment used for an operation can affect the amount of shielding provided. The range of outdoor farming operations (and the range of machinery employed) is illustrated by the following examples:

- Workers hand-picking fruit or vegetables on foot and using no machinery
- Workers on foot but near machinery that could provide shielding (for example, workers hand-picking fruit or vegetables and loading them onto a field conveyor or packer)
- Workers operating tractors with open top seats or cab enclosures
- Workers operating specialized machinery, such as self-propelled combines, which usually have enclosed cabs

- Workers driving trucks, which are almost always enclosed

Photographs of three major types of machinery are presented in Figures 7.2, 7.3, and 7.4. Figure 7.2 shows a medium-sized, open top tractor of approximately 80 horsepower. This tractor might be used for utility operations on a large farm or as the main tractor on a small farm. Shielding from electric fields can be provided by the fenders, steering wheel, and exhaust stack. In addition, many farmers mount umbrellas and radio antennas on their open top tractors.

Figure 7.3 shows a larger (105 horsepower) tractor with an enclosed cab. The trend in modern agriculture is toward larger tractors because they are more cost-effective. (The trend is toward enclosed cabs also, because they are more comfortable and protect workers from dust, debris, and the elements.) Workers in enclosed cabs are shielded almost completely from electric fields.

Another major category of farm machinery is self-propelled implements. Figure 7.4 shows a grain combine, also with an enclosed cab. A combine can be adapted to harvest almost any type of grain and is the primary piece of machinery used at harvest time. Shielding is provided not only by the enclosed cab, which is typical of almost all self-propelled combines, but also by the elevated metal components behind the cab. (Some models have the engine mounted to one side of the cab, thereby increasing shielding.) The relationship between activity factor and shielding is naturally very close. The relationship shows up in the range of activity factors that were measured for various vehicles in this study. Table 7-2 lists typical values of activity factors for some farm vehicles. Appendix A provides a detailed listing of activity factors for a variety of farming activities.

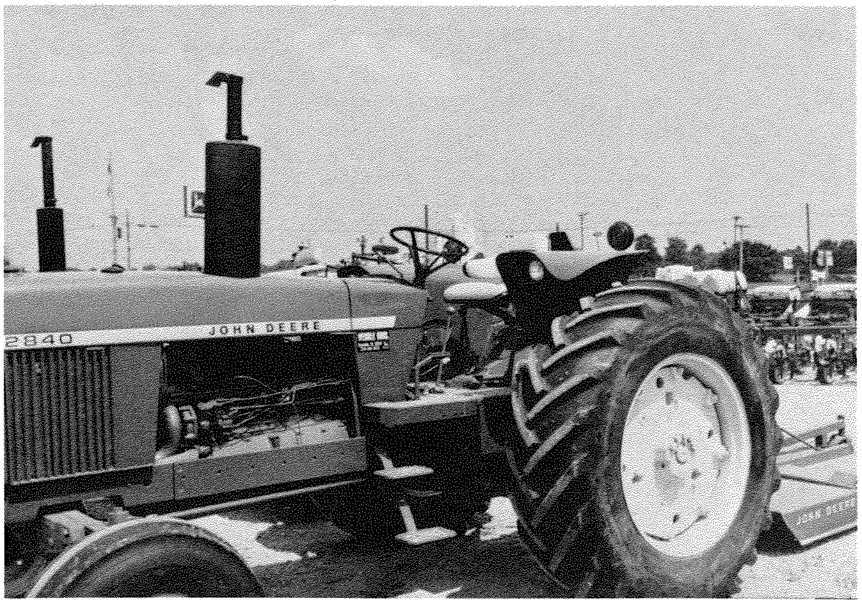


Figure 7.2. Example of an Open Top Tractor, 80 HP

Figure 7.3. Example of a Cabbed Tractor, 105 HP

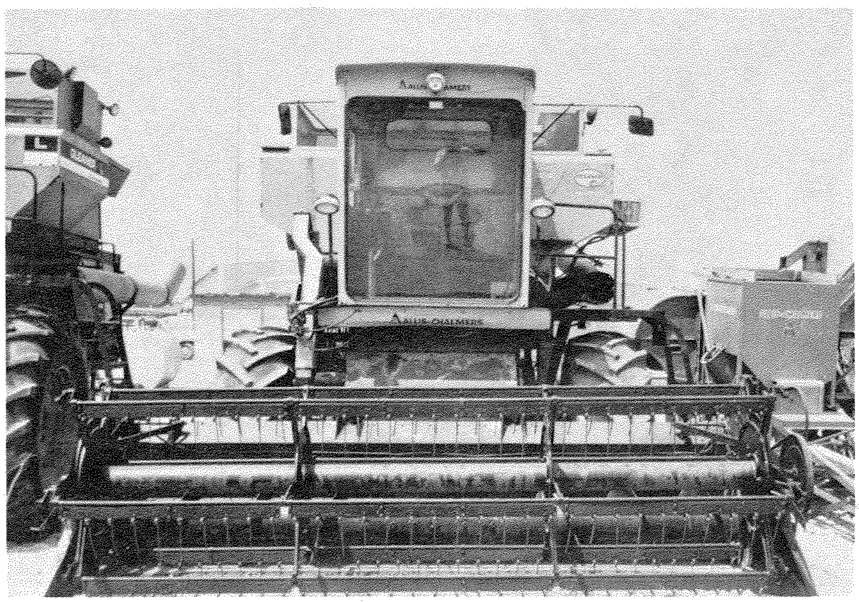


Figure 7.4. Example of a Cabbed Self-propelled Combine

As it became obvious that the existence of cabs (that shield the electric field) on farm machinery would play a major role in estimating exposure on the farm, an effort was made to find out the relative proportion of cabbed equipment in this country. This task was difficult at best because apparently no national organization keeps such data. The organizations we consulted include the USDA, the major farm equipment associations, farm equipment experts from various universities, and the Nebraska Tractor Test Program. The major tractor manufacturers would provide only guesses, because they were very reluctant to release sales figures.

The consensus of the manufacturers was that almost 100% of today's larger tractors (over 80 horsepower) are sold with cabs and that very few tractors--approximately 10%--under 80 horsepower have cabs. These numbers corroborate the data presented in Table 7-3, where Census Bureau production statistics on tractors (6) are compared with the number of models of tractors appearing in the Implement & Tractor Redbook (7). For 261 tractor models, Redbook lists statistics such as horsepower rating and whether a cab is standard, optional, or not available. These numbers are presented in Table 7-3; although they are not as good as the--unavailable--sales statistics on each model (not all models sell at the same rate), they do concur with industry estimates. (An informal survey of the farmers visited in the measurement program described in Section 6 indicated that almost all major farm work is done with cabbed tractors and that small open top tractors are used for miscellaneous tasks around the farm.)

Table 7-2

ACTIVITY FACTORS FOR SELECTED FARM VEHICLES

Vehicle	Activity Factor Range (fraction)	Activity Factor Typical (%)
Open top tractor	1/8 - 5/8*	42
Standard sizes		
Variable soil conditions	1/3 - 1/2	40
Working in 1 m vegetation	--	30
Very dry soil	--	12
Small size		
Variable soil conditions	3/8 - 5/8	45
Very dry soil	--	20
Cabbed tractor	--	2
Combine	--	0.4
Pickup truck	1/200 - 6/200	1
No vehicle (person walking in workboots)	13/20 - 19/20	90

* This range can be broad. It combines all sizes of farm tractors. The lowest values are for large tractors on dry soil, and the upper values are for small tractors on very wet soil.

Table 7-3

CABBED VERSUS NONCABBED TRACTOR MODELS CLASSIFIED BY HORSEPOWER

Tractor Horsepower	Production* (1981)	Availability of Cab** % of models			Total Number of Models
		Standard	Optional	Not Available	
Under 60	19,045	7	29	64	98
60-80	10,537	8	38	54	50
80-100	11,749	38	54	8	13
100-120	15,492	47	42	11	19
120-140	28,579	69	23	8	13
140-160	10,396	86	14	0	7
160-180	6,015	88	12	0	8
180 and over	17,974	87	9	4	53
Total	119,787	36	28	37	261

* Number of farm tractors produced, U.S. Census Bureau (6).

** Implement & Tractor Redbook, 1981 data (7).

TYPICAL FARMS

One of the steps in validating any model is applying it to a realistic and representative problem. For the exposure model, there were two apparent choices: (a) to locate and analyze various real farms throughout the country, and (b) to construct a statistical composite farm for a given area (for example, a state) based on census and USDA data. Choice (a) was realistic but probably not representative. Choice (b) was representative but probably not realistic.

Fortunately, the USDA has provided an ideal compromise in their Census Typical Farm Program (8). The typical farms were developed for use by Congress and the USDA in evaluating the impact of legislative agricultural policies on representative farms. These eighteen typical farms are designed to be representative of selected areas of the United States and to be realistic in their size and crop composition. Figure 7.5 shows the areas these farms represent and Table 7-4 lists the acreage and crop mix of each. Typical farms are not actual, existing farms, but they are statistical composites, representative of actual farms in their areas. The exact procedure for selecting the typical farms is given in Reference 8.

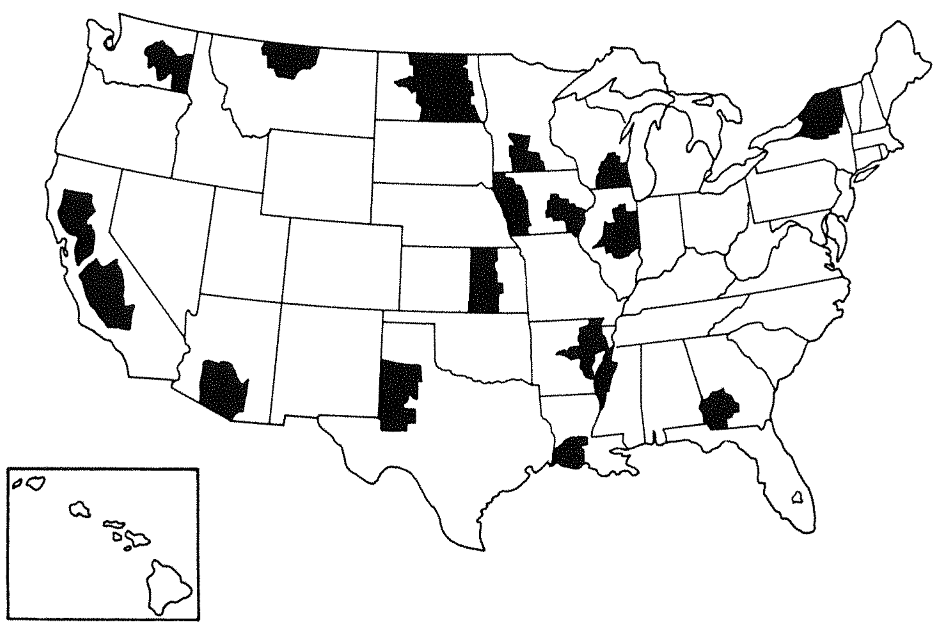


Figure 7.5. Locations of the Eighteen Typical Farms

Table 7-4

DESCRIPTION OF THE EIGHTEEN USDA TYPICAL FARMS

Location	Total Land	Cropland	Enterprise	Units*
Arkansas	720	640	soybeans--irrigated	200
			soybeans--nonirrigated	180
			rice--irrigated	260
Arizona	910	760	cotton--irrigated	760
California	640	440	cotton--irrigated	440
California	680	480	rice--irrigated	480
Georgia	720	520	peanuts	80
			soybeans	220
			corn	220
Illinois	380	360	corn	180
			soybeans	180
Iowa	360	320	fed cattle	120
			corn	200
			soybeans	100
			alfalfa	20
Iowa	300	240	pigs	100
			corn	140
			soybeans	60
			oats	40
Kansas	580	480	wheat	360
			alfalfa	80
			sorghum	40
			beef cows	15
			stockers	30

Table 7-4 (continued)

Location	Total Land	Cropland	Enterprise	Units*
Louisiana	520	480	rice--irrigated	160
			soybeans--dryland	320
Minnesota	340	320	corn	160
			soybeans	160
Mississippi	1280	1040	cotton	480
Delta			soybeans	560
Montana	2140	1920	wheat	780
			barley	180
			fallow	960
New York	300	160	milk cows	50
			alfalfa	30
			other hay	50
			corn	20
			corn silage	30
			pasture	30
North Dakota	960	760	wheat	320
			fallow	320
			barley	120
Texas	780	680	cotton--irrigated	680
Washington	1280	1080	wheat	540
			fallow	540
Wisconsin	180	160	milk cows	45
			alfalfa	60
			green chop	20
			corn	30
			corn silage	30
			oats	20

Source : (8).

* Units for crops = acres; units for livestock = head.

The geography of each typical farm was implemented into the exposure model by the following procedure, which was developed through detailed meetings with several USDA managers and staff members. (The layout of a typical farm is shown in Figure 7.6.)

1. The farm is made square with the southwest corner at the origin.
2. The farmstead/homestead is assigned to a square area in the southwest corner. The farmstead is considered to be the general farm working area--the barn, the feedlot, fuel and equipment storage, grain and hay storage, the livestock operation, and so on. The homestead is the area immediate to the home used more for family activities than for farming activities.
3. The homestead is assigned to a square area halfway up the east side of the farmstead/homestead area.
4. Each crop is assigned to rectangular strips extending from the northern to the southern edge, according to the acreage of the crop.
5. The leftover area along the western edge, comprising woodlot, pasture, waste land, roads, and so on, is classified as "other land".
6. A 345 kV transmission line (similar that shown in to Figure 7.7) is positioned across the middle of the farm from west to east. This positioning may not be the same as on a real farm. (Some states have rules establishing minimum distances between transmission lines and homes. Placement of the transmission line was based on this consideration. In this study, the arbitrary minimum distance between any farmstead/homestead and transmission line was about 700 feet.)

Once the farm geography is established, each of the four area types is assigned labor hours by the following rules:

- Crop Areas--USDA hours per acre are assigned to each crop. Labor is subdivided into preharvest labor, harvest labor, and other labor, which includes irrigation labor. The "other labor" category is assigned a minimum of 0.1 hour per acre.
- Other Land--other land is assigned 0.25 hours per acre.
- Farmstead--This area is assigned 10% of all field crop hours plus all livestock hours. This total is divided by farmstead acreage.
- Homestead--This area is assigned 300 hours to account for miscellaneous outdoor activity by all farm workers near the home. This total is divided by homestead acreage.

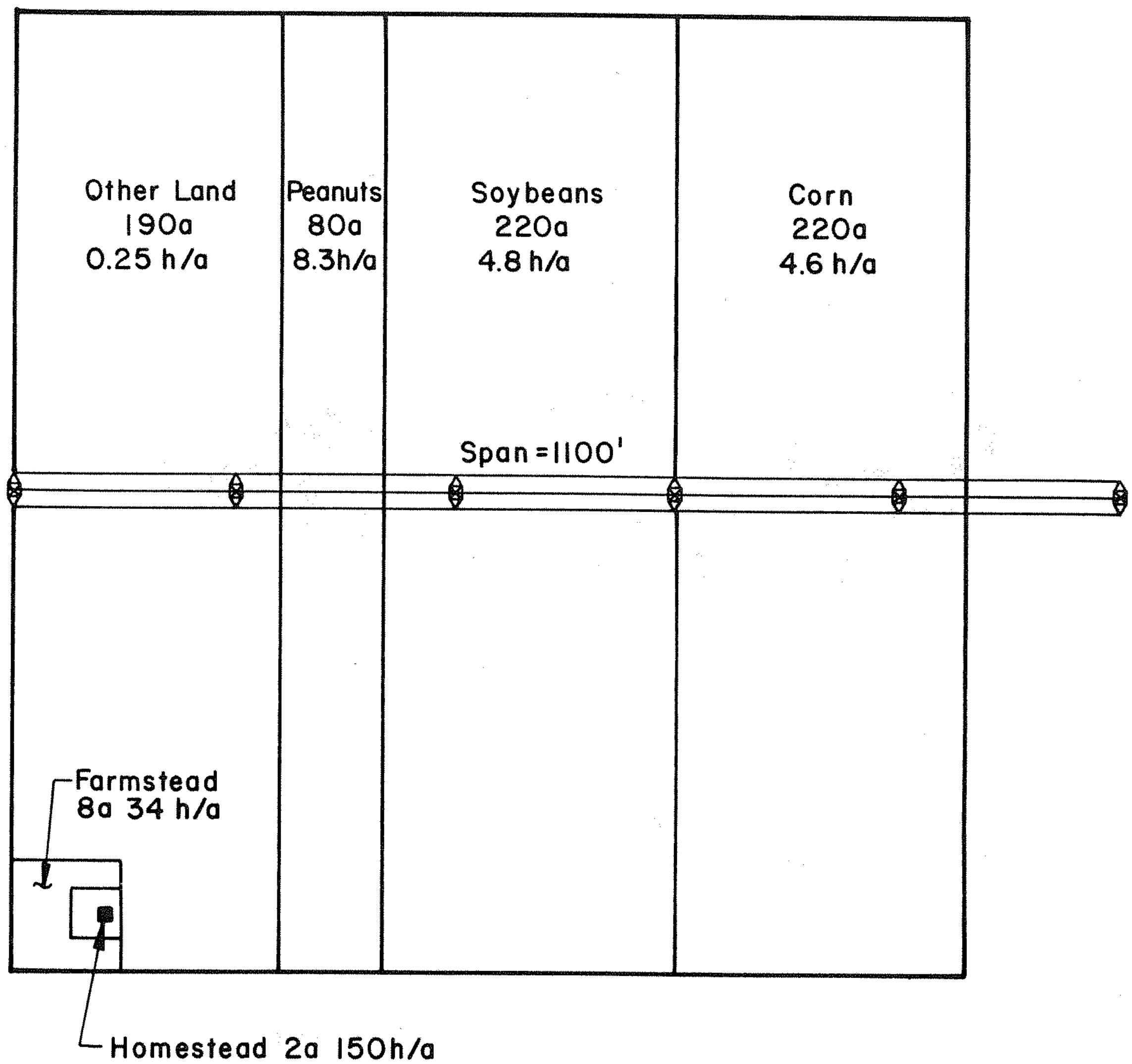


Figure 7.6. The Layout of a USDA Typical Farm (Georgia: 720 Acres)

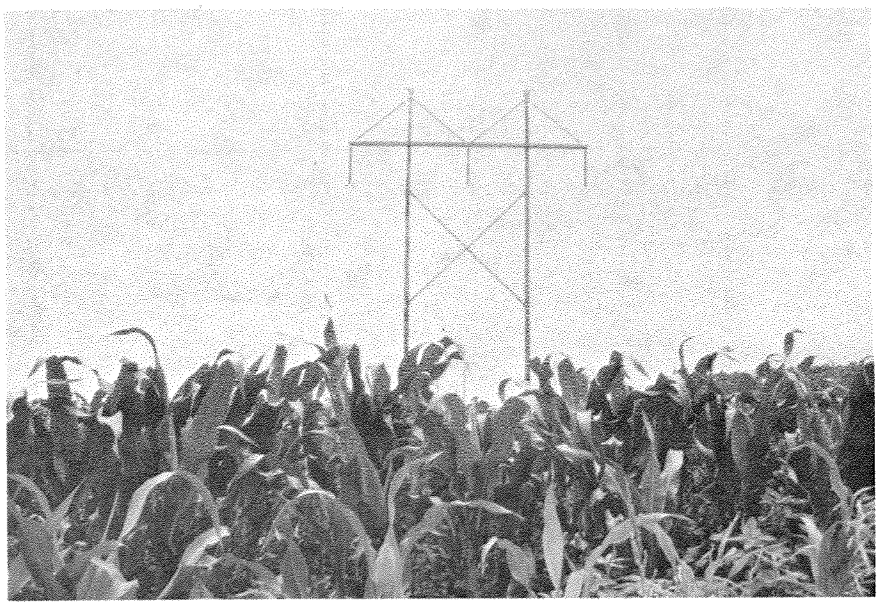


Figure 7.7. Corn under a Typical 345 kV Line in the Midwest

In the crop areas, the activity factors assigned for all preharvest labor were representative of work done with an open cab tractor. All harvest labor was assigned an activity factor representative of work done with a closed cab tractor or combine. The "other labor category" was assigned an activity factor of 100%. In the "other land", homestead, and farmstead areas, the activity factor assigned was for walking on the ground (90%, except for a minimum of 0.1 hours per acre at 100%).

RESULTS OF THE TYPICAL FARM ANALYSIS

All eighteen of the USDA typical farms were analyzed using the Activity Systems Model. The analysis produced a wide range of exposure results; this outcome was to be expected because of the wide range of farming practices in this country. Table 7-5 provides a summary of the results.

The total exposure on each farm is divided among the three farm worker categories in proportion to the amount of labor that each category contributes. Because there could be more than one hired worker on a farm, it was assumed that a hired worker would work approximately 1500 hours per year (a number based on Census of Agriculture data, discussions with agricultural economists at USDA and land grant universities, and a survey conducted by the project team on 31 farms across the United States and Canada ranging in size from 50 to 5000 acres). The number of hired workers would be equal to the total hired labor hours divided by 1500 hours per worker, rounded to the nearest whole number. Therefore, the farms showing the larger values for total exposure would actually have that exposure spread out over several individuals.

The total exposure estimate is closely related to total labor, as Figure 7.8 shows. The coefficient of correlation on the linear regression of exposure versus labor is 0.89, a fairly high correlation. This correlation disappears when the regression goes to the individual level. On the other hand, exposure versus farm size (Figure 7.9) yields a correlation of 0.11, essentially no relationship. This outcome is possible because so many other variables besides size--degree of mechanization, crop type, and so on--can affect exposure. For example, the Montana typical farm, even though it is the largest (at 2140 acres), has a very low total exposure because of the farming practices in that area. That is, half of the cropland on the farm is fallow, and the other half is planted in wheat and barley, two crops that require only a few hours per acre. However, we must note that the diverse nature of farming and the assumptions used in the exposure estimating process preclude any detailed interpretation of the correlation coefficients.

Actual exposure values are very likely to be lower than calculated exposures because electric field values are usually overestimated. The following situations tend to affect electric field values:

- Ground clearances on actual spans are almost always higher than design minimum clearances.
- The model in this study assumed flat terrain, whereas the terrain that transmission lines pass through does vary. Irregular terrain can affect electric field values.
- All work, besides harvesting, is assumed to be done on an open top tractor without a cab. This assumption is conservative because of the widespread use of cabbed tractors.
- Hand labor and "other labor" were assigned activity factors of 100%. (The assumption here of wet shoes on wet soil is conservative.)

- The exposure model used in this study did not account for shielding by nearby objects (which can be important), whereas in the real world, of course, shielding may be the rule rather than the exception. Almost any object--a tree, a building, a vehicle, telephone lines, vegetation, and so on--can provide significant shielding from electric fields.

In addition to the exposure estimates, the time spent in equivalent electric fields was also tabulated. The standard bins outlined in Section 2 were used to disaggregate the times (shown Table 7-6), which are expressed in terms of the percentage of total labor hours for each farm. It can be seen that almost all of the farm workers' time was calculated as being spent in electric fields equivalent to household levels (that is, 0-50 V/m). On the other extreme, an average of 0.1% of each farm worker's time (say, 1-2 hours per year) was spent in equivalent electric fields of more than 3 kV/m, which corresponds to the approximate human threshold of electric field perception (9). Average values are presented in Figure 7.10.

Table 7-5

SUMMARY OF ANNUAL EXPOSURE RESULTS FOR EIGHTEEN TYPICAL FARMS
(345 kV Case)

Farm	Size (Acres)	Total Labor (Hours)	% of Labor (USDA)			No. of Hired Laborers	Cumulative Annual Exposure (kV/m)h			
			Operator	Family	Hired		Operator Exposure	Family	Each Hired	Farm Total
AZ	910	15335	18	5	77	8	126	35	68	702
AR	720	4901	49	11	40	1	100	22	81	201
CA1	640	8751	24	6	70	4	113	28	82	470
CA2	680	5291	45	13	42	1	92	27	86	205
GA	720	3364	80	11	9	1	79	11	9	99
IL	380	1970	75	3	22	1	51	2	15	68
IA1	360	3025*	84	6	10	1	44	3	5	52
IA2	300	4164*	73	14	13	1	31	6	6	43
KS	580	2507*	71	13	16	1	34	6	8	48
LA	520	2314	91	4	5	1	69	3	4	76
MN	340	1711	96	4	0	0	76	4	0	80
MS	1280	8331	29	6	65	4	73	15	41	251
MT	2140	2665	66	11	23	1	26	4	9	39
NY	300	6683*	47	13	40	2	11	3	9	23
ND	960	1488	79	11	10	1	25	4	3	32
TX	780	9282	24	6	70	4	116	29	84	482
WA	1280	1508	72	11	17	1	20	3	5	28
WI	180	5303*	57	16	27	1	17	5	8	29
Avg	726	4922	60	9	31	2	61	12	16	163
Low	180	1488	18	3	0	0	11	2	3	23
High	2140	15335	96	16	77	8	126	35	86	702

*Includes livestock labor.

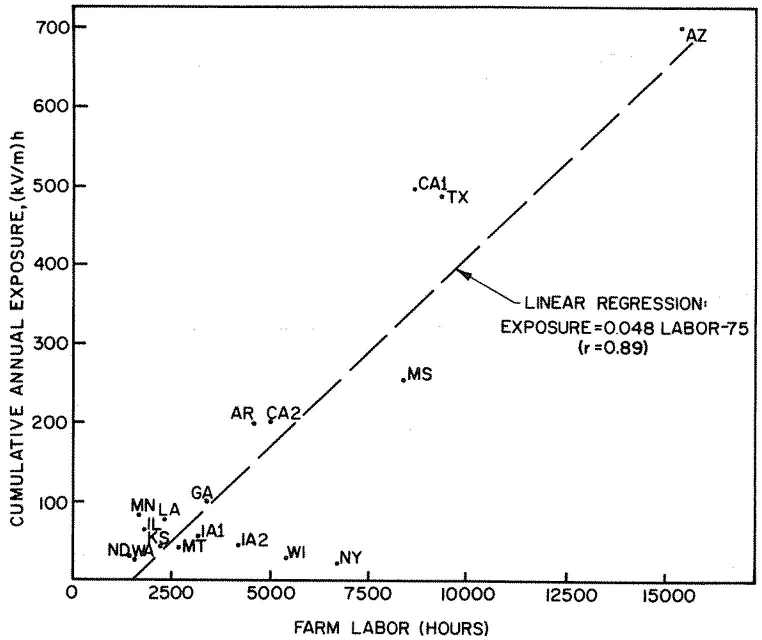


Figure 7.8. Total Farm Exposure versus Total Farm Labor

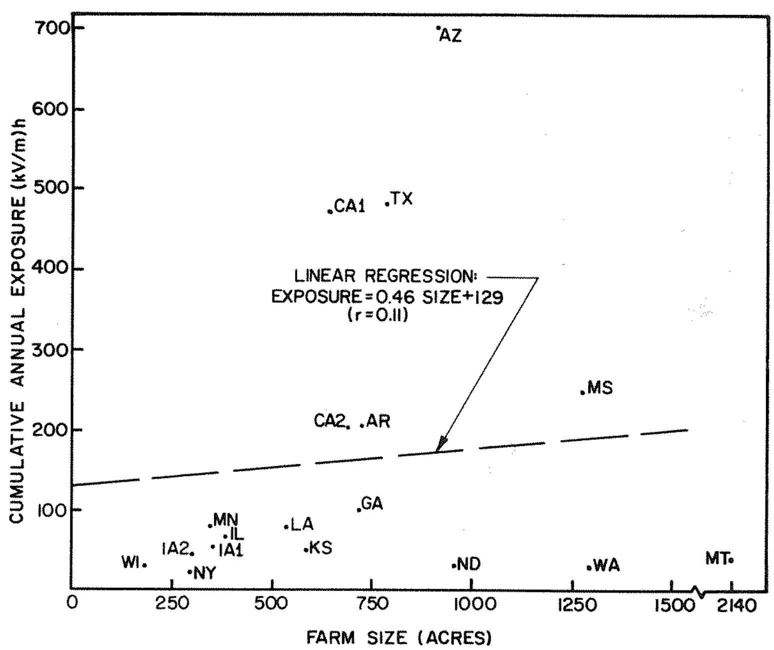


Figure 7.9. Total Farm Exposure versus Total Farm Size

Table 7-6

SUMMARY OF TOTAL TIME SPENT WORKING IN
EQUIVALENT ELECTRIC FIELD RANGES

(345 kV Case)

Farm	Total Labor Hours	Percent Time Spent in Equivalent Field Ranges (kV/m)				
		0 - 0.05	0.05 - 0.25	0.25 - 1.0	1.0 - 3.0	3.0 - 6.0
AZ	15335	94.0	2.8	1.7	1.2	0.3
TX	9282	93.0	3.2	2.0	1.5	0.3
CA1	8751	92.9	3.3	2.1	1.3	0.3
MS	8331	95.4	2.2	1.6	0.7	0.2
NY	6683	99.2	0.5	0.2	0.1	0.1
WI	5303	99.0	0.6	0.2	0.1	0.1
CA2	5291	94.1	2.9	1.7	1.2	0.2
AR	4901	93.9	2.7	2.1	1.1	0.2
IA2	4164	98.2	0.9	0.6	0.3	0.1
GA	3364	94.5	2.4	2.2	0.8	0.1
IA1	3025	96.9	1.7	0.9	0.5	0.1
MT	2665	97.3	1.4	0.9	0.4	0.1
KS	2507	96.1	2.1	1.2	0.6	0.1
LA	2314	94.3	2.6	2.0	1.0	0.1
IL	1970	93.7	3.3	1.9	1.0	0.1
MN	1711	92.6	3.6	2.2	1.3	0.2
WA	1508	96.6	1.7	1.1	0.5	0.1
ND	1488	96.2	1.9	1.1	0.7	0.1

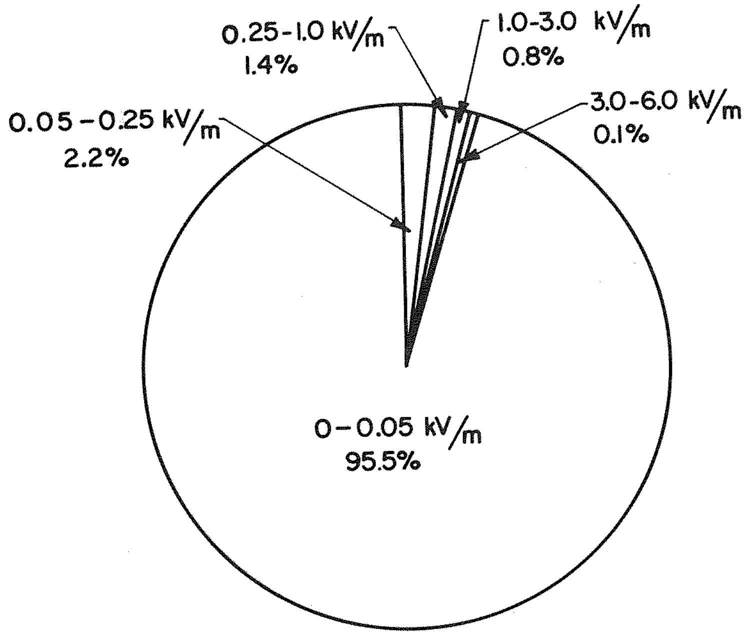
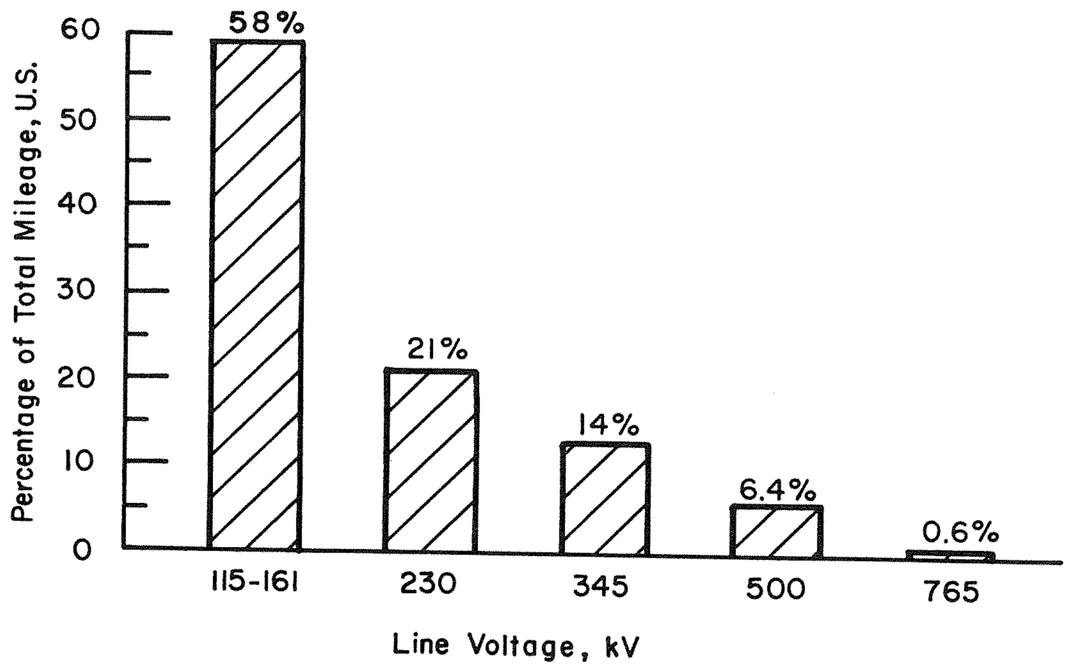


Figure 7.10. Average annual exposure breakdown for the 18 USDA typical farms of Table 7-6 (345 kV case).

VOLTAGE CLASS ANALYSIS

The analysis of typical farms in this chapter was done using a 345 kV transmission line because this voltage class is more representative, in terms of circuit miles, and because use of this class was considered to be more conservative than use of the more common (115 kV to 230 kV) classes (which comprise 80% of total line miles, as shown in Figure 7.11). However, it is important to show the spread in exposure that would result for a variety of line designs in the 115-765 kV range. It was decided to select the most typical farm from the 18 USDA farms for this exercise. The Illinois typical farm was used to assess the differences among voltage classes. Typical 765 kV, 500 kV, 345 kV, and 345 kV double circuit designs were taken from the EPRI transmission line reference book (9), and 115 kV and 230 kV designs were taken from the USDA/REA standard designs (10, 11). Table 7-7 compares the design details used in this analysis. All other input to the model (input not related to transmission line design) remained identical to the original Illinois typical farm 345 kV case.



Voltage Class, kV	Circuit Miles in Service, U.S.
115-161	180,165
230	65,986
345	42,436
500	20,116
765	1,919
Total :	310,622

Source: NERC (1984)-for end of 1983 (230-765 kV)
NEMA (1982)-estimate for 1984 (115-161 kV)

Figure 7.11. Circuit Miles of Each Voltage Class

Table 7-7

LINE DESIGN PARAMETERS FOR VOLTAGE CLASS ANALYSIS

Design Parameter	Voltage Class, kV: 115	230	345	345--double	500	765
Configuration	flat	flat	flat	vertical	flat	flat
Voltage, kV	121	242	362	362	525	800
Conductor, in.	1x1.063	1x1.213	2x1.108	2x1.108	3x1.213	4x1.165
Ground wire, in.	0.375	0.375	0.375	0.375	0.385	0.385
Phase spacing, ft.	12.5	19.5	24.0	24.0	31.0	45.0
GW spacing, ft.	14	20	36	35	50	72
Ruling span, ft.	800	1000	1100	900	1300	1400
Attachment ht., ft.	46	54	70	70	85	101
Ground clear., ft.*	26	29	35	35	38	45
Source	REA	REA	Redbook	Redbook	Redbook	Redbook

* At 90 degrees F.

The results of this voltage class analysis are plotted in Figure 7.12. There is essentially no surprise, as the total farm exposure rises smoothly with the increase in line voltage. Table 7-8 breaks down the results by subarea, and it is evident that the percentage of total exposure contributed by each subarea is consistent throughout the analysis. It can be seen that total exposure can vary dramatically with voltage class--by a factor of 16 between 115 kV and 765 kV cases. This effect is mitigated somewhat by the fact that 765 kV line mileage amounts to a very small proportion of the total line mileage (see Section 10). Still, some farm workers will receive a greater level of exposure than the average.

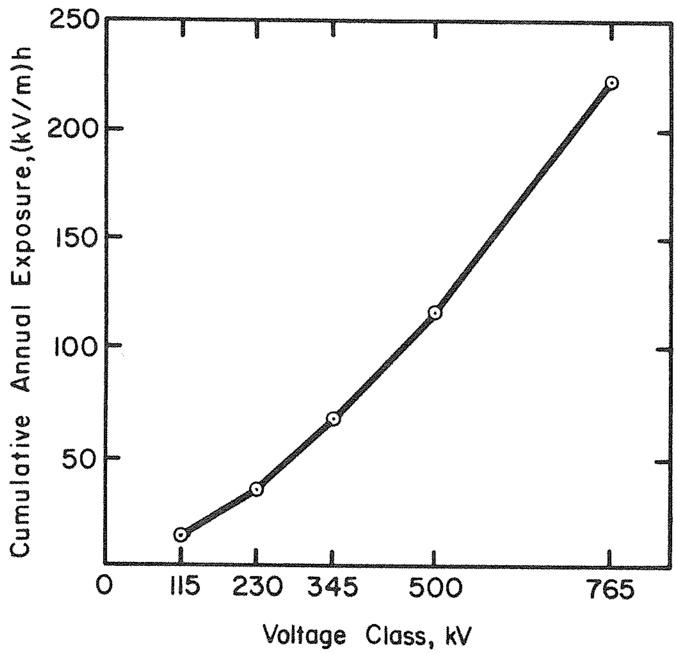


Figure 7.12. Plot of Total Exposure versus Voltage Class

Table 7-8

RESULTS OF VOLTAGE CLASS ANALYSIS BY SUBAREA

Area	Total Farm Exposure ((kV/m)*h) for Voltage Class (kV)					
	115	230	345	345--d	500	765
Homestead	0	0	0	0.637	0	0.356
(%)				(1.0)		(0.2)
Farmstead	0	0	0	0.384	0.058	0.275
(%)				(0.6)	(0.0)	(0.1)
Other land	0.063	0.155	0.275	0.237	0.453	0.830
(%)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
Corn	6.199	15.395	29.711	28.519	54.007	98.020
(%)	(44.8)	(43.5)	(44.0)	(42.6)	(46.2)	(43.9)
Soybeans	7.571	19.847	37.576	37.122	62.462	124.007
(%)	(54.7)	(56.1)	(55.6)	(55.4)	(53.4)	(55.5)
Total	13.833	25.397	67.562	66.948	116.969	223.488
(%)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)

The data from Table 7-8 have been expanded to provide a more detailed summary of results for three different transmission line designs on the USDA Illinois typical farm. This detailed analysis, presented in Table 7-9, provides annual estimates of time spent in a wide range of equivalent electric fields for the principal workers (operators) using the labor distributions of Table 7-5.

Table 7-9

EXPOSURE ESTIMATES FOR ILLINOIS FARM

Electric Field Eeq (V/m)	Illinois Farmer - Annual Time (hours) 115 kV	345 kV	765 kV
0 - 1	1295	1087	605
1 - 2	37	77	280
2 - 4	34	71	152
4 - 8	26	56	101
8 - 16	23	43	76
16 - 32	20	34	58
32 - 64	12	29	46
64 - 125	7	22	39
125 - 250	9	15	34
250 - 500	13	15	21
500 - 1000	3	14	19
1000 - 2000	1	14	21
2000 - 4000	0	2	21
4000 - 8000	0	1	6
>8000	0	0	1
Maximum Eeq, (kV/m)	1.5	4.5	10.5

Note: The data are for one person performing outdoor work only.

In Table 7-9 we can easily see the impact of transmission line voltage on the exposure estimates. The 115 kV line creates no exposure time above 2 kV/m. Both the 345 kV and 765 kV lines, however, have increasingly higher fields and exposure time. For all three line designs it is significant to note the large portion of the total time spent in equivalent electric fields of a few volts per meter.

DOUBLE CIRCUIT LINES

The results of modeling a double circuit (vertical configuration) 345 kV transmission line also are presented in Table 7-8. The effect of the double circuit design was to flatten out the electric field map; that is, the peak fields near the line were slightly lower, whereas the edges of the farm registered slightly higher fields (approximately 2 V/m rather than zero). The effect was that a small amount of exposure time was calculated for the homestead/farmstead area in the double circuit case, whereas no exposure time had been calculated in the single circuit case. If one considers peak fields, the double circuit case (with unlike phasing) offers the lowest peak field: 3.73 kV/m as opposed to 4.34 kV/m. The double circuit case, however, showed slightly less exposure in the crop areas. Over all, the two effects canceled each other, and there was essentially no difference between the single and double circuit cases for the Illinois typical farm.

SUMMARY

Exposure on the farm is summarized in the following statements:

- By virtue of the large number of farm workers in the United States, the large amount of time they spend outdoors, and the use of agricultural land by transmission line rights-of-way, farm workers are a sector of society that has a high likelihood of some exposure to electric fields.

- Almost all farm vehicles currently produced have cabs to protect farm workers from dust and weather. Cabs also shield farm workers from electric fields, reducing exposure to less than 5% of what workers would receive standing on the ground.

- For the exposure estimates in this section, a large proportion of a farmer's outdoor time is spent in equivalent electric fields of 0-50 V/m; this level is comparable to household levels. The proportion of time spent in such fields ranges from 92% to 99%, according to Table 7-6.

- Cumulative exposure levels from Table 7-5 show that farm operators in the example cases accumulate an average of about 60 (kV/m)*h per year; cumulative levels range as high as 126 (kV/m)*h for the 345 kV case. These levels are on the same order of magnitude as cumulative household exposures (see Section 9).

- A certain amount of time is likely to be spent in electric fields much higher than those found in the home. This exposure would most likely be on the order of about 80 hours per year for equivalent electric fields above domestic levels. Of that exposure, about 2 hours per year would be above 3 kV/m, for the 345 kV case. If a farmer averaged ten operations per crop, then on any one day in the field he could spend about 15 to 20 minutes above that level.

- In the 765 kV case, the same farmer may spend on the order of 160 hours per year above domestic levels. Of that exposure, about 20 hours per year could be above 3 kV/m (with 1 hour above 8 kV/m).

- Differences in voltage class make a large difference in exposure level: a 765 kV line could cause about four times as much exposure as a 345 kV line. A 115 kV line causes about one-fifth of the exposure of a 345 kV line.

- There is no appreciable difference in exposure between single and double circuit lines. (This would mean that there is no change in exposure for a doubling of the power transfer capability.)

- Actual exposure values on real farms are likely to be somewhat lower because of the conservative assumptions used in this study; line voltage and clearances; shielding from buildings, objects, and vegetation; and the trend toward cabbed farm vehicles.

REFERENCES

1. H. Thomas Frey. U.S. Department of Agriculture. Economic Research Service. Major Uses of Land in the United States. Washington, D.C.: Government Printing Office, 1982. Ag. Ec. Report 487.

2. U.S. Department of Agriculture. Agricultural Statistics. Washington, D.C.: Government Printing Office, 1981.

3. U.S. Department of Agriculture. ESS. Economic Indicators of the Farm Sector: 1979. Washington, D.C.: Government Printing Office, 1981. Stat. Bull. 657.

4. W. C. McArthur and F. T. Cooke, Jr. Cotton Production Practices and Costs in the United States. Athens, Ga.: Univ. of Georgia: Ag. Experiment Stations, 1980. Research Report 365.

5. U.S. Department of Commerce. Bureau of the Census. 1978 Census of Agriculture. Washington, D.C.: Government Printing Office, 1981.

6. U.S. Department of Commerce. Bureau of the Census. "Tractors." Current Industrial Reports. Washington, D.C.: Government Printing Office, 1982.

7. Redbook. Implement & Tractor Magazine 97, no. 3 (1982).

8. T. C. Hatch et al. "A Typical Farm Series: Development and Application to a Mississippi Delta Farm." Southern Journal of Agricultural Economics, Dec. 1982.

9. Transmission Lines: 345 kV and Above. 2nd ed. Palo Alto, Calif.: Electric Power Research Institute, 1982.

10. U.S. Department of Agriculture. Rural Electrification Administration. De-sign Manual for High Voltage Transmission Lines. Washington, D.C.: Government Printing Office, 1981. REA Bulletin 62-1.

11. U.S. Department of Agriculture. Rural Electrification Administration. Elec-tric Transmission Specifications and Designs. Washington, D.C.: Government Printing Office, 1980. REA Form 805.

Section 8

RECREATIONAL EXPOSURE

INTRODUCTION

Recreational activities are a possible source of public exposure to electric fields from transmission lines. A power line right-of-way (ROW) may be a large tract of accessible land and may be attractive for a number of recreational activities. (However, for most ROW easements, landowners still exercise control over access). Exposure during recreation is random. Exposure patterns are very different from those in farming, in which the activities tend to be distributed over the land. Many recreational activities are linear--that is, they have a direction or follow a route (as skiing and horseback riding, for example, do). Unfortunately, the route is not always clearly defined. This characteristic makes recreational exposure a bit more difficult to estimate than agricultural exposure. Though ROW policies vary from utility to utility and in some cases preclude recreation use, it is still important to provide the information necessary for estimating potential exposure. This section presents an overview of outdoor recreation and sources of data. Experimental measurements of various recreational activity factors also are provided. Some exposure estimates are made to demonstrate use of the methodology.

OVERVIEW OF RECREATION

As the amount of free time individuals have has increased, so too has participation in a variety of outdoor sports and recreation activities. With an extensive network of national and regional parks available for general public use and with over 2.2 billion acres of land and water, the United States possesses an abundant recreational resource base. Many of the most popular activities take place outdoors. Each must be considered on a local or regional basis, since it is impossible to estimate which may occur on rights-of-way. Many factors, such as shielding by trees, can dramatically lower exposure estimates. Such factors must be properly evaluated. The various activities can have variable grounding conditions, depending on weather, soil, and equipment (if any). A great variety of recreation experiences are available. The following are some of the most popular activities, in approximate order of popularity, from three different studies:

Table 8-1

SPORTS POPULARITY

Study A	Study B	Study C
Visiting zoos, aquariums, fairs, carnivals, amusement parks	Swimming	Swimming
Picnicking	Bicycling	Calisthenics
Driving for pleasure	Fishing	Jogging
Walking or jogging	Camping	Bicycling
Swimming or sunbathing outdoors	Boating	Softball/baseball
Visiting historical or natural sites	Bowling	Weightlifting
Attending outdoor sports events	Physical Conditioning	Basketball
Other outdoor sports or games	Jogging or Running	Football/rugby,etc.
Fishing	Roller skating	Tennis/squash, etc.
Walking to observe nature, bird-watching, or photographing wildlife	Pool or billiards	Pool or billiards
Bicycling	Softball	Boating
Attending outdoor dances, concerts, or plays	Tennis	Aerobic dancing
Boating	Basketball	Bowling
Playing Tennis outdoors	Skiing	Table tennis
Camping in a developed area	Table tennis	Skating
Hiking or backpacking	Hunting	Volleyball
Driving vehicle, motorcycles off-road	Volleyball	Skiing
Camping in primitive area	Ice skating	Golf
Sledding	Water skiing	Soccer
Hunting	Golf	Gymnastics
Canoeing, kayaking, or river running	Football	Wrestling
Water skiing	Baseball	Horseback riding
Golfing	Raquetball	Archery
Ice skating outdoors	Motorbiking/motorcycling	Other team sports
Horseback riding	Sailing	Handball
Sailing	Snowmobiling	Hockey
Snowmobiling	Soccer	Fencing
Downhill skiing	Handball	Lacrosse
Cross-country skiing	Archery	
	Paddle tennis	
	Ice hockey	
	Platform tennis	
	Squash	

Sources: Study - A (1); Study B - (2); Study C - (3).

One study (3) found that 19% of all Americans can be classified as avid sports participants, whereas 29% do not participate in any physical activities on a regular basis. The majority, 52%, can be classified as moderate participants. Some of these activities may occur on or near a transmission line right-of-way; most probably do not. Any assessment of electric field exposure during recreation must assume some location, participation rate, duration per event, speed (where applicable), equipment utilized, and other variables. Data on recreational activities are available from a variety of local, regional, and national sources.

SOURCES OF PARTICIPATION DATA

Recreation data are generally not as well organized as farming data. They tend to be elusive and fragmented. Therefore, exposure investigators must be resourceful and diligent in obtaining necessary information. Recreation information sources range from national studies (1-4) to very detailed regional or local data on sports demographics gathered by various associations, clubs, and organizations. Two good references are the Encyclopedia of Associations (5) and The New American Guide to Athletics, Sports, and Recreation (6).

Electric field exposure estimates can vary from person to person. It is very important to remember that participation may range from very active to only casual. (In addition, some activities may take only one hour and others all day). In this study, where participation rates were not available they were estimated using a compound binomial - Poisson distribution model and the data in Reference 1. (This statistical method is presented in Appendix F.) The following general information represents some of the assorted data available.

Jogging and Running

Jogging, especially in the past ten years, has grown quickly in popularity. About 20 million adults jog today (7-9). However, recent information (8) indicates that 68% of people who call themselves runners actually jog less than 10 miles per week, and 40% jog less than 5 miles per week. In fact, serious runners may number only about 3-4% of the total. Another study indicates that about half the joggers cover less than 2 miles per outing, the average distance being about 1.6-2.3 miles per run (9). This distance increases to about twice as long for the more serious runner who belongs to an organization (10). The level of participation may have seasonal and geographic variations.

Bicycling

Bicycling is one of the most popular of all recreational sports (2). There are estimated to be 64.5 million bicycles in use and 105 million riders (11). Other studies estimate a lower number of participants, about 70-80 million (2,4). Of the U.S. adult population (age 18 and over), it is estimated that 26.7 million people ride a bicycle at least once per year (12). The population for this age group was 166 million in 1981 (4), so the riders are about 16% of the U.S. adult population. The following levels have been estimated (12,13):

Adult Riders	Frequency	Distance
35%	1-9 days/yr	5-10 miles/trip
33%	10-25 days/yr	5-20 miles/trip
32%	25+ days/yr	10+ miles/trip

The estimated mean activity rate among participants is about 7 times per year (1). One survey reveals that most people use their bicycles for short trips, for commuting, or just for fun. Only about 3% would consider riding in rough terrain (14).

Motorcycling and Motorbiking

There are about 7 million motorcycles in use in the United States (15) . The number of participants is estimated to be about 12 million (16); 92% of the owners are male (2). There is a national estimate of 3.1 motorcycles owned for every 100 persons, with a regional low in the East of 2.1 and a high in the West of 4.0 (15). The state with the highest ownership is Alaska, with 7.7. The lowest ownership occurs in Washington, D.C., with 0.2. Of the estimated 12 billion annual miles traveled by motorcycles, 85% were highway miles and 15% off-highway miles. Average use of off-highway vehicles (including motorcycles) has been estimated at 8-10 days per year (1). The following data (15) summarize use:

Motorcycle Use	Annual Average Use	Seasonal Use
Highway	2,456 mi/yr	83%--spring-summer
Off-highway	499 mi/yr	72%--spring-summer

Skiing and Snowmobiling

Trails used for snowmobile, cross-country, or snowshoe activities are often used by other outdoor recreationists during nonwinter months. Trails can be used for hiking, horseback riding, bicycling, and other trail-based activities. Somewhere between 8 and 14 million people go snowmobiling (2,4,16,17) on an estimated 190,000 miles of snowmobile trails in North America. The estimated mean activity rate for participants is about 5 times per year (1). Another popular winter activity is snow skiing (including both downhill and cross-country skiing), with about 19 million participants (2). About 75% of skiing participants ski only 0-2 times per month on an annual basis (3), with an estimated mean activity rate of 4-5 times per year.

Horseback Riding

The approximately 3.2 million horse owners in the United States keep an estimated 8.3 million horses, 80% of which are owned for recreational use (18,19). Participation can range from pleasure riding to show and competitive events. The remaining 20% of horses are used for a variety of profit-oriented activities, including racing, professional exhibition, breeding, agriculture, and logging. There are about 25 million horseback riders, and the average rate of participation is about 5-6 days per year (1,4). One study (3) indicates that over half of the participants go riding less than once per month and that only about 10% go riding once or twice a week.

Wildlife-Associated Recreation

A large category of leisure activity is wildlife-associated recreation. It includes hunting (17 million participants), fishing (42 million), and nonconsumptive forms of recreation (83 million). The last category includes observing, photographing, and feeding of wildlife and other nonharvesting activities. A major study of this subject has been conducted by the U.S. Fish and Wildlife Service and the U.S. Bureau of the Census (20). This study included a nationwide sample of more than 116,000 households. The following data summarize participation rates reported in this study:

Activity	Average Annual Rate	Average Duration
Big game hunting	10 days/hunter	7 hours/day
Small game hunting	12 days/hunter	4 hours/day
Migratory birds	8 days/hunter	5 hours/day
Freshwater fishing	20 days/fisherman	5 hours/day
Nonconsumptive	7.6 days/person	--

EXAMPLE CALCULATIONS

The coincidence of recreational activities and transmission lines is highly--but not totally--random. The methodology outlined in this report can be applied to recreational situations near transmission lines. First, a few general assumptions are made about (1) details of line design, (2) path or trajectory of the activity relative to the transmission line, and (3) details of the activity (equipment used, speed, frequency of the event, and so on). It is important to remember that recreation exposure estimates can vary widely and are strongly affected by items 2 and 3. Therefore, care must be taken when selecting the details that define the activity to be studied and its spatial relation to a transmission line.

For the example calculations that follow, we chose two transmission lines that had existing paths on the right-of-way that could be the logical route for a linear type of recreational activity. The choice of such lines reduced the difficulty in assuming a path or route for recreational activity near the lines. The line design and operational details are known, since the lines are in existence. We used activity factors that had previously been determined (see Appendix A). Therefore, the main assumptions for these examples are the activity details (which are based on some of the assorted recreation data described earlier in this section).

The first sample calculation is for a double circuit 230 kV line located in the western United States (shown in Figure 8.1). A portion of this transmission line right-of-way has been converted to a greenbelt type of park--with shrubbery, small trees, playground areas, and outdoor light standards. A concrete walkway or path winds along the right-of-way between the center and edges. The study path is a little over 1/2 mile long. This location was selected to demonstrate sample exposure calculations for jogging and bicycle riding along the path.

Figure 8.1. Aerial view of a portion of the 230 kV transmission line and park area.

The second location for sample exposure calculations was for a 345 kV transmission line situated in the north central United States (see Figure 8.2). A suburban residential area is adjacent to portions of the transmission line right-of-way. A small dirt path or trail meanders along the right-of-way between low shrubbery, vegetation, and a small marshy area--generally following the local topography. The study route is almost 2 miles long. This location was selected to demonstrate sample exposure calculations for cross-country skiing.

Figure 8.2. Aerial view of a portion of the 345 kV transmission line location.

Several general assumptions were made for all of the example calculations:

- No shielding has been considered from the vegetation, shrubbery, small trees, outdoor light standards, or terrain.

- All recreational activity is assumed to take place on the transmission line right-of-way for the study path or route. Participants are assumed to go back and forth at this location (with some random rest stops) until a distance is covered that is appropriate for the activity duration.

- The additional travel time to reach the recreation site is part of the overall activity time but was not considered here for exposure estimates. (Also, it is very probable that portions of a specific annual recreational activity will occur at other locations.)

- Exposures are calculated on an annual basis for assumed participation rates, with some seasonal adjustments.

- The transmission line is always assumed to be energized (nominal operating voltage plus five percent).

Table 8-2 presents the activity details used for the sample calculations.

Table 8-2

SUMMARY OF ACTIVITY DETAILS

Activity	Speed	Annual Distance Traveled at Site	Average Activity Factor
Jog	8-9 min/mi	85 mi	80%
Bicycle	12 mph	125 mi	82%
Ski	4 mph	45 mi	78%

Results of the sample exposure calculations are presented in Tables 8-3 and 8-4.

Table 8-3

SUMMARY OF SAMPLE EXPOSURE CALCULATIONS

	Annual Exposure, (kV/m)*h		
Exposure Bins, V/m	Jog--230 kV	Bicycle--230 kV	Ski--345 kV
0 - 50	0	0	0
50 - 250	0.42	0.48	0
250 - 1000	4.33	3.84	4.80
1000 - 3000	1.37	1.20	5.92
3000 - 6000	0	0	4.68
ANNUAL TOTAL	6.12	5.52	15.40

Table 8-4

EXPOSURE ANALYSIS FOR SAMPLE CALCULATIONS

Exposure Bin, V/m	Percentage of Annual Exposure		
	Jog--230 kV	Bicycle--230 kV	Ski--345 kV
0 - 50	0	0	0
50 - 250	8	9	0
250 - 1000	71	69	31
1000 - 3000	21	22	39
3000 - 6000	0	0	30

DISCUSSION

Sample calculations reveal that, for the situations modeled, most exposure occurs in equivalent electric fields above 50 V/m. The reason is that the subjects' activities are assumed to be confined to the right-of-way. Also, all shielding by objects and vegetation is neglected. If cumulative exposures are considered, however, annual exposures for these samples are only about 10-20% of annual domestic exposure levels. Of course, the estimates would change with different line designs and activities. For example, a larger voltage classification transmission line would increase exposure, if all other variables were held constant, and a lower voltage line would decrease exposure.

Recreational activities can be modeled to estimate exposure to 60 Hz electric fields. The most difficult parts of the process are the assumptions relating to the path taken during an activity, and its orientation to a transmission line; the duration and frequency of participation in the activity; line voltage and design; and shielding by objects.

REFERENCES

1. U.S. Department of the Interior. The Third Nationwide Outdoor Recreation Plan. Washington, D.C.: Government Printing Office, 1979, Appendix II--Report 4, pp. 78-80, Report 1, p. 206.

2. News Release for July 15, 1982--Sports Participation Study Including Sports Participation Table for 1982. Northbrook, IL: A.C. Nielsen Company.

3. The Miller Lite Report on American Attitudes Towards Sports. Milwaukee, Wis.: Miller Brewing Company, 1983, p. 35.

4. U.S. Department of Commerce. Bureau of the Census. Statistical Abstract of the United States. 103d Ed. Washington, D.C.: Government Printing Office, 1982-83, pp. 234-236.

5. Encyclopedia of Associations. 18th Ed. Detroit, Mich.: Gale Research Co. 1984.

6. C. Norback and P. Norback. The New American Guide to Athletics, Sports, and Recreation. New York, 1979.

7. Runner's World, December 1983, p. 7.

8. Information Release for October 10, 1983. White Plains, N.Y. American Sports Data.

9. Information Release for January 30, 1983. Princeton, N.J. The Gallup Poll.

10. 1983 Membership Questionnaire. Washington, D.C.: American Running and Fitness Association.

11. Some Facts About Today's American Bicycle Market. Washington, D.C.: Bicycle Manufacturers Association of America, November 9, 1983.

12. "Marketing and Merchandising Newsletter" 2, no. 9. Bicycling Magazine, November-December 1983.

13. Personal communication with Mr. Imre Barsy, assistant to the publisher of Bicycling Magazine. Emmaus, Pa., December 8, 1983.

14. Bicycling Subscriber Profile. Bicycling Magazine research data study. Emmaus, Pa., October 1982.

15. Motorcycle Statistical Annual. Costa Mesa, Calif.: Motorcycle Industry Council, 1983.

16. Recreation Fun and Jobs for America. Washington, D.C.: American Recreation Coalition, 1983.

17. Snowmobiling Fact Book. Annandale, Va.: International Snowmobile Industry Association: July 1983.

18. Horse Industry Directory. Washington, D.C.: American Horse Council, 1983.

19. American Horse Council Equine Population Data. Washington, D.C.: American Horse Council, 1983.

20. U.S. Department of the Interior, Fish and Wildlife Service. National Survey of Fishing, Hunting, and Wildlife-associated Recreation. Washington, D.C.: Government Printing Office, November 1982.

Section 9

DOMESTIC EXPOSURE

OVERVIEW

The study of exposure to electric fields from high voltage transmission lines can be put in perspective by an evaluation of exposure to the power frequency electric fields present in a domestic environment. In a house, an office, or a commercial building there are electric fields generated by the power supply wires and by the devices attached to them. These fields are lower than transmission line fields but are encountered for much longer periods of time. Therefore, at least one index of field exposure--the cumulative one expressed by the product of field and exposure time, (V/m)*h--could be comparatively significant.

Exposure expressed in (V/m)*h for a domestic environment provides one basis for comparative evaluation of exposures to transmission line fields. It is important to obtain estimates of this background exposure, which is applicable to the general population. It is important also to determine whether there are specific sources of 60 Hz field induction in a domestic environment comparable with induction caused by high voltage transmission lines. For instance, electric blankets have been cited in the literature as a possible source of comparable induction. The sources of 60 Hz electric fields in a domestic environment are wires, light fixtures, appliances, and other devices connected to the power supply. As a result of being connected to the power supply, a number of conductive parts acquire a potential with respect to ground--normally 110 V rms. If these parts are not completely shielded, with the shield connected to an electrical ground, they will either directly create an electric field in the surrounding space or induce voltages in surrounding objects, which would in turn contribute to creating an electric field. The majority of sources of electric field in a domestic environment can be considered point sources. In fact, their dimensions are small compared with those of a human body. As a result, the electric field may be highly nonuniform. Measurements of electric fields in houses and offices have been reported previously (1,2,3).

The electric field alone, however, does not adequately characterize the electrical quantities that may be induced. This study addressed the question of such characterization and concluded that each field source can be described by an equivalent radius and the space potential at that radius. A law of decay of the space potential was found that describes in first approximation the field region around the source. This law can be expressed by Equation 9-1.

$$V = V_o*(R_o/R)**n \qquad (9\text{-}1)$$

where:

V = the space potential at the distance R from center of induction source

V_o = the space potential at the distance R_o from center of induction source

n = an exponent that depends on the type of source and on the proximity of the source to a wall or a ceiling

Measurements have shown that $1 < n < 2$, with n approx = 1 in most cases. For example, measurements close to an incandescent lamp (see Figure 9.1) have resulted in:

$R_o = 0.2$ m, $V_o = 25$ V, n approx = 1.1

At a distance R, the space potential calculated with Equation 9-1 is $V = 4.3/(R)^{1.1}$ and the electric field is $E = -dV/dR = 4.7/(R)^{2.1}$ V/m. Thus, at a distance R = 0.5 m, V = 9 V and E = 20 V/m.

The current induced in the body of a person in the region around a field source is a function of many variables, including:

- The shape and value of the equipotential lines
- The person's position
- The electrical grounding of the person
- The harmonic content of the electric field waveshape

Estimates of exposure of people to electric fields in a domestic environment can be made using two different approaches. One approach consists of the following steps:

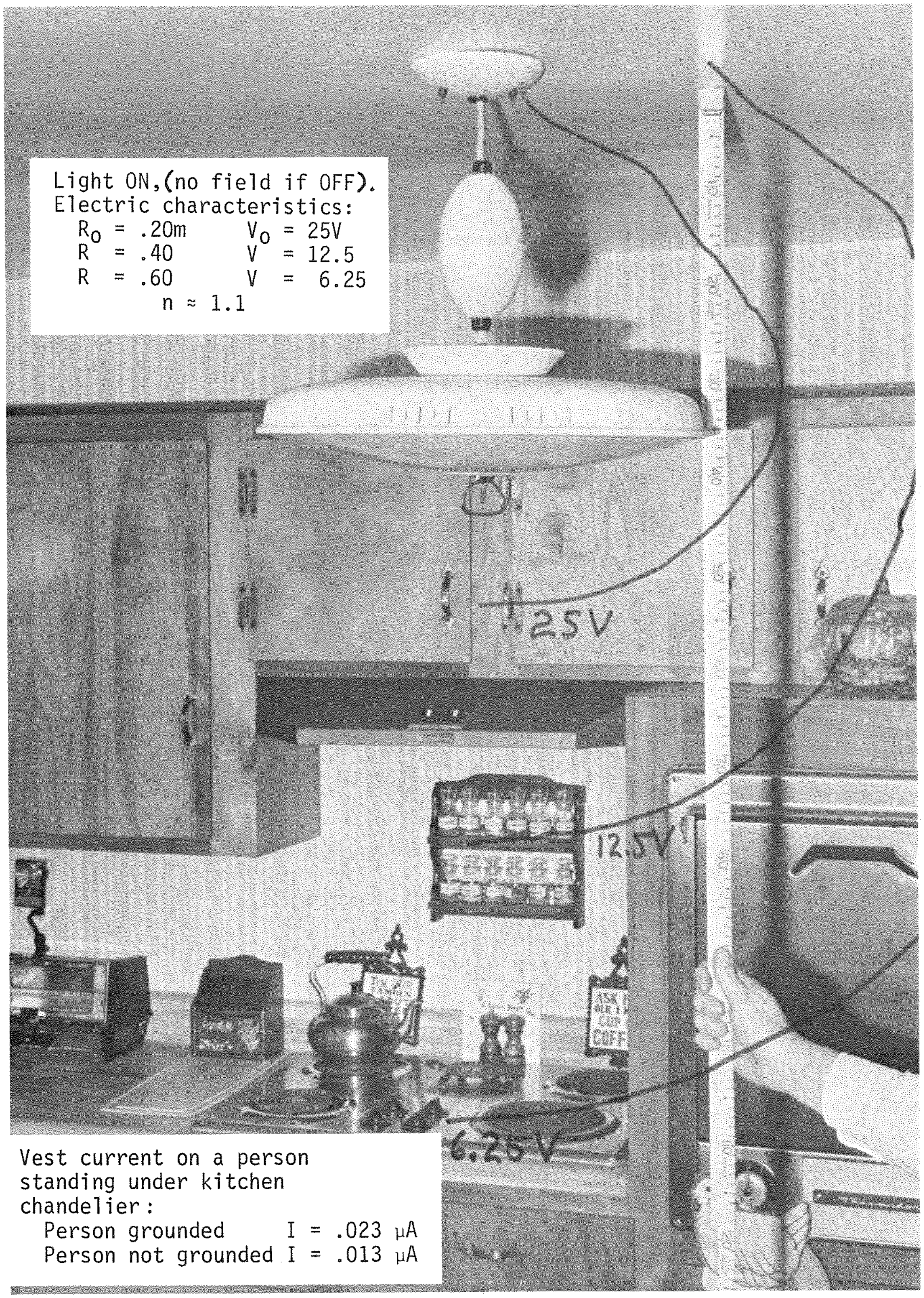


Figure 9.1. Electric Field Close to a Kitchen Chandelier

1. Characterization of the sources of induction

2. Determination of the relationship between the characteristics of the inducing field and the currents induced in the body

3. Estimation of the time of exposure for different sources

4. Integration of the exposure results

A second approach was found more practical. It uses the same measuring system and sensor vest used to measure exposure to transmission line fields, to measure field exposure during the execution of various domestic tasks and during typical domestic situations. This second approach provides direct exposure data but requires an interpretation of the vest readings that takes into account the complex domestic environment.

EQUIVALENT ELECTRIC FIELD

The value of the electric field at a point where a particular part of the body will be situated has little meaning because it is not directly correlated to the induced currents, not even those induced in that part of the body. For domestic exposure, as was the case for transmission line field exposure, it is convenient to define equivalent field (Eeq). Equivalent field is the field that would induce the same current in the reference position (person erect and electrically grounded in a uniform field). To clarify this concept and illustrate the difference between actual and equivalent field, we present the following example.

A person is standing on a carpet close to an incandescent lamp hanging from the ceiling. The electric field at the center of the person's head, measured without the presence of the person, is 80 V/m. The measured current induced in the head and flowing through the neck is 80 nA. It would take a uniform electric field of 15.9 V/m to cause the same current if the person were in the reference position. Thus the equivalent field is 15.9 V/m. Unfortunately, the equivalent field would be different if, instead of the neck current, the current in another section of the body or the electric field on the surface of the body were considered. For instance, in the same example, the field on the forehead and the current in the vest correspond to equivalent fields of 35 V/m and 12.3 V/m respectively. Thus, even for the same conditions, differences can be expected in equivalent fields calculated for different electrical quantities applied to the body.

The majority of the domestic exposure measurements made during the course of this work were made using a vest rather than another device as a sensor because of the relatively large area a vest covers. In fact, small sensors were found to be extremely dependent on the position of the part of the body on which the sensor was applied and on the orientation to the electric field source. The relation between vest current and forehead field and neck current was determined in a domestic environment for different positions of the person (standing, sitting), different distances between the person and the source of induction, and different degrees of electrical insulation (that is, well insulated or grounded). Three equivalent electric fields (Eeq-v, Eeq-f, and Eeq-n) were defined on the basis of vest current, forehead field, and neck current measurements respectively. It was found that:

For a person on good insulation:

$$0.06 < \frac{E_{eq\text{-}f}}{E_{eq\text{-}v}} < 4.0$$ with a median value of 1.41

$$0.30 < \frac{E_{eq\text{-}n}}{E_{eq\text{-}v}} < 6.0$$ with a median value of 1.33

For a person well grounded:

$$0.12 < \frac{E_{eq\text{-}f}}{E_{eq\text{-}v}} < 3.0$$ with a median value of 0.95

$$0.40 < \frac{E_{eq\text{-}n}}{E_{eq\text{-}v}} < 1.6$$ with a median value of 1.16

The large dispersion in the relation between vest measurements and the other electrical quantities is caused by the extreme nonuniformity of the electric field and the large possible variations in body position in a domestic environment.

The effect of the insulation between body and ground is greater in a domestic environment than under a transmission line. In both cases insulation has the effect of reducing currents induced in the body, but in a domestic environment this reduction may be significantly larger. Furthermore, good insulation, such as that provided by carpets, wood, or linoleum or vinyl floors, is relatively common in a household environment, whereas in a transmission line environment most insulation is provided by the shoes. Shoes, however, allow for a significant body-to-ground capacitance, which has the effect of keeping a person close to ground potential. The large effect of insulation is another reason that the induction in a domestic environment cannot be characterized by the applied field alone without knowledge of the way a person is electrically connected to ground. Vest measurements, on the other hand, give the overall effect of field and insulation directly. The limits of validity of measurements taken with a vest are expressed by the relationship between vest current and other body quantities previously illustrated. When the person is on good insulation, which is the most common condition, vest measurements tend on average to underestimate the forehead fields and the current flowing through the neck by 30% to 50%. On the other hand, vest measurements overestimate currents and fields relative to the lower part of the body. Clearly there is a tradeoff, but vest measurements are, in general, reasonable estimates of equivalent uniform electric field exposure.

ELECTRIC BLANKET

A 1978 estimate of electric blanket use indicated that about 65% of wired homes in the United States have electric blankets (4). The survey indicated that there were over 79 million wired homes, over 51 million of them with electric blankets. Over 5 million new electric blankets were shipped in 1981. Electric blankets have been cited (5) as possibly significant sources of 60 Hz field induction because of the close proximity between energized wires and the surface of the human body. The currents induced in the body under an electric blanket have a quite different distribution in the body than the currents induced during other field exposure situations. In the case of an electric blanket, induced currents predominantly enter one side of the body and exit on the other side, rather than following the route from upper body to lower body that is characteristic of other types of induction. A set of measurements of surface fields and induced currents were made using an ordinary electric blanket and a special mannequin made of insulating material. The surface of the mannequin was covered with conductive paint. The currents through the various sections were measured through breaks in the conductive paint (see Figure 9.2). In addition, the surface field was measured with a current probe consisting of a small patch connected to the mannequin through an ammeter, as shown in Figure 9.3.

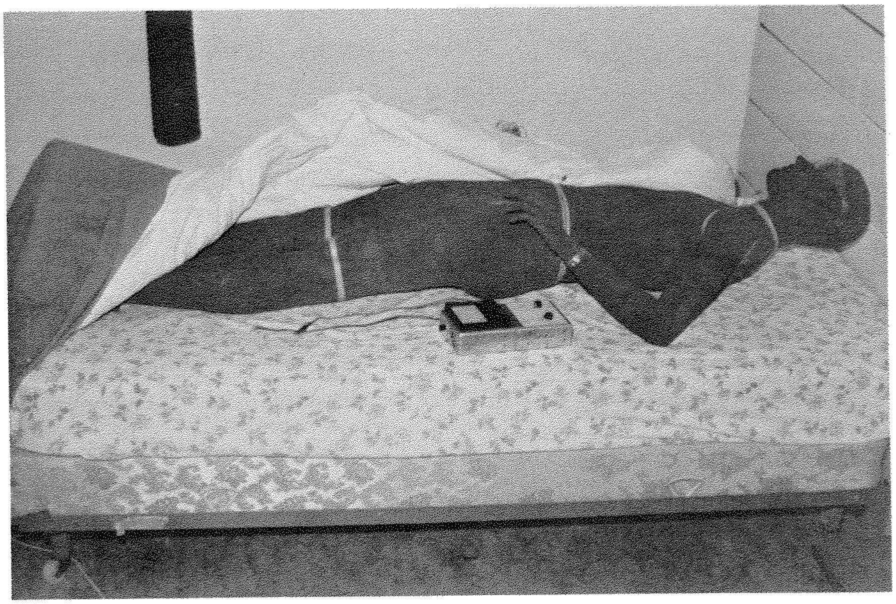


Figure 9.2. Mannequin Used for Electric Blanket Measurements

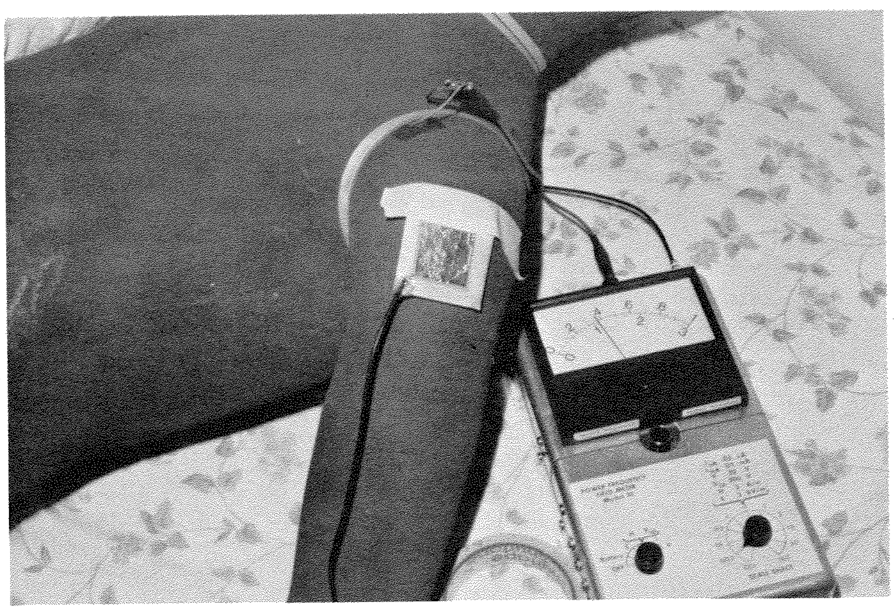


Figure 9.3. Measurements of Surface Field Using a Mannequin

Relatively high surface electric fields (exceeding 1 kV/m) were measured. For instance, on the surface of the thorax facing the electric blanket, an electric field of 1.75 kV/m was measured. A field of this intensity on the surface of the thorax requires an unperturbed field of about 320 V/m if the person stands erect under a transmission line. (However, since the current paths are different from those for erect humans, a smaller body current is generated.) The measured currents flowing in the neck and waist were 0.24 μA and 0.50 μA respectively. Currents at these levels would be obtained in equivalent uniform transmission line fields of 50 V/m and 40 V/m respectively.

Arriving at a single, typical value for electric blankets is difficult, but because of the desirability of making comparisons, an attempt has been made to arrive at one value. It is important to remember that variations are so extreme that any practical interpretation is subjective. The variables that affect electric blanket exposure include:

- Construction of heating element wires
- Orientation of electric plug
- Type and construction of bed frame
- Position of bed
- Type of room construction
- Type of floor covering
- Position of user

The following measurements of current through body joint cross sections of the special mannequin were made with a surface current patch. Values are weighted on relative biological importance assumed by the investigators:

Location on Body	Equivalent Field	Weighting Factor
Waist	40 V/m	4
Left knee	10 V/m	1
Right knee	30 V/m	1
Neck	50 V/m	4

This analysis provides a single, equivalent uniform electric field value of 40 V/m. (It is important to remember, however, the relatively high local surface fields that were also measured.)

DOMESTIC EXPOSURE MEASUREMENT PROGRAM

Transmission line electric fields are often compared with electric fields in the domestic environment (households and stores or shops). Measurements of electric field intensity near consumer appliances and lighting fixtures have been made with commercially available free-body type electric field meters. The question is whether these measured domestic fields can induce the same body electrical quantities as a uniform field of similar magnitude near a transmission line. Portions of the body may experience local surface fields of the same magnitude as those produced by uniform fields, but the geometric variations (nonuniformity) in the domestic environment produce body electrical quantities (for example, current density in the waist) that are smaller than those produced by uniform fields. Therefore, it was important to properly characterize domestic exposure in order to compare it with exposure estimates for outdoor activities near transmission lines.

Little information on domestic exposure to electric fields has been published. Most studies have focused on a few measurements of local fields near consumer products as the basis for estimating exposure. One Canadian study (6) used typical electric field strength reported in the literature and an assumed house plan and home appliance configuration to produce annual exposure estimates (see Table 9-1).

Table 9-1

ESTIMATED ANNUAL EXPOSURE TO DOMESTIC ELECTRIC FIELDS

(Adapted from Reference 6)

Activity	Exposure ((kV/m)*h)
Working and sitting in small kitchen (4 hours/day)	15
Watching TV (3 hours/day)	25
Reading under lamp (3 hours/day)	10
Sleeping with head near bed lamp (8 hours/night)	30
Subtotal for all the above activities	80
Using electric blanket (8 hours/night, 8 months/year)	500
Total (for all the above activities)	580

A review of Table 9-1 indicates that, for the assumptions in the Canadian study, exposure to fields induced by electric blankets is important. Indeed, it is estimated to be about six times greater than exposure from all other domestic sources. This finding underscores the need to further investigate exposure to electric blankets and other household or domestic sources. Further study would make possible a better comparison of domestic activities with farming and other activities near transmission lines.

For purposes of estimating domestic exposure to electric fields, two key elements are needed:

1. An accurate description of domestic electric fields

2. A good understanding of how people spend nonworking time

In this study, Item 1 was investigated using the special exposure vest instrumentation described in Section 4. A series of measurements were made for a number of common domestic activities that might result in exposure to electric fields. As to Item 2, a rich body of human time budget data is currently available.

A University of Michigan survey (7) has provided detailed estimates of yearly uses of time on a household basis. This survey generated the measurements of time use from a national probability sample of U.S. households. The survey data were based on a large number of individuals from 74 sample points in 37 states. These people kept detailed logs of time spent in various activities. The sample group was representative of the four major geographical regions--the Northeast, the north-central region, the South, and the West--each of which was represented in proportion to its population.

The survey information was also used to estimate time use in synthetic weeks for a large number of occupations. These synthetic weeks are statistical composites that account for activity time on a yearly basis and are adjusted for factors such as geographical and seasonal variations and differences between weekday and weekend activities. The values listed in Table 9-2 are based on the survey data for a variety of categories. The survey data are reported in minutes per week and have been adjusted to hours per year. Detailed descriptions of each activity category are given in Reference 7.

Table 9-2

ANNUAL TIME BUDGET ESTIMATES FOR VARIOUS HUMAN ACTIVITIES

Code	Activity	Average Person (h/yr)	Farmer (h/yr)	Working Man (h/yr)
1	Normal work	1132.12	2207.75	2061.33
2	Unemployment activities	4.58	0.00	3.08
5	Second job	22.72	99.49	46.55
6	Lunch at work	46.09	14.99	78.28
7	Before-after-other	19.74	4.94	40.29
8	Coffee breaks	24.10	1.30	40.75
9	Travel to work	113.43	67.77	207.64
10	Meal preparation	245.79	78.43	59.91
11	Meal cleanup	75.90	37.44	11.86
12	Indoor cleaning	170.50	54.95	36.46
13	Outdoor cleaning	52.91	34.06	64.90
14	Laundry	74.59	93.69	5.08
16	Repairs, maintenance	66.59	164.67	105.41
17	Gardening, pet care	50.50	7.80	35.21
19	Other household	41.62	15.17	36.06
20	Baby care	32.57	9.88	12.61
21	Child care	35.33	24.09	12.58
22	Helping, teaching	5.27	14.39	4.03
23	Reading, talking	10.27	12.22	4.45
24	Indoor playing	9.76	0.00	7.33
25	Outdoor playing	4.85	0.00	3.83
26	Medical care--kids	2.77	0.00	0.88
27	Babysitting--other	22.45	0.00	5.55
29	Travel, child care	19.50	17.68	11.53
30	Everyday shopping	115.29	112.75	69.97
31	Durable, household shopping	5.81	0.00	9.18
32	Personal care services	10.14	8.41	3.75
33	Medical appointments	14.13	0.00	4.54
34	Govt. financial services	8.79	16.38	7.44
35	Repair services	8.42	1.04	5.80
37	Other services	6.47	9.62	7.96
38	Errands--NA kind	2.39	0.00	1.14
39	Travel--goods, services	95.68	85.71	71.60
40	Washing, dressing	254.39	221.09	234.10
41	Med. care (self--HH Adl)	6.29	0.17	3.05
42	Health care	60.30	179.92	55.60
43	Meals at home	330.23	369.89	307.83
44	Meals out	124.26	170.30	158.78
45	Night sleep	2925.04	2899.95	2834.42
46	Naps, resting	154.24	75.23	108.41
48	NA activities	120.12	258.44	87.07
49	Travel--personal	93.17	175.41	108.30
50	Students' classes	31.23	0.00	12.53
51	Other classes	9.37	0.00	12.68
54	Homework	31.51	0.00	22.09
56	Other education	3.21	0.00	1.14
59	Travel, educational	11.24	0.00	8.69
60	Prof. union organizations	2.11	0.00	1.70
61	Identity organizations	7.98	8.23	6.88
62	Political citizen organizations	0.92	0.00	0.80

Table 9-2 (continued)

Code	Activity	Average Person (h/yr)	Farmer (h/yr)	Working Man (h/yr)
63	Volunteer-helping organizations	4.25	0.00	0.69
64	Religious groups	21.41	13.26	18.75
65	Religious practice	55.92	46.71	42.74
66	Fraternal organizations	5.48	0.00	7.08
67	Child-family organizations	8.75	0.00	7.85
68	Other organizations	16.67	17.42	8.19
69	Travel--organizational	24.87	20.19	19.57
70	Sports events	13.39	0.00	21.01
71	Miscellaneous evening	3.90	15.17	5.04
72	Movies	13.73	0.00	10.76
73	Theatre	5.03	0.00	4.64
74	Museums	2.01	0.00	1.40
75	Visting others	259.80	197.25	179.95
76	Parties	27.27	5.11	23.08
77	Bars, lounges	27.93	12.83	36.39
78	Other events	6.94	15.34	5.48
79	Travl--events, social	67.98	42.81	65.05
80	Active sports	39.08	5.46	56.00
81	Outdoors	48.13	18.46	53.29
82	Walking, biking	18.78	26.26	20.24
83	Hobbies	17.22	0.00	26.03
84	Domestic crafts	66.15	50.70	9.69
85	Art, literature	4.94	0.00	1.85
86	Music, drama, dance	3.55	0.00	3.96
87	Games	40.47	17.07	25.49
88	Classes, other	17.54	0.00	16.85
89	Travel--active leisure	28.93	6.85	32.35
90	Radio	19.50	0.00	13.67
91	TV	736.16	426.05	658.68
92	Records, tapes	19.41	0.00	15.91
93	Reading books	26.87	5.55	17.24
94	Reading magazines, NA	85.37	46.11	53.10
95	Reading newspapers	86.34	97.07	82.87
96	Conversations, phone	97.62	44.55	78.29
97	Letters	13.34	0.00	5.53
98	Other passive leisure	81.00	48.45	58.99
99	Travel-passive leisure	7.77	7.37	8.07

Note: Code values correspond to survey activity codes and therefore are not numerically consecutive. Total time does not add to exactly 8,760 hours because of small rounding errors in individual time logs. Average person is composite of all groups, including students, unemployed, retired.

The next step in the process of estimating domestic electric field exposure was to collect exposure data with the vest instrumentation. The domestic measurements made with the vest are expressed in terms of equivalent uniform electric field. About 70 measurements were made at two homes in California; one home in Kansas; one commercial building in Hawaii; one home and office in Massachusetts; and three homes, a grocery store, and a large shopping mall in Pennsylvania. The measurements included a wide variety of exposure situations, carpet types, shoes, and body positions. The measurement program was not a rigorous study of the domestic electric field environment, but rather a representative collection of data that can be used to develop an "index" or rough estimate of exposure magnitudes. The results of the domestic measurement program are presented in Table 9-3. Some of the actual measurements in progress are shown in Figures 9.4 through 9.8.

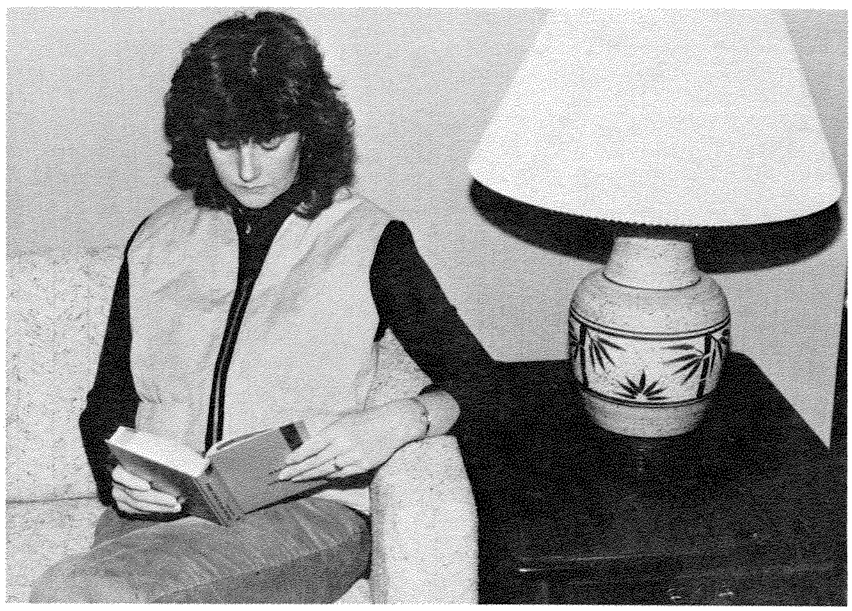


Figure 9.4. Exposure Measurement near Household Lamp

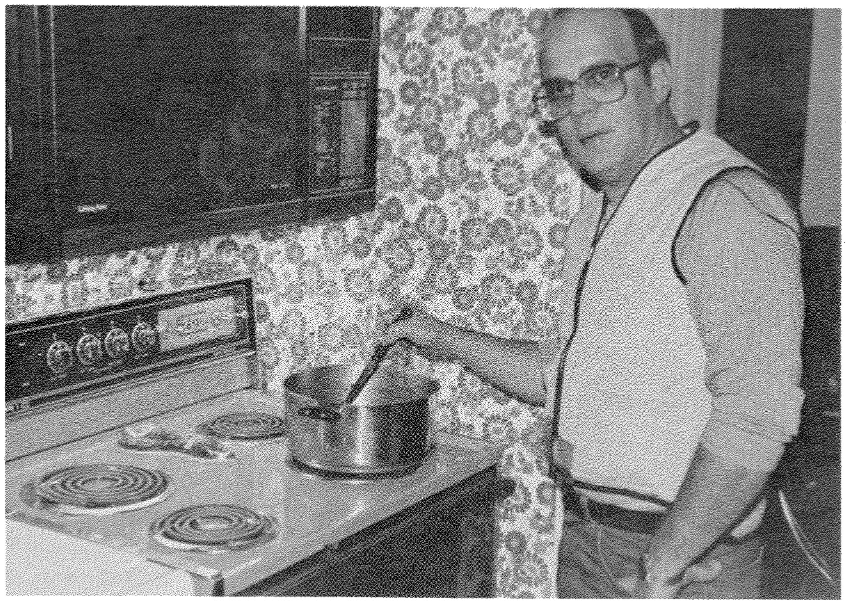


Figure 9.5. Exposure Measurement in Kitchen

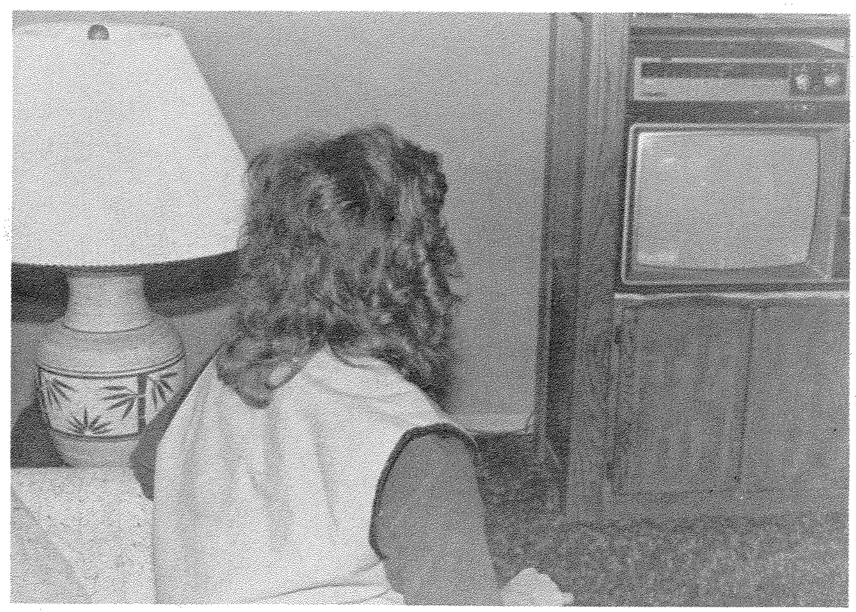


Figure 9.6. Exposure Measurement While Watching TV

Figure 9.7. Exposure Measurement while Reading in Bed

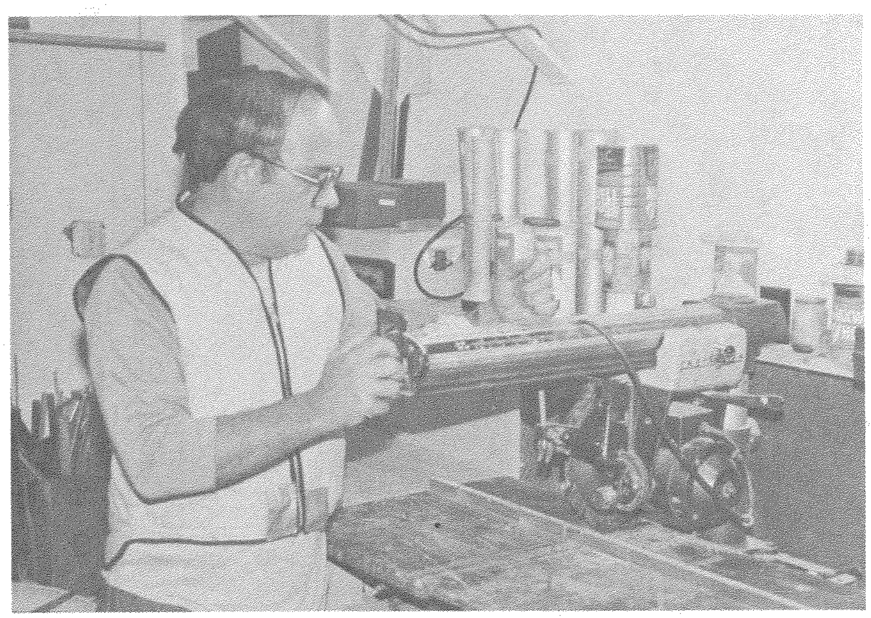


Figure 9.8. Exposure Measurement in Basement Workshop

Table 9-3

SUMMARY OF DOMESTIC EXPOSURE DATA

Item No.	Domestic Activity	Number of Measurements	Eq (V/m) Range	Eq (V/m) Average
	Sitting:			
1.	Sofa/chair by lamp	12	4.3-14.3	8.8
2.	Recliner by lamp	1	--	7.3
3.	Work desk with lamp	2	3.1-4.5	3.8
4.	Under fluorescent light	2	4.2-6.8	5.5
5.	Sofa near Christmas tree	1	--	6.0
6.	Watching TV (4 to 5 feet away)	5	1.8-4.5	3.0
7.	Standing 12 inches from color TV	1	--	12.5
8.	Sewing room	1	--	2.3
9.	Computer terminal	2	1.3-1.9	1.6
10.	Middle of room	6	0.6-3.7	1.7
11.	Family room, near lamp	1	--	6.6
12.	Dinner table	3	1.4-8.5	4.0
13.	Bedroom	3	9.6-10.8	10.2
14.	Japanese tea room, on rice mats	1	--	3.6
15.	Near stereo cabinet *	1	--	37.4
16.	Playing electric organ	1	--	3.6
17.	Reading in bed	1	--	2.3
18.	Car ride into city	1	--	0.1
	Standing:			
19.	Near large light fixture on wall	1	--	21.0
20.	Near 24 inch fan	1	--	6.7
21.	Playing with electric trains	1	--	3.5
22.	1 meter from living room lamp	1	--	9.0

Table 9-3 (continued)

Item No.	Domestic Activity	Number of Measurements	Eeq, (V/m) Range	Eeq, (V/m) Average
	Active:			
23.	Working with vacuum cleaner	1	--	7.8
24.	Workshop with electric tools	1	7.9/55 **	11.5
25.	Sleeping under electric blanket	1	10/50 ***	40.0
26.	Shopping at grocery store	1	--	3.7
27.	1-1/2 hours at church services	1	--	6.3
28.	Kitchen	3	2.5-5.2	3.6
29.	Bathroom	5	1.0-8.5	3.6
30.	Large shopping mall	2	4.9-6.5	5.7
	Special Experiments:			
31.	Sitting in living room by lamp A	1	--	11.3
32.	Sitting in living room with lamp A unplugged	1	--	2.7
33.	Sitting in den by lamp B watching TV	1	--	9.9
34.	Sitting in den by lamp B with TV unplugged	1	--	7.8

* Contained large tape deck equipment

** For this measurement, approximately 10% of exposure occurred at Eeq > 50 V/m.

*** Value depends on exposure equivalence criteria. Some localized equivalent surface fields were a few hundred volts per meter (see text).

The final step in producing domestic exposure estimates is to combine the time budget data from Table 9-2 with typical values of equivalent uniform electric field from Table 9-3. If one assumes about 120 nights out of the year with an electric blanket, the results presented in Table 9-4 for annual exposure (nonwork time) are obtained.

Table 9-4

ANNUAL DOMESTIC EXPOSURE ESTIMATE
(Using detailed time data from Table 9-2)

Person Type	Annual Exposure ((kV/m)*h)
Average person (composite)	76
Farmer	71
Working male (all categories)	69

The results presented in Table 9-4 are based on a very detailed division of time for a large number of activity categories. Similar results can be obtained, however, by using a less detailed allocation of time, such as the method shown in Table 9-1. Table 9-5 presents a set of sample calculations for working males based on some simple assumptions (the data in Reference 7 and approximate allocation of time by room size) and the equivalent field data of Table 9-3. The investigators selected typical electric field values on the basis of practical experience gained in the domestic measurement program. One other approach to producing exposure estimates was also used: preliminary calculations at the beginning of this study, using a rough three-dimensional computer model of the fields in a typical home, predicted an annual exposure of about 70 (kV/m)*h.

In summary, similar results were obtained with three different approaches. However, it should be noted that domestic exposure values calculated here are considerably lower than the values estimated by Reference 6 (Table 9-1).

Table 9-5

SAMPLE CALCULATION OF DOMESTIC EXPOSURE

Activity Location	Annual Hours	Eeq (V/m)	Annual Exposure ((kV/m)*h)
Work	2,060	†	†
Living room (950 hours)			
By lamp (TV/read)	750	9.0	6.75
Middle of room	40	2.0	0.08
Close to stereo	20	37.4	0.75
By desk lamp	140	6.0	0.84
Dining room (400 hours)			
Middle of room	250	8.5	2.13
Edge of room	150	4.0	0.60
Bedroom (3100 hours)			
Electric blanket--120 days	960	40.0	38.40
In bed--no electric blanket	1,920	2.3	4.42
In bedroom	220	10.2	2.24
Kitchen (220 hours)	220	4.0	0.88
Bathroom (480 hours)			
Near sink	280	8.5	2.38
Shower and other	200	4.0	0.80
Laundry and Workshop (200 hours)			
Laundry	50	6.7	0.34
Workshop--general	100	5.5	0.55
Workshop--electric tool	50	55.0	2.75
Yard and Outdoor (150 hours)	150	1.0	0.15
Away (1200 hours)			
Grocery or other stores	200	3.7	0.74
Shopping malls, etc.	500	5.7	2.85
Church	100	6.3	0.63
Other	400	2.0	0.80
		Total Annual Domestic Exposure:	69.08

† Work exposure is not included in this table.

HARMONICS

The waveshape of the electric field caused by the electrical wires and devices connected to the power supply in a household environment may deviate significantly from a pure sinusoid. Harmonics of the fundamental 60 Hz waveshape may be generated because of nonlinear loads and because of the presence of nonlinear dielectrics in the field region. This situation contrasts markedly with the case of transmission line fields, which have a negligible harmonic content. If the electric field contains harmonics, the currents induced in the human body by the field will contain an even greater amount of harmonics. In fact, the electric field induces currents proportional to its time derivative, which is proportional to the field and to the frequency. For instance, if the electric field contains a third harmonic equal to 5% of the fundamental, the induced current will contain a third harmonic equal to 15% of the fundamental.

Measurements of electric field exposure with a sensor vest do not distinguish between the fundamental wave and its harmonics. The current that enters the measuring instrument, in fact, is proportional to the mean value of the induced rectified current. In most cases, especially close to the most significant sources of induction, the mean value is not significantly sensitive to the harmonic content. For instance, a third harmonic with peak value equal to 50% of that of the fundamental will change the mean value of the total current waveshape by an amount ranging from -17% to +17%, depending on the phase relation between fundamental and harmonic waves.

As the order of harmonics increases, the effect becomes less significant; a 50% fifth harmonic will change the mean value by an amount between -10% and +10%. Thus, measurements with a vest are well correlated with exposure to the fundamental 60 Hz electric field.

The value of the harmonic field exposure levels can be derived from the 60 Hz exposure level by estimating the harmonic contents in the induced currents. For this purpose, a series of measurements were made of the electric field and vest current waveshapes in proximity to some common sources of electric field in a domestic environment. These waveshapes are shown in Figures 9.9 through 9.14.

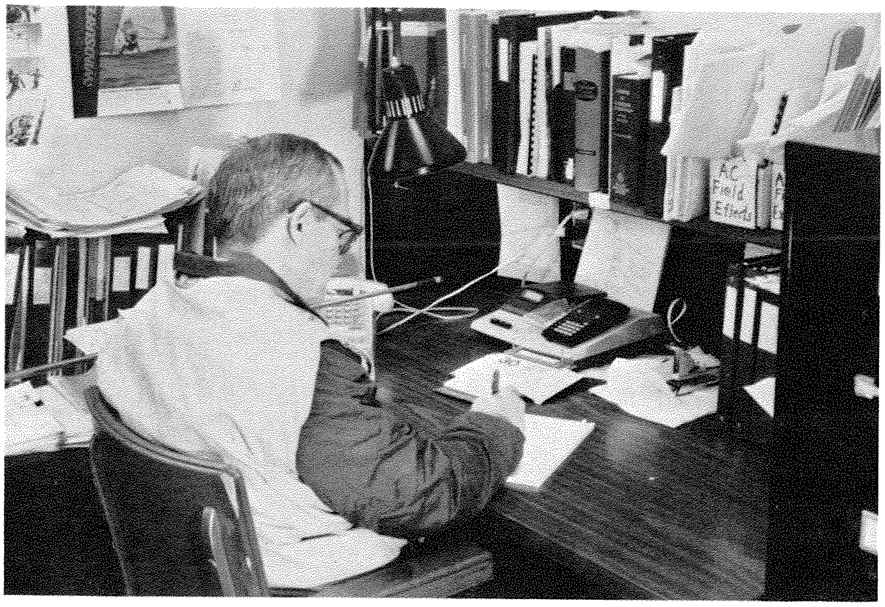


Figure 9.9. Measurement of electric field exposure using a sensor vest at a desk with an incandescent lamp.

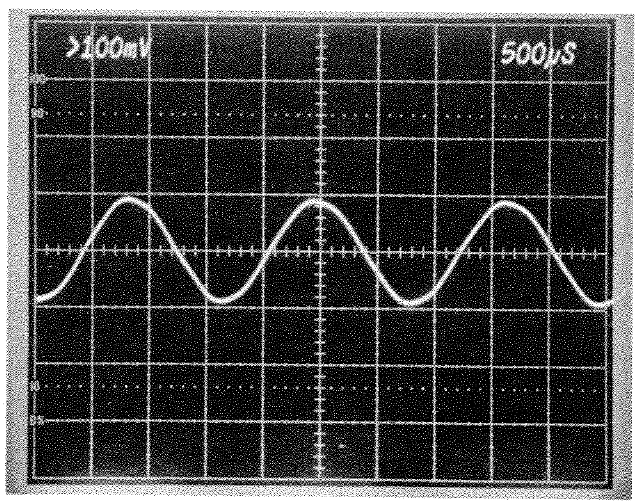


Figure 9.10. Waveshape of the electric field generated by the incandescent lamp of Figure 9.7.

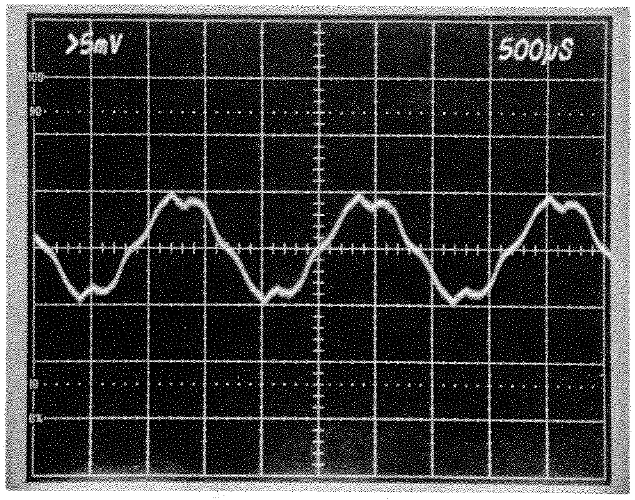


Figure 9.11. Waveshape of the vest current induced by the incandescent lamp of Figure 9.9.

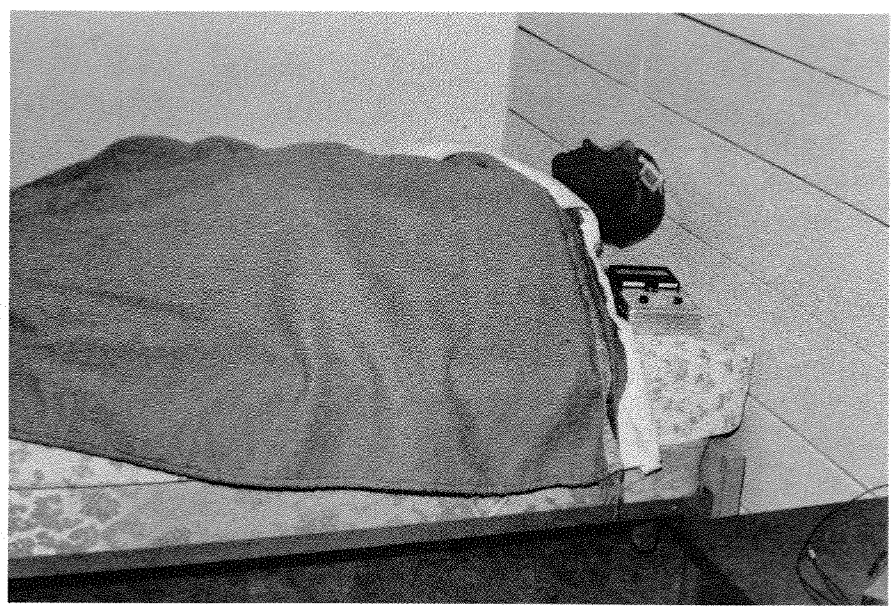


Figure 9.12. Measurements of surface electric fields on a mannequin under an electric blanket.

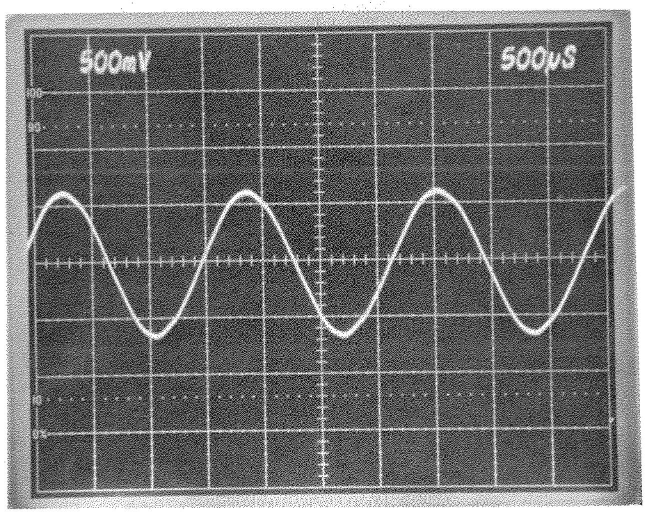


Figure 9.13. Waveshape of the electric field generated by the electric blanket of Figure 9.12.

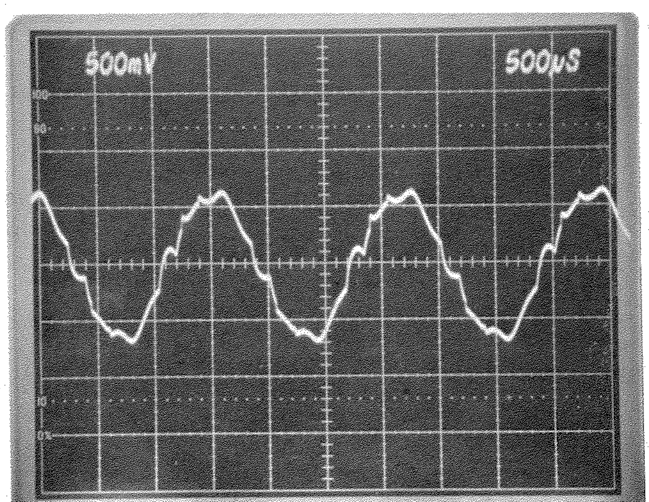


Figure 9.14. Waveshape of the electric current induced by the electric blanket of Figure 9.12.

DISCUSSION

Several significant findings resulted from this investigation and domestic measurement program:

1. The use of equivalent electric fields is necessary for comparing the complex fields in the domestic environment with the uniform fields of transmission lines.

2. Measurements with electric field meters very close to appliances overestimate the equivalent uniform electric field for most body electrical quantities. At distances over 1-2 meters from an appliance, the equivalent uniform field measured by the vest is in general agreement with the electric field meter readings.

3. Typical electric field exposures in the home generally occur in equivalent electric fields ranging up to about 60 V/m.

4. Electric blankets may account for a large part--about half--of the total annual domestic exposure, even with only conservative use. The presence of an electric blanket in a room can raise exposures in the room in general. Though the case can be made that some people do not use electric blankets, the number of people who do use them is so large that their inclusion in the domestic exposure estimates is appropriate.

5. Exposure to electric blankets (when averaged over the body) is probably not as high as was previously estimated. It appears to be about one-sixth of the value reported in the Canadian study. However, local, (perturbed) surface fields on the human body under an electric blanket can be quite high (1-1.75 kV/m on some parts of the body).

6. Besides electric blankets, the predominant sources of exposure in the home are lamps, because they are used in large numbers and because people spend large amounts of time near them.

7. Appliances and other electric devices need not be turned on--but only plugged into an energized wall outlet--to produce electric field exposure.

8. The degree of grounding is highly dependent on shoe type and carpet or floor covering type. Some of the lowest values of exposure measured were in rooms with linoleum or vinyl floors. Many carpets, on the other hand, do not insulate well. One reason is the presence of dirt in the fibers. Another reason is the prevalence in today's homes and businesses of anti-static carpets which are semiconducting.

9. In most practical situations, measurements of exposure to the fundamental 60 Hz electric field in a domestic environment using a vest are little affected by the electric field harmonics. Exposure to electric field harmonics can be approximated from measurements of exposure to the fundamental 60 Hz field by estimating the harmonic content of the predominant electric field sources.

REFERENCES

1. Transmission Line Reference Book--345 kV and Above. 2d ed. Palo Alto, Calif. Electric Power Research Institute, 1982, p. 348.

2. Sheppard and Eisenbud. Biological Effects of Electric and Magnetic Fields of Extremely Low Frequency. New York: New York University Press, 1977, p. 3.3.

3. Caola, Deno, and Dymek. "Measurements of Electric and Magnetic Fields In and Around Homes near a 500 kV Transmission Line". IEEE-PAS, Vol. 102, October, 1983, pp. 3338-3347.

4. Telecom with Merchandizing Magazine (New York City) Feburary 1, 1983.

5. Biological Effects of High-Voltage Electric Fields: An Update. Palo Alto, Calif. Electric Power Research Institute, 1979, pp. 5-15. EA-1123.

6. Epidemiological Study of Workers Maintaining HV Equipment and Transmission Lines in Ontario. Montreal: Canadian Electrical Association, 1979.

7. Time Use in Economic and Social Accounts. Ann Arbor, Michigan: University of Michigan, 1977.

Section 10

APPLICATION OF RESULTS

USE OF EXPOSURE ESTIMATES

Electric field exposure estimates lend themselves to three broad applications: 1) exposure information can be incorporated into risk assessments, 2) exposure of a general population or subpopulation (farmers, for example) can be compared with available laboratory studies, and 3) estimates of exposure can be used in the design and planning of future research projects. Some sample applications are presented in this section to demonstrate the utility of the exposure estimates. The data provided in Table 7-9 (reproduced here as Table 10-1) summarizes the annual exposure estimates for the Illinois typical USDA farm for three different transmission line designs. This data will be used for the sample applications in this section.

Table 10-1 has been divided into two parts, separated by a horizontal dotted line. The top part is the approximate range of equivalent electric fields from domestic sources (based on the data in Section 9), and the bottom part represents fields above these levels. A review of the data in Table 10-1 reveals that, even when a high voltage transmission line crosses a farm, about 90-98% of a farmer's time is spent in equivalent electric fields below about 64 V/m. The rest of the time is spent in fields ranging up to a few thousand V/m, depending on the transmission line design. In this section of the report we consider the exposure estimates in these two divisions to demonstrate possible applications of exposure assessment results.

Table 10-1

EXPOSURE ESTIMATES FOR ILLINOIS FARM

Eeq (V/m)	Annual Time (hours) 115 kV	345 kV	765 kV
0 - 1	1295	1087	605
1 - 2	37	77	280
2 - 4	34	71	152
4 - 8	26	56	101
8 - 16	23	43	76
16 - 32	20	34	58
32 - 64	12	29	46
64 - 125	7	22	39
125 - 250	9	15	34
250 - 500	13	15	21
500 - 1000	3	14	19
1000 - 2000	1	14	21
2000 - 4000	0	2	21
4000 - 8000	0	1	6
> 8000	0	0	1
Maximum Eeq (kV/m)	1.5	4.5	10.5

Note: The data are for one person performing outdoor work only.

EXPOSURE TIME HISTOGRAMS

For the sample applications that follow, the information in Table 10-1 is reproduced as three separate time histograms (Figures 10.1 through 10.3). These histograms provide a better visual interpretation of the distribution of time spent in various levels of equivalent electric field.

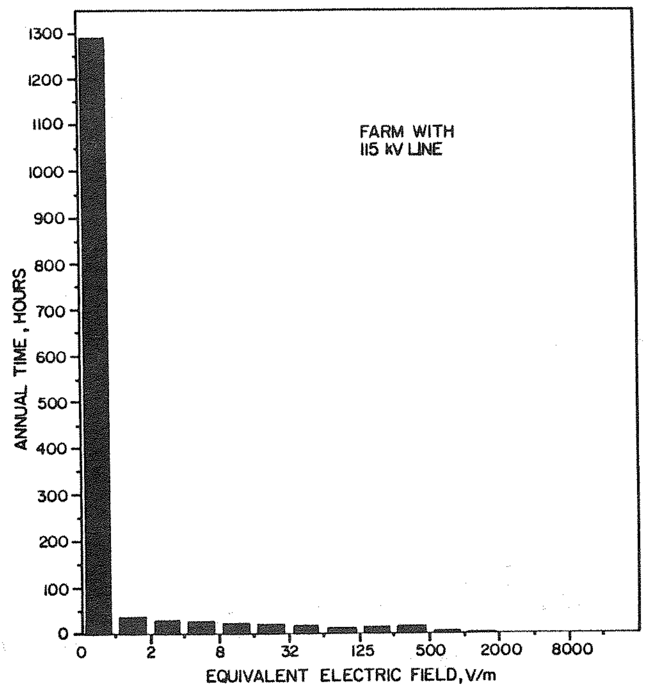


Figure 10.1. Histogram of time in electric fields: Illinois farm with 115 kV line.

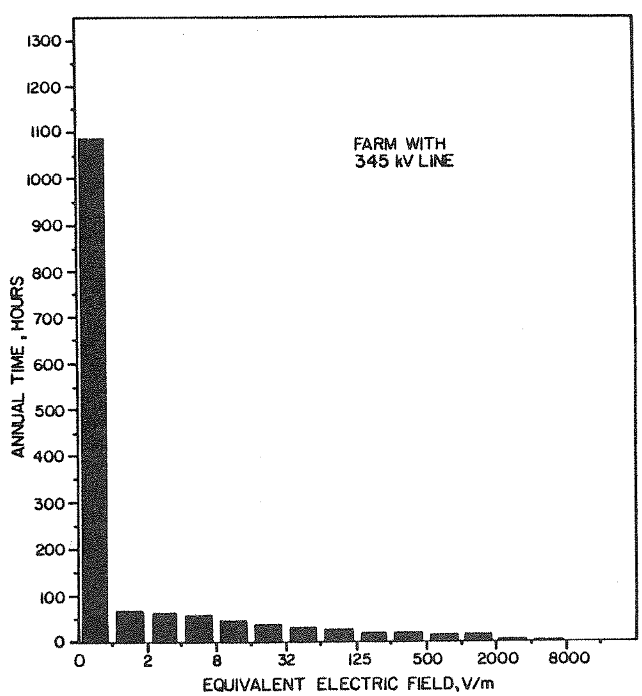


Figure 10.2. Histogram of time in electric fields: Illinois farm with 345 kV line.

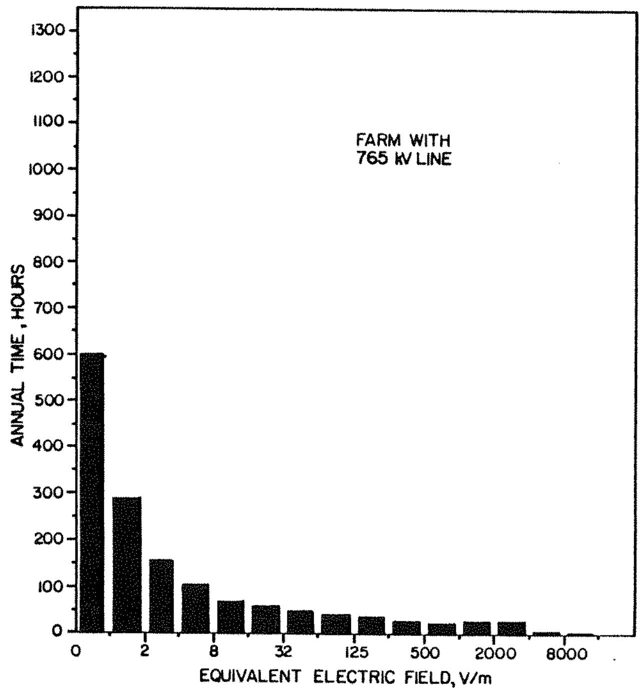


Figure 10.3. Histogram of time in electric fields: Illinois farm with 765 kV line.

The histograms clearly reveal that most time is spent in the lower ranges of electric field intensity. However, some time is spent in the higher fields. As Table 10-1 indicates, peak values of equivalent field range from 1.5 to 10.5 kV/m, depending on line design.

SAMPLE COMPARISON WITH DOMESTIC EXPOSURE

The next step in the review of the two parts of Table 10-1 is to consider the estimates of domestic exposure presented in Section 9. A typical annual distribution of time spent in domestic electric fields is provided in Figure 10.4. The graph is meant to be general, but it is basically derived from the values recorded in Table 9-5. A broad peak encompasses the most common sources of exposure, such as lamps and appliances. The second peak is caused by an electric blanket, phonographic equipment, and electric tools.

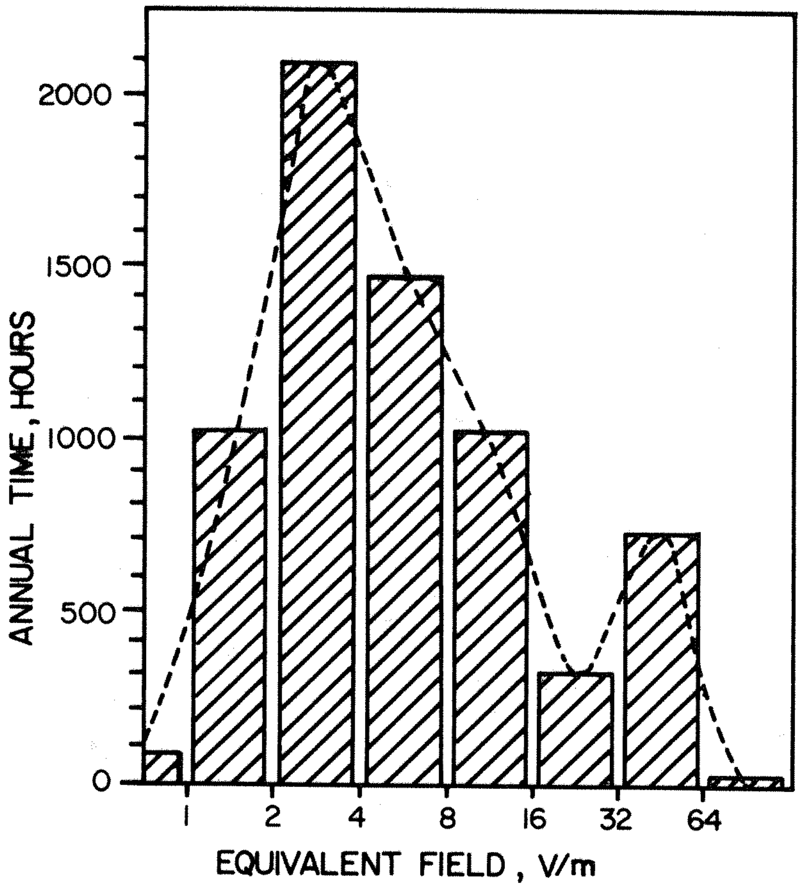


Figure 10.4. Typical Distribution of Domestic Exposure

To compare exposure from domestic sources with that from transmission lines, the time histograms for the 345 kV and 765 kV cases are converted to frequency curves (by connecting the midpoints of the histogram rectangles) and superimposed on the domestic electric field plot (see Figures 10.5 and 10.6). This comparison indicates that more time is spent in the lower fields from domestic sources than in the lower fields from transmission lines. This example also shows that about 90-98% of the time spent outdoors on the farm is in equivalent electric fields that are not much different from fields from domestic sources.

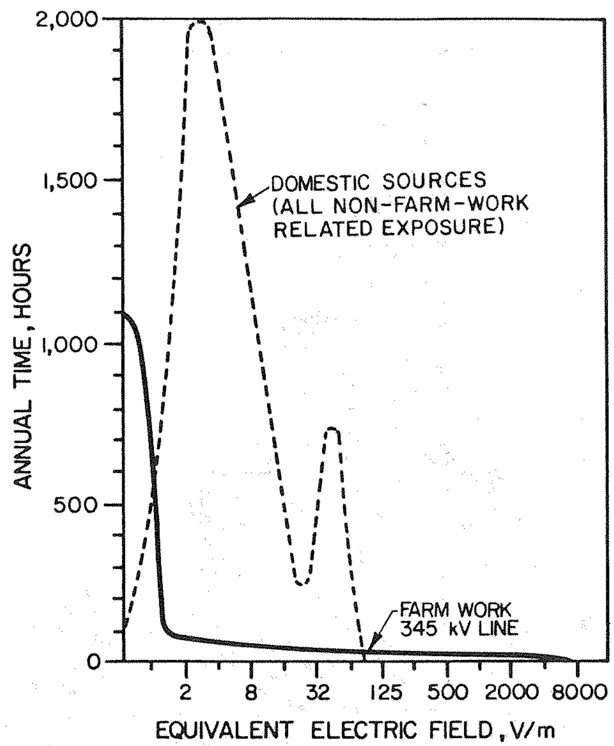


Figure 10.5. Time spent in equivalent electric field: domestic vs farm with 345 kV line.

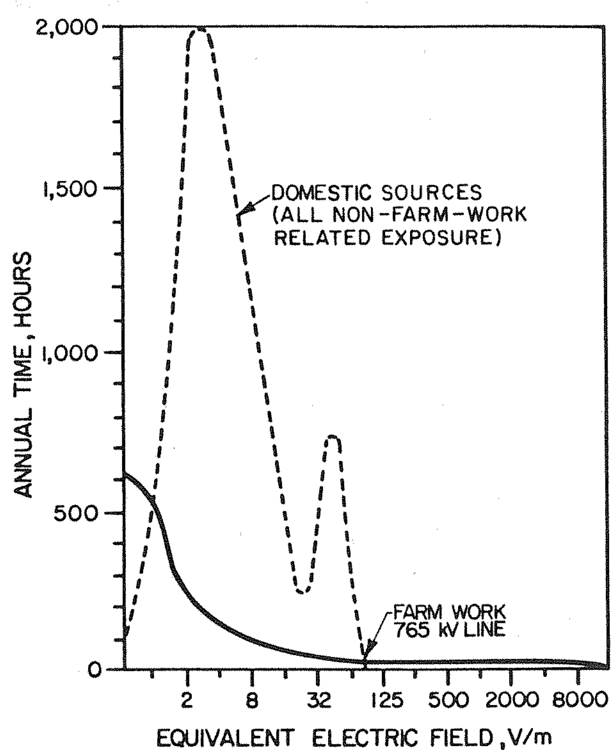


Figure 10.6. Time spent in equivalent electric field: domestic vs farm with 765 kV line.

SAMPLE COMPARISON WITH LABORATORY ANIMAL EXPERIMENTS

The time spent in electric fields above domestic levels must now be considered. Data from exposure at these levels, especially levels as high as several kilovolts per meter, are often compared with laboratory animal studies so that conclusions can be drawn about humans. This approach is considered here in three ways. (No attempt was made in the analysis to deal with any of the physiological considerations that are necessary for comparisons between laboratory animals and humans).

First, we consider a plot of electric field exposure accumulated by month during a year of farm work. Such a histogram is shown in Figure 10.7. This graph depicts the accumulated time-integral of exposure, by month, for a farm in the southeast crossed by a high voltage transmission line. The exposure totals increase in the spring months with ground preparation and planting, decrease in midsummer, and peak in the fall during harvest. (Exposure can be greatly reduced by use of cabbed vehicles; non-cabbed vehicles throughout were assumed in this analysis.) This comparison demonstrates an important aspect of time spent in the higher levels of electric field: exposure time is distributed throughout the year and does not occur all at once. Exposure of laboratory animals, on the other hand, is usually continuous and at relatively high levels.

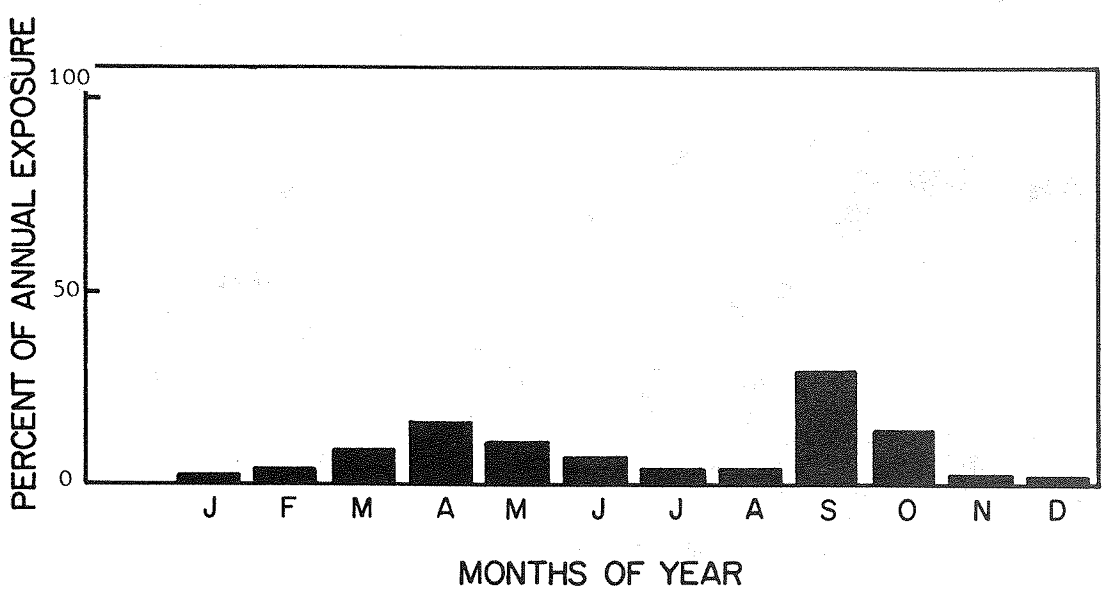


Figure 10.7. Exposure by Month for a Farm with a 500 kV Line

The second method of comparison uses the equivalence of current density. Suppose that the method of comparison is based on current density in the thorax. The farmer exposure histograms of Figure 10.1 through 10.3 are now converted to histograms of time spent at various levels of current density (using the values in Reference 1) in the thorax. (See Figures 10.8 through 10.10). These new histograms, provided to demonstrate the utility of exposure assessment data, are for the 115 kV, 345 kV, and 765 kV examples of Table 10-1. These histograms of current density are supplemented by a plot of the current density of a laboratory rat exposed to electric fields in a typical experiment. Only one histogram, that of the 765 kV line, has values that reach the current density of the laboratory animal. Notice that the laboratory rat of this example spends considerable time at a high level of current density. Significantly, the rat is exposed to this level almost continuously for as many as 3,000 hours, whereas the person described by the data in Figure 10.10 spends 6-7 hours at this level, spread out over an entire year.

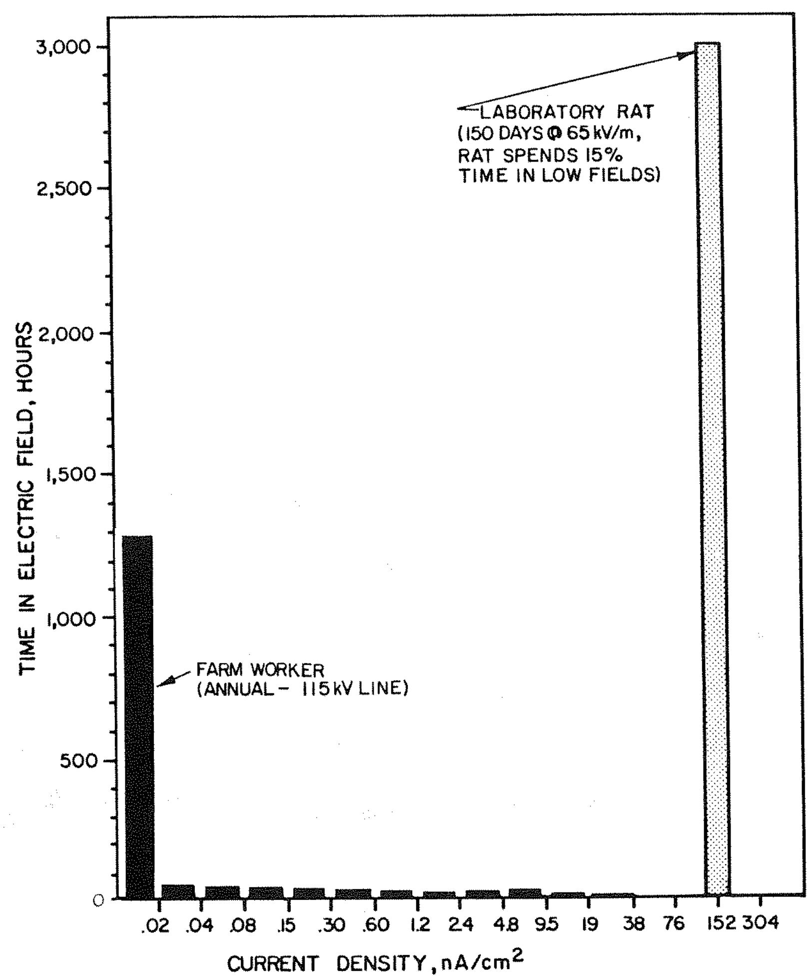


Figure 10.8. Comparison of Current Density (115 kV Case)

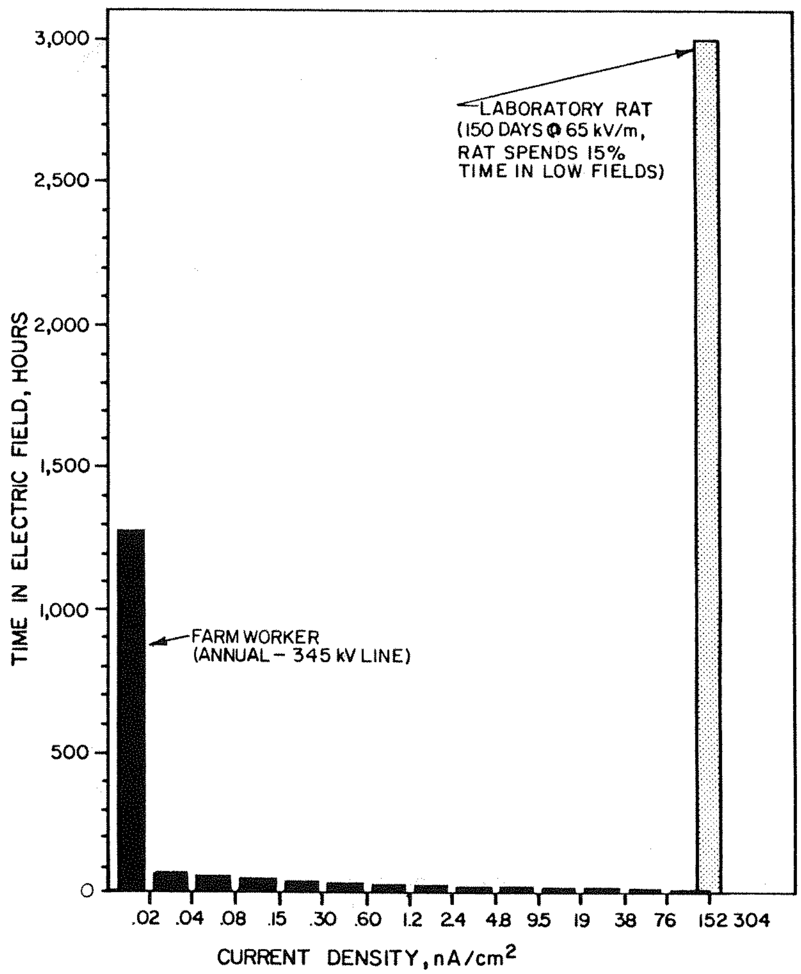


Figure 10.9. Comparison of Current Density (345 kV Case)

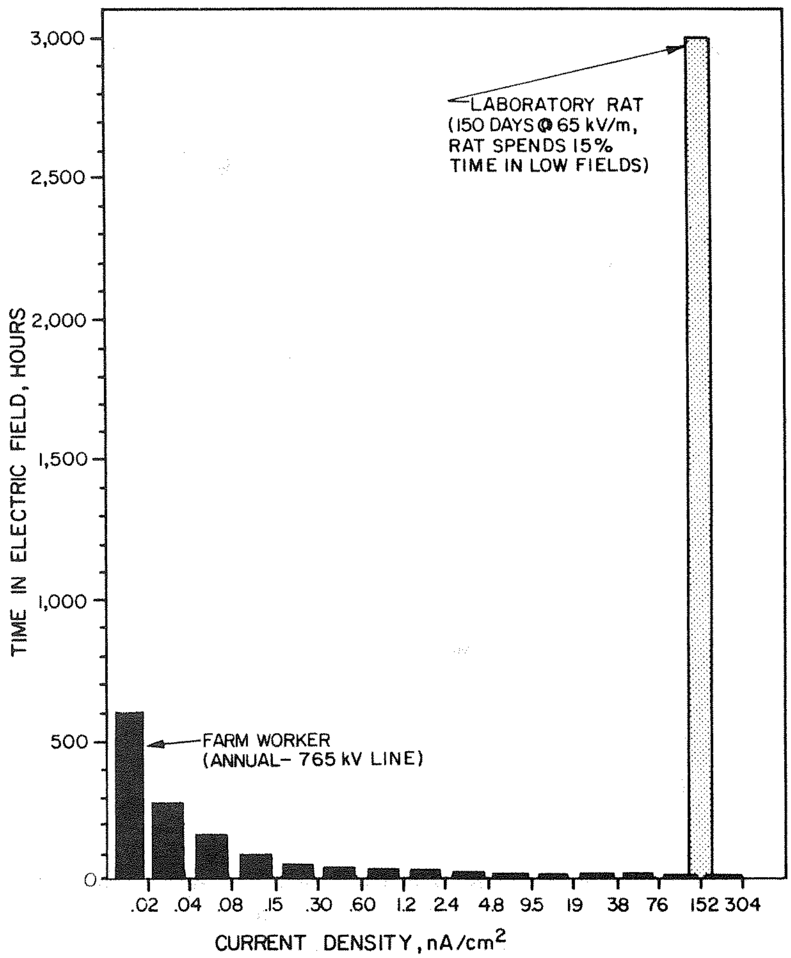


Figure 10.10. Comparison of Current Density (765 kV Case)

Another third important comparison with laboratory data considers perception of the electric field. To perform this comparison, we need a value for the threshold of perception of humans and rats. A median threshold for perception of 6-7 kV/m has been reported for humans (2). Rats have reportedly been able to detect electric fields in the 4-8 kV/m range (3). The data in Table 10-1 have been refined to provide data in the electric field ranges of interest. Also, additional line designs have been added. This new information, along with corresponding values for rats, is provided in Table 10-2. This table demonstrates the difficulty of making direct comparisons with laboratory data, without proper understanding of human exposure estimates and other biological factors. It shows that experimental electric field levels in the laboratory may not be equivalent to the electrical environment experienced near high voltage lines if time spent above the perception threshold is important.

Table 10-2

TIME SPENT ABOVE THRESHOLD OF PERCEPTION

Subject	Electric Field Range	Time at Eeq > Threshold
Farmer (115 kV)	< 2 kV/m	0
Farmer (230 kV)	< 3 kV/m	0
Farmer (345 kV)	< 5 kV/m	0
Farmer (500 kV)	< 9 kV/m	1/2 hour/year
Farmer (765 kV)	< 12 kV/m	3 hours/year
Laboratory Rat	65 - 130 kV/m	1200 - 3000 hours

Note: The threshold of perception for humans is about 6-7 kV/m, and that for laboratory rats is 4-8 kV/m.

Next, a computation is performed on a very hand-labor-intensive USDA typical farm--an irrigated cotton farm in a western state. A 765 kV line was placed on this farm (although lines of this voltage are not used in the West) to determine an upper bound estimate for Table 10-2. For this situation, 14-15 hours of a farm worker's time could be spent on an annual basis at fields above 6 kV/m.

During recreation, it is possible to spend time at locations where electric fields are above 6 kV/m. Exposures at this level did not occur for the examples of Section 8, because the transmission lines were not capable of generating fields of that intensity.

TRANSMISSION LINE MILES IN THE UNITED STATES

Use of exposure estimates in risk assessment must consider the relative spatial distribution of people and transmission line voltage classes. The underlying assumption in this study has been that any given farm has a high voltage transmission line crossing it. Common sense and experience tell us that this situation is the exception rather than the rule. It would be very beneficial to this study, or to any associated risk assessment study, to know what proportion of farms contain parts of transmission line rights-of-way, and to what degree the rights-of-way interact with the land use of the farms. That is, if a farm property is intersected by a right-of-way, does the right-of-way cut through the middle of the farm, as in our typical farms? Does it cut off an unused corner of the property? Does it pass relatively close to the farmstead? Unfortunately, there are no such statistics for the nation as a whole. In fact, many individual utilities would be hard pressed to account for all land use along their own rights-of-way.

One set of data that is available, though, is the circuit miles of high voltage transmission line that currently exist in each voltage class in the United States (4,5) (see Table 10-3).

Table 10-3

CIRCUIT MILES OF TRANSMISSION LINE IN THE UNITED STATES BY VOLTAGE CLASS

Line Voltage (kV)	Circuit Miles	Typical ROW Width (ft)	ROW Acres
115-161	180,165	75	1,637,800
230	65,986	100	799,800
345	42,436	150	771,600
500	20,116	175	426,700
765	1,919	250	58,100
Total:	310,622	Total:	3,694,000

There are about 3 million square miles, or 1.92 billion acres of land in the contiguous 48 states (6). Transmission line rights-of-way occupy less than 0.2% of this area, a conservative estimate in that the line mileage given in Table 10-3 and used for this computation is in circuit miles. The actual number of miles of line is less (many lines are double circuit). Also, the ROW widths shown are somewhat higher than the actual average. With lines and farming activities assumed to be uniformly and randomly distributed, a rough estimate is that a farmer would have a 99.8% chance of not being in a ROW at any given time. The probability of a farmer's not being at a location of 3 kV/m or more is even greater, since fields of this value are situated only on a small proportion of some of the ROWs.

EXPECTED VARIABILITY OF EXPOSURE ESTIMATES

Soft versus Hard Numbers

Any application of results using exposure data must consider the variability of the data when reaching conclusions. The Activity Systems Model for estimating exposure to 60 Hz electric fields uses a variety of inputs. Some of these inputs come from well understood phenomena and can be specified precisely. Other inputs are less well understood. Also, some phenomena can be represented by nonstochastic variables and parameters, whereas others may have random properties. This combination of varying degrees of knowledge and, in some cases, random variables means that exposure estimates are soft numbers.

For example, the description of the geography of a farm or recreational location is straightforward. Also, the knowledge and data required to calculate the electric field are in a standard engineering handbook (2). In contrast, information about an activity is either a statistical estimate from a probability sample, or a range of values thought to be typical for the activity. Before this research project was undertaken, knowledge about activity factor parameters was even sketchier; most studies estimated exposure assuming the worst case--setting these factors at 100%. Thus, the type of knowledge incorporated in the model ranges from standard to newly created.

The computer model developed in this study uses single values to represent all variables, random or deterministic. Therefore, in estimating exposure, the assumption is made that reasonably accurate results can be generated by using the expected values of random variables. Furthermore, this assumption implies that results should be interpreted as random variable results--that all results have a distribution that reflects the statistical variation of possible results. Taken together, stochastic variation and uncertainty due to lack of knowledge or data imply that exposure estimates should be interpreted and used as soft numbers. Let us examine the uncertainties associated with soft numbers in more detail.

Uncertainty in Exposure Estimates

Estimates of electric field exposure are calculated on the basis of three types of knowledge: functional relations, a set of parameters of these functions, and a set of variables that characterize the system. In the model, the system variables might be the distance of a person from the line, the operating voltage, and the line height. The model parameters might include the activity factor(s), or the shielding factor of a tree. There are two possible sources of uncertainty in the exposure estimates. First, because of the limitations of measurement precision and the fact that some variables are truely random, one can never know the values of the variables and parameters exactly. The uncertainties in these values translate into uncertainties in the predicted exposure values. The second source of uncertainty concerns the structure of the model itself: Are the functional relations well known? Are all of the relevant parameters included in the model?

Questions that immediately arise are: When can one ignore these uncertainties? Can't one make practical calculations using just best-estimate or point values for model parameters and the input values of the system variables? The answers to these questions depend on the context and the use of predicted values of exposure.

Variability Analysis

A Monte Carlo version of the Activity Systems Model for the farming case was constructed to assess the amount of uncertainty and variation associated with exposure estimates. This model included sources of variation for system random variables and parameters and for random errors of evaluation, for example, measurement and calculation errors. Both sources contributed to the envelope of uncertainty surrounding exposure estimates, but the former accounted for somewhat more of the uncertainty in the envelope. Perhaps surprisingly, the uncertainty envelopes were rather small. The plots of these envelopes can be found in Appendix D.

Another measure of the accuracy of the Activity Systems Model exposure estimates is the range of estimates divided by their expected values. These expected value estimates were computed over the 100 Monte Carlo simulations. For exposure, this value was 36%. For exposure times, the range divided by expected value is only 5%.

The Monte Carlo approach was used to assess the importance of knowledge of activity factors. This assessment was performed by comparing computer runs with activity factors represented by random variables (calibrated by field measurements), with runs for which activity factors are assumed to be 100% all the time. The estimate of total exposure computed without knowledge of the activity factors was 4.7 times greater than that computed with these parameters, a further indication of the importance of such knowledge. A second Monte Carlo model was constructed to assess the simple case of jogging in the right-of-way of a 500 kV line. The results for this simpler case were even less uncertain than those for the farming case because the uncertainty envelopes were tighter.

In summary, exposure estimates are soft numbers, but the uncertainty attached to interpreting and using these numbers seems well within the range of other random variables commonly employed in engineering and environmental assessment.

REFERENCES

1. W.T. Kaune and R.D. Phillips. "Comparison of the Coupling of Grounded Humans, Swine, and Rats to Vertical 60 Hz Electric Field." Bioelectromagnetics. Vol. 1, No. 2, 1980, pp. 117-129.

2. Transmission Line Reference Book--345 kV and Above. 2d ed. Palo Alto, Calif.: Electric Power Research Institute, 1982.

3. S. Stern et al. "Behavioral Detection of 60 Hz Electric Fields by Rats." Bioelectromagnetics. Vol. 4, No. 3, 1983, pp. 215-247.

4. Electric Power Supply and Demand 1984-1993. Princeton, N.J.: North American Electric Reliability Council, July 1984.

5. Eighth Biennial Survey of Power Equipment Requirements of the U.S. Electric Utility Industry. Washington, D.C.: National Electrical Manufacturers' Association, March 1982.

6. U.S. Department of Commerce. Bureau of the Census: Statistical Abstract of the United States. Washington, D.C.: Government Printing Office, 1982.

Section 11

CONCLUSIONS

This report describes a framework that can be used to develop estimates of exposure to 60 Hz electric fields of transmission lines for a variety of human activities. The method, called the Activity Systems Model, simulates human activities in situations where exposure to electric fields is possible. The model provides the framework that combines electric field maps, activity maps, and experimentally determined activity factors to produce histograms of time spent in various levels of electric field strength. Researchers developed a portable measurement system that employs a vest containing sensors and used it to measure exposure at a number of locations throughout the United States for a variety of activities near transmission lines. The main findings of this study are:

- Human exposure to 60 Hz electric fields cannot be evaluated using the unperturbed electric field alone. Rather, it is necessary to introduce the concepts of equivalent fields and activity factor. Equivalent field is the unperturbed uniform field that would cause the same electrical quantities to be applied to the body as those that would be applied in a well-defined reference situation. Activity factor is the ratio between exposure during an activity and the theoretical exposure that would occur in the reference situation for the same unperturbed field.

- Equivalent fields or activity factors for farming operations, recreational activities, and domestic situations are reported. These data were the results of an experimental measurement program involving transmission lines ranging from 115 to 1200 kV. This measurement program verified the accuracy of the exposure estimates produced by the model presented in this report. It was found that equivalent fields are generally only a fraction of unperturbed fields and that activity factors are much less than unity (they approach unity only rarely). Exposure was found to be significantly reduced by the shielding provided by vehicles, farm machinery, and vegetation and by deviations of body posture from the erect position. Electrical insulation of the body from ground, which may be provided by shoes and the surface underfoot, reduces exposure also.

- The relative evaluation of exposures depends on the quantity selected to characterize human exposure to electric fields. The Activity Systems Model gives detailed histograms of exposure in different ranges of equivalent fields. These histograms can be used to provide different types of exposure quantities. Two quantities were found to be particularly useful: the time spent above a given equivalent field (for instance, the threshold of perception), and the total time integral of equivalent field, (kV/m)*h.

- The annual exposure of farmers to the electric fields of high voltage transmission lines crossing their farms was estimated for eighteen typical U.S. farms (as defined by USDA) and for different voltage classes. For a typical farm the average time spent above the threshold of perception is zero for transmission voltages up to 345 kV, about one hour per year for 500 kV, and a few hours per year for 765 kV. The annual exposure of operators (principal workers) on farms crossed by a 345 kV line ranges from 10 (kV/m)*h to 120 (kV/m)*h, depending on the type of farm, with an average value of about 60 (kV/m)*h.

- Differences in voltage class make an important difference in farm exposure level; a 765 kV line could cause about four times the exposure of a 345 kV line. No significant difference was found between single and double circuit lines.

- The principal sources of variability in estimates of farmers' exposure are line voltage class, type of farm, and uncertainties in the parameters of the Activity System Model. The effect of these latter uncertainties is a variance of 36% of the mean or average exposure estimates.

- Annual exposure of farmers to transmission line fields was compared with estimates of annual exposure to 60 Hz electric fields in the home. No equivalent field above the threshold of perception is present in the home or domestic environment. Equivalent electric fields are generally a few volts per meter and probably do not exceed about 60 V/m. However, people spend a considerable amount of time in the domestic environment, and total cumulative exposure is comparable to that of farmers near power lines. Average annual domestic exposure is estimated to be about 70 (kV/m)*h, about half of which is related to use of electric blankets.

- Recreational activities on rights-of-way are generally of the linear type (jogging, bicycling, horseback riding, skiing). Exposure depends on path position and orientation with respect to a transmission line, line voltage class, and duration and frequency of the activity. No systematic data on recreational activities on the rights-of-way are available. Recreational activities, therefore, must be examined on a case-by-case basis. Cumulative exposures were evaluated for a few examples and were found to be generally lower than agricultural and domestic estimates. There is always the possibility of a subject's being in peak fields for longer periods of time than a farmer is. However, locations suitable for recreational activities having equivalent electric field above the threshold of perception (for example, directly underneath the conductors) are not common for the higher voltage lines.

- Comparison of human exposure to the exposure of laboratory animals depends on the assumptions made about possible biological mechanisms. The exposure data resulting from the application of the Activity Systems Model are in a flexible format, and a more detailed use of these results can be made as the understanding of biological mechanisms improves. Using the simple exposure criteria developed during this study, it was found that (1) human exposure is spread out over long periods of time rather than being concentrated, (2) farmers and most other people spend little or no time above thresholds of perception, whereas many laboratory animals are generally exposed to electric fields above their perception during the entire duration of an experiment, and (3) cumulative exposure during some of the typical laboratory animal experiments is two to four orders of magnitude greater than cumulative equivalent exposure for a human during one year of outdoor work on a farm crossed by a transmission line.

Appendix A

SUMMARY OF ACTIVITY FACTORS

Item No.	Activity Description	Number Measurements	Activity Factor-% Range	Activity Factor-% Average
	Standing:			
1)	Workboots	20	68–96	89
2)	Various regular shoes (leather/sneakers/rubber/crepe)	36	60–96	79
3)	Barefoot on rocky soil	1	--	95
4)	Jogging shoes	5	67–79	73
5)	Regular shoes – 2' grass	3	55–56	55
6)	Regular shoes – 4' grass	4	30–31	31
7)	Regular shoes – 6' grass	4	7–17	12
8)	Running shoes ≥ 15' from man	1	--	71
9)	Running shoes – 10' from man	1	--	69
10)	Running shoes – 5' from man	1	--	67
11)	Running shoes – 2' from man	1	--	54
12)	Running shoes – 1' from man	1	--	46
13)	Running shoes – almost touch	1	--	39
14)	Walking on residential sidewalk	1	--	78
15)	Moving through heavy brush, saplings	1	--	21
	Very Wet Grass:			
16)	Workboots (wet) – standing	1	--	99
17)	Workboots – slow walk	1	--	96
18)	Workboots – brisk walk	1	--	89
19)	Workboots – running	1	--	82
	Working Bent Over:			
20)	Regular shoes	3	52–76	65
21)	Regular shoes – 2' grass	2	52–53	52
22)	Regular shoes – 4' grass	1	--	19
23)	Regular shoes – 6' grass	1	--	6
	Working with Jeep or Small Truck:			
24)	Inside vehicle – metal top	3	2–4	3
25)	Inside vehicle – fiberglass top	5	2–9	6
26)	Standing at door	3	41–67	51
27)	Stand on front bumper	1	--	72
28)	Running shoes ≥ 15' away	1	--	71
29)	Running shoes – 10' away	1	--	65
30)	Running shoes – 5' away	1	--	52
31)	Running shoes – 1' away	1	--	18
32)	Getting in and out	2	18–22	20
33)	Getting in and out – 4' grass	1	--	9
34)	Siting in half ton pick-up truck	2	--	0.7
35)	Loading/Unloading hay wagon	4	61–68	66
36)	Sitting at bench	4	39–62	54

SUMMARY OF ACTIVITY FACTORS (Continued)

Item No.	Activity Description	Number Measurements	Activity Factor-% Range	Activity Factor-% Average
	Driving a Tractor:			
37)	Open top seat (all sizes)	25	11-63	42
38)	Open top: 1 m tall vegetation	1	--	30
39)	Open top with sun umbrella	2	18-20	19
40)	Rollbar cage	1	--	8
41)	Closed cab	5	1-5	2
42)	Driving self-propelled swather	3	20-43	30
43)	Driving combine	5	.3-.4	.4
44)	Sitting on a horse	2	85-87	86
45)	Riding horseback	2	80-83	82
46)	Sitting on a trail motorcycle	2	72-73	73
47)	Riding on a trail motorcycle	2	--	59
48)	Sitting in lawn chair	2	43-53	48
49)	Swinging on swingset	2	57-63	60
50)	Playing on playground equipment	5	18-38	28
	Around a Picnic Table:			
51)	Sitting	8	42-69	53
52)	Standing	3	76-86	80
	Playing Tennis:			
53)	Metal racket	9	50-72	61
54)	Wood racket	4	63-70	67
	Around a Blanket:			
55)	Standing:	2	73-82	77
56)	Sitting - insulated	4	31-37	34
57)	Sitting - grounded	2	38-39	39
58)	Prone - insulated	3	2-17	8
59)	Prone - grounded	2	19-25	22
60)	Supine - insulated	2	11-22	17
61)	Supine - grounded	2	23-24	24
	Riding Bicycle:			
62)	Hands on grip	1	--	78
63)	Hands on metal handlebar	1	--	86
	Sitting In a Boat:			
64)	Aluminum boat - insulated	1	--	28
65)	Aluminum boat - grounded	1	--	30
66)	Rowing	1	--	33
	Fishing:			
67)	Seated - insulated	1	--	7
68)	Seated - grounded	1	--	12
69)	Standing, moving about	9	44-74	60
70)	Working in garden shrubbery	1	--	42
71)	Hiking with backpack	13	73-104	90
72)	Hunting with shotgun	3	57-61	58
73)	Cross country skiing	1	--	78
74)	Snowshoeing	1	--	86

Appendix B

SOURCES OF DATA

This appendix will review the major sources of statistical information that were found to be of value in the course of the study. It is not a reiteration of the section references, although there is certainly some overlap. It is written as a convenience to the reader who may not be familiar with the diverse nature of these sources and the even more diverse efforts required to track them down.

The sources are arranged in the order: general information, agriculture, recreation, electric field, and time budget. Each source is listed with a title, author, data of relevance (not necessarily the publication date), publisher and city, and a one paragraph description of the contents. The description focuses on the portions of the data source relevant to this report.

Some of the government sources are available free from the authoring agency, or at a nominal cost. All publications obtained through the Government Printing Office must be paid for. The first title, "Information, U.S.A." is an excellent starting point for tracking down information through the Federal Government.

Source No. 1

Title: Information, U.S.A.

Author: Lesko Matthew

Date: 1983

Publisher: Viking Press, New York (990 p.)

Description: This is a comprehensive guide to all departments and agencies of the Federal government. Each agency is broken down into its constituent divisions and offices, which are described in detail. Names, addresses, and phone numbers of information specialists are provided for each office. In addition, cross-references are provided by subject to track down the proper information source.

Source No. 2

Title: Statistical Abstract of the United States

Author: Bureau of the Census, Department of Commerce

Date: 1982-1983, 103rd ed., published annually. (1008p.)

Publisher: Government Printing Office, Washington, DC

Description: This is an annual summary of statistics on the social, political, and economic organization of the United States. It is designed to serve as a convenient volume for statistical reference and as a guide to other statistical publications and sources. Its 32 sections address almost every conceivable subject that can be described by statistical tables. The level of detail is not as fine as is sometimes needed, however, data sources are provided for further pursuit. In addition, references are given for statistical abstracts for each state.

Source No. 3

Title: Encyclopedia of Associations

Author: Gale Research Company

Date: 1984, 18th Ed.

Publisher: Gale Research Company

Description: A very comprehensive listing of organizations to be found in the United States, in every conceivable category. Each organization is described by name, address, phone number, membership, purpose and scope. This encyclopedia is a very valuable source for initializing an information search.

Source No. 4

Title: Bureau of Census Catalog

Author: Bureau of the Census, Department of Commerce

Date: 1980, Published annually, (124 p.)

Publisher: Government Printing Office, Washington, DC

Description: This is a catalog/bibliography/abstract of Census publications. The Bureau provides censuses not only of Population, but also of Agriculture, Geography, Construction and Housing, Manufacturing and Mineral Industries, Transportation, etc. Most Census data is available on machine-readable magnetic tape at nominal cost.

Source No. 5

Title: Handbook of Labor Statistics

Author: Bureau of Labor Statistics, U.S. Department of Labor

Date: 1980 (490 p.)

Publisher: Government Printing Office, Washington, DC

Description: This book makes available in one volume the major series produced by the Bureau of Labor Statistics. Of major interest to this report, statistics for the labor force are compiled by state, occupation, and age classification.

Source No. 6

Title: Pennsylvania Abstract

Author: Pennsylvania Bureau of Statistics, Research & Planning

Date: 1982, 24th Ed., Pub. Ann., (240 p.)

Publisher: Pennsylvania Department of Commerce, Harrisburg, PA

Description: State version of the U.S. Statistical Abstract, though not as comprehensive. Data sources are well documented. This publication is an example of data available on the state level.

Source No. 7

Title: Agricultural Statistics

Author: United States Department of Agriculture

Date: 1981, Published annually, (601 p.)

Publisher: Government Printing Office, Washington, DC

Description: Provides statistical tables on agricultural production, supplies, consumption, facilities, costs, and returns. In regard to this study, the book provides information on land use distribution, hired labor, labor hours for crops, and farm machinery. Most of the statistics are compiled by state and data sources are given, although most of the information is generated within the USDA.

Source No. 8

Title: Firm Enterprise Data System

Author: Economic Research Service, USDA

Date: 1982, Pub. ann., (1360 p.)

Publisher: Economic Research Service, USDA, Dept. of Agricultural Economics, Oklahoma State University, Stillwater, OK

Description: These "crop budgets" are based on annual surveys of approximately 10,000 farmers in 200 agricultural areas across the United States. The purpose of the FEDS is to compile economic information of crop production costs and returns. In doing this, the ERS collects data on how much time is spent on different crop operations, and what type of machinery is used. This information is used to calculate an hours per acre value for a specific crop in a specific area, broken down by month. The FEDS is the primary source of farm labor information in the country, however, it is limited mostly to grain crops. Fruit, nut, and vegetable crop budgets and other valuable information can usually be obtained from the agricultural economics department of the land grant university in the state of interest.

Source No. 9

Title: 1978 Census of Agriculture - United States

Author: U.S. Bureau of the Census

Date: 1981, Published every 5 years, (510 p.)

Publisher: Government Printing Office, Washington, DC

Description: A very complete, accurate, and detailed compilation of census data on American farming, including land use, farm size, hired labor, machinery irrigation, livestock, and all conceivable crop types. Statistics are compiled by region and state. The main drawback is that Census Bureau data categories are not consistent with corresponding USDA categories. For instance, there are nine Census regions and ten USDA regions with inconsistent groupings of states within the regions. Crop groupings are also inconsistent.

Source No. 10

Title: 1978 Census of Agriculture - California

Author: U.S. Bureau of the Census

Date: 1981, Published every 5 years, (474 p.)

Publisher: Government Printing Office, Washington, DC

Description: The state censuses are analogous to the national census, only with the data compiled by county rather than by state.

Source No. 11

Title: A Guidebook to California Agriculture

Author: University of California; Sheuring, A.F., Ed.

Date: 1983, (414 p.)

Publisher: University of California Press

Description: Although not replete with the hard statistics required in the exposure study, this book provides an excellent introduction to agriculture for outsiders who know little about it. The book was obtained because California agriculture is such a special case (with fruit and vegetable farming) that it deserved special attention.

Source No. 12

Title: Economic Indicators of the Farm Sector

Author: National Economics Division, USDA

Date: 1979, (90 p.)

Publisher: Government Printing Office, Washington, DC

Description: Provides historical data for many statistical categories, compiled by USDA region. Especially useful in this study were the estimates of total farm labor hours, total farm machinery, and land use.

Source No. 13

Title: Midwest Farm Planning Manual

Author: Agriculture Dept., Iowa State University

Date: 1979, Published about every 5 years, 4th Ed. (298 p.)

Publisher: Iowa State University Press, Ames, IA

Description: Designed for use by farmers in management of Corn Belt farms, and agriculture students. This publication is a good example of information on farming practices that can be found on a local level. Many land grant universities publish these for their own state (e.g. Penn State University, University of Illinois). The Midwest Farm Planning Manual has sections on crop information, labor requirements, machinery and equipment, and farm structures, which could be of value in exposure estimation.

Source No. 14

Title: Implement & Tractor Redbook

Author: "Implement & Tractor" Magazine

Date: 1982, Pub. ann. (448 p.)

Publisher: Intertec Publishing Corp., Overland Park, KS

Description: Provides detailed descriptions of hundreds of models of tractors, combines, and other pieces of farm equipment. It also provides the latest results of the Nebraska Tractor Test Program, an ongoing program of standardized tests and measurements of farm tractors conducted by the University of Nebraska .

Source No. 15

Title: The Hired Farm Working Force of 1979

Author: Pollack, Susan L., USDA/ETRS

Date: 1979, (60 p.)

Publisher: Government Printing Office, Washington, DC

Description: Contains statistics on the number and characteristics of hired farm workers in the United States.

Source No. 16

Title: Bibliography of Agricultural Bibliographies

Author: U.S. Department of Agriculture

Date: 1977, (344 p.)

Publisher: U. S. Department of Agriculture

Description: Contains approximately 2000 entries of bibliographies and other sources of compiled information, on a wide range of topics related to agriculture.

Source No. 17

Title: The Third Nationwide Outdoor Recreation Plan

Author: Heritage Conservation and Recreation Service, U.S. Department of Interior

Date: 1979, approx. 1600 p. in 7 volumes

Publisher: Government Printing Office, Washington, DC

Description: The Outdoor Recreation Plan provides a detailed compilation of the results of a nationwide survey on recreation. Its purpose was to assess the existing supply, demand, and opportunities associated with outdoor recreation in America. It is the basis for many of the recreation statistics citations used in this report.

Source No. 18

Title: Miller Light Report on American Attitudes Toward Sports

Author: Miller Brewing Company

Date: 1983, (238 p.)

Publisher: Miller Brewing Company, Milwaukee, WI

Description: A comprehensive survey of several different sports demographics, including, what constitutes a sport, popularity of different sports, participation rates, and spectator rates.

Source No. 19

Title: Sports Participation, 1982 (News Release only)

Author: A.C. Nielson Company

Date: 1982

Publisher: A. C. Nielson Company, Northbrook, IL

Description: The $7000 price tag of the full report could probably not be justified in an exposure study. The survey is evidently designed for business marketing and not scientific research. A free news release was obtained, however, which summarizes the number of participants in each sport and the growth of the sport over the last 10 years.

Source No. 20

Title: New American Guide to Athletics, Sports, and Recreation

Author: C. Norback and P. Norback

Date: 1979

Publisher: New American Library, New York

Description: A "how-to" guide for recreation. Gives recommendations on participation rates, durations, etc.

Source No. 21

Title: Recreation, Park, and Open Space Standards and Guidelines

Author: National Recreation & Park Association

Date: 1983, (136 p.)

Publisher: National Recreation & Park Association, Alexandria, VA

Description: Lists recommended dimensions and space standards for many recreational activities. For example, the proper dimensions of tennis courts are listed, along with the recommendation of one court per 2000 people, with a service radius of 1/4 to 1/2 mile.

Source No. 22

Title: National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, 1980

Author: Fish and Wildlife Service, U.S. Dept. of Interior

Date: 1982, (156 p.)

Publisher: Government Printing Office, Washington, DC

Description: Provides detailed participation statistics on hunting (big game, small game, migratory bird, and other), fishing (freshwater, Great Lakes, and saltwater), and non-consumptive wildlife use (observing, photographing, and feeding wildlife). This was a major source of participation data used in this report.

Source No. 23

Title: Motorcycle Statistical Annual

Author: Motorcycle Industry Council

Date: 1983, Pub. ann. (46 p.)

Publisher: Motorcycle Industry Council, Costa Mesa, CA

Description: This is a motorcycle trade report that provides statistics on motorcycle sales, use participations, on and off-road use, and per capita ownership. Many of the tables are compiled by state. This publication is an example of the type published by many recreational interest groups.

Source No. 24

Title: Transmission Line Reference Book/345 kV and Above

Author: General Electric Company, Project UHV

Date: 1982, 2nd Ed., (626 p.)

Publisher: Electric Power Research Institute

Description: This is a comprehensive handbook for the design of high voltage transmission systems. Two particular chapters are very closely related to this study: "Chapter 3 - Electrical Characteristics of EHV-UHV Conductor Configurations and Circuits" provides a compendium of transmission line designs, and "Chapter 8 - Field Effects of Overhead Transmission Lines and Stations" provides discussions on electric field induction in people, biological effects, and shielding. The "Redbook" provided much of the technical basis for this report.

Source No. 25

Title: Time Use in Economics and Social Accounts

Author: F. Thomas Juster, et al.

Date: 1977

Publisher: Institute for Social Research, University of Michigan, Ann Arbor, MI

Description: Documentation for a large data base containing the results of a survey of 2400 adults, based on a national probability sample. The data represent a compilation of time diaries kept by the participants. Time is broken down into the minutes per week spent at approximately 100 categories of time use, e.g., watching TV, indoor cleaning, hobbies, etc.

Appendix C

SENSITIVITY ANALYSIS

A vital step in the evaluation of any model is determining the sensitivity to change in the results as a function of changes in the input parameters and data. This "sensitivity evaluation" was done for the Activity Systems Model (implemented into a computer program) by defining a base case consisting of a typical 500 kV transmission line positioned at the center of an arbitrary square of land, 2000 feet on a side, diagrammed in Figure C.1. Once the base case results were established, the influence of each input parameter was tested by making several computer runs while changing only that particular parameter over a range of values bounded by practical extremes.

The parameters that were evaluated may be classified into three categories: intrinsic to the model, geography related, and transmission line related. The following list should best illuminate the definitions of these three categories:

<u>Intrinsic</u> (Determined by the user):

- Grid resolution
- Conductor Height increment
- Lateral distance increment

<u>Geography - Related</u>:

- Size and Location of the Study Area
- Hours/acre spent by the subject in each study area

<u>Transmission Line Related</u>:

- Sag/Temperature (Minimum Ground Clearance)
- Phase Spacing
- Conductor Sizes
- Voltage

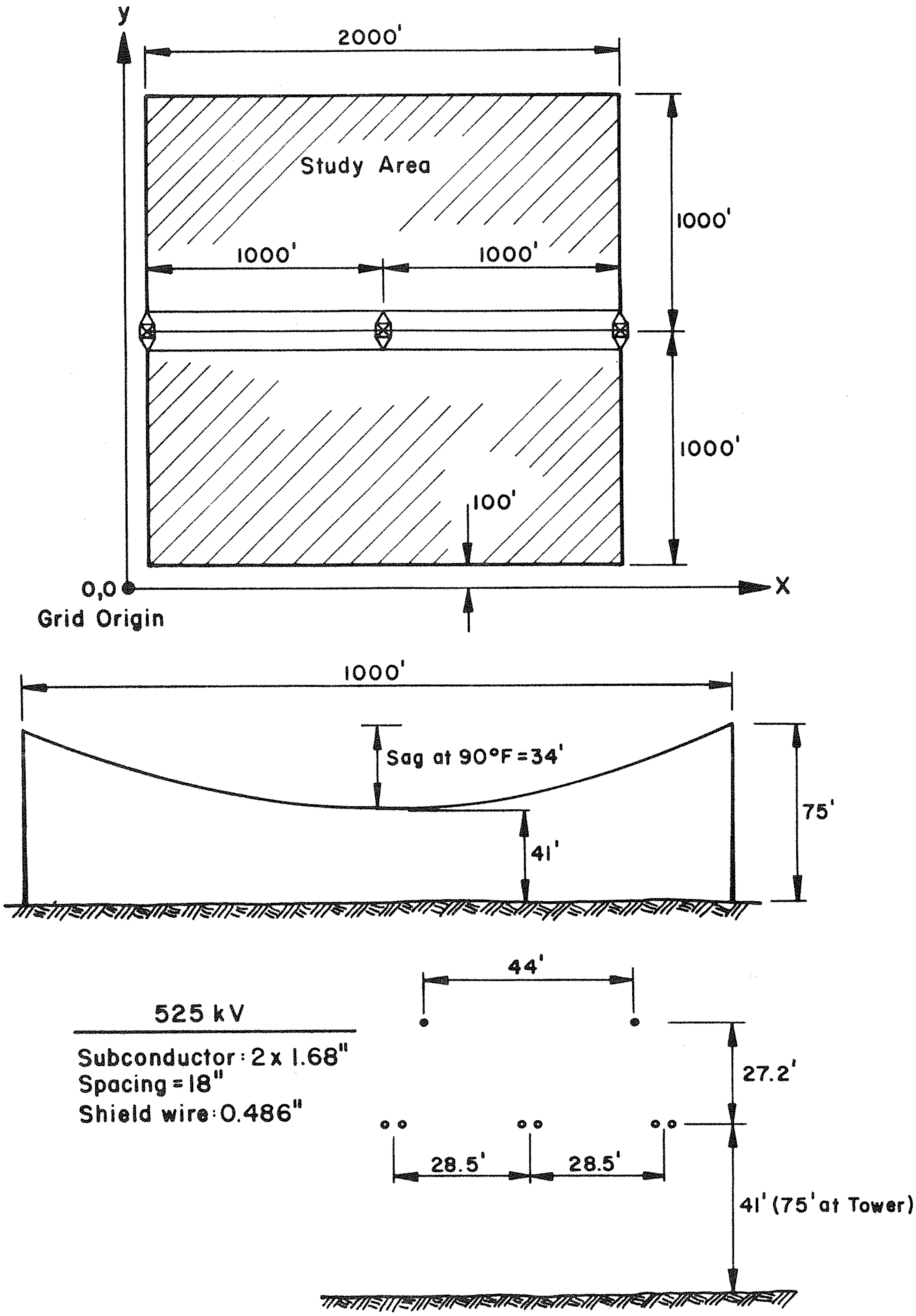


Figure C.1. Geometry and Design Details for Base Case Sensitivity Analysis

The results of the sensitivity analyses on the above-listed parameters may be classified as linear, smoothly curved, scattered but convergent, or scattered with no apparent pattern. In the following discussion, the results and appropriate statistics of each of the parameters will be given.

GRID RESOLUTION

This parameter was analyzed first because it was considered important to find a resolution fine enough to yield accurate results in subsequent tests but course enough to provide fast computation times, in view of the large number of tests that lay ahead (ultimately more than 200 computer runs). Figure C.2 (figures start at the end of the text) shows a plot of normalized exposure vs. grid resolution (in feet). It can be seen that, as the resolution becomes finer, the points converge to almost a single value, a close approximation to the true integral of exposure. Computation time, however, increases approximately in proportion to the inverse square of the resolution, so that a computer run at 10 feet resolution would take approximately 25 times as long as a run at 50 foot resolution. For the remainder of the sensitivity study, the 50 foot resolution was chosen for the base case.

CONDUCTOR HEIGHT AND LATERAL PROFILE INCREMENT

The conductor height increment affects the resolution of the method used to determine the electric field by the computer. A test of increment values between 1 and 20 feet showed that this parameter was one of the least sensitive analyzed, as can be seen in Figure C.3. Even at the extreme increment value of 20 feet, only a 2% error was encountered.

The lateral profile increment also affects the resolution of the method used to compute the electric field. The results of the analysis of this parameter (Figure C.4) are quite different from the conductor height increment. Once again the points were scattered for the larger increments but convergent to a definite value that corresponded with the base case result.

Part of the reason for the scattering has to do with how well the lateral profile points coincide. If the points coincide exactly, then there is no need for interpolation in the horizontal direction in the look-up table. This is the case in the sensitivity analysis where, with a grid resolution of 50 feet, lateral profile increments of 5, 10, 25, and 50 feet all provided identical results. In choosing increments not divisible into 50, the results are less accurate because of the need for more interpolation.

SIZE AND LOCATION OF THE STUDY AREA

The effect of an error in the input of study area geography depends, of course, on the electric field in the area where the error was made. Therefore, an error far away from the line should not be as significant as an error near the line. This hypothesis was tested by separately adding 5% to the study area the vertical and horizontal directions. In the vertical case, a 50 foot wide strip of land was added to the north and south ends of the study area, parallel to the transmission line. The resulting exposure estimate was 0.03% higher than the base case result. When 50 foot bands were added to the east and west ends, perpendicular to the transmission line, the result was 3.5% higher.

HOURS PER ACRE

Although one of the important factors in the activity systems model, a sensitivity analysis on the hours per acre parameter is a trivial case. By definition, the amount of exposure at a given grid point is directly proportional to the hours per acre represented at that point.

TEMPERATURE (SAG)

The effect of conductor temperature was evaluated by varying the conductor sag to correspond to conductor temperatures ranging from 30 to 120 degrees Fahrenheit, incremented by 10 degrees. This is assumed to encompass the range of most farming activities. As shown in Figure C.5, the results are quite linear and indicate that a difference of 10 degrees in conductor temperature will yield a difference of about 1% in the estimate of exposure.

PHASE SPACING

Phase spacing was varied from 25 to 35 feet, a range of values found in a published summary of typical 500 kV line designs (1). Figure C.6 shows a very linear relationship between exposure and phase spacing. A one foot increase in spacing results in a 3.5% difference in exposure.

SUBCONDUCTOR NUMBER AND SIZE

The effect of subconductor specifications was tested by evaluating exposure for bundles of 2 (base case), 3, and 4 subconductors of the following four sizes: 1.00, 1.30, 1.68 (base case), and 2.00 inches. These results are summarized in Figure C.7 and show that exposure is linear with subconductor diameter and increases with the number in the bundle. A one-tenth of an inch increase will produce an increase in exposure of approximately 0.4 to 0.7%. The increase in exposure over the base case due to the increase in the number of subconductors was 11% for 3 and 22% for 4.

VOLTAGE

The variation of voltage in this sensitivity analysis is a trivial case in that the electric field, and thus exposure, is exactly proportional to the line voltage. Slight shifts in the voltage will, however, cause slight changes in the configuration of the electric field map. This results in a small amount of variation in the distribution of exposure within different electric field ranges, shown in Figure C.8.

VOLTAGE CLASS

A sensitivity analysis was performed using the same line design parameters used in the voltage class analysis described in Section 7 (see Table 7-7). The difference here was that the analysis was conducted using the base case geography, a much more controlled environment. The results are presented graphically in Figures C.9 through C.13, not in terms of the actual units of exposure, but in terms of the percent of total exposure contributed by successive 50 foot bands away from the centerline. In addition, results within each band are broken down by electric field ranges, the standard windows described in Section 2. Since the activity factor was set at 100%, the units on these ranges are in kV/m of unperturbed electric field.

The Figures show that 70 to 90% of exposure on any class of line occurs within 100 feet of the centerline. If one applies the typical right-of-way widths from Table 10-3, it can be approximated that the exposure within the right-of-way will be about 70% in each case.

Figure C.14 summarizes and compares the actual exposures calculated for the five cases, with an insert showing the peak electric fields encountered. Figure C.15 combines the peak field data from Figure C.14 with the voltage class line miles from Section 10 (Table 10-3). This graph essentially shows the probability that a person who finds himself on a right-of-way could be on the same right-of-way where the indicated peak electric field could be found.

DISCUSSION

This sensitivity analysis brought out the computational strengths and weaknesses of the Activity Systems Model, as implemented on the computer. Normally, the design characteristics of the transmission line would be known, so that the line-related parameters would be reasonably accurate, and little error should occur because of these. Errors, due to the model, should be minimal with the geography-related features, although it should be noted that farm labor, in hours per acre, is a "soft" number. Overall, the results show that the model is stable but should be used with the finest resolution possible for the greatest accuracy.

REFERENCES

1. Transmission Line Reference Book/345 kV and Above, 1982, Electric Power Presearch Institute, Palo Alto, CA.

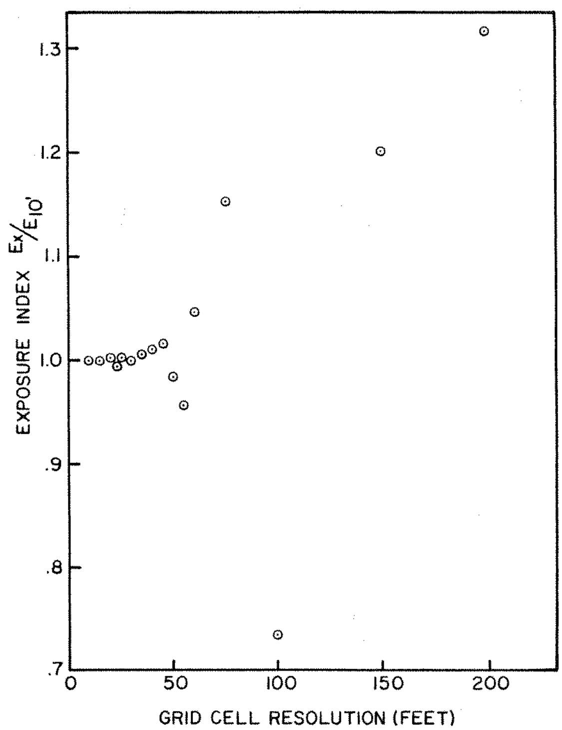


Figure C.2. Sensitivity Due to Grid Cell Resolution

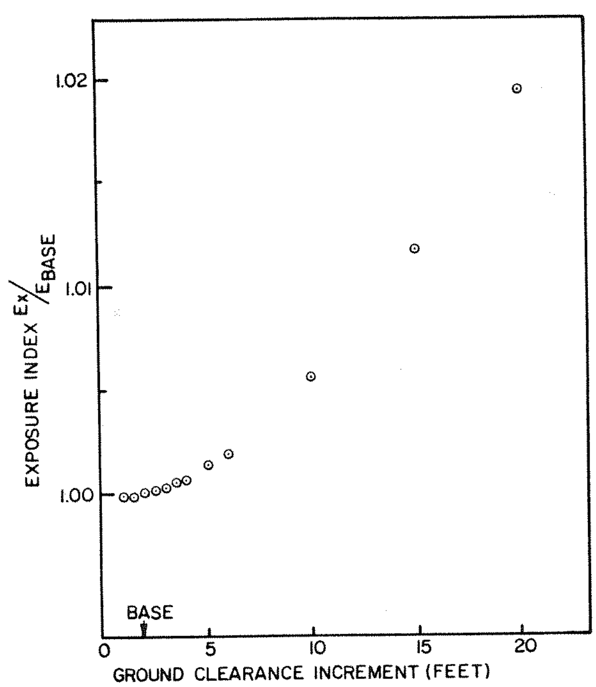


Figure C.3. Sensitivity Due to Ground Clearance Increment

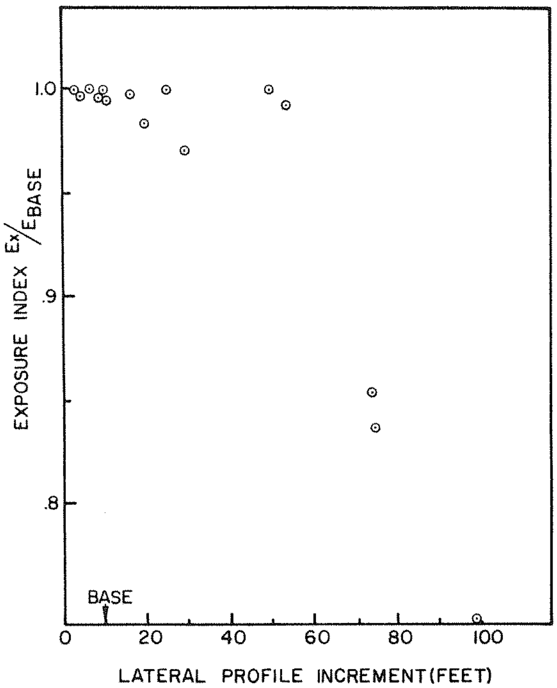


Figure C.4. Sensitivity Due to Lateral Profile Increment

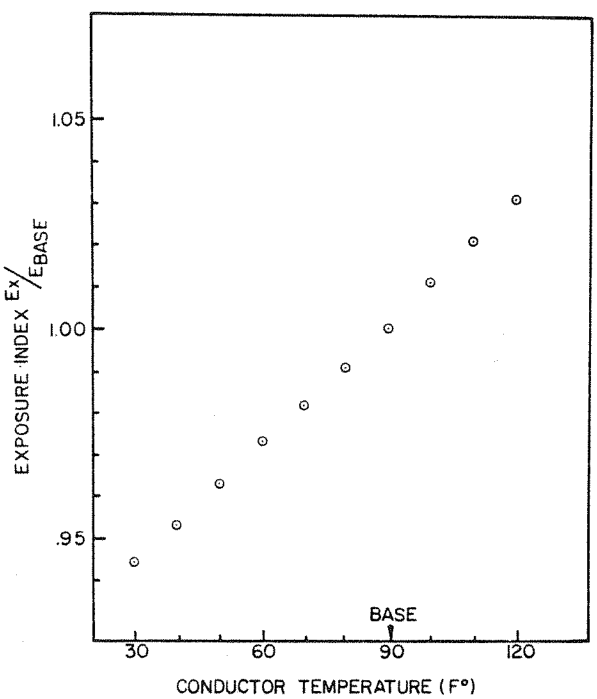


Figure C.5. Sensitivity Due to Conductor Temperature

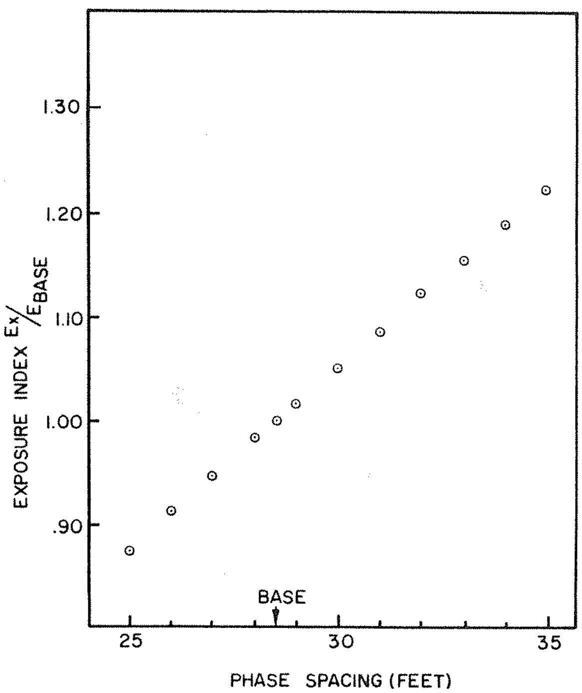


Figure C.6. Sensitivity Due to Phase Spacing

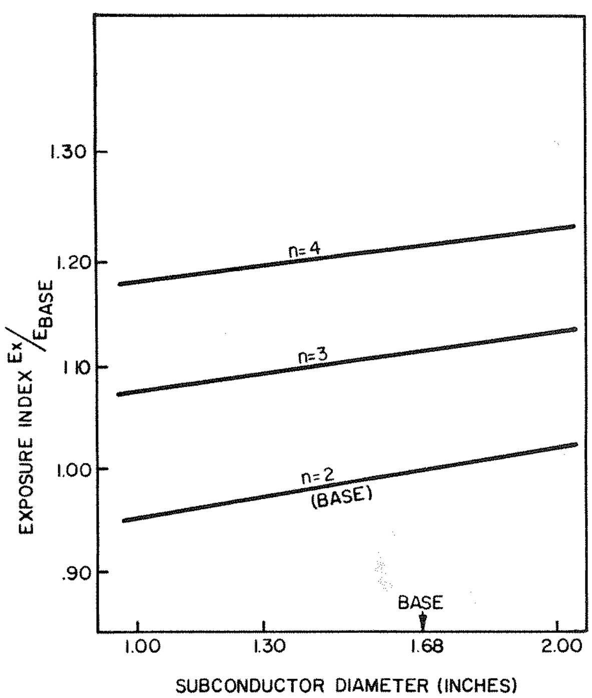
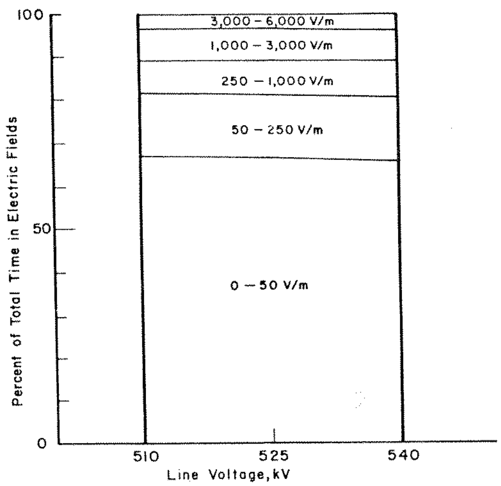


Figure C.7. Sensitivity Due to Subconductor Number and Size



Bin, V/m	510 kV	525 kV	540 kV
0-50	66.4	66.1	65.7
50-250	14.5	14.7	15.0
250-1,000	8.0	8.0	8.2
1,000-3,000	7.6	7.5	7.1
3,000-6,000	3.5	3.7	4.0
	100 %	100%	100%
E, max	5.67 kV/m	5.84 kV/m	6.00 kV/m

Figure C.8. Sensitivity Due to Voltage, within Bins

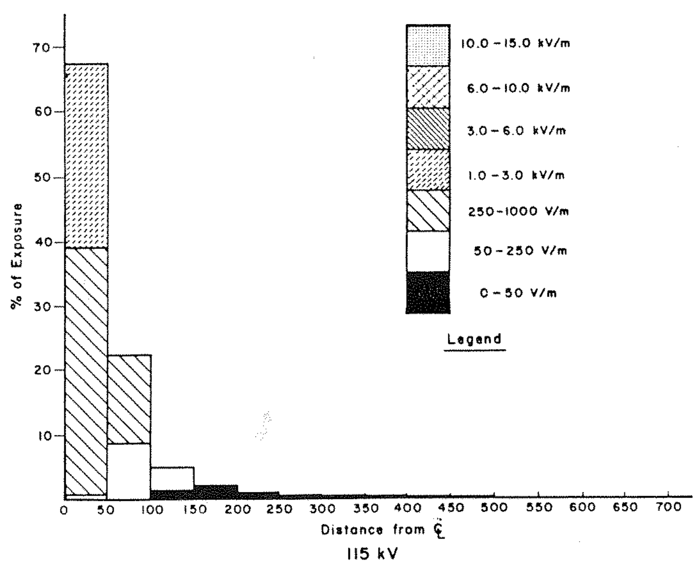


Figure C.9. Exposure Percent as a Function of Distance - 115 kV Case

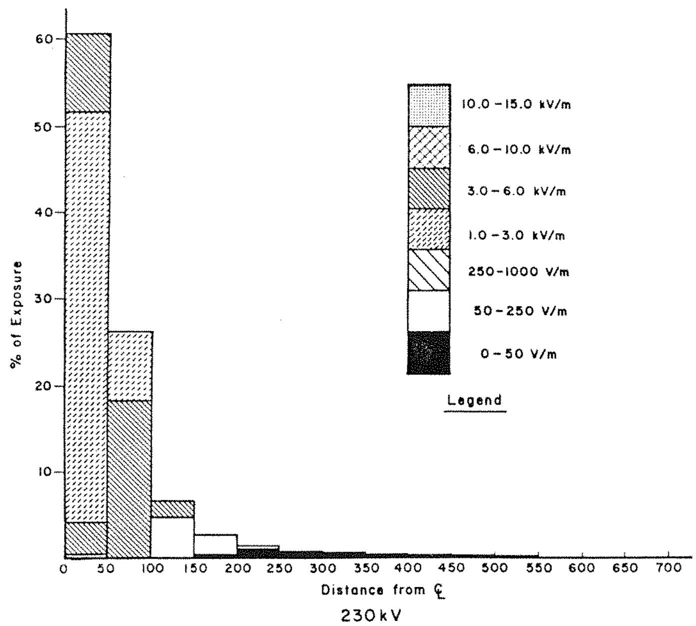


Figure C.10. Exposure Percent as a Function of Distance - 230 kV Case

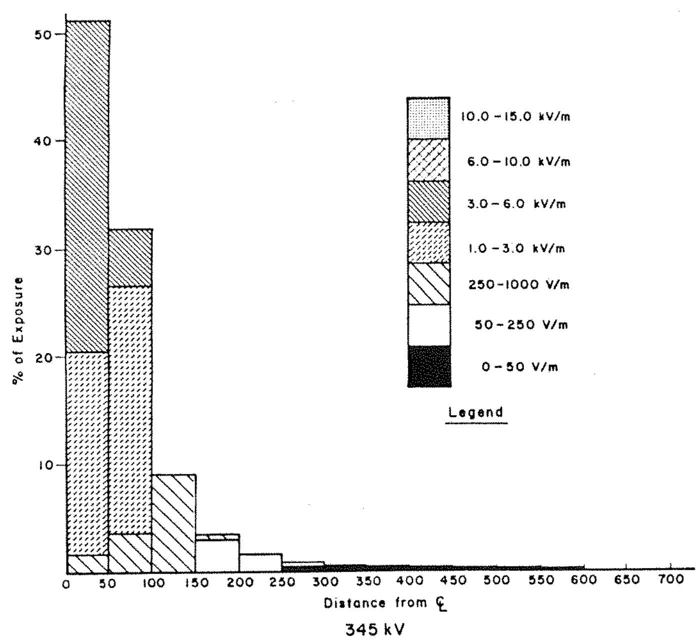


Figure C.11. Exposure Percent as a Function of Distance - 345 kV Case

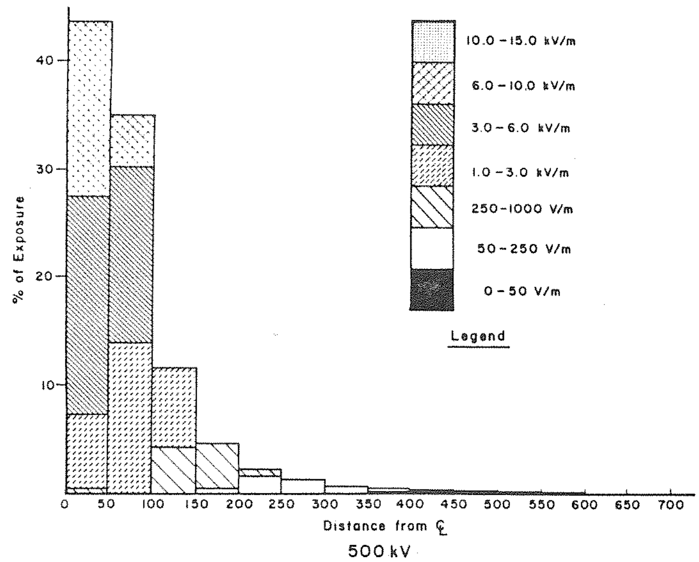


Figure C.12. Exposure Percent as a Function of Distance - 500 kV Case

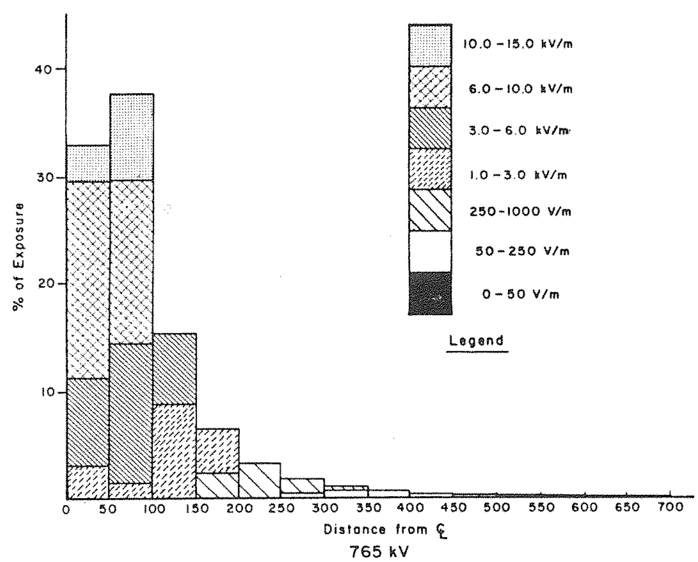


Figure C.13. Exposure Percent as a Function of Distance - 765 kV Case

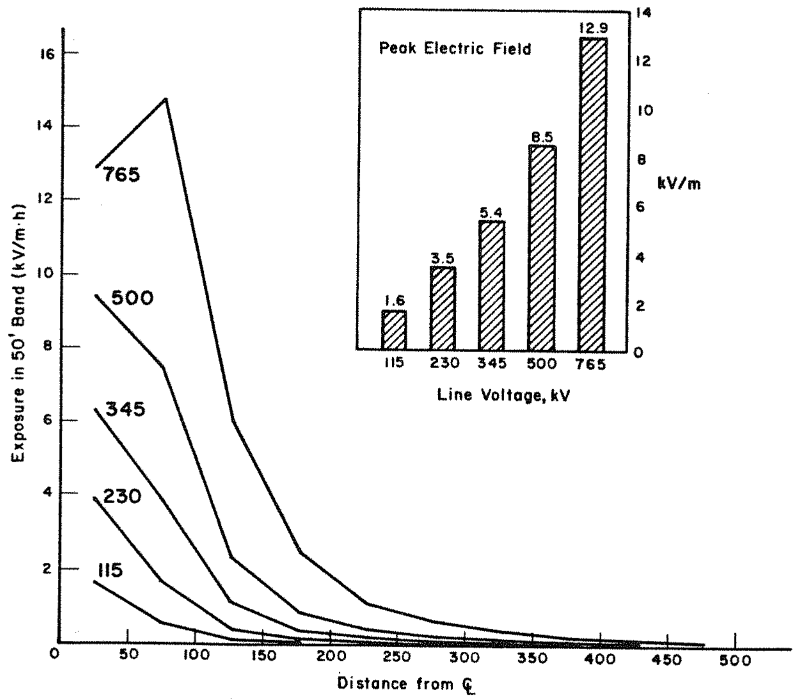


Figure C.14. Summary of Exposure Results by Voltage Class

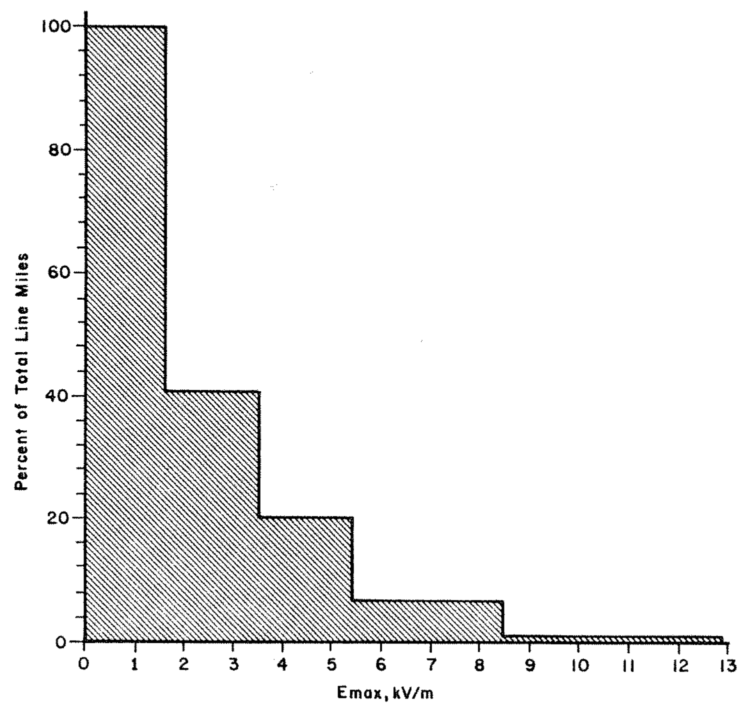


Figure C.15. Frequency of Maximum Electric Fields for HV-EHV Transmission Lines

Appendix D

VARIABILITY ANALYSIS

The Activity Systems Model has been used in this report to produce estimates of human exposure to 60 Hz electric fields for two classes of activities: farming and recreation. These estimates are the result of combining methods of calculation, field and laboratory data, surveys of activities, and few assumptions. The computer model used to compute the results reported in Section 7 treats all information as if it were deterministic rather than stochastic, and makes the assumption that all errors of calculation and data cancel out. In other words, the computer model is based on the assumption that random errors and system random variables can be represented by their expected values. This section of the report evaluates this assumption.

Each component of the model is examined, and where appropriate, random variables are introduced to represent the variability of the real world. Then Monte Carlo simulation is used to evaluate the combined effect of treating all parameters and data values as stochastic variables. In this way, the overall accuracy of the method and model is assessed.

SOURCES OF VARIABILITY

Table D-1 displays the categories of variability used in the Monte Carlo analysis. Variables can be characterized as either deterministic or stochastic. They can also be distinguished by their role in the analysis: some represent system variables, while others represent errors of evaluation. Cross classifying these two dichotomies yields the cells in Table D-1.

Table D-1

SOURCES OF VARIABLILITY

	DETERMINISTIC	STOCHASTIC
System Variables	• Conversion Factors • Unperturbed Field Values	• Activity Factors • Voltage Fluctuations • Sag Variations • Vehicle Capacity • Repetitions Per Year
Evaluation Errors		• Terrain Calc Errors • Vest Measurement Errors • Grid Definition

System Variables

First, a few system variables were treated deterministically. An example is the conversion factor used by the USDA to convert tractor characteristics to human labor time. Also, the unperturbed electric field was treated as a deterministic vector of values. It should be noted, however, that other factors which affect these electric field values were treated stochastically, and that electric field values range from a few volts per meter up to the peak field of several kilovolts per meter.

Stochastic systems variables included the activity factors, line voltages, sag variations, farm vehicle work capacities, and crop operations per year. Data from the field research on activity factors show that three ranges of values describe variability of activity factors. The first range applies to walking in a field (0.8 - 0.9), the second to driving an open tractor (0.3 - 0.5), and the third to driving an enclosed tractor or other vehicle (0.01 - 0.05). A uniformly distributed random variable was constructed for each activity factor condition. These conditions were weighted by a conservative estimate supplied by USDA of the percent of time a farmer spends walking (5%), in an open vehicle (50%), and in a closed vehicle (45%). Simulated activity factors were used to convert unperturbed electric field values into equivalent electric field values in the Monte Carlo analysis.

Voltage fluctuations were represented stochastically using an empirically derived curve that describes the percent of time a line is operated at some multiple of its nominal voltage. The data used in constructing the curve came from a survey conducted during this study of utility company operating practices (based on annual records of line voltage fluctuations).

The sag of a transmission line varies as a function of both operating loads and ambient temperature conditions. The sensitivity study of Appendix C systematically varied these temperatures and found that exposure changed over a range of plus or minus 3%. Therefore, variations in the sag of the transmission line were represented by a uniform density function that adjusted unperturbed field values by plus or minus 3%.

Another stochastic source of variation concerns the capacities of farm vehicles. The USDA uses a formula to estimate these capacities as a function of vehicle speed, width, and field efficiency. Field efficiency refers to the percent of time that the machinery is actually operating once it is in the field. Down time includes breakdowns, adjustments, field repairs, etc. The USDA formula yields estimates of acres per hour for each vehicle type. In the Monte Carlo analysis, speed, width and efficiency were treated as independent uniform random variables with ranges determined by published data on farm vehicles. It is realized that these variables are probably not independent. However, the independence assumption is conservative, and this treatment of vehicle capacities will not, in all likelihood, underestimate variation in exposure.

The last system variable included in the Monte Carlo analysis is the number of crop operations per year; i.e., plowing, discing, planting, harvesting, etc. Again, the range of published USDA values for different crop types was used to create a uniform random variable for operations in the Monte Carlo model.

Evaluation Errors

A second source of variability concerns errors of evaluation and measurement. The electric field cannot be calculated perfectly. The exposure measurement system of the vest does not perform perfectly. When these errors of evaluation are combined and treated stochastically, it is possible to estimate their overall effect on estimating exposure.

In calculating the electric field, it is assumed that the transmission line traverses a flat plane. Of course, many real transmission lines cross territory that is not flat. The method of electric field calculation used in the Activity Systems Model was compared with an internal General Electric 3-D computer model, actual measurements during site visits, and with published results from a TVA study (1). It was found that electric field values were accurate within plus or minus 10% over most terrain conditions. Thus, the Monte Carlo model included a uniformly distributed error factor with this range.

The second evaluation error concerns the resolution of the grid system used to calculate field values in the exposure model. In making exposure estimates, a grid is used to define a set of points over a farm or recreation site. Electric field values and times are computed for each grid point. Obviously, the courser the grid, the greater the inaccuracy in both the electric field values and estimates of time. The sensitivity study of Appendix C systematically varied grid size from 10 to 50 feet and determined that exposure varied only plus or minus 3%. A uniform random error factor of this range was included in the Monte Carlo analysis.

Finally, laboratory measurements determined that the vest measurement system was subject to three types of measurement error: calibration errors - 5%, integrator errors - 1.5%, and timing errors - 1%. Again, uniform random error factors were created to fluctuate activity factor values by these amounts.

THE MONTE CARLO SIMULATION MODEL: FARM CASE

At this point, the structure of the Monte Carlo simulation model for the farm case is briefly presented. First, the exposure is calculated at each of N grid points. Exposure at a point is the product of the equivalent field at that point and the time spent at the point. Total exposure is simply the sum of the exposure values at each grid point.

Time spent at a grid point is a function of the number of crop operations through a field, vehicle work capacity, and grid definition errors. The equivalent electric field is a function of the unperturbed field, the voltage fluctuation factor, the terrain calculation error, the sag variation factor, and the activity factor - adjusted for measurement errors.

The Monte Carlo analysis used the same base case data that were reported in the sensitivity study: a hypothetical square farm, 2000 feet on side, with a 500 KV line through the middle. A single run estimated the time, equivalent electric field, and exposure for each of 1681 grid points. Total exposure was also computed. For each run, tabulations were made of:

- the cumulative percent of time spent in equivalent electric fields of a certain strength or less;
- the cumulative percent of exposure received in equivalent electric fields of a certain strength or less.

Each analysis consisted of 100 runs, and cumulative distribution curves were plotted for each run. Thus the importance of sources of variation can be shown by plots of 100 repetitions of the model. These plots clearly show the envelope of uncertainty that surrounds estimation of exposure to electric fields.

Results

Figures D.1 through D.15 show the results of the Monte Carlo simulation analyses. Each figure is a plot of cumulative per cent of time (the upper curve) and/or cumulative per cent of exposure (the lower curve) associated with an equivalent electric field value. The scale of the electric field axis is logarithmic.

The interpretation of each time curve is: Y percent of a person's time is spent in equivalent electric fields of strength X or less. For example in Figure D.1, 50% of a person's time is spent in electric fields of about 10 volts per meter or less. The interpretation for the exposure curve parallels the time curve: Y percent of the exposure a person receives occurs in equivalent fields of X volts per meter or less. Again, in Figure D.1 we see that 50% of a person's exposure is received in equivalent fields of approximately 440 volts per meter or less.

Figure D.1 presents cumulative time and exposure curves with all the stochastic parameters of the Monte Carlo model turned off. Thus these curves present the expected value curves of the simulation.

Figure D.2 is the cumulative time curve with all stochastic parameters included in the model. Over the 100 runs, total simulated time spent in electric fields had a mean value of 377.6 hours with a standard deviation of 4.7 hours. The maximum and minimum were 366.9 and 387.4 hours. These results indicate that the envelope of uncertainty surrounding time of exposure due to sources of variation is fairly tight. The range, maximum less minimum, is only about 5% of the total exposure time.

Figure D.3 is a histogram of the exposure times for the 100 farm case runs. The shape of the distribution does not suggest that the tails would be greatly extended if the number of runs were expanded.

Figure D.4 is the cumulative exposure curve with all stochastic parameters included in the model. Total exposure, over the 100 runs, had a mean value of 34.7 kV/m*h and a standard deviation of 2.4 kV/m*h. The minimum and maximum were 28.5 and 41.0. Figure D.5 is a histogram of the 100 total exposure values. Again, we see that the envelope of uncertainty is reasonably tight. The range of values over the 100 runs is about 36% of the mean value. It seems reasonable to conclude that estimates of exposure are well within an order of magnitude in accuracy.

Figures D.6 through D.11 present further results from the simulation of sources of variation. The relative importance of evaluation errors is contrasted with the importance of system variations. The Monte Carlo model was run under the assumption that no errors of calculation or measurement affect exposure estimation. Thus uncertainty is generated solely from system variable sources. These plots are shown in Figures D.6 and D.7. Then the assumptions were reversed; the system variables random variables were turned off, leaving only evaluation errors. These results are shown in Figures D.8 and D.9. Random system variables seem to influence uncertainty more than evaluation errors, although both make an important contribution of the total uncertainty envelope.

Finally, the base case farm data were used to examine the importance of knowing the activity factors. Figures D.10 and D.11 present the curves for simulation runs with the activity factor parameters set to 100%. Exposure times are not affected. However, estimates of exposure are increased by a multiple of 4.7. This increase is sufficient to shift the entire uncertainty envelope of Figure D.11 out of the envelope of the basic run with all stochastic parameters included. Thus including knowledge of activity factors increases our ability to estimate human exposure to electric fields.

THE MONTE CARLO SIMULATION MODEL: JOGGING CASE

A Monte Carlo model was also developed to analyze a simple recreational activity case, that of a jogger running along a path a) at the edge of the right of way and b) directly under the outside phase of a transmission line. The line used in the calculations was the same 500 kV line of the farm case. Also unchanged were the line voltage fluctuation, sag, terrain, and vest measurement parameters. The jogging distance was fixed at 2 miles, and grid points were set every 50 feet for the edge-of-the-right-of-way runs, and every 20 feet for the under-the-outside-phase runs. Repetitions per year was represented by a uniform random variable ranging from 40 to 100 times per year. Jogging speeds were represented by a uniform random variable that ranged from 4 to 8 miles per hour.

The activity factors for these analyses were generated randomly with the following probabilities: activity factor of 75% with probability of 0.3, 85% with probability of 0.5, 95% with probability of 0.15, and 100% with probability of 0.05. Again, the results are based on 100 two mile simulated runs.

Results for Jogging Case

The same time by equivalent field and exposure by equivalent field graphs are used to present the results of the jogging simulations. Figure D.12 displays the cumulative percent of time for jogging at the edge of the right of way with all parameters treated as random variables. Figure D.13 displays the corresponding run for cumulative percent exposure. The first result is obvious; the jogging case exhibits much less variation than the farm case. The envelopes are much narrower and the time curve nearly matches the path of the exposure curve. This result reflects the much narrower range of activity factors, and the influence of remaining in electric fields that do not vary over three orders of magnitude. The estimate of total exposure time is 24.4 hours with a standard deviation of 0.5 hours, and a range of 23.0 to 25.8 hours. The corresponding values for total annual exposure are a mean of 28.3 kV/m*h, 0.7 for a standard deviation, and a range of 26.6 of 30.0.

Figures D.14 and D.15 display the curves for jogging year-round, directly under the outside phase. The total exposure times were almost identical to the previous case; mean of 24.3 hours, standard deviation of 0.3, and range of 23.6 to 24.9 hours. Total annual exposures are higher, reflecting the higher electric fields; mean of 86.4 kV/m*h, standard deviation of 1.3, and range of 83.4 to 89.5.

These numbers suggest that estimates of cumulative exposure and time along or in the right of way can be made quite accurately. The range of total exposure values over 100 Monte Carlo runs is only 5% to 7% of the mean value. The standard 95% confidence interval would be even tighter.

DISCUSSION

The variability analysis, in combination with the sensitivity analysis in Appendix C, show the Activity System Model to be quite stable in a variety of situations. "Soft" numbers input to the model tend to cancel out, but the user should be aware that "soft" input could mean "soft" output.

REFERENCES

1. TVA's 500 kV Electric and Magnetic Fields Measurements and Analyses, Draft Final Report, September, 1983, Tennessee Valley Authority, Chattanooga, TN.

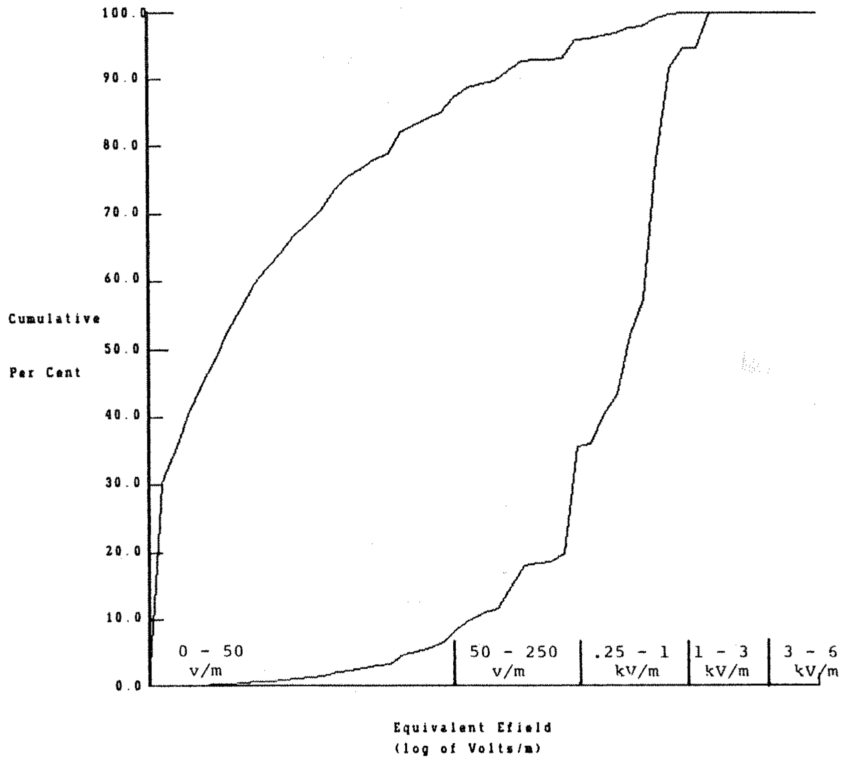


Figure D.1. Time and Exposure - No Variation

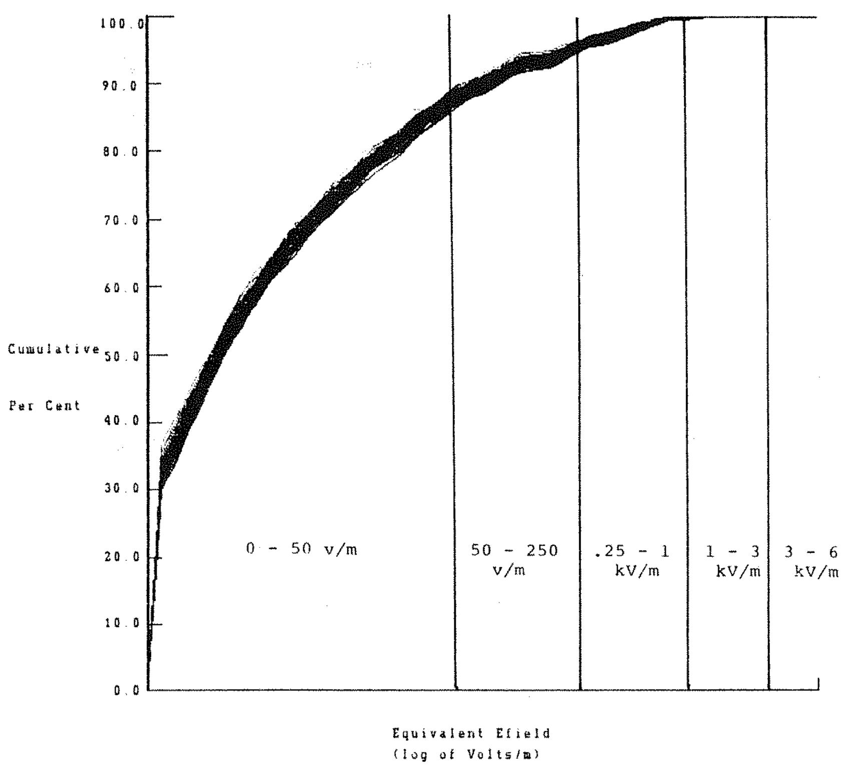


Figure D.2. Time Spent in Equivalent Electric Fields - Full Variation

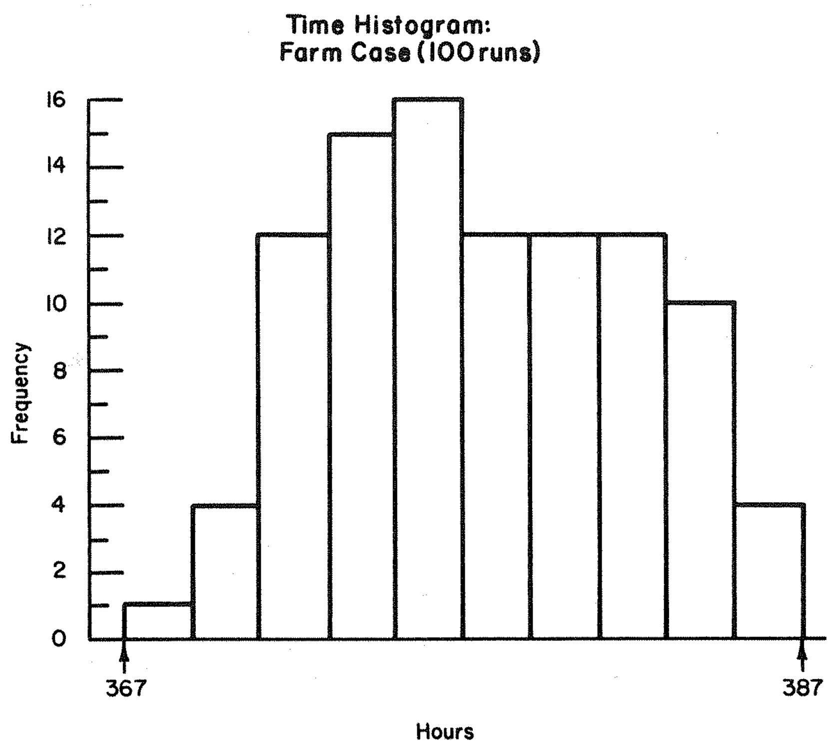


Figure D.3. Time Histogram - Farm Case (100 Runs)

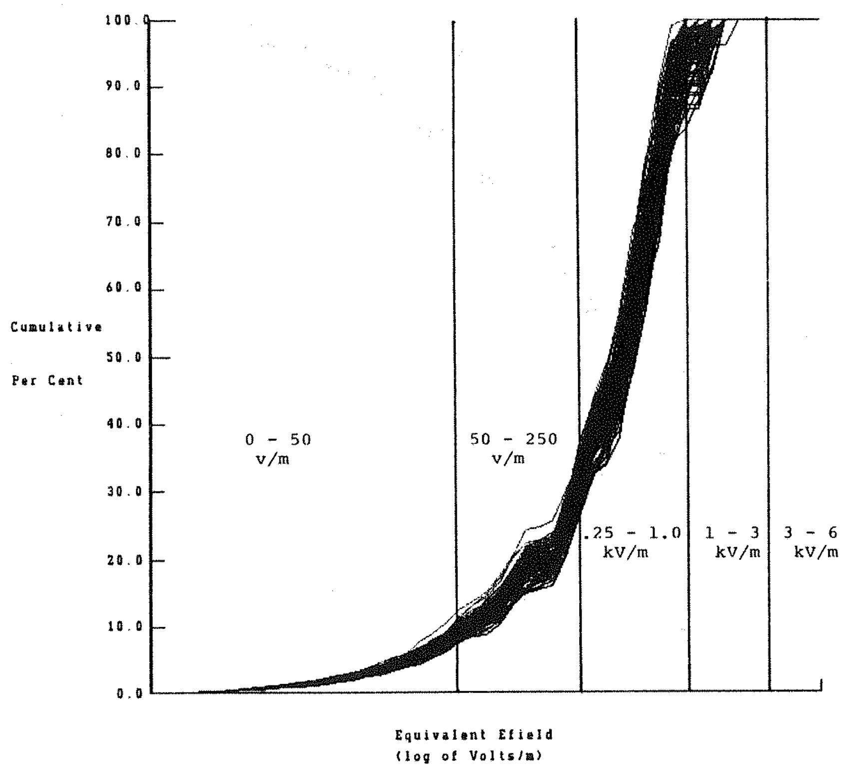


Figure D.4. Exposure - Full Variation

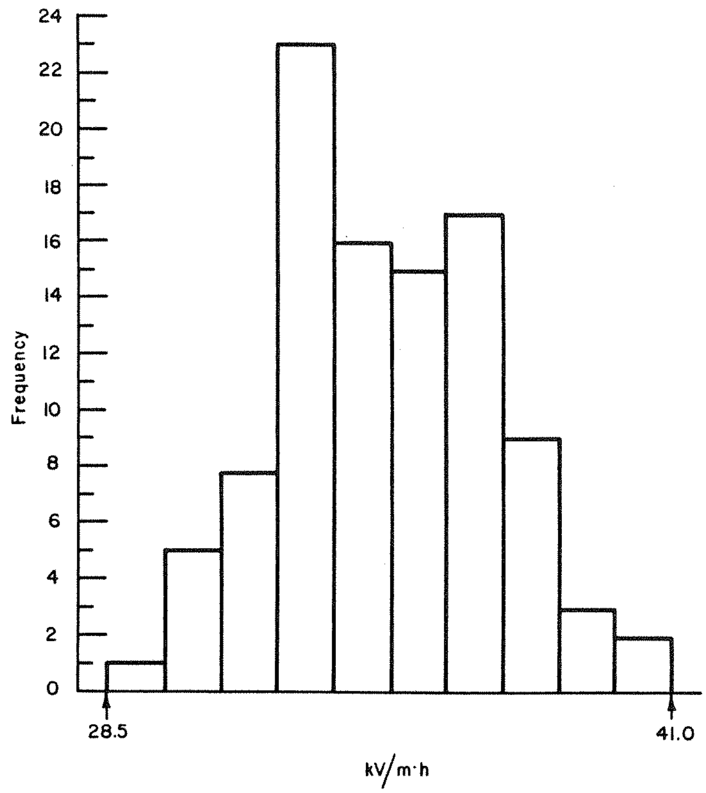


Figure D.5. Exposure Histogram - Farm Case (100 Runs)

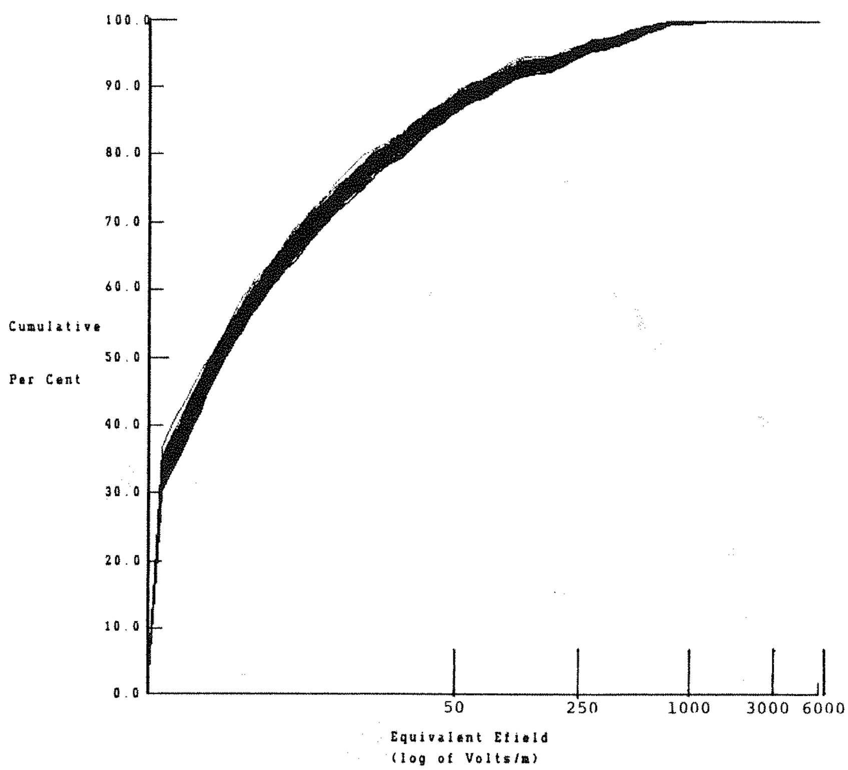


Figure D.6. Time in Efields - No Evaluation Variation

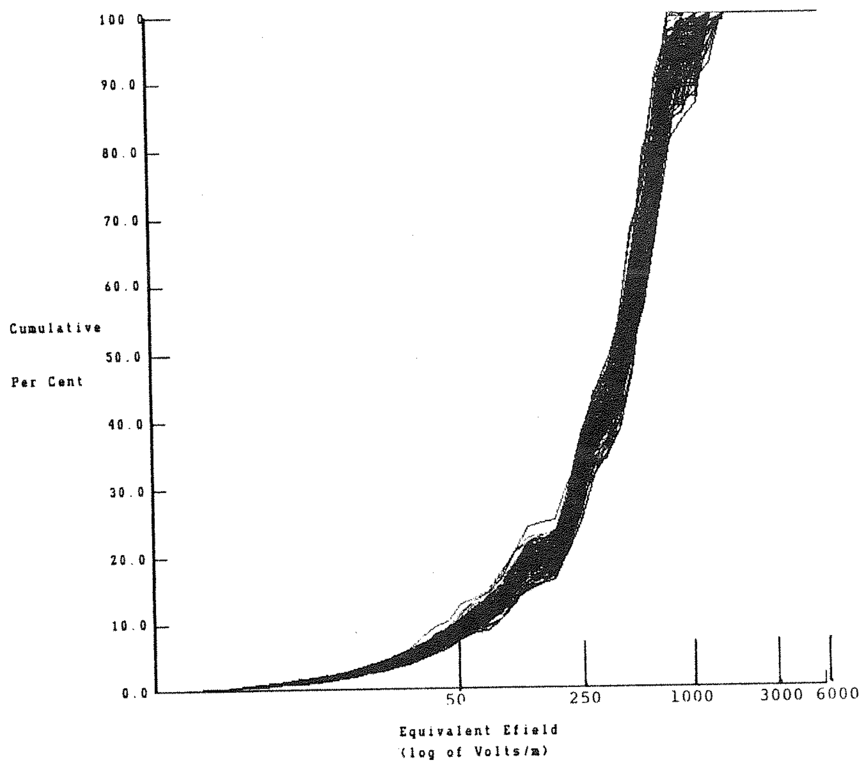


Figure D.7. Exposure - No Evaluation Variation

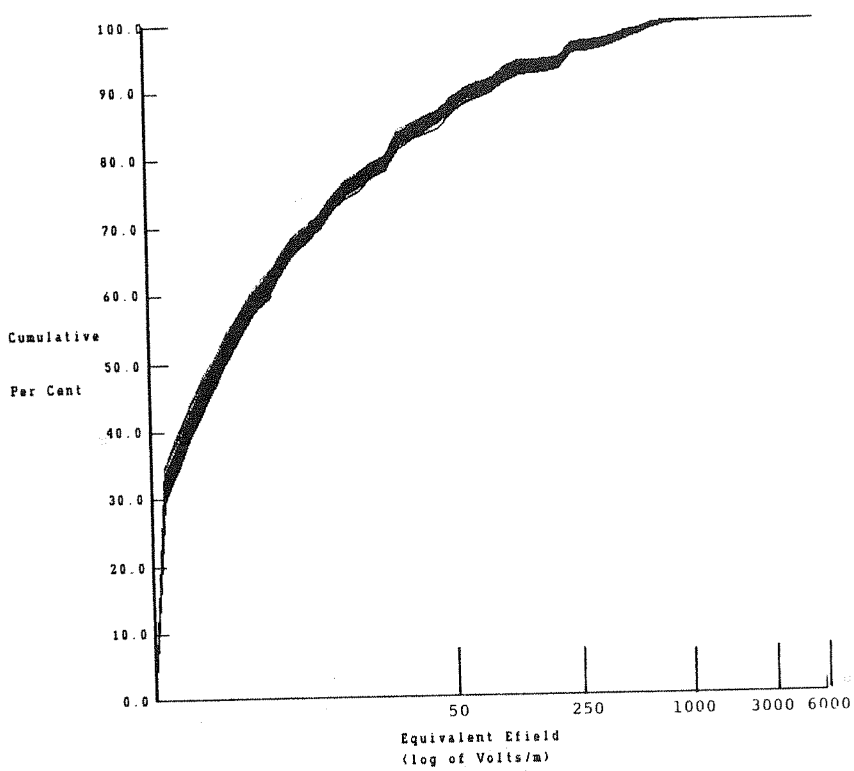


Figure D.8. Time in Efields - No System Variation

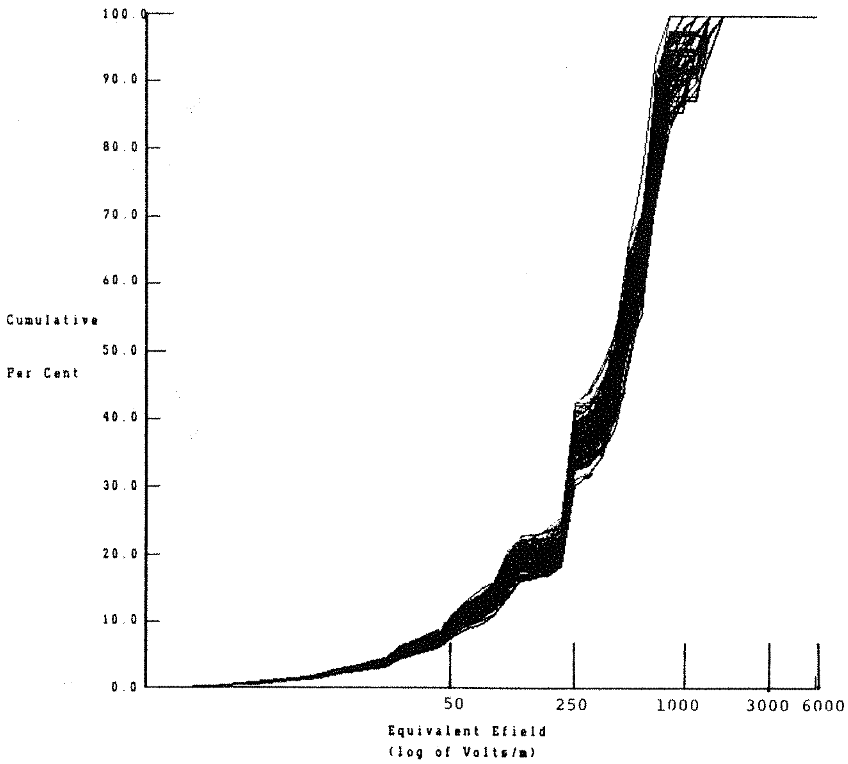


Figure D.9. Exposure - No System Variation

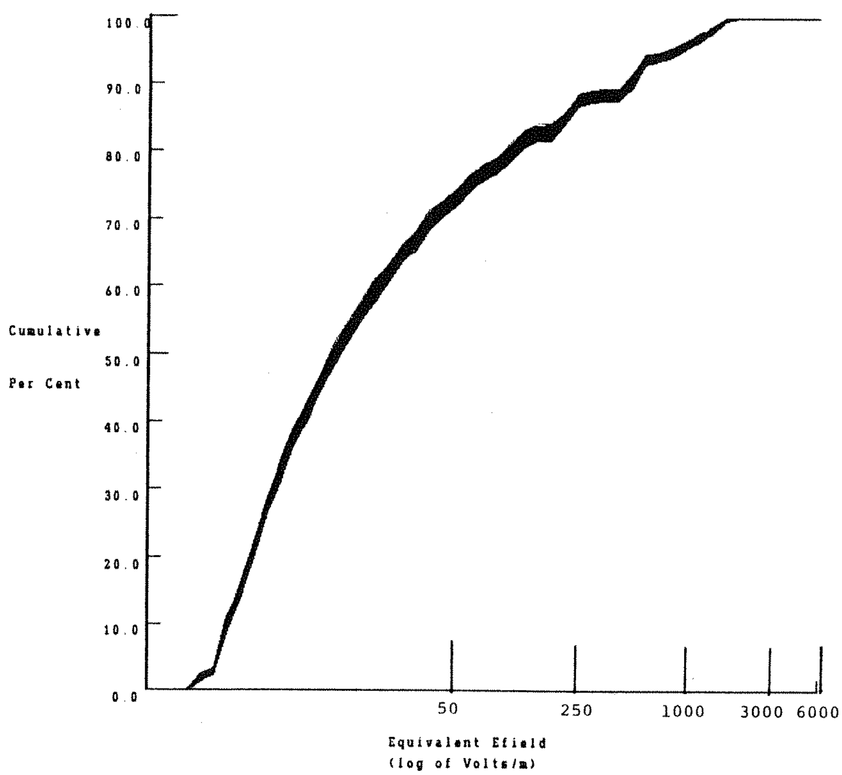


Figure D.10. Time in Efields - Full Variation; Activity Factor 100%

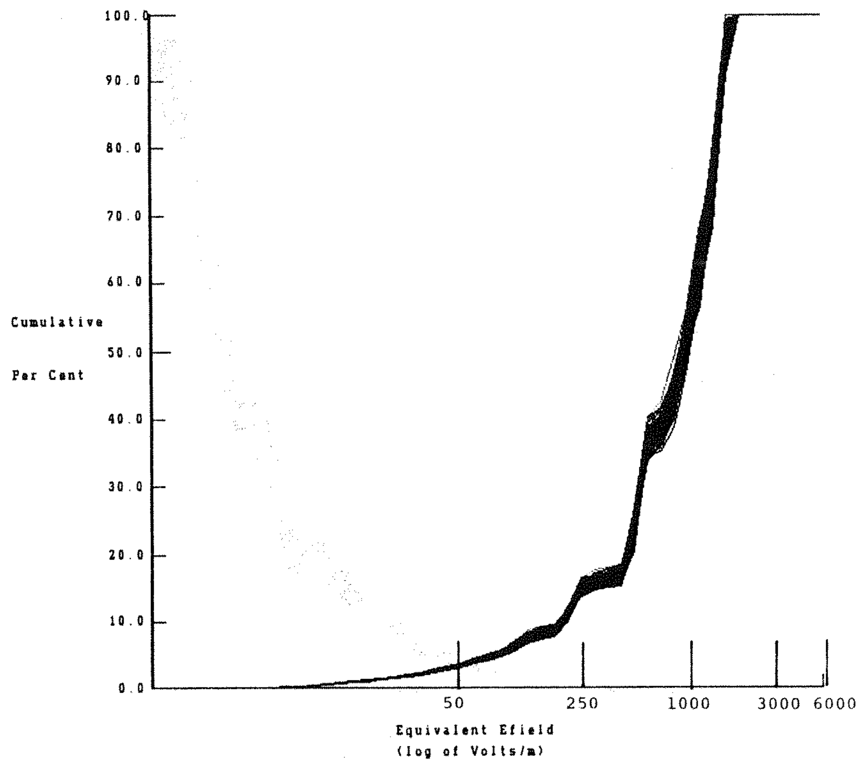


Figure D.11. Exposure - Full Variation; Activity Factor 100%

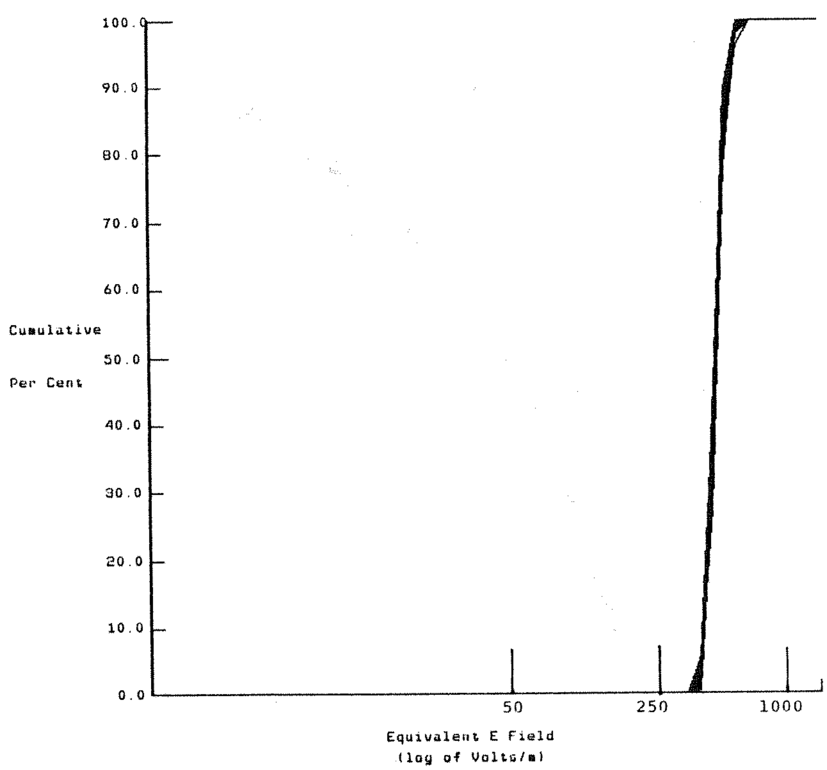


Figure D.12. Edge of ROW Jogging Case: Time in Efields

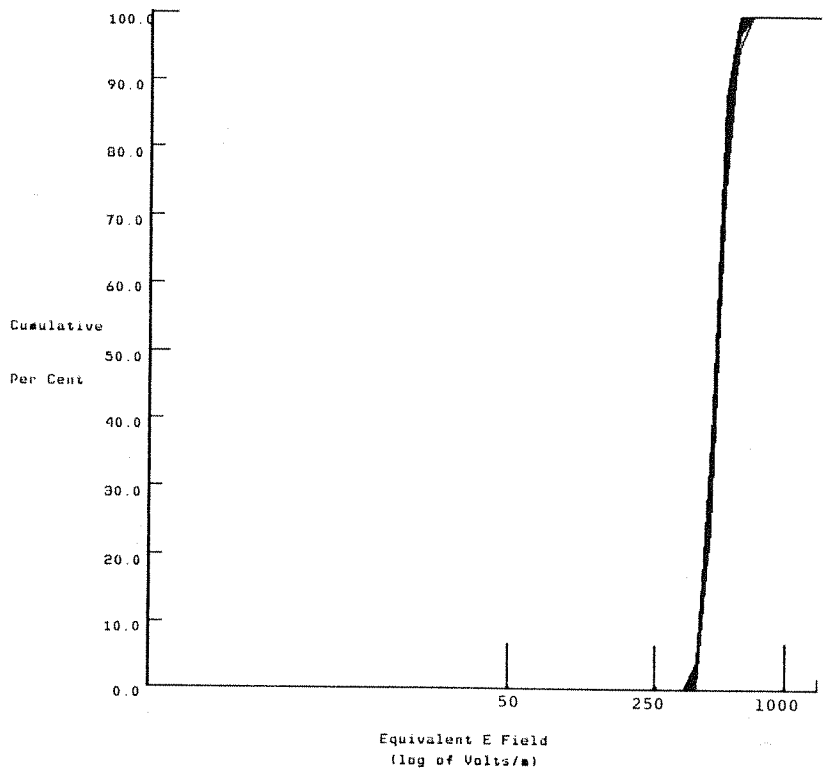


Figure D.13. Edge of ROW Jogging Case: Exposure

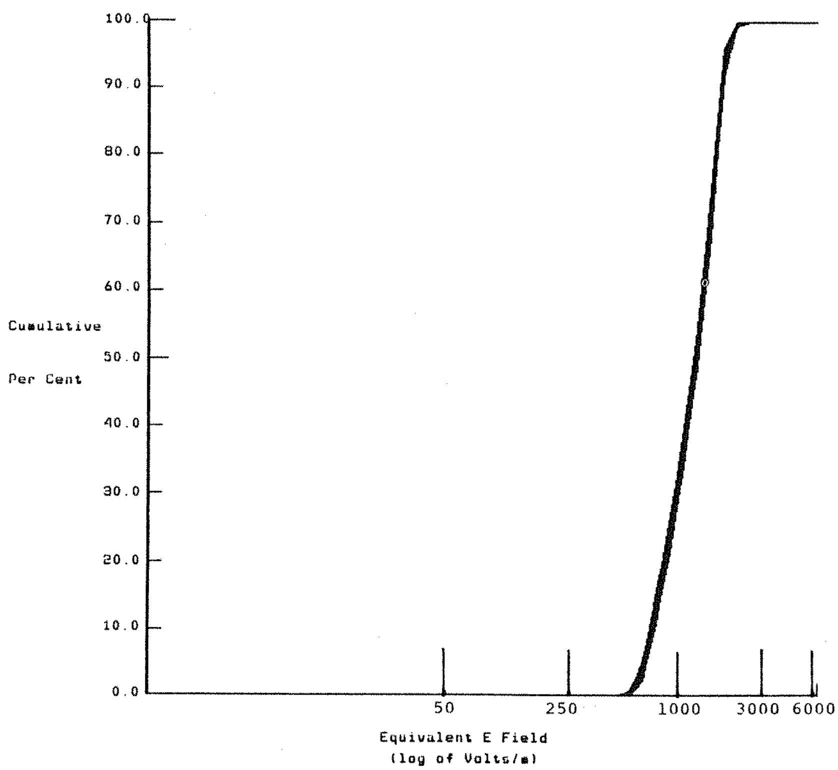


Figure D.14. Outside Phase Jogging Case: Time in Efields

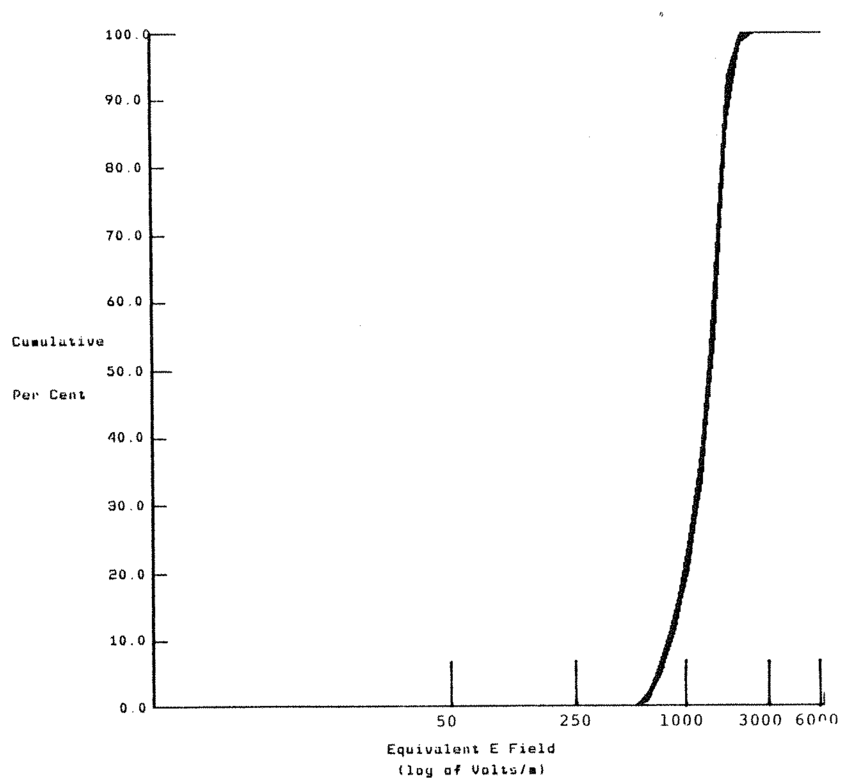


Figure D.15. Outside Phase Jogging Case: Exposure

Appendix E

LIFETIME EXPOSURE ESTIMATES USING COHORT MODELING

The cohort modeling method of demography can be used to extrapolate estimates of annual exposure to 60 Hz electric fields to estimates of lifetime exposure. The method has utility because human activities are often age dependent in systematic and predictable ways. This application of the method is based on a key assumption: that exposure could involve a cumulative process. To date there is no scientific evidence to support a cumulative lifetime exposure process that could be applied to humans for the electric field intensities produced by 115-765 kV transmission lines. This appendix is a supplement to Section 3.

A cohort is a population whose members are all born during the same period of time. A cohort can be defined for a single year, or a set of years (1). In demographic analysis, 1 and 5 year cohorts are most commonly used. Cohorts can be defined for any subpopulation, e.g., the subpopulation of farmers born between 1940 and 1944. Cohort models describe some experience of the cohort over a lifetime, and are typically used to estimate statistical values of that experience for the total cohort. For example, the standard "life table" is a cohort model that describes the probabilities of surviving from one age to the next and is commonly used to estimate life expectancies. A cohort model of farming would describe the age specific probabilities of "being a farmer" and could be used to estimate the expected number of years a cohort of farmers would engage in farming over a lifetime.

Empirically, cohort models use transition probabilities to represent the age dependent experiences over a lifetime. Data on these transition probabilities are available for some occupations, including farming (2). In situations where true cohort data are not available, synthetic cohorts are constructed from cross-sectional data and synthetic cohort transition probabilities are substituted for the real cohort probabilities. A cohort model of any segment of the work force could be based on the following transition probabilities, (the empirical values of these probabilities are found in (2)):

- P_{10} - the probability that a person of age x that is currently in the workforce will leave the workforce by age x+1.

- P_{01} - the probability that a person of age x that is currently not in the workforce will enter the workforce by age x+1.

- P_{11} - the probability that a person of age x that is currently in the workforce will continue to be in the workforce to age x+1.

- P_{00} - the probability that a person of age x that is currently not working will also not be working at age x+1.

- P_d - the probability that a person of age x will die before reaching age x+1.

These probabilities are defined so that:

$$P_d + P_{10} + P_{11} = P_d + P_{01} + P_{00} = 1 \qquad \text{(E-1)}$$

These age-to-age transition probabilities can be used to construct a Markov chain model of work life for farmers. Such models have analytic solutions for the means, variances and and other parameters such as number of years "in farming". See Reference (3) for a discussion of the mathematics of Markov chain models. Semi-Markov models extend these analytic results to inclusion of a value for being in a particular age dependent state. For example, hours of farming per year is age dependent, and can be incorporated into the estimates of hours of work over a life time. Empirical results can also be generated by Monte Carlo simulations based on these probabilities and other age dependent data. Figures 3.2 and 3.3 resulted from such simulations.

The following demonstrates how synthetic cohort data may be applied to estimate the lifetime electric field exposures received by a farmer while working land traversed by a transmission line. Let $f_x(P)$ be the cumulative distribution function (c.d.f.) for the number of hours of participation in activity A per year at age x. Let $g_x(E)$ be the c.d.f. of average exposure per hour of activity A at age x. Let F_{cc} be the vector of correlation coefficients between $f_x(P)$ and $f_{x+1}(P)$. Finally, let G_{cc} be the array of correlation coefficients between $g_x(E)$ and $g_{x+1}(E)$. A histogram of lifetime exposure can be generated by repeatedly performing the following stochastic simulation:

Beginning at age x=0 and proceeding throughout the lifetime, take random samples from $f_x(P)$ and $g_x(E)$ and multiply the two samples to obtain a sample of exposure for age x. Sum the annual exposures for all ages to get a sample of lifetime exposure. To obtain samples of $f_x(P)$ and $g_x(E)$ that correlate with $f_{x-1}(P)$ and $g_{x-1}(E)$ as given by F_{cc} and G_{cc}, respectively, one can use Choleski's method (4) for generating correlated random variables.

Due to limitations in available data, considerable simplification has been made on the above general model. First, we will assume that the subject receives the same annual "occupational" exposure from the line for each year that he works. In other words, assume that $g_x(E)$ is the same for all x. Next, assume that the exposure from the line for each year that the subject works is very well known, so that $g_x(E)$ becomes a unit step function at an exposure of E' units per work-year. Now $g_x(E)$ can be taken outside the age-by-age summation described above, so that lifetime exposure is merely:

$$\text{Lifetime exposure} = [\ E'\ ]\ [\ \text{number of years worked in lifetime}\ ] \qquad \text{(E-2)}$$

DISCUSSION

The method described in this appendix is based on a synthetic cohort approach to modeling lifetime exposure. It presumes that exposure to electric fields is a cumulative process - as yet, unproven. The formulation presented here is mathetically sound, but at this time lacks some of the data for a broad application.

REFERENCES

1. N. Keyfitz. Applied Mathematical Demography. Wiley & Sons, 1977.

2. S.J. Smith. "New Worklife Estimates Reflect Changing Profile of Labor Force". U.S. Department of Labor, Bureau of Labor Statistics: Bulletin 2157, November 1982.

3. John G. Kemeny, and J. Laurie Snell. Finite Markov Chains. D. Van Nostrand Company, Inc.: Princeton, N.J., 1960.

4. Dalquist and Bjorck. Numerical Methods. 1974.

Appendix F

COMPOUND BINOMIAL-POISSON PROBABILITY MODEL

INTRODUCTION

A compound probability model was developed to estimate recreation activity rates (average events per year) based on data published in The Third Nationwide Outdoor Recreation Plan (1). The data from this survey are not suitable for exposure analysis in their published form because of the format of the questions used in the survey concerning participation in recreational activities. Respondents were asked whether they had engaged in an activity during the last twelve months. If they responded positively, they were asked whether they had participated more than four times. Thus the published survey contains categorical information on the proportions of the U.S. population that are involved in a list of 30 activities for zero, one to four, and five or more times per year. To be useful for exposure analysis, these data must be used to estimate mean activity rates per year.

METHOD

The most obvious probability model for these data is the Poisson distribution. This model is most commonly used to describe the likelihood of relatively rare events, and in the context of all the activities that people engage in, recreational activities are relatively rare. The Poisson distribution has a single parameter, the mean event rate per unit time, and estimating this parameter from the categorical information would appear to be a solution to the problem.

Unfortunately, the simple Poisson model does not fit the data in reference 1. The actual and estimated proportions of the population that do not participate are quite different, with the actual being greater than the estimated. To remedy this poor fit, a binomial probability model is appended to the Poisson model to form a compound binomial-Poisson model. The binomial model parameter represents the probability of being a participant, and the Poisson parameter represents the mean activity rate of participants.

This type of formulation has precedent. Models of geographic mobility often distinguish "movers", people with relatively higher probabilities of moving, from "stayers", people with relatively lower mobility probabilities, by using a compound probability model (2).

MODEL AND ESTIMATION

The model can be represented by a probability tree diagram of the number of activities per year. (See Figure F.1). This diagram states that an individual does not participate in a recreational activity with probability (1 - p), and does participate with probability p. For participants, the number of times they engage in the recreational activity each year (0, 1, 2, 3, 4, ... , n) is described by the Poisson probability model. To determine the overall probability for both participants and non-participants, one computes the product of the probabilities of each branch starting with the main node and working to each end-state. For example, the probability that an individual participates in only one activity per year is P times the Poisson probability of 1 event.

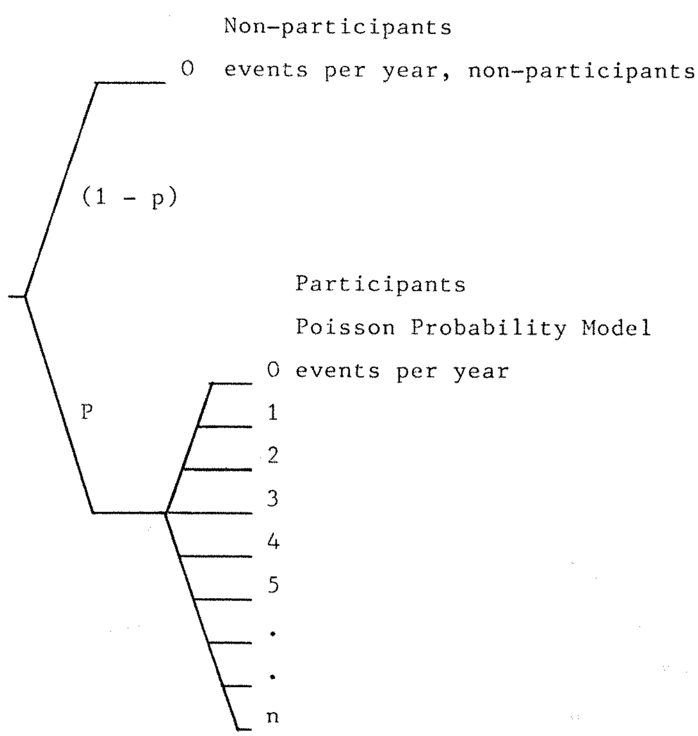


Figure F.1. Probability Tree Diagram of Activities Per Year

The binomial part of the model has parameter p, the probability of being a participant, and the Poisson has parameter v, the mean activity rate of participants. The mean or expected activity rate of the U.S. population is $(1 - p)0 + pv = pv$.

The observed proportions of the population in the categories 0, and 1 to 4 activities can be used to estimate parameters P and v. The estimating equations can be written from the diagram. Let:

P_o = proportion 0 activities,
P_1 = proportion 1 to 4 activities,

The proportion of the population that did not engage in a recreational activity during the previous year is the sum of two branches in the probability tree diagram. It is:

$$P_o = (1 - P) + P\,(v^o/o!)e^{-v}$$

Solving this expression for P as a function of P_o and v yields.

$$P = (1 - P_o)/(1 - e^{-v}) \qquad \text{(F-1)}$$

The proportion of the population that engaged in from 1 to 4 activities is the sum of four branches.

$$P_1 = P(ve^{-v} + (v^2/2!)e^{-v} + (v^3/3!)e^{-v} + (v^4/4!)e^{-v})$$

On substituting Equation F-1 for p, and rearranging, the equation becomes

$$P_1 = ((1 - P_o)/(1 - e^{-v}))ve^{-v}\,(1 + v/2 + v^2/6 + V^3/24) \qquad \text{(F-2)}$$

Equation F-2 is only a function of v, and can be solved numerically using a non-linear root finding algorithm. Given a value for v, back substitution into F-1 yields an estimate of p, the probability of being a participant.

The variance of the activity rate of the participant population is v. The variance for the whole population is

$$v = (vP)^2\,(1 - P) + \sum_{K=0}^{\infty}(K - VP)^2 P\,(v^K/K!)e^{-v} \qquad \text{(F-3)}$$

RESULTS

Table F-1 reports the estimated mean activity rates (events per year) for a few of the thirty most common outdoor recreation activities according to reference (1). In addition, Table F-1 reports the proportions P_o and P_1, the estimated values of P and v and the 95th percentile for the number of activities per year for the population.

The estimated values of P and v indicate the importance of separating participants from non-participants. For example, among cross-country skiers, the activity rate is 4.65 events per year while the mean rate is only .09 per year. For more common activities, these values are much closer together.

Table F-1

SELECTED RECREATION PARTICIPATION RATES FOR U.S. POPULATION

(Source: Thirty most popular outdoor activities in reference 1).

Activity	prop 0	prop 1-4	prob active	lamda v	mean rate	95% tile
Picnic	0.28	0.23	0.72	5.74	4.14	10.70
Walk or jog	0.32	0.11	0.68	7.12	4.84	12.81
Bicycle	0.53	0.08	0.47	7.02	3.30	11.20
Tennis outdoors	0.67	0.09	0.33	6.08	2.01	8.40
Hike or backpack	0.72	0.12	0.28	5.05	1.42	6.55
Canoe, kayak, or river run	0.84	0.11	0.16	3.66	0.60	3.72
Golf	0.84	0.05	0.16	5.79	0.93	5.59
Horseback ride	0.85	0.07	0.15	4.83	0.73	4.59
Snowmobile	0.92	0.03	0.08	5.37	0.43	3.63
Cross-country ski	0.98	0.01	0.02	4.65	0.09	1.54

(Note: Column headings defined on next page)

The column headings in Table F-1 are defined here:

- prop 0 = proportion of population that did not participate in activity in past 12 months.
- prop 1-4 = proportion of population that participated 1 to 4 times in past 12 months.
- prob active = estimated probability of being a participant.
- lamda, v = estimated mean activity rate among participants.
- mean rate = estimated mean activity rate for U.S. population.
- 95% tile = estimated 95th percentile activity rate for U.S. population.

REFERENCES:

1. Third Nationwide Outdoor Recreation Plan, Appendix I, Survey Summary., U.S. Department of Interior, Heritage Conservation and Recreation Service, Washington, D.C., 1979. Table 1, page 10.

2. Blumen, I., Kogan, M., McCarthy, P.J., The Industrial Mobility of Labor as a Probability Process, Vol VI of Cornell Studies of Industrial and Labor Relations, Ithaca, N.Y.: Cornell University Press, 1955.