EFFECT OF ELECTRICAL FIELDS, IONS AND NOISE ASSOCIATED WITH HIGH VOLTAGE DC TRANSMISSION LINES ON NEARBY CATTLE AND CROPS

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ABSTRACT

A three-year study was conducted in central Oregon to determine the possible effects of a ±500-kV direct-current (d-c) transmission line on cattle and crops. Two herds totalling 100 beef cows and six bulls were confined in pens beneath the d-c line. The cows were paired and the other members of the pairs were maintained in two herds in control pens 2,000 ft west of the line. The management facilities under the power line were duplicated in the control area. There were no significant differences in consumption of feed, minerals or water between the line and control herds. Also, no effects were found on breeding, conception, calving, calf birth date, calving interval, average daily gain, adjusted mwaning weight, cow weight, condition, carcass weight, and mortality. Differences were found between years for calf birth date, average daily gain, adjusted weaning weight, and cow weight. These differences were attributed to condition and age of the cows entering the study and their adjustment to pen confinement.

Alfalfa hay and winter wheat were produced for two years near two span midpoints of the d-c line. Crops were raised in strips extending in both directions beneath and perpendicular to the line. An identical set of control plots were placed 2,000 ft from the line. Analysis of data from line vs control plots showed no consistent statistical differences for production, seasonal growth stages or heights, hay or grain quality, or infectious disease. Wheat heights were slightly shorter among line plots than among control plots, although this was not clearly a response to the d-c

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line. There was limited evidence of slightly increased but biologically insignificant tipburn on wheat directly beneath the d-c line. Wheat plants were exposed to a d-c electric field in a laboratory test to establish corona onset levels. Based on this lab test, plants beneath the line experienced frequent daytime corona, but this could not be visualized in the field.

Data from four separate efforts were integrated to provide exposure estimates for cattle and crops. The Bonneville Power Administration provided measurements of d-c electric fields and air ions at ten fixed and one mobile station. The mobile station measured electric field, ion current, and space charge density at 25 locations in the cattle pens and crop area for 1 to 2-week periods.

The electrical measurements provided the data base for modeling the electrical environment in the entire study area. Monthly average levels of electric field, ion current density and ion density were estimated for locations within the cattle pens and along the crop plantings. Estimates of variation for the electrical parameters were also included in the models developed by T. Dan Bracken, Inc.

Observations of cattle location in study pens were used to develop estimates of time spent by the cattle at various distances from the d-c line. Location data for calves were also collected to permit estimates of their distribution. The estimated levels for electrical parameters were combined with the location data to yield a monthly time-integrated exposure for the average cow.

To translate the electrical environment measurements to a dose-related quantity, ion currents were collected with a full-scale cow model under the d-c line. Measurements were made at several locations in unshielded and shielded situations. These measurements were related to laboratory measurements using the simple geometric model. The exposure model measurements and dosimetry analyses were performed by Battelle Pacific Northwest Laboratories.

The following is a summary of a 450 page report, which contains details of the research site, experimental methods and results, plus a literature review. The full final report may be ordered as follows: "Joint HVDC Agricultural Study: Final Report", U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon.

INTRODUCTION

Background. There are various phenomena associated with high voltage (hv) direct-current (d-c) transmission lines which theoretically could affect plants or animals. These include 1. electric fields, 2. the quantity, electrical features and chemical nature of ions produced by corona at the surface of line conductors, and 3. noise. The chemical nature of ions produced in this study was not determined. With d-c power transmission, ozone and magnetic fields are infinitesimal, and limited data collected in this study confirmed their insignificance.

In contrast to alternating current (a-c) lines, d-c line conductors generate many charged ions that get into the environment. Ion movement is influenced by the wind, so the electrical environment around the transmission lines frequently changes.

The following terms may be helpful in reading this summary:

a) Voltage on the transmission line is expressed as kV = thousands of volts. A plus sign (+) indicates voltage traveling in one direction, a minus sign (-) indicates voltage traveling in the opposite direction. For paired transmission line conductors, each carrying 500 kV, this is described as ±500 kV for the line.

b) Corona is electrical discharge which occurs when molecules of air, water, dust, insect and other objects ionize on the surface of line conductors. It is accompanied by noise and light. The intensity of corona varies with the line voltage and environmental conditions. The light usually is too faint to see.

c) Electrical fields are expressed as kV/m, which is thousands of volts per meter. There may be contributions from both the static electric field around line conductors and electric field contributed by charged ions.

d) The amount of current carried by ions is expressed as nA/m^2, or billionths of amperes per square meter.

e) The numbers of ions found at different locations is expressed as ion density = $k\text{-ions}/cm^3$, which is thousands of ions per square centimeter.

Interest in the possible environmental effects of high voltage d-c (HVDC) transmission lines developed as a result of public controversy over the need for a ±400-kV d-c line in Minnesota. Surveys conducted after the line was energized in 1978 indicated that some people believed the line had adversely affected people, wildlife, and livestock.

However, a scientific committee formed by the State of Minnesota concluded that the survey was inadequate and inconclusive.

A majority of the Minnesota committee also concluded that there was no scientific evidence to indicate that short-term exposure to the d-c line posed a risk to human health. One committee member, however, concluded that the air ions produced by the line represented a potentially significant hazard. All of the committee concluded there was virtually no information on the possible long-term effects of exposure to elevated air ion concentrations. Among their recommendations was that there was need for studies of crops and livestock raised near a d-c line.

A study of dairy cattle in Minnesota was subsequently conducted (1). Dairy cattle production was assessed by examining Dairy Herd Improvement Association records from before and after the d-c line was energized. Other than general estimates of distances of herds from the d-c line, no information on electric field or air ion exposures were developed. The study found no chronic or acute effects attributable to the line on milk production, reproductive problems, or incidence of abortions. The researchers added, however, "If, in fact, substantial exposure to air ions and electric fields is present on a few farms, then this study could not have observed power line effects".

No studies of crop growth near the d-c line in Minnesota have been reported. Wheat growing at various distances from the D-C Intertie in Oregon was studied when the intertie was operated at ±400-kV. At harvest time, no significant differences were found in plant height, or in quantity, number, or germination of seeds that were related to the d-c line.

The studies discussed above are the only previously published field studies on the possible effects of commercial HVDC lines on animals and plants. There is a large and controversial body of literature involving laboratory studies of people, animals, and plants exposed to d-c electric fields and air ions. Most of this research, however, was not specifically done to assess the possible effects of d-c power lines.

Other reviews of the literature on effects of air ions on people and animals was published in 1987 (2, 3). This review concluded that reported effects of air ions are generally small in magnitude, and transient (effects were no longer present after exposure to air ions was stopped).

The reviews monitored above generally concluded that short-term adverse effects of air ions or d-c fields are unlikely. Research on possible long-term effects, however, is limited. Only three previous studies of animals and plants living

near an HVDC line have been published and both involved ±400-kV d-c lines (4, 5, 6). For these reasons, the present study was developed to examine possible long-term effects of air ions and d-c fields produced by the first commercial ±500-kV d-c transmission line in North America. Beef cattle, wheat, and alfalfa were selected for study because they are commonly raised along the D-C Intertie Line in Oregon.

Objectives and Design. The Bonneville Power Administration (BPA) determined that both environmental and electrical monitoring studies would be done when the Pacific DC Intertie was upgraded from ±400-kV to ±500-kV in 1985. Nine other utility organizations from the United States and Canada joined with BPA in sponsoring an agricultural study involving the line. The project was conducted from 1985 to 1988 by researchers from Oregon State University and the Agricultural Research Service, USDA.

Research objectives were to determine the potential effects of a ±500-kV d-c transmission line on production and reproduction of beef cattle and on crop growth, health, and reproduction.

Overall, the study assessed whether operation of the ±500-kV d-c transmission line resulted in any detectable effects (beneficial or detrimental) on livestock or crops, under controlled simulated ranching and farming conditions. Livestock and crops were located on the transmission line right-of-way and received long-term exposure to maximum electric field and air ion concentrations. The study was designed to provide data on end points and parameters of primary interest in commercial ranching and farming operations.

This study simulated a "worst case" condition in terms of exposure to the d-c line. In farming, crops are grown directly under the power line, whereas, in livestock operations, the animals generally are managed on various size pastures with the power line transecting them. In this study, 100 cows and six bulls were confined in pens directly under and extending 200-ft on either side of the transmission line center. One hundred cows and six bulls in identical control pens were located 2,000-ft from the d-c line.

The study area was typical, with respect to climate, topography, and vegetation of most of the land under the Celilo-Sylmar d-c line across Oregon and much of California. The site was in central Oregon near Madras on the Crooked River National Grassland.

METHODS

One hundred cows with their calves were managed directly under the line with a corresponding group in the control area for three production and reproduction cycles. Parameters compared between line and control groups were conception, calving difficulties, calving interval, calf and cow weights, nutrient intake, health, behavior, and slaughter characteristics.

For the plant study 60 wheat and 60 alfalfa plots were established in 400-ft strips transecting the power line with corresponding plots in the control area for two growth and production cycles. Parameters compared between the line and control areas included: phenology and other growth characteristics, yield on both crops, the quality measures of protein and fiber for the alfalfa, and protein and germination of the wheat.

The electrical study conducted by BPA, while not directly part of the OSU contract, was an integral part of the combined Grizzly Mountain HVDC Research Facility. The electrical study was designed and in place before the agricultural study began. A coordinated program was developed to minimize potential areas of conflict between the two studies.

Measurements of electrical parameters were taken at fixed locations at distances of 26, 75, 500 and 1,000-ft from the center of the line on both positive and negative sides of the line. In addition, a portable monitor was used to measure electrical parameters at selected locations within the pens. Meteorological variables were recorded on a continuous basis.

In a field study which investigated the possible effects of an operating transmission line on biological systems, there was a need to identify and quantify the exposure of the study subjects to the electrical environment. Documentation of exposures can provide information for dose-response analyses and on thresholds for effects. Exposure quantification can also provide the basis for comparison of exposures in this study to exposures in laboratory studies and to actual exposures received from this and other d-c transmission lines.

The principal electrical exposure parameters in this study were the d-c electric field, the ion current density and the ion density. Because these parameters are dependent on transmission line and meteorological factors, they are highly variable and are best characterized by measured levels whether in the short term or the long term.

The principal electrical exposure parameters at the Grizzly site were measured almost continuously at five locations within the treatment area near the line and at one location in the control area. In addition, measurements were made at various locations within the study area using a portable measurement system. From the measurements at the five permanent locations in the treatment area, the electrical environment over the entire treatment area encompassing four cattle pens under two spans was modeled to produce a quantitative description of the fields, ion currents and ion density to which the cattle and crops were exposed.

Average cattle exposures were estimated based on the field (or other parameter) levels at a location and the time the cattle spent at that specific location. Cattle location distributions were estimated from monthly observations. Thus, in an analogous fashion to exposure models for air pollution and 60-Hz electric fields, time, location and level data were combined to produce an estimate of monthly and total time-integrated exposure for the average cow. Monthly means of electrical parameters provided a direct estimate of exposure levels for the plants; since the crops are stationary, averaging over different locations is not required.

There is no identified mechanism of interaction which produces effects on biological systems for any of the three principal electrical parameters. Therefore, a meaningful exposure metric to characterize interactions between electrical quantities and biological systems cannot be established. For this study time-integrated average exposures over a month or longer were selected as the exposure metric, because they were considered indicative of long-term exposures. In the event that a more biologically significant or appropriate method of expressing exposure is identified in the future, the collected data are available in a form that can probably accommodate any particular metric.

The average monthly levels of electrical parameters which were used to express exposure levels say nothing about dosimetry (i.e., what dose of field or ions an animal actually receives). Questions of dosimetry such as the effects of animal shape, size, and posture were addressed in a study by Battelle Pacific Northwest Laboratories, performed under a subcontract to Oregon State University.

RESULTS

Livestock Parameters. The livestock study included three production and reproduction cycles (1985, 1986, and 1987). No statistically significant differences occurred between line and control groups for any of the production or reproduction parameters. Conception rates for line and control

herds were 86 and 82, 100 and 100, and 98 and 100 percent, respectively, for the three breeding seasons. Average daily weight gains for calves in each year were 1.64 and 1.56, 2.15 and 2.08, and 1.94 and 2.04 lb for line and control groups, respectively. There were ten deaths in the line group and ten in the control group during the entire study. The animals went on feed readily and at no time in the study period was there any significant difference in nutrient intake between line and control animals. The live animal condition scores, carcass condition ratings and antemortem examinations showed no significant differences between line and control animals.

Behavior of cattle was quantified by monitoring their locations at feed bunks and their distribution and activity in 16 subdivisions of the pens during afternoon loafing periods, night bedding periods, and 24-hr watches. No disparities of biological significance were detected in cattle activities or in their selection of feeding locations. Statistically significant relationships were detected in the distribution data. These suggested one to four percent fewer cattle remained in areas under the d-c line conductors than in corresponding areas of control pens. This finding did not appear to be correlated with either the electric field or the audible noise produced by the d-c line.

Plant Parameters. No line vs control differences were found for the primary production parameters of wheat and alfalfa fields, and quality of wheat grain and alfalfa hay. Similarly, few if any differences were found for the primary production parameters when side of the line or distance treatments away from the line were considered. A difference in wheat height might be related to the electrical environment, but plot-to-plot variation and effects from factors other than the transmission line were equally likely to have been responsible for these differences.

Control area plots were intended to provide relatively uniform data away from the d-c line. However, control plots varied as much or more than line plots. This reduced our ability to determine significant differences between line and control area plots. Influences other than presence of the transmission line may have resulted in occasional patterns of crop response in both line and control plots. This was most apparent with occasional exceptional center plot responses in comparison to all other plots, but there were several measurements in which significant trends were seen with distance from the midpoint of blocks. It is also possible that the elongated block design caused a differential plant growth away from the midpoint of the blocks. However, we do not believe that these negate the importance of our

findings. Within the limits of design and management capabilities, no commercially important differences were detected above normal variation.

Leaf tip and awn damage on wheat growing beneath the d-c line was not easily detected by plant specialists. These effects appeared to be no greater than natural tip burn that occurs in the region. Theoretical crop losses from such tip burn would be so small that no detectable production responses would result. Laboratory data for corona on wheat leaves and awns, in conjunction with measured and calculated field and ion levels near the transmission line, support the contention that corona probably does occur at times on sharp plant parts protruding above the ground plane beneath the conductors. However, no corona was observed on crops using an image intensifier due to several possible factors. These include the fact that most intense corona would occur during daylight hours when it would be impossible to visualize. At night, corona might occur, but would be faint enough to be obscured by high ambient star light levels.

Dust did not accumulate differently on crop foliage near or away from the transmission line. No infectious disease problems occurred during the two-year study. Measurable animal damage was limited to rodents. Where this damage was abundant, crop yields were corrected for rodent damage.

Exposure Estimates. Exposures of the cattle and crops to electrical fields were quantified, using data from the electrical measurements program and the cattle location observations. The principal electrical parameters in this study were the d-c electric field, the ion current density, and the ion density.

Electrical parameters at the study site were measured almost continuously at five locations near the line and at one location in the control area. In addition, measurements were made at various locations within the study area, using a portable measurement system. From these measurements, the electrical environment over the entire line and control areas was modeled to produce a quantitative description of exposure. Cattle exposures were estimated based on the field (or other parameter) levels at a location and on the time the cattle spent at that specific location. Since the crops were stationary, averaging over different locations was not required.

The total accumulated electric field exposure was approximately 5,000 (kV/m) days for an average cow in the line group. This corresponded to exposure to an average electrical field of 5.5 kV/m over the duration of the project. The total accumulated ion current exposure in the line group

was about 3,700 (nA/m^2) days for an average cow. This corresponds to exposure at an average ion current of about 4.1 nA/m^2 for the entire project. The total accumulated ion density exposure was about 12,000 (k-ions/cm^3) days for an average cow in the line group. This level corresponds to exposure at an average of about 13 k-ions/cm^3 over the duration of the project. Depending on the parameter under consideration, exposures in the line area were five to 30 times greater than exposures in the control area.

The exposure levels experienced by the study cattle were related to that received by rodents in other recent laboratory studies. A series of measurements at the study site of the ion current collected by various animal models was compared to the exposure levels in the study and to those of the three EPRI-sponsored air ion research projects. Relative dose for an animal was expressed as the product of the collected ion current and the duration of exposure divided by the weight of the animal. Using this exposure metric, the relative exposures ranged from 21 to 0.25 for the laboratory studies and 1.8 for the study of cattle.

Maximum exposures for the crops occurred directly under the d-c line. The maximum average electric field exposures were approximately +9 and -16 kV/m. The maximum levels in line plots exceeded minimum levels by four to 30 times, depending on the parameter. The maximum exposures in the line plots exceeded exposures in the control plots by a factor of 30 to 100 depending on the parameter. Similar differences were seen for ion current density and ion density.

CONCLUSIONS

This experimental study found no evidence that continuous exposure to a ±500-kV d-c transmission line affected the production of beef cattle, wheat, or alfalfa. Extensive electrical monitoring indicated that electric field and air ion exposures received by cattle and crops raised near the line, were substantially greater than exposures in the control area. For cattle, these exposures were greater than would typically occur because the animals were confined beneath the line. This further decreases the likelihood that effects would occur to livestock normally exposed to a d-c transmission line.

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