RESEARCH ASSESSING THE IMPACT OF ENVIRONMENTAL AGENTS

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ABSTRACT

Throughout geological history environmental changes have been occurring, and these changes have had an impact on life. The effects have been both beneficial and detrimental. As populations have increased and technologies expanded, there are new and different environmental changes. The world is deluged by ever increasing byproducts of the present age of technology. In addition to the benefits of the technological advances, there also negative impacts from the application of these technologies and their byproducts. People of the world are faced with the need to sort out the positive and the negative impacts of technology in order to maintain the most ideal conditions for all life. There are many factors that have hindered an accurate assessment, however, especially of the negative impacts resulting from technological byproducts.

As an example this paper considers the potential negative impacts from exposure to the electricity that is added to the environment where living organisms exist. The specific case presented primarily involves effects on dairy cattle, but it is also applicable in other places and for other living organisms. Attention is given to different positions taken regarding possible electrical effects, the information gleaned from research and investigations, and the conflicts that have emerged. The paper presents the basic mechanisms for effects and areas of insufficient information, and it suggests a research methodology for providing a more comprehensive picture of the issues.

INTRODUCTION

Detrimental effects from environmental agents have been common throughout human history. The disposal of human wastes and its effect on water supplies has been and continues to be a major factor in affecting health. Better understanding of health issues, technological advances, and increased economic resources have made it possible for many countries of the world to limit the health effects from the pathogens from wastewater. Unfortunately there are still many people of the world who do not have safe and adequate water supplies.

Our greatest vulnerability today, however, comes from the many environmental agents that are byproducts of technological advances and applications. Environmental agents include such things as chemical wastes from manufacturing, toxic chemicals used as herbicides, insecticides, and pesticides, and also various forms of electrical energy. These are, in general, new exposures, and we lack sufficient information for determining health effects from specific agents or from all of them together. The irony of these scientific developments is that they also have been very beneficial for the well being of humanity. As a consequence the introduction of these chemicals and energies into the environment has been justified on the grounds of the expected ultimate good for humanity. Although one cannot discount the potential value of these developments, we know from experience that at some point the value could be surpassed by an increase in negative impacts. This increase in negative effects can be triggered by increases in environmental exposures due to the buildup of toxic agents in the environment, and by an increase in sensitivity to these agents associated with length of time of exposure.

Decision making about the level of health effects that is acceptable, as a trade-off for their beneficial value, must be placed in the hands of society. Usually governmental bodies are assigned the task of making decisions concerning the use of the various chemicals and energies. Ultimately it is scientific research that provides information for making the decisions. In a perfect world, research should be done by scientists who have both the freedom and the integrity to impartially and honestly present their research results. In addition, those who are affected or have witnessed the effects on non-human living organisms should have input into the research questions to be analyzed. However, we don't live in a perfect world. Much of the relevant research is financed by companies and organizations that have financial interests in the sale of chemicals or energies, and there is little input from those affected. Consequently, there can be a tendency to report only research supporting the value of the product. Those findings showing negative effects are less likely to be reported. Historically, companies have not been interested in funding research that might negatively affect their financial well-being. In recent times one of the most far-reaching and documented overt efforts to control research and information involved the tobacco industry.

Some information for decision making is gleaned from laboratory research. Other information is obtained from other sources, and it is important to keep in mind that all information contributes to the understanding of effects from environmental agents. As is the case in any diagnostic work, whether in a doctor’s office or a veterinary clinic, the self-reported symptoms of the people affected and the perceptions of the owners of animals affected are valuable sources of information. In the case of chemicals, a category of information that has received little recognition among research scientists and governmental agencies involves the development of sensitivity to chemicals, sometimes called multiple chemical sensitivity (MCS). A common experience of those that experience MCS is an exposure to a high level of some toxic chemical, after which their tolerance to all chemicals is radically decreased. In some cases those who have become chemically sensitive are forced to live a totally isolated life in specially designed rooms or homes. It is not uncommon today to see signs in public places asking people, to the extent possible, to avoid using colognes, fragrances, and other perfumed products, because some people who work or frequent these places are adversely affected by these chemicals. Sick Building Syndrome has frequently been associated with poor air quality and the toxic chemicals emitted by the contents of buildings. Organizations and groups have sprung up around the world to aid those who have become chemically sensitive and to encourage the recognition of this problem. At this time very little research has been conducted utilizing this information, and scientists have been slow in recognizing its value.

Similarly, in recent years more people have become abnormally sensitive to electricity (ES). These people have to avoid exposure to many electrical sources. As in the case of MCS, those who become electrically sensitive often need to find living space that offers the least possible exposure to electricity. ES appears to begin among individuals who spend a considerable amount of time in areas of high electrical exposure. The cause of ES is not well understood, but frequently if a person is chemically sensitive, that person is also electrically sensitive. In addition, the health effects experienced by MCS and ES victims can be quite similar.

All humans and animals live in an environment where exposure to various manufactured chemicals and to electrical energies from human activity is nearly inescapable. Although the perceptions of people experiencing MCS and ES do not prove cause and effect, they do suggest that a number of people suffer significant and diverse effects from exposure to chemicals or electrical energy or both. If the interest of society is to maintain the well being of living organisms, there ought to be research methodologies developed that can assess the whole range of these adverse effects and the MCS and ES syndromes. Today the greatest effort in research is placed on considering a single effect and one possible cause. Although this type of research is necessary to our understanding of how environmental agents affect living organisms, we also need research methods that allow for the evaluation of multiple effects from a number of different agents. It should be noted that traditional research involving a single environmental cause is difficult in itself, even in laboratory settings, because of the presence of so many environmental agents that have the ability to affect health.

ENVIRONMENTAL EXAMPLE

DESCRIPTION

The use of a specific problem will illustrate the research difficulties in assessing effects from environmental agents. Research and farm investigations over many years have shown an association between exposure to electricity and behavioral, production, and health effects in dairy cattle. Historically, the name *stray voltage* has been attached to this problem, but through the years, the term itself has become surrounded in controversy. In this paper *stray voltage* is used as a general term for electrical causes and health effects.

For over 50 years the dairy industry has been aware of the need to maintain a trouble-free electrical system in the environment of the dairy farms. Dairy cows are known to experience a set of behavioral, health and production effects when an electrical problem exists proximate to dairy farms where electricity is short-circuited into the earth. Dairy operators perceive these effects to be a general attack on the well-being of the cows. While stray voltage is most often associated with the dairy industry, it can also be found elsewhere. Industry, dairy operators, and agricultural schools of universities have all struggled with the problem, searching for solutions. Diverse models have been proposed to explain the cause or causes, and various mitigation procedures have been implemented to assist the dairy operators in managing their herds.

HISTORY

As electrical use has increased on farms and generally throughout society, increasing numbers of dairy operators have experienced behavioral, health and production problems in their dairy herds that seem to have no obvious cause. Consequently during the 1970’s, specialists in the dairy and electrical industries began to suspect the implication of electricity. Potential electrical problems were investigated especially if dairy operators experienced electrical shocks in their barns

The initial field investigations on dairy farms revealed that dairy cattle were affected by electricity. When electricity was suspected as the cause of health and production effects on dairy farms, searches were conducted to locate any possible problem in the electrical system on the farm. When a problem was found and it was the cause of the health and production effects for the cows, correcting it also eliminated the adverse effects. If the adverse effects continued after correcting all electrical problems on the farm, a search of off-farm electrical problems was undertaken. A fundamental cause for adverse effects in dairy herds from off-farm electrical sources is a ground fault. In a ground fault, electric current enters the ground, goes through the ground, and returns to a neutral or ground point. If a ground fault is discovered on a nearby farm and is found to be the cause of the adverse effects, correcting it eliminates the effects.

Another off-farm electrical source is associated with electric distribution systems. Since the neutral wire of the electric distribution (primary) and farm (secondary) electric systems, in general, are connected together, primary neutral current can enter the secondary neutral, and then it enters the ground in the barn and on the farm. This current from the primary neutral that goes into the secondary neutral must enter the earth through the secondary grounding system in order to return to the substation. In the electric distribution system current entering the earth through the grounding system creates a ground potential, and can cause a potential difference between two contact points in a dairy barn. Initially, a current produced by a potential difference between two cow contact points was considered to be the cause of the reported adverse effects. It was assumed that the potential difference produced a current sufficiently high to cause a shock response. Experience, supported by experimentation, showed that reducing these sources of electricity often produced significant improvements in behavior, health and production of the cows. Initially only on-farm and off-farm sources of electric currents that entered the earth and grounding system in the barn were considered as possible causes of stray voltage and adverse effects on cows. As measurement procedures were developed, the potentials between the primary neutral and remote ground and the secondary neutral and remote ground, together with the cow contact potential, became the standard measurements for assessing the existence of stray voltage.

University researchers and extension personnel became much more involved in the stray voltage problem in the late 1970s and early 1980s. Because they are concerned with problems in agriculture, they were diligently searching for causes and solutions to the stray voltage problem (Lefcourt, ed. 1991). The specialists involved made the operational assumption that stray voltage was merely the "shock" current to which an animal is unintentionally exposed as a result of certain electrical conditions (Gustafson 1984). These persons held that the results of the shock effect included a cluster of herd problems such as poor and uneven milkout, extreme nervousness while in the parlor or stall, reluctance to enter the parlor or stall, reduced feed intake in the parlor, reluctance to drink water, increased manure deposition in the parlor, recurring mastitis that is resistant to treatment, and lowered milk production (Gustafson 1982). These notions were based mostly on qualitative information, and without access to specific experiments and theory clarifying the parameters of the problem of stray voltage.

An ad hoc group representing agribusiness, universities and utilities met in Syracuse, New York, in March of 1981 to discuss the stray voltage problem on dairy farms. The sixteen conferees recommended controlled research in three major areas:

1. sensitivity threshold of cows to electrical currents when such exposure is chronic,
2. short and long term physiological effects of stray voltage on dairy cows,
3. the relationship of utility distributions systems, on-farm electrical systems, and on-farm equipment and facilities to stray voltage problems (ASAE. 1985.p. v).

As a result of this meeting a research council was set up to contract research personnel from universities to perform research in these areas. In 1984 a stray voltage symposium was held for the presentation of the research results. In all of the research the shock model was used in studying possible effects of stray voltage, and the results of the research involving this model were presented at the symposium. The conclusions from these research projects were disturbing to dairy operators for two reasons. First, the presenters at the symposium concluded that milk production and health could not be correlated with exposure to shock currents commonly present in dairy barns. The focus was on acute effects caused by the response to shock currents, and little attention was given to possible chronic effects. Second, no research was conducted that studied the sensitivity threshold for chronic exposure of cows to electric currents. Chronic exposure implies electric currents continuously present in the cows as opposed to shock currents which are experienced by cows only when they touch a water cup or another conductor. In general cows are in contact with the water cup or other conductor for less than 1 % of the time.

Throughout the 1980s and 1990s additional university research was conducted to refine the conclusions presented at the 1984 symposium. In December 1991, the report "Effects of Electrical Voltage/Current on Farm Animals" was published by the U. S. Department of Agriculture (USDA) as a definitive representation of controlled stray voltage research. In considering the history of stray voltage one of the authors, Appleman, made some important observations:

> The first farms in which stray voltage/current problems were identified were suffering severe losses of milk production and income. The producers were generally aware they had problems and had spent considerable time and money attempting to improve their feeding program, the milking equipment, their milking procedures, and hygiene. But, nothing seemed to help. Finally, when stray voltages/currents were measured and appropriate corrective procedures were completed, favorable responses were often immediate and dramatic. Increases in daily milk production of 10 to 15 pounds per cow (20 to 30 percent) were commonplace. Improved cow temperament and a significant reduction in the time required to complete milking chores were often cited by farmers. Improved udder health, less mastitis, and improved milk quality were also frequently reported responses (Lefcourt, ed, p. 1-2,3).

It has indeed been common for dairy operators to search for nutritional causes, equipment failures, errors in milking procedure, water quality problems, or anything else other than electricity that could produce the observed effects. They also consulted with specialists from related industries, university extension people and veterinarians to help find answers. It seemed as if dairy people would consider an electrical cause only as a last resort, unwilling to believe that electricity could cause these problems.

A mechanism for explaining possible consequences of stray voltage gradually emerged. Perhaps as a result of human experience and early assumptions, electric shock was the single mechanism selected to explain how electricity affects cows in a dairy barn. The general assumption was that electrical shock is the only possible mechanism, and without an overt physical response, health and production cannot be affected. Therefore, persons working on this problem based their assumptions solely on this shock mechanism, and did not allow for other possible mechanisms. Thus the important measurement became the electric potential (voltage) difference between two points that the cows might touch, such as the barn floor with which their feet make contact and the water cup with which their mouths makes contact. The current flowing through the animal's body from this electrical potential between two contact points is in general of short duration and definable as a shock current. The shock appeared to be associated with certain behavioral problems such as reluctance to enter parlor or stall; cattle continuously moving their legs while in stalls; cattle kicking off milkers; and unusual and adverse behavior while in the barn, sometimes impossible to control. The assumption was that when the shock was sufficiently intense the additional stress would result in health and production problems in the dairy animals. Such effects were uneven, incomplete, and/or slow milkout; poor water consumption; multiple and recurring mastitis (not responding to treatment); high somatic cell count; breeding problems and reduced milk production; cow production peaking early and not holding; and swollen legs and joints.

SUMMARY OF FINDINGS OF THE 1991 USDA REPORT

Consistent with the chosen mechanism, the majority of stray voltage research has concentrated on determining the responses of cows to intermittent exposure to electrical current from small potential differences. Logically one could postulate that at certain levels of electrical shock, the health and production of dairy cattle could be adversely affected. Demonstrations and research clearly indicate that shocking livestock with alternating currents in the range of one or more milliamps can cause behavioral responses (Albright et al. 1991). The empirical evidence gathered in field investigations of affected dairy herds correlated many of the health and production effects with the behavioral responses (Appleman 1978; Fairbank 1977; Lillemars 1980).

Laboratory research involving dairy cows could not establish a direct causal link between electric shock and the health and productivity of the cows. Thus the researchers used only observed behavioral responses to assess the extent of the stray voltage problem on farms.

The 1991 USDA report provides a summary of the positions held by the majority of persons associated with stray voltage research and by electric utility personnel. Selected quotations and concepts from this report are presented as a synopsis of the understanding of the stray voltage problem as gleaned from university laboratory research. The basic problem is presented as an electrical exposure characterized as a shock causing a cow to physically respond.

As stated by Aneshansley and Gorewit, "The magnitude of current needed to elicit minimal behavioral responses is very similar to the magnitude of current that can just be perceived by humans (0.5-2 mA) for a given voltage, a lower body impedance results in a larger current". They also stated, "*Current level is of critical importance because animals respond to the current passing through their bodies, and not directly to the voltage that generated the current*" (Lefcourt, ed., 1991, p. 3-1).

Lefcourt's assessment of the stray voltage problem is similar: "The most common method for gauging responses of cows to electric current is to measure changes in behavior. The magnitude of current needed to elicit minimal behavioral responses in cows is very similar to values given for perception of current in humans. The current necessary to elicit specific behavioral responses varies from cow to cow and depends to a lesser degree on the two points of contact, e.g., mouth to four hooves or front leg to rear hock. The voltage needed to deliver these currents depends on the body impedance of the cow, the contact impedance between the cow and the conductive structures, any impedance of the conductive structures, and any impedance of the voltage source.

A very conservative estimate for a worst-case total impedance is 500 ohms. A more realistic estimate of total circuit impedance is 1,000 ohms" (Lefcourt, ed., 1991, p. 7-1).

Aneshansley and Gorewit present some assumptions and evidence gleaned from stray voltage research. First, "Cows feel the passage of small electrical currents through their bodies, and all cows have similar capabilities to feel these currents. Therefore, differences in how cows respond to current depend not on their ability to feel the current but, instead, on their perception and interpretation of it". The assumption is made that the sensitivity differs for each cow and that difference is based on genetic heritage or past history. (Lefcourt, ed., 1991, p 3-19) Second, "Behavioral responses to stray voltage vary by cow and circumstance. Variations in responses are due to how the cows perceive current and not differences in the ability of cows to feel current. Some important considerations in dealing with behavioral responses to electrical stimulation are 1) that the farmer's reaction to behavioral changes may magnify existing problems and 2) that even when the stray voltage is eliminated or effectively suppressed, behavioral problems may continue because of the effect of conditioning" (Lefcourt, ed., 1991, p. 3-23). Third, "Evidence from stray voltage experiments suggests that as a result of the genetic selection of animals for productivity, the ability of those animals to respond to noxious stimuli has been reduced. In dairy cows, electrical stimuli during milkings and between milkings do not cause any significant physiological response despite exaggerated behavioral responses. In other species of animals, electrical stimuli of similar magnitude cause large and easily detectable physiological changes, including increases in heart rate, respiration rate, and levels of stress hormones in blood" (Lefcourt ed. 3-20).

The research in this report indicates that currents below 6 mA administered for short periods (21 days) do not affect production, reproduction, and animal health; nor is there a significant effect on levels of hormones naturally released during milking or in response to stress. Moderate behavioral problems occur for exposure to currents between 3 and 6 mA. Behavioral problems may require additional time from dairy operators. In a small percentage of cases direct economic impacts have been shown at potentials of 4 V and above. These potentials were assumed to produce currents in the cows of 8 mA and above. Experiments involving long term exposures indicated that cows acclimate physiologically and behaviorally to constant and intermittent shock current below 6 mA. It is projected that cow contact potentials between 1 and 4 V, which is considered equivalent to between 2 and 8 mA, may cause behavioral problems requiring special attention from dairy operators. The suggestion is made that it may be necessary for dairy operators to choose to use extra time and care in handling possible behavioral problems rather than spending the money to mitigate the electrical cause (Lefcourt, ed., 1991,).

Appleman writes, "The primary impact of stray voltage/current on milk production involves changes in behavior. Because the effects of stray voltages/currents are primarily behavioral rather than physiological, good milk yield can probably be maintained despite the presence of moderate levels of stray voltage/current if the farming practice is good. One important conclusion concerning behavioral responses to electrical stimulation is that a farmer's reaction to animals behavioral changes can magnify existing management problems or even create new and more serious problems" (Lefcourt, ed., 1991, p 1-4).

Aneshansley and Gorewit concluded, "As shown by research under controlled conditions and by many field observations, the primary reason for any loss in milk production by cows exposed to currents of 4.0 to 6.0 mA appears to be due to the farmer and the way affected animals are handled. Affected animals may cause milking machine operators to become frustrated and less patient and to employ inconsistent, hurried, and less desirable milking practices" (Lefcourt, ed., 1991, p. 3-21).

Dairy operators have most frequently associated a stray voltage problem with an increase in mastitis. Developing a scientific model that can explain the cause and effect link and connect it to electrical shock has been difficult for research personnel. Lefcourt states that, "Attempts have been made to link mastitis with stray voltage. Mastitis is a fact of life in the dairy industry. Mastitis is caused by infection of the udder and not electricity. Electrical current can affect the incidence of mastitis only indirectly. For example, a milking machine kicked off by a cow in response to current exposure may be reattached without first being cleaned" (Lefcourt, ed., 1991, p. 7-2).

Aneshansley and Gorewit emphatically express their conviction, "Electrical current cannot directly cause infections. It can affect the etiology of mastitis only indirectly, e.g., when a milking machine kicked off by a cow is reattached without first being cleaned" (Lefcourt, ed., 1991, p. 3-2).

The report proposed a scenario that if the milking time is increased because of the cows kicking off milkers or delay in entering the parlor, the farmer takes shortcuts in the milking routine in order to make up for the lost time. It claims that a likely consequence is an increase in bacteria left on the udders and an increase in mastitis.

Even though dairy operators are especially cognizant of management issues, there was a frequent emphasis on causes that were not electrical. As stated by Aneshansley and Gorewit, "It should be emphasized that factors such as mistreatment of cows, milking machine problems, disease, poor sanitation, and nutritional disorders can cause cows to exhibit all the symptoms that have been reported to occur on farms reporting stray voltage" (Lefcourt, ed., 1991, p. 3-2). They also offered, *"A careful analysis of all possible causes of unusual animal behavior and/or poor animal performance is necessary if proper corrective procedures are to be found* (Lefcourt, ed., 1991, p 3-15) (Italics added).

In the early 1990s there was a general agreement among those involved in the writing of the USDA report that the stray voltage problem had been solved. As Appleman wrote, "Today, stray voltage/current is a recognized phenomenon. The theoretical basis for stray voltage/current problems is understood, sources can be identified, and cost-effective solutions exist" (Lefcourt, ed., 1991, p.1-4). Craine qualified the optimism by pointing out, "*The basic physiological mechanisms by which electrical energy affects animals are well documented. The effects of electrical energy on neural electrical/chemical interactions in animals are complex, and examining those effects is beyond the scope of stray voltage specialists*" (Lefcourt, ed., 1991, p. 6-2 (Italics added)

The research scientists also developed methods for mitigating the levels of cow contact or shock currents in the dairy barn. Ludington expresses the sentiment of the authors that the level of concern is known, and, "Only if a voltage which the animal contacts (E c) is sufficient to produce a current at a level of concern, is it then *necessary* to make the appropriate measurements to determine the source(s) and devise a mitigation process" (2-17). If the shock currents were above the level of concern the necessary measurements and mitigation procedures were advised. The sentiment seemed to be that there were dairy farms where mitigation was necessary.

The usual approaches for mitigating stray voltage are voltage reduction, gradient control (equipotential plane and transition zones), active suppression (EGS), and isolation. Each of these involves various methods of reducing the cow contact or shock potentials. Lefcourt pointed out that the group recommended, "That new facilities for housing and handling animals incorporate an equipotential plane which is carefully bonded to the electrical neutral/ground system" (Lefcourt, ed., 1991, p. 7-2).

Although the equipotential plane has become a requirement in a number of states in the U.S., the mitigation most often used is isolation. Isolation implies the separation of the utility neutral from the farm neutral, which significantly reduces the current going from the primary neutral into the farm grounding system. The equipotential plane does not prevent the primary current from reaching the floor of the barn, and it is usually installed only in parlors where cows are milked and in the stalls where cows are milked and housed part of the day. There have been some endeavors to assess the improvement in the behavior, health, and production of dairy cattle resulting from the installing of Electronic Grounding Systems (EGS), and of isolating devises. The most notable has been the attempt to assess the mitigating value of isolation.

Appleman and colleagues from the University of Minnesota surveyed a number of farms in Minnesota in order to determine the effectiveness of isolating the primary and secondary neutrals on dairy farms. Of the 394 farms identified as having isolation transformers, 121 also had DHI data available for the necessary survey period. The results of the survey revealed that for the 121 farms there was a 4 percent average increase in milk production during a period of 12 months following isolation, as compared with milk production at the time of isolation. None of the other production and health characteristics showed a significant change during this same period. The researchers also discovered that when the milk production records for 84 of the herds were averaged, milk production trends for the period before and after isolation were similar to herds on non-isolated farms in the area. For the other 37 herds (31 %), average production went from 14,687 lbs of milk 12 months before isolation, to 14616 at the time of isolation, and to 16,444 during the period 12 months after isolation. For neither group were there significant changes in any other health and production characteristics.

As presented by Aneshansley and Gorewit, "Based on the results of this Minnesota study, it was concluded that 69 percent of the herds isolated failed to show a response in milk production different from that of all herds in the region enrolled in the DHI program. Thus voltages present at the barn service entrance 1) failed to be accessed by the cows, 2) were insufficiently high to result in lowered milk production, or 3) were high enough to cause moderate behavioral problems, but the farmer had been successful in coping with the problems to the extent that milk production was not increased by isolation. On the other hand, 31 percent of the herds isolated showed a marked improvement in milk production, namely, over 7 lbs more milk per cow daily" (Lefcourt, ed., 1991, p 3-16).

In Indiana 31 problem farms were studied. Ten of these farms had a tingle voltage filter installed reducing the cow contact potential from an average of 0.7 to 0.06 volts. For nine of these ten farms there was an improvement in behavior and a small increase in milk production.

In the summary and recommendations of the USDA report, Lefcourt wrote, "Based on the results of numerous controlled research experiments, the following are recommended. Neutral -to-earth voltages in excess of 4 V should be mitigated regardless of the existence of an identified stray voltage/current problem. Similarly, contact voltages in excess of 2 to 4 V should be mitigated. Reducing contact voltages to below 0.5 to 1.0 V is unwarranted. Reducing neutral-to-earth voltages to below 1.0 V is also unwarranted, based on our knowledge of relationships between neutral-to-earth voltages and contact voltages as well as field measurements of these relationships. It may be advantageous to reduce neutral-to-earth or contact voltages in the range of 1.0 to 4.0 V, particularly if such voltages appear in the milking parlor. However, action should be taken only after careful consideration of potential costs and benefits" (Lefcourt, ed., 1991, p. 7-2,3)

ADDITIONAL SOURCES OF INFORMATION

The USDA report provides one source of information relevant to the stray voltage problem. It is also instructive to take notice of the information that is obtained from stray voltage investigations, and the descriptions provided by dairy operators and their consultants. While every stray voltage story is different, the information gathered from investigations and from many dairy operators and their consultants shows striking similarities among affected farms

FROM INVESTIGATIONS AND SURVEYS

Field investigations or case studies have been carried out on hundreds of dairy farms. It is a matter of economic survival for the dairy operators to find the solution to problems affecting profitability. As problems in the dairy herd develop, the farmer treats them in the accepted manner. It is usually the case with problems in a dairy herd that the farmer suspects that improved management might be the answer.

With all good dairy operators, there is a lifetime of experience to draw from in analyzing management causes. Obviously management issues such as nutrition, milking equipment, care of cows, pathogens, etc., are each considered. It often happens that the dairy operator exhausts all options for management solutions, but conditions do not improve. In growing frustration, the farmer calls in a series of farm consultants and experts. These individuals are asked to analyze the feed, check for any unusual disease, test the milking equipment and look for any management deficiency. The focus of attention is always on the dairy herd, since it is the dairy herd that provides the income for the farm operation. The consultants make suggestions ranging from procedural changes to buying equipment or special services from the consultants themselves. The farmer acts on the information immediately, spending a considerable amount of money having new equipment installed, introducing a more expensive feeding system, and beginning an extensive vaccination program.

Most often, on a stray voltage farm, none of these approaches resolve the problems, and the conditions continue to deteriorate. After spending a considerable amount of money making changes, the dairy operator continues to lose cattle and production. The consultants have no more suggestions, except to recommend that the farmer consider stray voltage as the cause. The typical owner of a dairy farm suspected of stray voltage problems is a good farmer, with a history of successful experience in the dairy business. While the farmer may have recently purchased the farm, or recently have made significant modifications in equipment or buildings, there is often no apparent reason for the appearance in the dairy herd of effects that are serious enough to require some type of immediate response.

In order to determine whether electricity may be causing problems on a dairy farm, there must be an identification of adverse electrical conditions in the barn and on the farm, a determination of the sources of this electricity, and an assessment of the effects that are perceived to be caused by the electricity. This information is gathered from dairy farm records, from the dairy operator himself, from research, and from investigations by university personnel and other experts.

ELECTRICAL MEASUREMENTS:

Electric utility personnel, university personnel, and other experts have measured various electric and magnetic parameters in the cow's environment. Efforts to establish an acceptable measurement protocol has been a continuing process. The traditional protocol concentrates on three measurements: 1) the AC potential between the utility neutral and a remote ground rod (primary NEV); 2) the AC potential between the farm neutral and the same remote ground rod (secondary NEV); and 3) the AC potential between the floor of the barn in a stall and some conducting part of the barn to which the cow can make contact (cow contact potential). These three measurements are a convenient protocol because they are easily measured and can be standardized for all types of dairy operations. In this protocol the only measurement that has any relevance to the cows' environment is the cow contact potential as experienced by the cow when it touches a conducting part of the barn.

A more complete protocol would include measurements of all electric currents accessing the cows from both AC and DC potentials, as well as measurements of electric and magnetic fields in the cows' environment. Measurements of short-duration potentials, fields and currents are also important. Measurement of electric current in conducting parts of the barn has been helpful in identifying the magnitude and the locations of the stray voltage problem in a specific barn. In some barns there are measurable currents in stall dividers and in other conducting parts of the barn. These parts of the barn are, at times, connected to the electrical system on the farm, but in some way they are always connected to the earth. The AC currents can vary from a fraction of a mA to 100 mA. Changes in electrical use, both on and off the farm, correlate with changes in the currents in these conducting members of the barn. In general, the greater the currents circulating in materials connected to the earth, the greater the adverse effects for the cows. In addition, the cows in stalls with the greatest currents in the stall dividers are, in general, the cows that experience the most severe effects. Another useful measurement is the quantity of current entering the ground on primary neutral grounding wires. This current is returning to a substation through the earth, and has the potential of interacting with any living organism in contact with the earth.

There is some evidence that the conductivity of the earth and/or the concrete floor of the barn can affect the health of both animals and people. When a concrete floor is new, its water content is higher and therefore its conductivity is higher. In construction of new buildings, carpenters are warned to not work on "green" concrete. A similar higher conductivity exists in the concrete of the new dairy barn. In the dairy industry, there is a phenomenon known as the "new barn syndrome." For some period of time after the construction of a new barn, the dairy cows experience more problems in the barn. Dairy farms in areas of high earth conductivity, often coincident with a greater water content of the soil, have a greater potential for problems. On these dairy farms, it is observed that certain electrical conditions tend to prevail even when the farm electrical power is turned off and the neutrals are separated. It is also observed that both alternating and direct currents are present in conducting parts of the barn, and that AC electric potentials are present between two independent ground rods in the region around the barn.

SOURCES OF ELECTRICITY:

Especially during the past 60 years electrical use has increased very rapidly; consequently electric current from this expanded use has increased throughout the regions of the earth where living organisms are found. Particles carry electrical energy from one point to another, and electricity can also move through space independent of any transfer agent such as particles. Electricity is naturally present in the environment, for example, in the electric field of the atmosphere and the magnetic field of the earth. Lightning is associated with the electric fields of the atmosphere, and the use and value of the magnetic compass is dependent on the consistency of the magnetic field of the earth.

Technological development of electrical energy has contributed many additional forms of electricity to the environment. These additions have significantly changed the level and type of exposure for living organisms. Television, radio and microwave transmitters add to the environment electromagnetic fields (EmF) at radio and microwave frequencies, and electric power systems throughout the world produce electric and magnetic fields at frequencies of 50 and 60 Hz, which are also added to the environment. All of these frequencies are nearly absent in the natural environment. In the United States every object that is connected to an electrical circuit, whether in use or not, has 60 Hz electric and magnetic fields surrounding it. Every electrical wire connected to a source of electrical energy is also surrounded by these fields. Large numbers of these sources surround living things continuously, thus significantly increasing their electrical exposure. In the course of the development of transmission systems for carrying electrical energy, direct current (DC) transmission lines have been introduced. These lines produce DC fields and add DC to the environment. Although DC is naturally present in the environment, the transmission lines make changes to the natural DC, and the exposure of life to DC energies is also changed.

One of the most far-reaching encroachments of 60 Hz energies into the environment is the current in the earth associated with the basic design of the entire electrical distribution system. Historically the distribution system that supplies electricity to the consumer was electrically isolated from the earth and therefore a self-contained system. At some point in the expansion of electrical use, a decision was made to connect the electrical distribution system to the earth and use the earth to carry some of the current. Of the possible reasons for this decision, one was to decrease the loss of electrical energy in the system. Another reason may have been to increase the ability to extend the length of the lines and to increase the energy carried on the lines. The overall effect is a national electric distribution system in which 65 to 75% of the current returns to the substations through the earth rather than through the wires (Hendrickson 1995, Gonen 1986, Morrison 1963). The earth becomes one terminal of the electrical distribution system, and electrical currents are, therefore, present to a greater or lesser degree in all materials in the environment. As a result of this environmental change, all living organisms are conductors of electricity and in contact with the earth and other materials carrying electric currents. They are plugged into the electrical circuitry of the distribution system. Living organisms are continually in contact with one terminal of the entire electrical distribution system of the North American continent. Human and animals literally stand on one terminal of the electrical system with no way of escaping that state. All living organisms become part of the electrical distribution system, experiencing electric currents in much the same way as the earth.

For most people, when the electricity reaches the earth, the current is, “out of sight and (therefore) out of mind.” When the electrical current was first routed through the earth, the amount of electricity in the ground was quite small and in general, dispersed, so the potential impact was quite small. The demand for electricity has increased exponentially, however, and the number of users has grown in the same way. The consequent growth in the number and lengths of the distribution lines and the acceleration in electrical use have significantly increased the use of the earth as a current carrying conductor. The quantity of electric current in the earth is no longer small, and the potential impact can be expected to increase accordingly.

PERCEIVED EFFECTS:

As effects are discussed, it is important to keep in mind that living organisms are simultaneously exposed to other environmental agents, and these agents can also cause some of the observed effects. It is important, however, to consider all noted effects on farms suspected of experiencing stray voltage problems. The more information that is available, the easier it is to sort out the separate or synergistic effects from multiple environmental agents.

Animals:

The actions and responses of cows in some dairy barns reveal that cows sense some adverse stimulus that seems to be continually present in the barn. Sometimes the cows also seem to respond to a random event that is present for only a relatively short period of time and then disappears. These effects are observed in stalls where the only cow contacts are their hooves as they stand on the floor of the barn. The overall well-being of the animals tends to degenerate in direct relationship to time spent in the barn.

Upon entering a barn where stray voltage is suspected of causing problems, the cows hesitate and place their noses at the floor surface. That action appears to be the determining factor as to whether or not the cows enter the barn. The same action is noted as a cow approaches the assigned stall. The actions of the cows while standing in the stalls are indicative of an animal that is experiencing a negative stimulus, and would like to escape that environment. They are uneasy, and are seen to "dance" in the stall. Location in the barn is also associated with the degree of behavioral, health, and production problems. In general, end stalls are worse, as are occupied stalls next to or between empty stalls. Other stalls may be uncomfortable without fitting into any clear pattern.

Health and production effects perceived to be caused by stray voltage occur in all types of barns, whether small or large and whether constructed of masonry material, wood or steel. The effects are also independent of the manner of housing and milking the cows. Stray voltage problems occur for tie stalls, stanchions, and parlors. Neither the type of milking system, nor a specific brand of milker, nor the use of milking buckets can prevent the problem. Upgrading from buckets to a milk line commonly increases the severity of the problem. Concrete barn floors are one consistent factor in all these situations. Although spending more time away from the barn and the concrete floor improves the health and production of the dairy cows, it does not eliminate the problems.

The dairy operator observes that conditions become worse when the cattle spend more time in the barn. The effects usually become more severe when ground moisture increases, when electric use in the region around the farm increases, and when there is an increase in underground installation of pipes or cables. The effects decrease when cattle spend less time in the barn and when there is a decrease in electrical usage near the farm. Conditions usually improve significantly when primary grounding wires are disconnected.

In a barn where stray voltage problems are suspected, proximity to any equipment using electrical power increases the problems. (It is interesting to note that in barns where stray voltage problems do not appear to exist, proximity to a piece of electrical equipment does not in itself cause problems.) Because of individual differences among the dairy cows, there can be notable variations in the type and seriousness of effects. In stray voltage barns there is a significant impact on heifers when initially brought into the barn after freshening. If a heifer survives the first lactation without any serious heath effects, the potential for surviving as a productive dairy animal is much greater.

For some dairy operations the onset of stray voltage problems is sudden, whereas with others the problems occur gradually. The cows develop new and undesirable behaviors, such as not eating and drinking in appropriate quantities, dancing back and forth in their stalls, and kicking off milkers. They refuse to enter the parlor or stalls, and they show signs of stress in the bulging of their eyes and other actions. Heifers and cows have trouble getting up, and their legs seem to be numb. They are unable to maintain weight in cold weather, and they experience inflamed sphincter valve (even among unmilked heifers). Under acute conditions the cattle succumb to an apparent heart attack, in some cases attributed to electrocution.

Cows develop multiple or recurring mastitis that does not respond to treatment. There is uneven, incomplete and/or slow milkout, an increase in somatic cell count, and cow production peaks early and does not hold. A persistence of these effects is followed by significant decrease in milk production. The dairy operator also encounters breedback difficulties and breeding problems such as silent heats, absorptions, and spontaneous abortions. The cows experience immune system failures resulting in chlamydia, pneumonia, and bovine viral diarrhea (BVD). They are also susceptible to leukemia/anemia. Many cows have swollen legs and joints, and it is common for leg sores to develop. The cause for the leg sores is normally attributed to a bacterial infection and has a standard treatment. On some stray voltage farms, however, veterinarians treating the sores are unable to find any treatment that can heal the sores.

In general each dairy operation has a veterinarian who is called in to treat health problems in the cows and calves. Treatment centers on ameliorating the symptoms in order to restore the health of the animal. However, treating the symptoms and not the cause has only short-term benefits, and sometimes the treatment is never able to eliminate the symptoms. Some health problems are diagnosed as being caused by viruses for which vaccines are recommended, but on stray voltage dairy farms the vaccines may fail to restore the dairy herd to its former healthy state. Frequently veterinarians are unable to maintain the health of the cattle. Their standard treatments do not work and the cattle do not get well. Veterinarians confirm the observation that the immune systems of the cattle are failing.

There is also the perception that on some farms calves experience significant problems. They may have a poor survival rate, and those who live seem unable to grow at a normal rate. Symptoms such as abscesses, sore gums, burnt knees, and loose hair are common. The calves are often unable to suck normally, and they may experience debilitating diarrhea.

Even pets on the farm can be affected. Cats seem to be more commonly affected than other pets. They may become sickly, with rough, dull and shaggy coats. They often can no longer bear litters, or they give birth to small, unhealthy litters. Some cats suffer from leukemia and often leave the farm and/or die. The dogs may develop stiff joints and become skittish at certain places on the farm property. Dogs, too, may have trouble bearing litters, and they seem to have an increased susceptibility to cancer. In some cases rodents seem to disappear.

Equipment:

Electrical problems may also occur more frequently on a stray voltage farm. Incandescent bulbs blow out, radios and TVs fail, there is an increase in electric motor burnouts, people occasionally receive a shock from water lines or faucets, and there is unexplained fluctuation in electric bills. Under certain conditions, especially near DC transmission lines or pipelines, the farmer may experience an accelerated corrosion of well casings or buried pipes and an unusually high rate of battery failure.

Humans:

The observed human health effects on a stray voltage dairy operation are most numerous and most severe among the members of the family who are the most involved in milking and who work in the barn for extended periods of time. Family members experience excessive fatigue, sometimes including those members of the family who are rarely associated with the milking. They may become accustomed to feeling generally unwell, with no specific apparent cause. Family members often feel under stress and are frequently irritable and forgetful. Some have tingling or numbness in their arms and legs, and sometimes weakness and pain in their legs. They have frequent headaches, and some vision problems, such as blurred vision or heavy eyelids; sometimes they feel pressure behind their eyes. Some family members have problems with breathing and with ringing in the ears. They may have frequent cold and flu symptoms, unexplained nausea, and an increased problem with allergies. One or more of the members of the family may develop rheumatoid arthritis. The women of the family often complain that they feel bloated, and they appear to be retaining body fluid. Most disturbing is the fact that one or more of the family members may develop an illness that health professionals have not been able to diagnose. If family members leave the farm for a period of time, most often the symptoms disappear, and when they return to the farm the symptoms also return. Even though the family members see a connection between their health problems and the problems on the farm, many stray voltage experts insist that it is impossible for stray voltage to have any effect on human health. In research reports many of these same symptoms are associated with what has been called "microwave sickness."

MITIGATION:

Traditionally a stray voltage problem is considered to exist only if there is a cow contact potential of greater than 0.5 VAC with a 500 ohm shunt on the meter. If the electric utility and electricians determine that there is a stray voltage problem, using this criterion, the electric utility and electricians search for the source. They begin by analyzing the farm electrical system. If no problem is identified there, the assumption is made that the source is off the farm. If the source of the cow contact potential is the utility neutral, an isolation system is installed, and the cost is frequently borne by the dairy operator. At the same time additional grounding is often added to the farm to reduce the cow contact potential. The dairy operator is also advised to add mitigation systems such as the equipotential plane.

The farmer may experience a number of results from these actions. There may be noticeable beneficial changes in cattle production, behavior and health. These changes may continue to be beneficial for a long period of time, or they may be temporarily beneficial for a week, a month or a year or more. Then, with no change in operation of the mitigation systems and with cow contact potentials below 0.5 VAC, the effects appear again, as serious as they were before any electrical mitigation was carried out. A large percentage of the dairy operators using an isolation system or other mitigation method experience only a temporary change in the stray voltage effects. The changes resulting from mitigation efforts can also be detrimental. Adding grounding, for example, is an option that is unlikely to cause any improvement in the problem; in fact, it more often aggravates the seriousness of the effects

Dairy operators who have installed an equipotential plane to solve a stray voltage problem have most often been disappointed with the results; in fact, the plane may become more of a liability than an asset. Dairy operators frequently observe an improvement in the dairy cows immediately after installing the equipotential plane, but within a week or two the cows' problems return. For some dairy operations the installation of an equipotential plane has significantly increased the original problems. In some cases facilities that had equipotential planes installed at the time of construction have had serious health and production problems in their herds from the beginning. Dairy operators who have equipotential planes installed at the time of the construction of a new facility have no means of assessing the value of the plane, or its possible detrimental effects, because they have no condition with which to compare.

The equipotential plane is a perfect theoretical model for protecting cows from being shocked, because everything with which the cows come in contact is at approximately the same electrical potential. Because the equipotential plane is connected to the neutral wire of the electrical system, the barn floor is normally placed at a different electrical potential from that of the earth surface around the barn. As a possible consequence of this condition, the cows may be reluctant to enter the barn for fear of being shocked when their front feet were on the barn floor and their rear feet on the earth. To mitigate this possible problem a variable potential ramp is installed at the entrances to the barn. Thus, it would appear that the equipotential plane should eliminate any possibility for cows to experience intermittent shock of sufficient magnitude to cause health and production problems.

The equipotential plane, however, can also increase the electrical exposure of cows. The wire mesh in the equipotential plane is close to the surface of the floor and every other conducting part of the barn is connected to it. The metal mesh of the equipotential plane increases the conductivity of the barn floor. Because the plane is connected to the neutral and grounding wires of the electrical system, more electric current is in the floor of the barn that has a plane than in the barn without one. Because the wire mesh and other connections have decreased the source impedance and the cows are in direct contact with the floor, they can actually experience more electric current. These currents can be either continuous from step potentials or intermittent from normal cow contact potentials. Some dairy operators have discovered that the only way their dairy operation could survive with the equipotential plane was to disconnect the equipotential plane from the neutral and from as many other barn components as possible.

INFORMATION SUMMARY:

If none of these recommended remedial actions are able to make the operation profitable, and the problems for the dairy cows persists, investigators assume that the dairy cows are being affected by some unknown entity—or that the dairy operator is unable to successfully manage the dairy operation. With the earlier help of management experts, however, the dairy operator has already examined the management of the operation, and management changes were not able to correct the problem. Even veterinarians were unable solve the health problems. From the information gathered in the search for a solution to the problem and from his experience, the dairy operator can only conclude that the major cause can be neither management nor intermittent electrical shock. Many dairy operators have observed that changes in the electrical system itself correlate with changes in the behavior, health, and production of their cows and have become convinced that some form of electrical exposure must have primary responsibility for these problems in their herds.

The operators of farms experiencing stray voltage problems not only encounter considerable financial losses, but they also spend thousands of dollars attempting to get the problem solved. They realize that as soon as they admit that problems have not been solved and that the farm is a stray voltage farm, it no longer has value as a dairy operation. The family faces the prospect of losing both their farm and their future. When no solution is found, stray voltage can destroy profitability. Milk production decreases, productive cows are lost due to death, unproductive cows have to be sold for slaughter, and replacement heifers are limited in number because of the high loss of calves.

EXPERIMENTAL WORK

Dairy operators and stray voltage investigators have performed many on-farm experiments to test hypotheses developed from observed electrical and health conditions on the dairy farm. While these experiments have yielded interesting and valuable information, they have not always been taken into account in stray voltage research.

In one type of experiment, AC was introduced into the ground to determine the impact on the cows. Even though the number of trials was small, in all cases there were documented effects on behavior, health and production. The health and production problems persisted for several days after the electricity was removed, sometimes for as long as a week or two.

Over the past number of years dairy operators and electrical experts have measured significant electric currents reaching the dairy barn from the primary neutral, even when there is no electrical wire connection between the primary neutral and the barn. These measurements have encouraged the dairy operators to take the desperate step of disconnecting the primary grounding on their farms, and sometimes even off their farms. This mitigation method is not approved by the electric utilities and is not recommended by electrical experts. Consequently only a small number of cases are documented. For 20 known cases, disconnecting the primary grounding wire had an immediate and beneficial effect on behavior, milk production, somatic cell count (SCC), water and feed consumption, and general health of the animals. On some farms disconnecting the primary grounding wires has been the only successful measure for preventing the death of the dairy animals. Unfortunately on many dairy farms, however, the length of time the primary grounding wire has been disconnected is inversely related to the benefits of disconnection. Thus disconnection of the primary neutral does not seem to be a permanent solution to the problem. In addition, when the grounding wires in and around one farm were disconnected, problems on nearby farms sometimes increased or decreased. For a number of the farms there are records available to document these changes. Measurements of cow contact potentials on these farms revealed values in the range of millivolts both before and after grounding wires were disconnected, leading to the conclusion that electrical shock does not account for the observed health problems.

On one farm the Minnesota Environmental Quality Board performed an experiment to determine the benefits of disconnecting the primary grounding wires. The results of this experiment have been interpreted differently by the dairy operators and the engineers from the electric utility. Dairy operators noted a small but distinct improvement in water consumption and milk production after the grounding wires had been disconnected, whereas the utility engineers concluded that no changes had taken place. The Minnesota Environmental Quality Board chose to interpret the results in the same way as the electric utilities. The problems and the subtleties of this experiment are presented in a report prepared by The Electromagnetics Research Foundation, Inc. (TERF) (Dahlberg, 1993).

On the same farm and a year earlier, a similar experiment was carried out by the dairy operator and a veterinarian. On and near the farm, two utility grounding wires had been disconnected for a number of years, and on April 14, 1992, the utility reconnected the two grounding wires. The dairy cows were monitored for a period of approximately one month, from about two weeks before to about 2 weeks after the connections. During that time period the dairy operator maintained the same management practices, the cows were checked by the veterinarian, and two blood samples were taken, one at the beginning and one at the end of the test period. During this experiment the only change on the farm was the connecting of the grounding wires, which increased the current going into the ground on the farm. Both observed and measured changes occurred in the behavior, health and production of the dairy cows. Among the measured changes were an increase in SCC, a decrease in water consumption, a decrease in milk production, and a change in the blood chemistry. The change in the blood parameters could be the indication of a breakdown in the immune system or of a precancerous condition (Hartsell, et al 1994).

Between cow contact points in dairy barns, DC potentials ranging from 0.3 and 1.0 volts are common. Experimental work in dairy barns has shown that continuous exposure to DC can affect the dairy cows both positively and negatively. These results have encouraged dairy operators to experiment with the use of DC for mitigating stray voltage problems. Dahlberg and Falk (1995) identify five farms that have used batteries or DC power supplies to neutralize the DC in the ground. Empirical methods were used to determine where and how to connect the DC source in order to produce beneficial effects. Inappropriate connections could and did cause adverse effects. In all cases when the appropriate connections were made, improvements in milk let down, SCC, behavior and milk production were noted. In only one case, however, did the benefits persist.

Dairy operators have discovered that raising animals off the floor and increasing the electrical resistance between the animals and the floor can have beneficial effects. Two specific methods have been used. One involves the buildup of a straw pack for dry cows and calves that increases the electric resistance between the animals and the concrete floor. In another strategy the cows are placed in a trailer that is electrically isolated from the earth and some distance (1-2 m) above the surface of the earth. Both of these methods have been quite successful in reducing the loss of calves and improving the health of dairy cows. The straw pack method was successfully used for calves in a university dairy barn; it has also been useful for both calves and dry cows on a number of dairy farms. One dairy operator has recorded success in significantly increasing milk production and improving the health of cows by using a trailer electrically insulated from the ground. In fact, this operator has had greater success in treating mastitis by housing the sick animal on the trailer without medication than by treating the animals with antibiotics in loafing pens. Other dairy operators have also used this method for improving calf survival and growth. Even though the positive impact of this procedure is sufficient to encourage its use, the cost in dollars and time is too great to make it realistic on a commercial scale. This procedure does not provide a solution to the problems on the dairy farm; it only mitigates the problems for the isolated animals. Perhaps the greatest significance of these experiments is the demonstration of a convincing direct relationship between the health and production of the dairy animals and the resistance of the medium separating the animals from the ground. While these experiments do not prove that a specific quantity or type of electricity is the cause of specific health and production effects, they clearly indicate an association between exposure to electricity and animal health.

An electric current trap was developed experimentally by Vulcan Engineering for the purpose of controlling ground currents on dairy farms. The determination of the trap location was based on the measurements among five copper-clad steel grids buried in the ground. The currents measured between each pair of grids provided information as to the main direction of current flow in the earth. Once this direction was determined, a large wire grid was buried in the earth in the path of the current flow toward the farm. The grid was a series of wires that appear to be able to create a resonant effect for the 60Hz frequency and its harmonics, or at least to divert current away from the farm buildings. The trap was not connected to the neutral of any electrical system; it was a free-standing unit not connected to any electrical energy source. When functioning as designed, the grid seemed to absorb energy, resulting in an increase in grid temperature. Some dairy operators observed that grass did not grow over the grid and that cattle avoided it.

Of five farms reported to have used such a trap, three experienced an unusual improvement in the behavior, health and production of the animals after the trap was installed (Dahlberg and Falk, 1995). The length of time that these improvements persisted ranged from a few months to approximately one year. On two of the farms additional traps on different sides of the farm were added in the path of lesser electric currents in the earth. Each time an additional trap was installed there were renewed improvements. Again these improvements did not persist for more than a few months. The fact that this approach has had some success, however, suggests that current traveling through the earth is accessing the farms and affecting the dairy animals.

In their attempt to maintain a profitable dairy operation, dairy operators have also experimented with burying a vertical conducting grid for redirecting the current in the earth. These buried vertical conducting grids have provided only occasional improvements. On some farms conducting cables or pipes are placed on the ground surface or dug into the ground to encircle the farm buildings. In some cases the current in these conductors is sufficient to light a small light bulb. Encircling the farm with conductors has been associated with some improvement in the health and production of dairy herds. More time is required to assess the long-term value of these mitigation methods. Some farmers have also tried trenching around animal housing and installing sheets of plastic vertically as a barrier to the electric currents in the earth. The overall impact of the plastic barrier is still under investigation.

Scientific principles provide support for the experiences of the dairy operators who have experimented with diverting or interrupting electrical currents in the earth. The earth is in electrical equilibrium determined by many factors, including the amount of electric current entering the earth, the relative conductivity of various regions of the earth, the location of electrical neutral connections to the earth, and the impedance of ground connections. The earth is a complex electrical structure, similar to an electrical circuit. When a source of electricity is disrupted, changes occur in the electrical equilibrium in the earth. These changes, in turn, can affect the electrical currents accessing cows in a specific barn, resulting in the improvement observed by dairy operators after they have disconnected grounding wires or deflected the currents in the earth. With time, however, the earth has a tendency to return to its long-term electrical equilibrium, and the stray voltage problem may reappear. Changes in the equilibrium can also occur as new sources of electricity enter the earth, and with changes in the quantities of current in the earth, the conductivity of the earth, and the impedance of the ground connection.

PARADOX

There are a number of inconsistencies between controlled research associated with stray voltage and the results of farm investigations and research.

DIFFERING CONCLUSIONS

Controlled research has determined that stray voltage is a recognized phenomenon. This research has documented basic physiological mechanisms of stray voltage, identified its sources, and offered solutions through the use of cost-effective mitigation procedures and equipment. Farm investigations and research, on the other hand, suggests a deeper and somewhat different problem for which mitigation has not proved effective and no solution has been found.

Controlled research has concentrated on acute behavioral effects of intermittent exposure of dairy cows to small shock currents. The basic physiological mechanisms identified by this research include potential physical responses brought about by exposure to intermittent electrical shock and conditioning to that shock. Some research has also considered the question of possible health and production effects from exposure to small intermittent shock currents. Because of the lack of a defined mechanism for possible health and production effects, these issues have not received as much attention. Electrical shock is well known to be able to cause a physical response from currents in the low milliampere range. Research has been primarily concerned with determining the level of shock current that can cause a physical response in dairy cows. It is believed that health effects are produced because of avoidance, such as not drinking sufficient water, or because of methods of managing behavioral problems. Controlled research has not developed physiological mechanisms for possible chronic health and production effects from intermittent 60 Hz shock currents, but claims that the consequences of physical responses can indirectly lead to production and health effects.

Field investigations clearly demonstrate that stray voltage can have a significant effect in dairy operations. In farm investigations carried out by dairy operators and by other professionals, consideration was given to laboratory research, observation and testing on farms, as well as to other research examining effects of electricity on humans and animals. The basic physiological mechanisms considered in controlled stray voltage research can be relevant, but they do not explain the overall stray voltage problem as recognized in field work. The results from field investigations emphasize that electrical shock cannot be the major cause of the observed effects, and behavioral changes are not the most significant response to electrical exposure. From the information they have gathered and from their field investigations, dairy operators and their consultants have concluded that exposure of cows to electricity can cause a wide variety of adverse effects. These effects include physical responses, decrease in milk production, numerous health problems (some associated with a failure of the immune system), reproduction problems, and death of calves. There is no evidence that these effects can be totally attributed to electric shock.

The documented effects, the electrical measurements on farms, and the research literature emphasize the need to consider other electrical interactions that can be caused by any or all of the electrical sources in and outside of dairy barns. Experimental work on farms shows that adverse effects on animal and electrical equipment most often correlate with the quantity of electric current entering the earth from electrical systems. Through the use and analysis of the results of questionnaires, a strong correlation was identified among effects on animals, electrical equipment, and people. Although farm electrical problems such as ground faults have been known to correlate with these effects, it is also evident that the current entering the earth from the electrical utility system also correlates. At this time the available information is unable to point to one single electrical measurement as the cause, nor to one single effect such as reduction in milk production. Both the electrical causes and the effects appear to be far too complex for a simple, single explanation.

According to results of controlled research, the sources of electric current are from either the farm or the utility electrical system, and the current accessing the cattle originates from wires that are in contact with the cows' environment. Field investigations also recognize that currents can reach the environment of cows by means of wires including the farm neutral, the utility neutral, telephone cables, and cable television. In addition to these sources, however, field work finds that currents in the earth are also able to reach the cows' environment. They may originate from grounding systems near the farm or even far away from the farm. These currents are identified as ground currents.

The only solution to the stray voltage problem offered by controlled research is to reduce the cow contact potentials below the level of concern. While the level of concern has not been exactly determined, it is in the range of 0.5 to 2.0 VAC. Based on these conclusions, mitigation is attempted by correcting any problems in the farm electrical system, by isolation, by installation of an equipotenial plane, or installation of an electronic grounding system. These mitigation methods are used primarily to reduce cow contact potentials.

Field investigations have also determined that the solution to the stray voltage problem requires a significant reduction of the electricity in the cows' environment. Reduction of cow contact potentials alone, however, has not been able to control stray voltage problems, although various mitigation procedures have at times been correlated with improvements in behavior, health, and production. At this time the most appropriate approach for dealing with the stray voltage problem is to begin the process of reducing overall electrical exposure for cows. Unless the source of electrical exposure is from the farm electrical system itself, however, a solution is out of reach of dairy operators.

Many dairy cattle specialists, including veterinarians, have experimented with changing rations, types of milking equipment, and management practices, but none of the changes have solved the problems. Even university experts in the field of stray voltage have not been able to provide solutions for the health and production problems that are occurring on these dairy farms. They may recommend to dairy operators who think they have a stray voltage problem that they should handle their cows more gently, and also to assess their management practices. Dairy operators and their specialists have concluded, however, that without new, definitive information that demonstrates management as the cause, the behavior, health, and production problems must have electrical causes in addition to those attributed to intermittent electric shock from cow contact potentials.

INCONSISTENCIES IN RESEARCH

The USDA report (Lefcourt, 1991) states that experiments involving long-term exposures indicate that cows can acclimate physiologically and behaviorally to constant and intermittent shock current below 6 mA. Also in the report, Aneshansley and Gorewit concluded that due to conditioning, behavioral problems may continue after cow contact potentials have been reduced below 0.5 to 1.0 VAC. It would seem that there is an inconsistency between reports of the experimental work and the conclusion concerning conditioning.

Aneshansley and Gorewit also point out that even though there may be exaggerated behavioral responses, electrical exposure during milking or between milking does not cause any significant physiological effects in dairy cows. They also note, however, that large and detectable health effects do occur in other animal species at similar exposure levels. Even though there can be differences in effects among species, it is unclear why one would expect to see effects from electrical exposure on other animal species, and yet find absolutely no effects on dairy cows from the same electrical exposure. Effects from chemical exposures, for example, are known to be comparable for humans and for most animal species.

Another of Aneshansley's and Gorewit's conclusions from the USDA report is this: "As shown by research under controlled conditions and by many field observations, the primary reason for any loss in milk production by cows exposed to currents of 4.0 to 6.0 mA appears to be due to the farmer and the way affected animals are handled. Affected animals may cause milking machine operators to become frustrated and less patient and to employ inconsistent, hurried, and less desirable milking practices" (Lefcourt 1991, 3-21). This is a very narrowly conceived conclusion and observation. Only on very few dairy farms is the cow contact potential in the range of 4-6 VAC (Relnes, et al. 1998). It is not clear where the controlled research on dairy farms was carried out to validate the Aneshansley and Gorewit conclusion. An investigation of handling of dairy cows on farms under controlled conditions would require a carefully designed protocol. Within the protocol there would need to be a procedure for monitoring electrical exposure, a procedure for measuring milk production, and a system for classifying the responses of the dairy operator to the specific actions of the cows. In addition, it would be necessary to have a set of dairy farms with no stray voltage problems that could be used as a control group. Because there is no record of this type of research in the peer reviewed literature, the value of this conclusion is questionable. Farm investigations find no uniform response of dairy operators to the adverse actions of cows. Some operators are very tolerant while others are not. Dairy operators know that the better they treat cows, the more profitable their dairy operation is likely to be, and this is one of the most important principles in dairy operation.

It is often emphasized in the USDA report that mastitis is caused by pathogens and not by electricity. There is evidence from other scientific studies, however, that environmental agents can interact synergistically or additively to produce health effects. Acid rain and the loss of forests provide an excellent example. In general the trees die from a combination of acid rain absorption and insect infestation. The cause may not be totally attributable to acid rain, but acid rain can weaken the trees so that a disease carried by insects is able to take over. The same could be true for the onset of mastitis. Electrical exposure may weaken the cows' immune systems so that the mastitis pathogen, which is always present, is able to infect the cows' utters. It is also possible that particular pathogens may become more active in certain electrical environments.

The USDA report suggests a scenario in which the milking time is increased because of the cows kicking off milkers or because of delay in entering the parlor, and the farmer then takes shortcuts in the milking routine in order to make up for the lost time. It claims that a likely consequence is an increase in bacteria left on the udders and an increase in mastitis. Although this is a possible scenario, it cannot account for the sudden increase in mastitis that has occurred on farms immediately after an electrical problem causing electrical exposure has developed. The most disturbing aspect of the onset of mastitis in these situations is the inability of normal antibiotic treatment to stem the increase.

In a Minnesota study investigating the value of isolation devices, 69 % of the isolated farms in the study had no increase in milk production one year after the installation of the isolation device. In the USDA report Aneshansley and Gorewit present three possible reasons for this research result. They suggest that the electric potentials from the utility neutral, before isolation, either 1) failed to access the cows, 2) were too low to affect milk production, or 3) were sufficiently high to cause some behavioral problems, and the farmer effectively dealt with the behavioral problem so the production was not affected. Although these factors may have played some role, other reasons should be considered. From the experiences of dairy operators, another possible reason for the 69% of farms not showing any increase in milk production is that even after isolation, sufficient current is reaching the cows from other ground sources to affect the cows and their milk production.

Aneshansley and Gorewit also theorized that the 31% of the dairy herds that improved after isolation had sufficiently high cow contact potential before isolation to account for the improvement in milk production. Unfortunately, there were no measurements of cow contact potentials provided as part of the study. While it may be that the improvement was only from the reduction in cow-contact potential, as suggested by Aneshansley and Gorewit, there are also other logical interpretations of the results from this study. Production improved after isolation, and isolation represents an electrical change. Isolation, in general, decreases the cow contact potential, but decreasing cow contact potentials does not necessarily cause an improvement in health and production (Relnes, et al, 1998). Isolation also changes how and where electric current from the primary neutral enters the earth, and this change influences the net current reaching the cows. According to the experience of dairy operators, on some farms a decrease in cow contact potentials through isolation correlates with improved milk production, and on other farms there is no change in milk production. The ratio of 69% with no change to 31% with improvement realistically portrays the true level of effectiveness of isolation. The fact that there was no improvement in the health of cows, either in the group of farms that had an increase in milk production or the group that had no increase, also suggests that isolation does not solve the problems. It is appropriate to conclude, from the results of this research, that electricity does affect dairy cows. The research leaves unanswered, however, the question of the mechanism by which electricity is affecting dairy cows.

RECOMMENDED PROCEDURE

This intractable impasse between laboratory and field research should encourage a more comprehensive study of this problem. Although it is well known that some of the behavior, health, and production effects observed in field studies can have causes related to management, a more comprehensive study of this problem must concentrate on electrical causes. Management cannot continue to be the scapegoat for problems that are not yet fully understood.

RESOLUTION

GENERAL CONCEPTS

When confronted with a perceived problem, for which the proposed understanding and solutions are deemed to be totally inadequate, it is important to consider this insight from the highly respected physicist Richard P. Feynman. He says, "When we see a new phenomenon we try to fit it into the framework we already have….It's not because Nature is really similar; it's because the physicists have only been able to think of the same damn thing over and over again (19)." This same concept could also be applied in the area of stray voltage. Stray voltage research groups have become attached to the shock syndrome, and it is apparently difficult for them to consider the possibility that the effects reported on dairy farms can be caused by an electric exposure even though the effects do not fit within the shock model.

In general, physical laws are proposed to give structure to our understanding. These laws are not the ultimate truth of physical reality; they are simply the best models that humans have been able to agree upon from present understanding. As more information becomes available, physical laws frequently change. Physical laws related to living organisms are especially likely to change in the face of new information.

Research involving the assessment of health effect in living organisms caused by environmental agents is probably the most difficult type of research. Its difficulty would be reduced if such research were totally mechanistic; that is, if exposure to an environmental agent could be expected to cause the same effect in all members of a specific species, and if there were a known mechanism connecting cause and effect. When electricity is the environmental agent under consideration, the most obvious mechanism involves the energy of electricity destroying some entity of the living organism. It may be the breaking of chemical bonds that causes molecular structure to be changed or destroyed. Research has established that large currents and microwave radiation can affect living organisms in this way. This mechanism, however, accounts for only the energy characteristic of electricity and for the physical change in chemical structure resulting from the breaking of bonds or the destruction of molecules. Other effects, not directly related to energy, may also play a role.

In electrical exposure, electric currents traverse the body of living organisms in direct proportion to the electric potential and the varied conductivity of the body. These currents in the body set up magnetic fields. If electric charge increases at a given point in the body, a localized electric field is produced. There may well be mechanisms that could describe interactions that occur simply because of the presence of the currents and fields, and these interactions could cause biological or health effects. If this is the case, such mechanisms will certainly be more difficult to identify, because the electric and magnetic properties of the entire body of the living organism have never been mapped. There is no comprehensive model for understanding all of the different ways that the body uses electricity for maintaining its integrity, or for the role of electricity in all body functions.

Experimental work always requires research specialists to make assumptions, select conditions, decide the questions to be asked, draw conclusions, and interpret those conclusions. Each of these steps contains a number of variables and a number of possible choices, and each of these could affect the outcome of the experiment. Several research specialists may each decide to study, for example the possible effect of DDT on birds. If they set up the experiments independently, it is unlikely that they would draw the same conclusions. Over time one procedure, one set of conditions, and one method of interpretation may be established in order to compare results. Whether these choices will be useful in finding the truth concerning the effects of DDT on birds is an unknown at the time the choice is made.

The search for the best model for research of a given problem may move in many different directions. For example a specific mechanism might be chosen to explain the interaction of DDT in birds. Research protocols would then be prepared to examine possible effects using the chosen mechanism. If research concerning the chosen mechanism is not able to match observation, other mechanisms or models must be considered. Research that applies a number of possible mechanisms has special value and may actually be required before cause and effect for any physical phenomenon can be fully understood.

It is the choices that are made in research that guide its results. Factors such as methods of data collection, approaches for analyzing data, and selection of individuals for performing the peer review operation all can affect the outcome. In addition, specific assumptions are made in interpreting the results. When a new research outcome is reported, it is necessary to carefully describe the choices and assumption used in that research. With new discoveries there is also a need to replicate the original results. Those attempting to replicate research must establish a protocol that is similar to the original work. As additional research is carried out under similar conditions, new information will be obtained. In the case of most human endeavors, there is never unanimity, and there may or may not be consensus in the interpretation of the results. For possible effects from electrical exposure in dairy barns, the acceptance of the shock model in stray voltage research has certainly been dominant.

When a mechanism has been adopted as unanimously as that of the shock model in stray voltage research, it is difficult for research scientists to embark on a new direction that involves the investigation of a different mechanism. At the same time there has been acknowledgement that the shock mechanism may not be the only possible means by which electricity can cause effects. One member of the research group that authored the USDA report, Professor Craine, writes, *"The effects of electrical energy on neural electrical/chemical interactions in animals are complex, and examining those effects is beyond the scope of stray voltage specialists"* (Lefcourt, ed., 1991, p. 6-2). Italics added. As discussed previously in this paper, Aneshansley and Gorewit also point out in the USDA report that large and detectable changes do occur in other animal species at similar electrical exposure levels.

One of the important principles of scientific work is never to ignore information. All information becomes useful in problem solving. When information is rejected because it is not prepared in a particular format, because it does not fit within existing paradigms, or because it conflicts with existing peer reviewed information, incomplete understandings and inappropriate assumptions are perpetuated. This is probably the major "road block" for discovering the cause or causes of adverse effects from any environmental agents. The evidence gathered by dairy operators and in farm investigations is an important set of information that must be studied and considered, but so far it has rarely been taken into account.

STRAY VOLTAGE PROBLEM

Many dairy operators are hoping for a resolution of the stray voltage problem, because present methods of analyzing and controlling the problem are not effective. In order to help them, it will be necessary to recognize the results of on-farm investigations and experimental work conducted by investigators and dairy operators, in addition to utilizing the results of past research. From farm-based information, it is clear that the scope of investigation must be broadened to include a greater variety of possible causes and effects. There are many reasons for broadening the scope, and some these are presented in the following paragraphs,

GENERAL REASONS:

A survey of research associated with other animals and humans reveals that numerous effects from electrical exposure have been extensively studied over a period of many years. The major general research activity has involved studies of possible health effects from electricity, primarily chronic effects caused by both long-term and short-term continuous exposures to fields and currents. With the exception of electrocution, little attention has been given to acute effects from shock. In general this research has focused on possible effects from levels of fields and currents that can exist in the regions where people live and work (Becker, et. al. 1982, Becker 1990, Binhi 2002, Cherry 2000, Lee, et. al. 1996, Nordenstrom 1983, Polk and Postow, Editors 1997, and Pressman 1970).

The general results of research involving effects from electrical exposure were presented in a letter to the US Congress by presidents of the American Bioelectromagnetics Society. From that letter is one statement, "A wealth of published, peer-reviewed scientific evidence indicates that exposure to different combinations of electric and magnetic fields consistently affects biological systems in living body as well as in laboratories" (Luben, et.al. 1996, p. 4). In the Introduction to his book, Binhi writes, "A large body of observational evidence gleaned over years strongly suggests that some electromagnetic fields pose a potential hazard to human health and are a climatic factor that is of no less significance than temperature, pressure, and humidity" (Binhi 2002, p.1). In his introduction Binhi also presents a number of issues that have confounded progress in establishing a clear understanding of the effects of electric and magnetic fields. Many research specialists studying effects from electric and magnetic fields recognize that exposure to these fields can produce both positive and negative effects. One of the difficulties is the fact that the physical mechanisms for the biochemical actions of very weak EM fields are not understood. From energy principles there is a paradox. This paradox is especially clear in research involving low frequency fields. The field energy quantum is approximately ten orders of magnitude below the characteristic energy of chemical bonds. There is no physical mechanism that can explain biological processes at those field levels (Binhi 2002).

From his research Pressman (1970) has concluded that because physical mechanisms cannot define biological effects from EM fields on living systems, a fundamentally new theoretical approach to biological effect is needed. His approach is based on information theory. Applying this theory he claims that in addition to energetic interactions, informational interactions have the dominant role in biological processes. Energetic processes in biological activity are in response to information provided. That information can be provided by electrical stimuli.

In his book Pressman wrote, "Thus, an examination of the mechanisms of energetic interaction of EmFs with biological media cannot provide a basis for an explanation of the high sensitivity of living organisms to EmFs. This means that we cannot base our approach to the problem of the biological effects of EmFs solely on the physical principles of interaction EmFs with the substance, as can be done for nonliving objects. Living organisms apparently have systems which are particularly sensitive to EmFs. These systems can be discovered and their mechanisms revealed only by biological investigations in which due regard is paid to the biological, and not the physical, principles of interaction of EmFs with living organisms" (1970, pp. 85,86). He further states that systems of living organisms are very sensitive to electrical exposure, and there are no analogs in engineering that can explain the electrical interaction. Research has provided a wealth of information concerning effects of EM fields. Studies have been performed on many types of organisms, from unicellular to complex. For some systems of organisms the effects from EM fields are independent of both frequency and intensity, which are both energy related. For other systems there can be a dependence on frequency or intensity or both. In experiments in vitro there is in general both an intensity and a frequency dependence whereas for experiments on whole organisms effects most often are independent of frequency and intensity.

There appear to be at least two phases for reactions to exposures. Low intensities or short term exposures produce opposite biological changes from those related to high intensities or long term exposures. Effects from multiple exposures are cumulative. One implication of the two-phase reaction is that living organisms exposed for a length of time could experience effects early in the exposure that could be reversed later. This could be one reason for the observation that EM fields act differently on different individuals. Another similar observation is that some systems of living organisms respond quickly to EM field exposures and others respond slowly. The fact that materials in the body rectify alternating currents is an added complication in efforts to understand the biological effects from electrical exposure. Different frequencies in the body are rectified to a greater or lesser degree. Therefore there are direct currents (DC) in the body from any and all exposures (Pressman 1970). The work of Nordenstrom shows that additional DC affects the naturally-occurring DC that controls functions of the living organisms (Nordenstrom 1983).

REASONS ASSOCIATED WITH DAIRY CATTLE RESEARCH:

If acute effects associated with electric shock were the only correct model for stray voltage problems, eliminating the shock current from the cows' environment should solve the problem. It is possible to decrease cow contact potentials in the dairy barn below those capable of producing a current large enough to cause a perceptible shock as defined in the USDA report. Research in Wisconsin has shown, however, that levels of cow contact potentials do not correlate with the severity of health problems (Relnes, et al, 1998). Mitigation of shock currents has been at times correlated with a decrease in behavioral problems, but it has had little impact on health and production. Improvement of overall behavior, health and production to a level that allows for a profitable dairy operation has not, in general, been attained with a reduction in cow contact potential. Beyond the research of intermittent shock currents in the range of 1 to 8 mA, there are only a few attempts at considering effects from currents less than 50 microamperes, and there is also little research that primarily considers chronic effects.

Burchard and his colleagues conducted studies of dairy cows exposed to a combination of a 10 kV/m electric field and a uniform magnetic field of 30 microtesla for a period of 28 days. An AC electric field induces a current in the body; an AC magnetic field induces a separate current in the body and also exposes the body of the cow to a magnetic field. If one considers the induced current as the only possible cause of effects, the currents are considered to be in the range of 20 to 30 microamperes. Effects were reported from three different research projects. One showed a decrease in milk fat. A second showed an increase in quinolinic acid and a trend toward an increase in tryptophan, which is consistent with a weakening of the blood-brain barrier that opens the cells of the brain to toxic chemicals in the blood. A third research project found decreased concentrations of magnesium in blood plasma, as well as increased concentrations of calcium and phosphorus and decreased concentrations of iron and manganese in cerebrospinal fluid of cattle (Burchard, et.al., 1996, 1998, 1999). Each of these findings represents biological changes that can affect the health and production of dairy cows.

In the 19 Farm Study done in Minnesota, step potentials between front feet and rear feet of the dairy animals were found to be in the range of 1 to 27 mVAC on the farms in the study. If one uses 500 ohms as the internal resistance of a cow between front and rear feet, the current for these potentials ranged from 2-54 microamperes. Step potentials were inversely correlated with milk production at a statistically significant level (MNPUC 1998, Polk, 2001).

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A major barrier in mechanism development for electric effects is the lack of a clear understanding of the electrical and magnetic systems of living organisms. Although electrical aspects of some systems of living organisms are known, a comprehensive understanding of the electrical and magnetic functioning of the entire organism has not yet been achieved. This information will be important for the establishment of possible mechanisms and testing them in research.

Stray voltage research has assumed that animal tissue generally behaves according to the simple form of Ohm's law: V=IR (electrical potential between two points on the body of living organisms is equal to the total current in the body times an average resistance). This use of Ohm's law is qualitatively adequate for explaining acute physical response from a shock current. If one wishes to study chronic effects, however, it is necessary to know where the current is going in the living organism and how it interacts with each part of the organism. Living organisms are complex organic systems with ionic components. Resistance of organic systems is a complex function of many variables. Consequently a more general form of the Ohm's law is required. This form states that the current density in an object is equal to the conductivity times the electric field ($J=\sigma E$). Conductivity, which is the reciprocal of resistivity, is obviously not a constant for organic and semiconducting materials. In fact conductivity can be a tensor when electrical conductivity has different values for current traveling in different directions in a material. In the case of animal tissue, resistivity is dependent on the direction of current flow, the direction of the applied electric field, the magnitude of current density, and frequency. Some body materials have diode characteristics, and are able to rectify AC. Other parts may be piezoelectric and generate electric currents when stressed. In addition there are orders of magnitude differences in conductivity of different parts of the body. Fluids, in general, have higher conductivity and fibrous materials have lower conductivity.

When electrical potential are applied between two points on the body of an animal, the fraction of the current in each part of the body is directly related to the electrical conductivity of that part. It is possible to determine what portion of the current is in the nerve fibers or the vascular system, for example, but only if the relative conductivity of the entire body can be mapped. Since many molecular structures in the body are polar in nature, capacitance can vary throughout the body. These many molecular structures also have different magnetic properties that can, therefore, have a different inductance. Predicting how current from an applied AC potential will vary from one part of the body to another requires knowledge of both capacitive and inductive reactance as well as conductivity. These complexities support the need to take a more general approach in the investigation of cause and effect from electrical exposure.

In a number of the laboratory research projects individual cows showed a significant decrease in milk production and other negative effects. There were also large variations among cows. The fact that cows responded differently suggests that there can be significant individual differences in observed effects from the same electrical exposure. This is consistent with the natural differences that occur in living organisms. The fact that cows respond differently to the same exposure provides valuable information for research protocol. Research has demonstrated that environmental agents can affect different members of the same species differently; they can also cause effects to be reversed as the length of exposure is increased.

In general approximately ten experimental cows have been used in laboratory research. When living organisms such as dairy cows are the subjects of research, their individual differences and length of exposure to an environmental agent can significantly skew research results gleaned from the application of statistical methods. Statistical methods are most appropriate for analyzing data from large numbers of experimental subjects. Even when statistical methods are used in looking for trends or associations, the value of the conclusions is highly dependent on the number of subjects. When working with small numbers of subjects, the quality of the information gathered is greatly enhanced by analyzing each subject separately, and by following the changes in each subject as a function of length of time exposed. There are experimental methods established for working with small numbers of subjects that can take into account these variables.

The electrical environment of all dairy facilities, whether university research barns or commercial barns, is very complex. The experience of dairy operators makes it clear that totally eliminating exposure to electricity in a dairy barn is impossible. As a consequence, even in university research barns there is the possibility that a certain level of electricity is always present and can affect cows. In any research project it is prudent to account for those exposures without prejudging their ability or inability to cause effects. Thus if both experimental and control animals are housed in the same dairy facility, it is difficult to satisfactorily determine effects from the ambient electrical exposure and how that exposure might interact with the experimental parameter. Unless researchers take into account the interaction between the ambient and the experimental exposures, experimental results will provide only limited information, and our understanding of effects on dairy animals from electrical exposure will continue to be incomplete.

It is a common approach in research to select cows that have a record of no known health problems and are determined to be healthy when entering the research project. It is often the case that cows are replaced in the project if they develop health problems. These practices, while they may seem logical and reasonable, could actually bias the results of the project. Because cows are known to have varying degrees of sensitivity to electricity, those cows that are most sensitive to electricity are also the most likely to be excluded from the experiment. Their health may already have been affected by the ambient exposure in the barn, resulting either in a record of health problems or in poor health at the time of selection. Thus the cows that become a part of the research may be those least sensitive to electrical exposure, and the research results cannot be generalized to all dairy animals. The research results will certainly not be valid for an operating dairy farm, since dairy operators are not free to exclude sensitive cows from their operation.

REEARCH PROPOSAL

It is time to consider new approaches to the study of the potential effects of electricity on dairy cows. Over a period of many years a set of behavior, health, and production problems in dairy operations has been associated with electrical causes. During this period there has also been a significant research effort to understand how intermittent shock currents affect dairy cows. At the present time, however, the problem has not been satisfactorily defined, and attempts at mitigation have provided only minimal relief.

The study outlined below is an attempt to point research in a new direction, drawing from existing farm-based information ad accepted problem-solving strategies. The purpose of the study is to identify the electrical exposures that can cause effects, determine the electrical sources, and catalog the effects.

When attempting to solve a problem believed to be associated with environmental agents, it is most appropriate to locate the study where the problem exists. It is also important to utilize all information that has general support. Under certain electrical conditions, there is general agreement that cows are adversely affected. The presence of a ground fault on or near a dairy barn, for example, is known to correlate with a certain set of behavior, health, and production effects. The basic electrical exposure from faults is electric current in the ground, which can result in a shock current, a low-level continuous current, or both.

Effective problem solving requires a protocol for choosing and evaluating essential information. In this case, the protocol must detail both the electrical parameters to be researched and the behavior, health, and production effects to be monitored. There may also be other causes of effects, and these must be watched carefully throughout the problem solving process. A similar protocol was developed in 1993 for a research project undertaken by the Minnesota Environmental Quality Board. This protocol is available from the Board and could be used as a model for the project described below.

Drawing from the accepted information on ground faults, an appropriate starting point for this study is to determine the impact of currents in the earth on dairy cows. From many previous measurements and from basic knowledge of electrical systems, it is clear that there is electric current in the earth and that this current interacts with cows in dairy barns. A clearer definition of the impact of these currents could be helpful in refining the protocol.

In order to perform the study at the location of the problem is, it should be carried out on a dairy farm with problems that experts have not been able solve by a thorough management analysis and that are perceived to have some electrical connection. A parlor milking system would be the most useful for research purposes. The first step in determining whether or not there is any electrical connection to the problems would be to provide an electrically free environment. Of course an electrically free environment in our world is unattainable, but under the right conditions it is possible to significantly decrease electrical exposures. The suggested procedure is to construct a facility capably of comfortably holding 8 cows, situated about 2 meters above the surface of the earth and electrically isolated from the earth. Such a facility can prevent most electric currents in the earth from reaching the cows and should significantly decrease any electric or magnetic fields associated with the connection of electric neutrals to the earth. Today micro and radio waves are commonly present throughout the country, and those could be somewhat mitigated by using an electrically conducting shell to enclose all parts of the facility except the floor. The facility would provide the same rations and water as are available to cows in the dairy facility on the farm.

The study would involve 16 cows near the beginning of their lactation, and to the extent possible matched in pairs. One set of cows would remain in the existing farm facility (control) and the other set of 8 cows would be house in the elevated facility (experimental). Both sets of cows would be milked in the same parlor and under the same conditions. In this study the experimental cows are almost totally isolated from any electrical exposure, except for the time spent in the milking parlor, and the control cows are exposed to whatever electrical conditions may exist in their living area.

During the study a number of electrical parameters will be monitored to provide information concerning the electrical exposure of both the experimental and the control cows. In addition, records of behavior, health, and production will be maintained for both the experimental and the control cows. In this step of the experimental process no assumption is made as to possible electric causes or effects. The ideal length of this study is a full lactation of the cows, which is approximately 10 months. If there is already a clearly identifiable difference between the groups after one month, however, the validity of these results could be tested by exchanging the control and the experimental cows for another month. At this point the study might continue by returning the original group to the experimental facility, or it might be concluded because of the information already obtained from the first two months.

From the analysis of the information obtained during the study, it should be possible to determine differences between the control and experimental cows. One would expect the control cows to have experienced effects similar to those experienced before the study began. If electrical conditions on the farm have been causing problems, there should be a reduction of these effects among the experimental cows. If a significant reduction is found, the research study can proceed to a second step.

The purpose of this second step is to determine whether electrical exposure associated with contact with the ground is responsible for affecting the cows. In order to demonstrate that cows are being affected by a specific electrical exposure, it is necessary to systematically expose the experimental cows to electrical conditions similar to those of the control group. Since there can be many exposure paths, this part of the study should compare the behavior, health, and production of the experimental cows when exposed and when not exposed to each exposure pathway. The experimental group will continue to be isolated as before, except for the exposure pathway being studied.

There are numerous exposure pathways that could be researched using this methodology. One pathway to consider is that of step potentials between the feet of the cows. These step potentials should be similar to those in the dairy facility. In order to obtain additional information, different step potentials can be tested, including pure 60 Hz, 60 Hz and harmonics, DC, and transients. The magnitudes can also be varied. A second pathway experiment could involve the use of electric fields. One experimental arrangement might be to have the cows standing on a conducting plate, and then to establish an electric potential between the plate and the exterior of the building. Many research variations are possible with either of these experimental arrangements. The information from this second step of the study would provide valuable guidance for preparing laboratory research projects to further investigate possible effects and exposure levels.

CONCLUDING THOUGHTS

The stray voltage problem is a classic example of the difficulties that can occur when a technological development provides many benefits for humanity throughout the world, but has never been examined to determine possible impacts on human and animal health. Without such an examination, perceived negative effects experienced by humans or animals are readily ignored or denied. Because of the complexities of any research involving environmental agents, and because of the power of vested interests in any technological development, the challenges to scientific research on the negative effects of electrical exposure are almost overwhelming.

Dairy farmers have been contending with the stray voltage problem for over fifty years. In spite of the fact that many electrical experts have been involved with the problem, the problem continues. As people from many other sectors of society have expressed their concerns, innumerable research projects have been undertaken to study the potential effects from many different types of electrical exposures. How electricity affects living organisms has probably been studied more than effects from any other environmental agent. Yet today the scientific community remains divided on this issue.

Because of its primary function in society, electricity is classified as a form of energy. The basic interaction of electricity with living organisms has been considered to be an energy exchange. In order to be deemed harmful, the energy must be capable of destroying living tissue, produce acute and at times chronic effects, or it must be capable of breaking molecular bonds to cause chronic health effects. There is another property of electricity that ought to be recognized, however. Electricity is the result of a fundamental property of matter called electric charge, and moving charges introduce magnetic fields. Since living organisms use this fundamental property of matter for the functioning of their systems, electric currents and electric and magnetic fields have the potential to directly affect the functioning of those systems. In proposing mechanisms of interaction, both the energy itself and the direct effect of fields and currents deserve attention.

The study of potential effects from electrical exposure most often addresses a single component, such as 60 Hz magnetic field or microwaves in a specific frequency range, whereas in every environment there are actually many components. There is direct exposure to fields from power frequency sources such as transmission and distribution lines; there is direct exposure from appliances, wiring, and structural elements in homes and workplaces; and electric currents reach living organisms through contact with the earth and with structural components connected to the earth. Electric currents are in the earth because the electrical distribution system uses the earth as a major carrier of that current, directly connecting one terminal of the system to the earth. Additional sources of exposure include microwave ovens, radar systems, television, radio and cellular transmitters, and direct current systems.

All living beings are exposed to a greater or lesser extent to all of these sources, and it must be assumed that each source, or all of the sources together, could be associated with similar and significant health effects. When researchers consider only one element of this complex picture, they can’t be certain how that element works separately and how it works together with all of the other parameters. The real world involves exposure to many different things, and two or more elements may work together synergistically, with differing effects from one organism to another. Research that is focused narrowly on a single parameter does not provide any way to account for possible effects from exposures other than those used in the research.

As discussed previously, there is evidence that effects from some electrical exposures are quite independent of frequency and intensity. There is also a significant quantity of research that demonstrates positive effects from some specific levels and types of electrical exposure and negative effects from others. Research in many areas has frequently shown that a large difference in effects can occur for different living organisms of the same species. Given the large number of variables that must be controlled for, indisputable results from any research are unlikely. In addition, statistical methods may not be able to produce a statistically significant correlation, even in situations where the electrical parameter does cause effects.

In order to develop a clearer understanding of how living organisms are affected by electricity in all of its forms, a far greater understanding of their operating electrical systems is needed. Understanding how electricity maintains the appropriate functioning of systems of living beings can help us to identify mechanisms of interaction between electrical exposures and electrical systems of the body. This understanding can also help to differentiate between electrical exposures that can cause negative effects and those that can cause positive effects. It is also important to keep in mind that thresholds may not be especially meaningful measures of possible effects. There is a real danger that research may not be able to supply sufficient information about safe levels of exposure to electricity of all kinds before widespread damage to human and animal health has already taken place.

Difficult though it may be, researchers must learn to look at living organisms not as mechanistic objects but as living, continuously changing subjects that are in constant interaction with the physical and living environmental agents around them. Research based on mechanistic principles alone cannot be effective in working with living organisms. A different research paradigm is required for adequately assessing how a living organism responds to electrical and all other environmental exposures.

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