Progress Report of the Science Advisors to the Minnesota Public Utilities Commission:

Proposed Research for Evaluating Possible Electrical Causes of Poor Health and Production in Dairy Cows

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Minnesota Public Utilities Commission
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EXECUTIVE SUMMARY

In May 1994 the Minnesota Legislature (Minnesota Laws 1994, Chapter 573) authorized the Minnesota Public Utilities Commission to establish a multidisciplinary committee of science advisors to examine the potential for, and actual effects of, "currents in the earth" on dairy herd health and milk production. This legislation was enacted in response to years of debate on the claim by some farmers that currents arising from the practice of bonding electric distribution system conductors to the earth cause persistent, unresolved adverse effects in farm animals.

As the Science Advisors, we are charged with additional activities that are relevant only if further research is found to be warranted. Specifically, we are authorized to identify the research questions that need to be addressed, recommend a research plan, seek funds to carry out the recommended research, and monitor and report on the research results. This is a progress report we have written to inform the Commission of the results of our analysis of published research and other available information relevant to possible effects of earth currents and other electrical parameters on dairy cattle. The report summarizes the many behavioral and health signs (e.g., high incidence of mastitis, low water intake, swollen joints, sores that do not heal, etc.) that describe the problem reported by farmers with concerns about currents in the earth; defines the relevant scientific terms; describes direct and some possible indirect mechanisms by which voltages and electric and magnetic fields could conceivably interact with dairy cows; and addresses possible sources of these currents. Finally, the report provides a research plan which outlines the specific field and laboratory studies that must be conducted to determine whether any electrical parameters other than cow contact stray voltage might be responsible for the reported problems.

We have reviewed the pertinent scientific literature as well as the information provided to us to date by Public Utilities Commission staff, research scientists, dairy farmers, utility representatives, and other interested parties. Our analysis of some key reports and other materials that we were charged specifically with reviewing is included in the appendices to this report. We conclude that the available information does not demonstrate any clear relationships between currents in the earth and persistent, unresolved dairy herd behavior, health and/or milk production problems.

It is already well-established in the scientific literature that intermittent cow contact voltages of one-half volt or higher can induce many of the problems cited by dairy operators who are concerned about earth currents. This report identifies several possible mechanisms other than exposure to cow contact voltages of one-half volt or higher through which electricity might affect dairy cows. However, all of these scenarios can be due to common stray voltage sources rather than earth currents from distant sources. This is because in a tie stall barn or a stanchion barn, there is a direct metal path from the farm's neutral to the cow through the waterline and stall metalwork. Thus it is more likely that, on truly and effectively isolated farms, these scenarios would be due to on-farm stray voltage sources or off-farm sources other than the primary distribution line leading to the farm. In addition, there are a variety of non-electrical factors (e.g., pathogenic bacteria and viruses and nutritional deficiencies) which have been thoroughly documented in the scientific literature to cause some of the same signs of health and milk production problems as those cited by farmers with concerns about electricity. The reported problems also could result from a combination of electrical and non-electrical stressors.

When multiple parameters in the dairy farm environment might be affecting the cows, it is very difficult and may be impossible to determine the specific contribution of any one factor without examining all of them. Since there has been no uniform and systematic effort to study possible effects of electrical parameters other than conventional stray voltage, conclusions cannot be drawn about their relative contribution to the persistent, unresolved dairy herd problems cited by concerned dairy operators. The only way to prove or disprove possible contributions of these other electrical parameters to the reported problems is to conduct targeted research.

The research plan presented in this report is organized into two distinct, but mutually informing programs of field and laboratory research. The proposed studies would be implemented over a term of approximately five years, with annual assessments of research results to determine whether, or to what extent, studies planned for subsequent years should be pursued. Overall, the research plan is designed to address two primary goals:

-- clarifying the exact nature and scope of persistent and unresolved behavior, health and milk production problems reported by dairy farmers who are concerned about currents resulting from the practice of bonding the primary electric distribution system to the earth, and

-- expanding the base of scientific information on whether and, if so, how man-made or natural sources of electricity can contribute to the reported problems.

The key elements of the plan are as follows:

Year I: <u>Protocol Development for Field Studies and Facility and Methods Development for Laboratory Studies</u>

<u>Survey research and analysis of Dairy Herd Improvement Association (DHIA) records</u>. Surveys of farmers, veterinarians and other farm advisors would be conducted to yield a more precise definition of the clusters of persistent, unresolved health, production and behavioral abnormalities believed by some farmers to be caused by electrical stressors and to help identify farms with ("cases") and without ("controls") these problems for a large-scale field ("case/control") study aimed at defining any associations between electrical parameters and the reported problems. In addition, analysis of milk production and related records for a sample of DHIA-member farms would be carried out for several reasons: (1) to collect some data on Minnesota dairy farms from which "normal" or baseline milk production levels and trends can be identified and used for comparison purposes; (2) to assist in the identification of cases for the case/control study; and (3) to document farmers' perceptions of milk production problems

with actual data on milk production. (Budget Est.: $75,000)

Development of new measurement protocols for electrical parameters not typically tested on and off farms and assessment/refinement of protocols more typically used by utilities and regulatory agencies. The field studies planned for subsequent years require well-established and tested protocols. However, measurement protocols for some of the electrical parameters to be characterized are not available. These would be developed and tested during this initial phase of the plan. For other parameters, a variety of protocols are available and the most appropriate ones need to be selected and perhaps refined. (Budget Est.: $80,000)

Equipping a laboratory for rigorous studies of possible electrical effects on dairy cows and development of a behavioral response indicator. A laboratory facility would be designed and equipped to carry out rigorous experimental studies on exposures of cows to steady state and transient voltages and fields from a variety of sources under multiple conditions that model the ones cows are exposed to in dairy barns. Work also would be initiated toward the development of less subjective, more quantitative dairy cow behavioral response indicators and reliable physiological response indicators needed for the laboratory studies proposed under Years II and III of this plan. (Budget Est.: $100,000)

Total Year I budget estimate, including all consultant and staff costs: $380,000

Year II: Pilot Field ("Case/Control") Study and Laboratory Studies on Threshold Responses of Dairy Cows to Specific Electrical Parameters

Pilot field (case/control) studies. A sample of 5 case and 5 control farms would be investigated in depth by a skilled research team in a pilot study with three principal objectives: (1) Test the measurement protocols developed in Year I, (2) Demonstrate the feasibility of conducting an expanded case/control study in Year III to identify possible associations between certain electrical or non-electrical risk factors and the observed health and production problems, and (3) Evaluate the feasibility of reporting findings of such an investigative team back to the dairy operators participating in the research and coordinating follow-up assistance to those who are interested in finding remedies to any problems identified. (Budget Est.: $85,000)

Laboratory research. Work in this phase of the laboratory research plan would focus on identification and application of reliable indicators of physiological responses in dairy cows and determining thresholds for behavioral and physiological responses of dairy cows to intermittent and continuous, but short-term (e.g., up to 24 hours) exposures to steady state and transient voltages and magnetic fields. One important outcome of establishing guidelines on true threshold levels of any possible effects of these parameters would be to give dairy operators, utilities, regulatory agencies and others some of the information they need to work together more effectively toward solutions to any known or new problems that may be identified. (Budget Est.: $100,000)

Total Year II budget estimate, including all consultant and staff costs: $310,000

Years III-V: Definitive Case/Control and Laboratory Studies to Address the Question of Whether Electrical Parameters Other than Conventional Stray Voltage Affect Dairy Cow Behavior, Health and Milk Production.

Expanded field (case/control) studies. Depending on the outcome of the pilot case/control study, a large-scale study would be launched in Year III to accomplish two principal objectives: (1) Demonstrate whether an association exists between the presence or magnitude of specific electrical parameters and specific health and production problems, and (2) Provide a large reliable database on "normal" and "abnormal" measures of a variety of electrical and non-electrical parameters which is currently not available for Minnesota dairy farms and is needed by farmers, utilities, regulatory agencies, farm advisors and others with concerns about the effects of various environmental stressors on dairy herds. (Budget Est.: $230,000/year)

Coordination of program to confidentially report results of individual farm investigations to participating dairy operators. Data collected on individual farms during the case/control field study would be particularly useful to the individual farmers participating in the study. If the program piloted in Year II for reporting back to and advising farmers on any actual or potential problems identified during the on-farm investigations is well-received, it could be continued during the course of the large-scale study and possibly, by some other mechanism, after the research is complete. (Budget Est.: $35,000/year)

Laboratory studies. More definitive studies of cause and effect would be initiated in the laboratory during Year III and extended as necessary into subsequent years. Priorities would depend on any relevant results of the Year II pilot case/control study and research going on independent of this plan. Current priorities include examination of behavioral and physiological effects of longer-term (i.e., at least 4-6 weeks) and continuous (e.g., front and rear hooves) or intermittent (e.g., through cow contact at water cup while drinking; neck contact at stanchion or tie chain) exposure to low level voltages; short- and longer-term exposure to AC magnetic field levels such as those that might be associated with ground currents in the dairy barn, with and without combined DC magnetic fields; and short-term and long-term exposures, both intermittent and continuous, to current and voltage transients. (Budget Est. $100,000/year)

Total Years III-V estimated budgets, including consultant and staff costs: $490,000/year

As charged in the authorizing legislation, we have conducted a preliminary assessment of possible private, state and federal funding sources to support the research plan. We recommend that attempts be made to follow-up on all of these possibilities. Further, we recommend that research collaborations be undertaken with agencies and/or research institutions from other states, whenever feasible. Regional or multi-state collaborations are not only a cost-efficient approach to research, but they have a greater potential for bringing about a more rapid resolution of the problems described in this report. We already have begun preliminary discussions on possible collaborative research projects with staff from the Wisconsin Department of Agriculture and the Wisconsin Public Service Commission and every effort should be made to continue in this direction.

The legislation authorizing this work calls for the Science Advisors to monitor, oversee the peer review of, and report on any research that is conducted. We recommend that the present process of providing an independent science advisory committee be continued beyond June 1996, the termination date in the current legislation, and until the proposed research is completed . Further, all of the research in this plan should be performed by scientists and other appropriate technical personnel. As envisioned in the original legislation, research proposals and research findings should be reviewed and approved by the Science Advisors, who also would seek advice from others with special or relevant expertise, as necessary. The most technically qualified contractors would then be selected to carry out the research. Many of the studies included in this plan, particularly the field studies, will require some cooperation and assistance from electric utility personnel. In addition, successful implementation of the survey and field study components would require the assistance of farmers and their professional organizations, as well as veterinarians and others who advise dairy operators. All of these groups should be apprised of any findings on a regular basis and given frequent opportunities to provide appropriate input into the overall process of the initiative.

The Science Advisors to the
Minnesota Public Utilities Commission
January 9, 1996

CONTENTS

I. INTRODUCTION

This is the third progress report of the Science Advisors to the Minnesota Public Utilities Commission (PUC)[1]. The Science Advisors are a multidisciplinary group representing the fields of agricultural engineering, animal physiology, biochemistry, electrical engineering, epidemiology, physics, soil science and veterinary science. They are charged with examining whether there is a "need for research on possible effects of currents in the earth on animal health and dairy cow milk production." If the Science Advisors find there is a need for further research in this area, then they are to design the research, identify possible funding sources, monitor the research and report to the PUC on the results. The Minnesota Legislature authorized the PUC to establish this committee of Science Advisors in response to over ten years of claims by some dairy farmers that the electric utility distribution system, through mechanisms other than traditional cow contact voltages, is responsible for unresolved animal behavior and health problems on their farms.

A listing of the animal behavior and health signs typically reported by dairy farmers to be associated with a problem or problems related to the electric distribution system (and sometimes other sources) has been prepared and reported by The Electromagnetics Research Foundation (TERF).[2] Frequently cited behavioral changes include the dairy cow's unwillingness to enter the barn, restlessness in the barn stall or milking parlor, refusal to eat or drink in the stall, dancing, kicking off milkers or kicking at farmer during washing, and difficulty getting up. Reported problems related to milking and milk production include uneven milkout and letdown (i.e., some quarters release milk well while others will not), long milking time, and peaking in milk production during first weeks of the lactation cycle. Rolling herd milk production averages also have been reported to change (as much as fifty percent in some cases), at least temporarily, with changes in the electrical distribution system. Typically reported adverse health or physiological outcomes include sudden onset of mastitis, inability to maintain weight, leg sores which will not heal, breeding problems, spontaneous abortions and others.

A variety of changes in the on-farm or off-farm electrical system have been reported by concerned farmers to coincide with the occurrence of the undesirable behavioral and health outcomes. Examples include the energizing of transmission lines or active cathodic protection systems on oil and natural gas pipelines proximate to the farm, installation of underground

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[1] Minnesota Public Utilities Commission. Progress Report, Team of Science Advisors. St. Paul, MN (January 18, 1995)
Minnesota Public Utilities Commission. Interim Report of the Science Advisors to the Minnesota PUC: Potential for Effects of Currents in the Earth on Dairy Herds and Related Research Questions. St. Paul, MN (October 30, 1995)

[2] Minnesota Laws 1994, Chapter 573 authorized the Minnesota Department of Public Service to contract with a dairy producer organization to prepare for review by the Science Advisors data and analysis related to ground currents and dairy herd health and production. TERF is the organization that received the contract.

telephone cable networks, addition of isolators on distribution lines, ground faults on the farm or a nearby farm, and disconnection and connection of ground rods.

The variation in behavioral and health signs reported by concerned dairy operators to be associated with a problem related to the electrical distribution system is large, and no unique sign or set of signs has been identified. Dairy operators and TERF members have indicated at meetings of the Science Advisors that traditional stray voltage,[3] as it is defined in this report, is not the issue of concern. Rather they define the scope of the problem as pertaining to the "electromagnetic energies" resulting from the utilities' practice of grounding the electric distribution system to the earth.

Included in this progress report are an overview of the history of stray voltage and earth current issues in Minnesota, a review of the authorizing legislation, definitions of the relevant scientific terms, an analysis of the information presented to the Science Advisors by individuals and groups claiming or studying effects of currents in the earth on dairy cows, a description of the possible direct and some of the indirect mechanisms by which stray voltage, earth and ground currents and associated electric and magnetic fields and other electrical parameters could interact with dairy cows, and a research plan designed to address the factor(s) which might be responsible for the various adverse animal behavior and health effects reported by dairy farmers.

This report differs from the October 1995 "Interim Report of the Science Advisors to the Minnesota Public Utilities Commission: Potential for Effects of Currents in the Earth on Dairy Herds and Related Research Questions" in that it addresses, when appropriate, public comments on the interim report; includes a proposed research plan; provides analysis of reports as authorized by legislation; and summarizes site visits, activities in other states and public input into the deliberations of the Science Advisors.

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[3] Stray voltage is the difference in voltage between two surfaces contacted simultaneously by an animal. When a dairy cow contacts these two points, it provides a conducting path for current to flow. (See sections IV and VI of this report.)

II. HISTORY OF STRAY VOLTAGE AND EARTH CURRENT ISSUES IN MINNESOTA

Some of the earliest indications that the electric distribution system might be associated with adverse effects in dairy cows were in Australia in 1948 and New Zealand in 1962. In these cases the concern was that small "stray voltages" were affecting the cows. The first stray voltage cases were reported in the United States and Canada in the 1960's. Stray voltage emerged as a widespread concern for dairy farmers in Minnesota in the late 1970's. Also during this period, local public concerns about possible health effects of electricity were heightened by plans to build a high voltage direct current transmission line through the state. Recognizing the need to understand and solve stray voltage problems, Minnesota utilities, the dairy industry and the University of Minnesota Extension Service developed methods to detect and mitigate stray voltage on dairy farms beginning in 1980. The appearance of numerous articles in the popular press in the years 1980-1983 marked the beginning of national and worldwide recognition of stray voltage. In Minnesota, several state agencies became involved in the issue after 1984, administering funds authorized by the Minnesota Legislature for research into stray voltage.

In 1985 the University of Minnesota presented a report to the Minnesota Legislature on stray voltage which included a bibliography of over 30 technical papers produced at the University with state and utility funding. This report addressed animal sensitivity to electric currents, electrical system characteristics relative to stray voltage, identification of stray voltage sources and mitigation strategies. At the same time, Dr. Duane Dahlberg of Concordia College in Moorhead, Minnesota, presented a report to the Legislature which introduced "electromagnetic synergistics," a concept intended to expand the definition of stray voltage to include any form of electromagnetic energy.

In 1986 the Minnesota Legislature appropriated funds to study farms which had persistent milk production problems that were not responsive to traditional stray voltage mitigation. The study was administered by the Low Livestock Productivity Board created by the Minnesota Department of Agriculture. The study involved extensive data collection on four farms by Dataright, Inc., an environmental consulting firm, but funding limitations at the time precluded detailed analysis of the data.

Also in the mid-1980's, several Minnesota dairy farmers organized a nonprofit association (now called The Electromagnetics Research Foundation or TERF) to address stray voltage concerns. Dr. Dahlberg is the principal scientific advisor to TERF. In the late 1980's TERF solicited national participation in a stray voltage survey through an announcement in a dairy magazine. The results were reported to indicate widespread, unsolved stray voltage and related problems in 20 states. TERF also expanded its base to Wisconsin where concerns about current in the earth were emerging. During the same period TERF sponsored or co-sponsored several seminars and conferences in Minnesota and Wisconsin on stray voltage, electromagnetic fields and related topics.

Public concern about health effects from electric energy use grew during the 1980's prompted by reports of a link between magnetic fields and cancer. In 1992 the United States government initiated a five year, $65 million research effort to understand interactions between biological systems and electric and magnetic fields. At around the same time the U.S. Department of Agriculture issued a report on detection and mitigation of stray voltage (Lefcourt, 1991).

The increasing concerns of farmers spurred the Governor of Minnesota to support an interagency investigation into stray voltage. A task force comprised of government agency representatives was established under the Minnesota Environmental Quality Board in 1989. The Board's 1991 report includes the following findings: stray voltage occurs on at least 11 percent of Minnesota's dairy farms; utility and state programs to deal with stray voltage work reasonably well; uniform stray voltage investigative procedures are needed; and research is needed to assess the impact of direct current, ground current, electromagnetic fields and transients.

In April 1992 the MEQB formed the Stray Voltage Steering Committee with representatives of state agencies, electric utilities and TERF. The Committee sponsored a stray voltage demonstration for MEQB Commissioners and the public. It also designed a protocol to study the effects of utility primary neutral grounding practices on dairy health and production. The study was conducted in the spring of 1993. In 1994 the MEQB concluded that changes in the primary grounding on the test farm had no significant effect on the dairy herd. One of the primary stakeholders in this study, TERF, reported concerns about how the data were interpreted, the study design, and some of the electrical conditions on the farm during the study.

Two other Minnesota agencies conducted additional activities related to the stray voltage issue in the early 1990's. The Public Utilities Commission (PUC) announced its intention to develop regulations governing stray voltage investigations and mitigation by utilities, and formed an advisory committee for the rulemaking process. The PUC rulemaking process is ongoing. The Department of Public Service held two seminars on stray voltage in the state. In 1993 local utilities issued interim investigation and mitigation guidelines for Minnesota utilities to use until PUC rules were adopted.

In response to persistent and unresolved reports by TERF that dairy herds were experiencing ill effects from the earth and ground currents that result from the Minnesota electric utilities' practice of bonding electric distribution system conductors to the earth, the Minnesota Legislature in May 1994 authorized the formation of a scientific advisory committee (Minnesota Laws 1994, Chapter 573). In the same legislation, the Department of Public Service was authorized to issue a contract for the collection and reporting of dairy industry information on the effects of stray voltage, earth currents and related phenomena on dairy herd production, and animal and human health. TERF was the sole bidder for this contract and was selected to prepare the report. On November 23, 1994, the Public Utilities Commission appointed nine Science Advisors to review evidence on possible earth current effects, determine if further research is needed, and develop and oversee any needed research.

III. AUTHORIZING LEGISLATION

Minnesota Laws 1994, Chapter 573, directs the Science Advisors to determine "the need for research projects to identify and examine the potential for and actual effects on dairy cow production and animal health of current in the earth, originating from utility distribution systems and other sources."

In addition, the statute authorizes the Science Advisors to:

-- review relevant information from other sources, including information from other states and from dairy producers or farm organizations;

-- make on-site visits to farms with formal and informal complaints to the PUC concerning stray voltage and the use of the earth as a conductor;

-- review information provided by the PUC on the extent to which electric distribution facilities use the earth as a conductor of electric current, whether intentionally or unintentionally; and

-- study the risks to dairy animal health and productivity associated with the practice of bonding distribution system conductors to the earth.

The statute also directs the Science Advisors to carry out certain activities that are relevant only if they determine research on possible effects of earth currents is needed. Specifically, the Science Advisors are to:

-- frame the specific research questions that need to be addressed;

-- explore the availability of non-state and non-utility funds to support research on possible effects of earth currents; and

-- make recommendations to the PUC on the design, scope, and estimated cost of any necessary research, identify researchers who would be appropriate to carry out the research, and monitor both the progress and the peer review of any such research authorized by the PUC.

IV. DEFINITIONS

It is clear from the information reviewed by the Science Advisors that there is a compelling need to clarify the definitions of the scientific terms commonly used in discussions of stray voltage, earth currents and related issues. The electrical parameters of particular interest can be classified broadly as voltage, current, transient voltage/current, electric fields and magnetic fields. Precise, scientifically sound definitions of these terms are given below to provide clarity to the analysis in this report and to offer a framework for future discussions among the interested parties.

A. **Voltage** is the electrical potential difference between two points; it is measured in volts. Voltage is commonly classified according to how it changes with time. *Direct current (dc)* voltages change slowly, if at all, with time. *Alternating current (ac)* voltages change polarity periodically. For example, electric power frequency ac voltages change polarity 120 times per second (i.e., have 60 complete cycles per second, each with equal positive and negative parts). Cycles per second are called "Hertz," thus the power frequency in the United States is 60 Hertz (Hz). *Radio frequency voltages* alternate polarity millions of times per second. Voltages may also be *transient*, or rapid, short-lived changes ("spikes").

1. **Stray voltage** is the difference in voltage measured between two surfaces that may be contacted simultaneously by a person or animal (typically less than 10 volts). Sources of ac stray voltage are neutral-to-earth voltages resulting from normal current flow on a resistive neutral system. Stray voltage may be enhanced by poor electrical connections, deteriorated insulation, or faulty equipment. Sources of dc stray voltage are cathodic protection systems, telephone systems, dc power lines, and electrochemical reactions occurring at the surfaces of buried metals. Stray voltage on a farm can exist between two metal objects, between a metal object and the ground, or between two points on the ground. When an animal contacts these two points, it provides a conducting path for current to flow.

2. **Neutral-to-earth voltage** (NEV) is the ac voltage measured between the grounded neutral conductor of an electrical system and the earth. The primary neutral conductor is on the power supplier side of the distribution system and the secondary neutral conductor is on the customer (i.e.. farm) side. Utilities may decide to separate the primary and secondary neutral conductors with an isolation[4] device to limit secondary NEV's to on-farm sources.

3. **Step potential/voltage** is the voltage between two points on the earth separated

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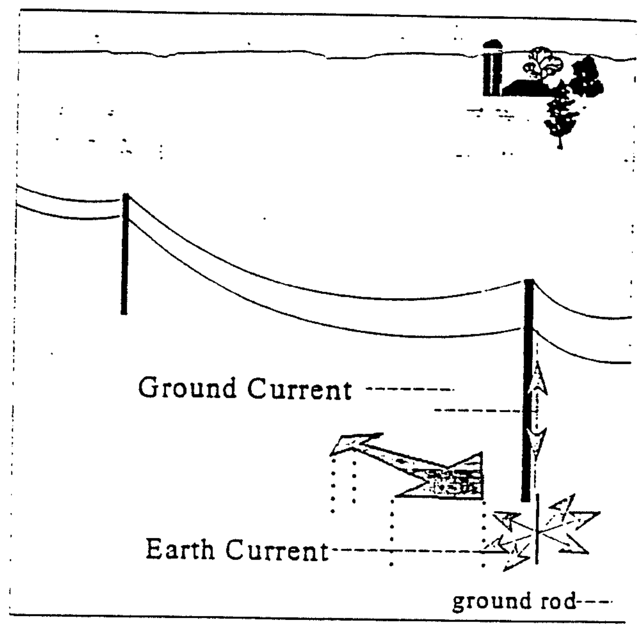
[4]**Isolation** is separation of all or part of a farmstead's grounded neutral conductors from the grounded conductor of the distribution system. Several types of isolation devices are used to automatically reconnect them in case of a lightning strike or fault condition.

by the length of one step. The voltage difference between the front and rear hooves of the cow is an example of a step potential.

B. **Current** is the flow of electric charge per unit time, measured in amperes; alternating current (ac) changes polarity periodically with time; direct current (dc) does not change polarity periodically with time; transient currents are current impulses of short duration that occur regularly or irregularly. Other examples of current (in addition to current which provides useful power for equipment) include earth current and ground current.

1. **Ground current** is current on a metal conductor connected between the neutral conductor of the electric power supplier's primary distribution system or the farm's secondary distribution system and the earth. Ground current flows on the primary grounding electrode system[5] which includes ground rods and substation grounding grids; it also flows on the secondary grounding electrode system which includes ground rods, metal stanchions, waterlines, well casings, reinforcing rod in concrete, etc.

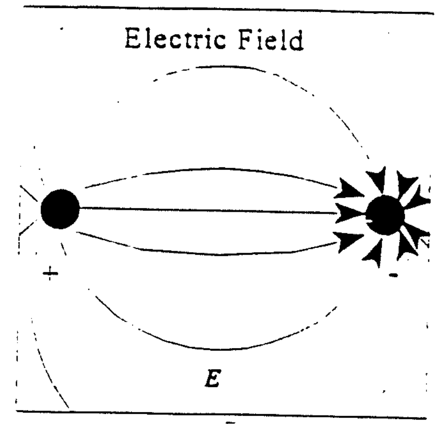


2. **Earth current** includes ac and dc current in the earth originating from man-made systems, such as primary and secondary electric distribution lines, and current from natural sources. Currents from the power supplier's and the farm's neutral conductors can return to their original source through the earth as earth currents. Another name for earth current is *telluric current*. According to a 1994 survey of Minnesota electric utilities by the PUC, a large fraction of current originating from utility, rural distribution systems returns to the substation through the earth, with the remainder on the neutral conductor.

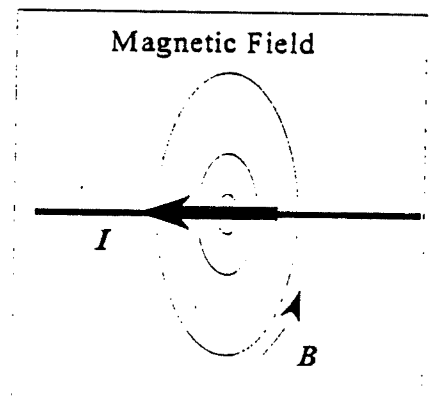
C. **Transient voltage and current** are non-repetitive voltage and current of short duration, less than one-half cycle, and possibly of larger amplitude than that of the normal steady state supply.

[5] **Grounding electrode system** is the system of conductors that provides an electrical contact to the earth.

D. **Electric Fields** originate on electric charges and are detected as forces on (other) electric charges. The direction of the electric field is the direction in which a positive charge would move when acted on by the field. The electric field gives the rate of change in voltage from one point to another, for example in the space between a power line and the earth. The electric field is expressed in terms of volts/meter, and sometimes as volts/centimeter (1.0 V/m = .01 V/cm). Sources of electric field include transmission and distribution lines as well as electrical wiring. The electric fields arising from the power distribution system are predominantly oscillating at 60 Hz. DC electric fields are generated by batteries, dc electric power sources and associated wiring, and by electric charges in the air.



E. **Magnetic Fields** always accompany the passage of electric current, and are detected as forces on moving electric charge. The magnitude of a magnetic field is usually expressed in units of its "flux density," in Tesla, Gauss, or milligauss. One Tesla is equal to 10,000 Gauss and one milligauss (mG) is one thousandth of a Gauss. The magnitude of the dc magnetic field of the earth at mid-latitude is about 0.5 Gauss. The magnetic fields arising from the electric power distribution system are associated predominantly with 60 Hertz (Hz) ac currents. DC magnetic fields are generated by the earth as the geomagnetic field (GMF), by dc currents in electric conductors, and by any other dc current sources.



V. INFORMATION REVIEWED BY THE SCIENCE ADVISORS

The Science Advisors held four public meetings from December 1994 through August 1995. During these meetings, the Science Advisors heard presentations, reviewed reports, and conducted other activities as charged in the authorizing legislation. The general public had the opportunity to present oral testimony at each meeting. In addition, written comments and information were solicited from the scientific community and the general public as one means of obtaining public input on the technical issues that should be reviewed by the Science Advisors. The Science Advisors also met for two and one-half days to conduct site visits on dairy farms that have filed stray voltage complaints with the PUC.

Information from a variety of sources has been reviewed for the purpose of determining whether earth currents can or actually do cause the negative effects (e.g., reduced milk production, high incidence of mastitis, low water intake, poor animal health, etc.) typically reported by dairy operators. Among the major documents reviewed are the report by TERF, reports on the Minnesota Environmental Quality Board's study on the effects of grounding changes on the Lusty farm in Minnesota, a PUC report on its survey of the age and condition of rural electric distribution systems, and related research underway in Wisconsin. The Science Advisors' analysis of this information is included in appendices A through F.

The Science Advisors have not attempted to conduct a comprehensive literature search; many literature reviews are already available on stray voltage, biological effects of electric and magnetic fields and other relevant topics. However, limited searches have been conducted on specific topics such as earth currents, ground currents, affecters of water consumption by dairy cows, and others. Each of the Science Advisors is well-aware of the relevant literature in at least one of the many scientific fields represented by the whole committee (e.g., agricultural engineering, biochemistry, electrical engineering, epidemiology, physics, soil science, veterinary medicine, etc.) and brings this knowledge to the deliberations of the committee. The Selected References section at the end of this report is not intended to be complete; rather it lists some of the publications and reviews considered by the Science Advisors to be of particular interest with respect to the issues that must be considered in meeting the charge.

VI. POSSIBLE MECHANISMS OF EARTH AND GROUND CURRENT INTERACTION WITH DAIRY CATTLE

External current can interact directly with a cow in only a few basic ways according to fundamental principles of physics. External current can interact if the voltage which causes it also causes a current to flow *through* a cow in direct contact with that voltage. This same voltage can also act *at a distance* via the resulting electric field in air. Finally, external current can interact at a distance through its magnetic field. Nature provides no other known, direct, interactive electrical mechanisms. Current also could affect a cow indirectly by altering certain features of the cow's physical environment. This section examines the direct, and some indirect mechanisms through which dairy cows could conceivably be affected by earth and ground currents.

A. Voltage

Current in a conductor (e.g. earth) results from voltage between points along its path. If the electrical resistance of a path is constant with respect to voltage and current, i.e., its voltage-current curve is linear, then the conductor is said to obey Ohm's law[6]. Voltage is the quantity of concern in a standard stray voltage investigation. It is also one quantity to be considered in an investigation of possible earth current effects. In either case, voltage cannot pose a problem for a cow unless the voltage is applied across the cow (causing current to flow through the cow). Further, the voltage source, points of contact, path of current through the cow's body, and the cow's body resistance all impact whether voltage will affect the cow. The pathway of lowest resistance in the cow's body is from the mouth to all four hooves through blood and muscle tissue .

Standard Stray Voltage. Standard stray voltage is the result of neutral-to-earth voltage (NEV) which accompanies current flow from the primary or secondary neutral conductor to earth via a resistive ground connection as shown in Figure 1a. The contribution to stray voltage by the primary distribution system is often mitigated by *isolation* of the primary neutral from the secondary neutral conductor at the farmstead's service transformer. This practice significantly reduces the influence of primary NEV's on the farm. Under true isolation conditions, farm NEV's would in most cases be caused by on-farm sources or sources other than the primary distribution line leading to the farm. Figure 1c shows an isolated service where primary NEV due to current on the transformer ground rod falls to some small level in the earth at the point where it intersects the nearest secondary ground. National Electric Safety Code rules require a 6 foot minimum separation between these grounds to achieve isolation. Beyond this distance, earth current from the primary ground is so diffuse as to be associated with little voltage. The intent of isolation is to reduce NEV on the farm. At the same time it reduces the

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[6]Ohm's law is a specific property of certain materials and is not a general law of electromagnetism. Some conductors do not obey Ohm's law, e.g., thermistors, transistors and rectifiers.

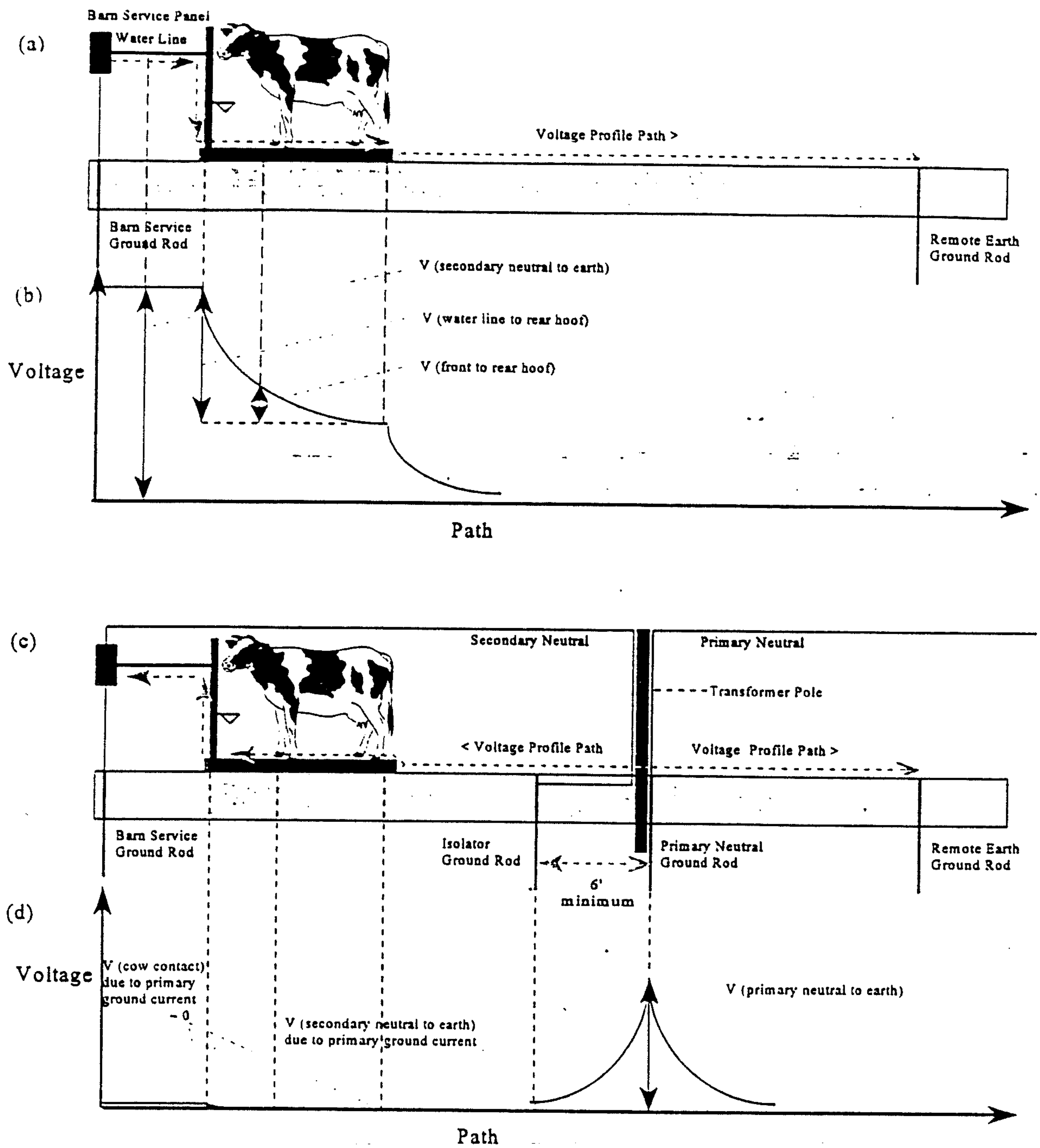

Figure 1: Standard stray voltage quantities resulting from neutral-to-earth voltages (NEV's): (a) path for current flow from secondary neutral to earth. (b) voltage profile corresponding to path "a", © path for current flow to earth from primary neutral at transformer pole on an isolated farm, (d) voltage profile corresponding to path "c". Isolation (separation of primary and secondary neutral conductors at the transformer pole) reduces the component of stray voltage due to the primary distribution system. Note that earth current from the primary neutral ground rod (and its associated voltage) diffuses in the earth before reaching the barn. Some small, normally negligible, voltage impinges on the isolator ground rod (and is transmitted to the barn via the neutral) resulting in imperfect isolation.

amount of ground and earth current around the barn. Another common method employed to reduce NEV's is to increase the number of ground points or improve the effectiveness of existing grounds on the neutral system. This reduces the resistance of ground paths, reduces NEV and increases current in the earth, all other factors including load remaining the same. In the cow's immediate environment, measures to reduce stray voltage include bonding all metal work in the barn and sometimes establishing an equipotential plane in the floor. These efforts likewise reduce the resistance of ground current paths and result in an increase in ground and earth current flow at the stall.

Earth Current-Associated Voltages. Current flows in the earth, as it does along any path, only when a voltage exists to cause it to flow (see Box A). Earth current attributable to a primary distribution line flows because its neutral system imposes a voltage difference (gradient) upon the landscape. This is because the neutral system consists of a neutral conductor connected to earth at many places along its length by ground rods. The voltage necessary to return current to the substation is thus shared at each grounded point along the distribution line by the neutral conductor and the earth. This voltage varies across the earth in complicated ways. To understand the general features of earth current-associated voltages, it is necessary to consider that there is a steady variation of voltage from one end of the distribution line to the other. Superimposed on these steadily changing voltages are local, higher voltages where ground rods are located. These two features of the neutral system are considered below.

Box A

Calculation of earth current-associated step voltage: The electric field in the earth associated with current density is given by $\mathbf{E} = r\,\mathbf{J}$ with the electric field **E** in volts/m, soil resistivity r in ohm-m, and the current density **J** in amp/m^2. If **E** in the earth is uniform between two ground rods spaced x meters apart, the voltage measured between them will be $V = x\,r\,J\cos(\theta)$ where θ is the angle between J and a line connecting the rods.

Example 1: What step voltage accompanies a current density of 5 mA/m^2 in soil with a typical soil resistivity value?
An average soil resistivity is 176 ohm-m. Then:
$V = J\,r\,x = (5 \times 10^{-3}\ \text{A/m}^2)(176\ \text{ohm-m})(1\ \text{m}) = 0.88$ V.
An earth current associated voltage of this magnitude could easily be detected with two ground rods and a multimeter.

Example 2: What earth current density results in a step voltage of 10 mV (typical cow contact potential between front and rear hooves)?
$J = V/r\,x = (10^{-2}\ \text{V}) / (176\ \text{ohm-m})(1\ \text{m}) = 0.057\ \text{mA/m}^2$.
It is evident that rather small current densities can be detected by measuring step potentials.

It is possible to estimate average voltages produced on the earth's surface by a neutral system carrying some nominal current even though the resistance of the neutral system cannot be known with much assurance or accuracy because the system is a complex and variable network of neutral conductors, ground rods and the earth. Such estimates can be made by considering first a simplified system -- the neutral conductor itself -- for which the resistance is known. In the case of a typical neutral conductor (i.e., a wire with resistance of 2.1 ohm/mile) carrying 10 amps across 10 miles, the total voltage would be about ($V = IR = 10 \times 21$) 210 volts. This corresponds to an average voltage of 0.013 volt across each meter of neutral conductor. If this neutral conductor is then connected at many places to earth, as it is in a real distribution system, the resistance must go down because a parallel return path, the earth, is added to the circuit. The average step voltage must then be *less* than 0.013 volt.

In actuality, neutral *system* (i.e., neutral conductor *plus* earth) resistances are typically about one-tenth of the 21 ohm neutral *conductor* resistance used in the above example.[7] The result of this change is that, for the same current of 10 amp, a smaller total voltage is required. That is, the total voltage across the length of the actual distribution line may be one-tenth of the 210 volts calculated above; step voltages are similarly smaller. Therefore, average step voltages associated with earth currents may be on the order of 0.001 volt, at least away from local effects of ground rods. Near ground rods, step voltages would be higher than this estimated average value. Neutral voltages are typically a fraction of 1 volt,[8] but may range upward to several volts. This voltage is shared by the earth next to the ground rod but falls to a small value within a few feet.

<u>Transient Voltages</u>. In addition to steady state voltages, cows are exposed to transient voltages. The limited amount of research published on this topic suggests that biological responses to transient voltages are similar to responses to 60 Hz voltages when comparisons are made based on total energy. Transient voltages may be associated with transient earth currents such as those which occur during a nearby lightning strike or a distribution system fault to ground. The frequency of occurrence and significance of earth current transients has not been determined.

B. Electric Field

If a cow is exposed to an external electric field, an internal electric field will be induced in the cow until charge on the cow's body surface redistributes to decrease the internal field to a small value. If the external field changes, current will flow on the cow's surface while the internal field readjusts. Because tissue is a much better electrical conductor than the surrounding air, the internal electric field at 60 Hz is typically ten million times smaller than the external field (in man). Thus 60 Hz electric fields do not have ready access to the inside of biological systems unless these systems make conductive contact with a current source. The ratio of external to internal electric field decreases with increasing frequency.

Exposure to electric fields in air has been shown to be biologically active in animals only when a very large voltage (hundreds of thousands of volts) exists between two conductors. Such voltages are found, for example, between a high-voltage transmission line and the earth. The electric field in air due to a typical 60 Hz earth current is negligibly small, probably much less than 1 volt per meter (see Section VI. A). This is at least 100,000 times smaller than levels

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[7]In a recent, comprehensive survey of rural distribution systems (Minnesota PUC, 1995), the median neutral system resistance was 2.25 ohm compared to 21 ohm for the neutral conductor example used here.

[8]A median neutral to earth voltage is 0.54 volt (Minnesota PUC, 1995).

which may have biological consequences. However, high frequency pulsed fields, such as produced by cow trainers, could possibly be biologically significant without conductive contact with the cow. The currents resulting from these pulsed fields could be strong enough to be sensed by cows.

C. Magnetic Field

Earth current produces a magnetic field. It is relatively easy to estimate magnetic fields from various sources and it is straightforward to measure them. However, the level at which magnetic fields become problematic is still debated within the scientific community. It is not the intent here to evaluate proposed biological mechanisms in detail. However, it is instructive to compare magnetic fields associated with earth currents.

In an idealized scenario, a uniform earth current will be accompanied by a uniform magnetic field (see Box B). If earth current density is the same over a large area, the magnetic field will be constant above it (i.e., will not vary with height so long as the height is much smaller than the extent of the current and the current density is horizontally uniform over a large area). The measured magnetic field may be due to current flowing at some depth, or distributed through some depth.

Unlike an electric field, a magnetic field has ready access to the inside of a cow. The field is nearly unimpeded by the cow's body.

Faraday Induction. Magnetic fields may influence living systems in a number of ways, one of which (but not the only one) is by Faraday's law of induction. Faraday's law determines the internal electric field and resulting current density that will develop inside a cow if the magnetic flux passing through it changes. An ac current is induced in the cow due to an incident ac magnetic field. This current is small for ac magnetic fields

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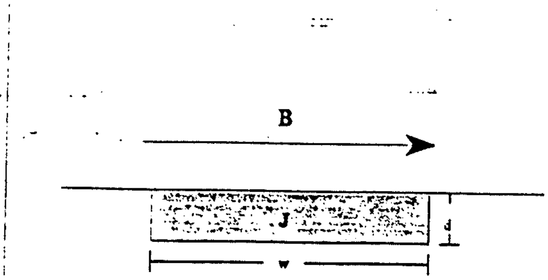
Box B



Calculation of magnetic field due to earth current: Consider a simple earth current model, a large, uniform earth current density (J) flowing (perpendicular to the plane of the paper) across an area of dimensions w by d (shown above). Using Ampere's law (applicable at low frequencies), $\oint \mathbf{B} \cdot d\mathbf{l} = \mu I$, where the left side of the equation is the line integral of the magnetic field (**B**) around the path enclosing current (I), and (μ) is the magnetic permeability, $4\pi(10^{-7})$ Henry/meter. If I is the total current enclosed in the area and w >> d, then I = Jwd and

$$B = 2\pi(10^{-7})Jd$$

where B is in Tesla, J is in amp/m^2 and d is in meters (m). **B** will be independent of distance from the current sheet at heights much smaller than w. The direction of **B** is horizontal (except near the edges of the area enclosing the current) and perpendicular to the flow of current.

Example: Total current I = 100 mA = 0.1 A; w = 10 m, d = 1 m. J = 0.1/wd. Then $B = 2\pi(10^{-7})(10^{-2}) = 6.28 \cdot 10^{-9}$ T = 0.06 mG.

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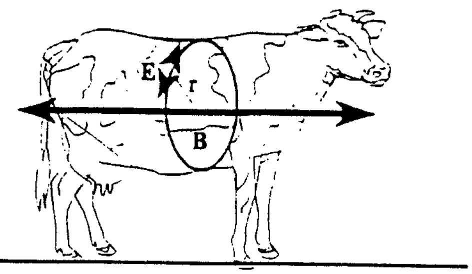
measured in dairy barns thus far.

For the purpose of illustration, consider a 60 Hz magnetic field of 0.7 milligauss (peak value, $B_0 = 1$ milligauss). This is the average magnetic field measured in approximately 100 Wisconsin dairy barns operated by farmers who have claimed that their milk production and health problems are associated with the electric distribution system. This average measurement includes the magnetic field contributions from all possible sources (e.g., wiring, lights, equipment, ground current, nearby distribution systems and presumably earth current). Applying Faraday's law, it can be shown (see Box C) that this magnetic field would induce an internal electric field of $7.5 \cdot 10^{-6}$ V/m in the body of a cow (corresponding to a current density of $3.75 \cdot 10^{-6}$ A/m^2). This induced field is probably too small to have biological consequences (see Section VI. D).

Consideration of the magnetic field resulting from a relatively large earth current is also instructive. To ensure a large earth current density, assume the worst case scenario under which *all* of the 100 milliamps of current flowing to earth at the transformer primary ground rod goes through the floor of the dairy barn on its way back to the substation. If this barn is 10 meters wide and the current flowing to it is distributed evenly in the barn floor to a depth of 1 meter, the current density will be 10 milliamp/m^2. This will result in a magnetic field of 0.06 milligauss in the barn (see calculation in Box B), 12 times smaller than the average magnetic field considered in the previous example. This earth current-generated magnetic field would be expected to induce an internal electric field of $0.6 \cdot 10^{-6}$ V/m in the cow model. Clearly it is not likely that even these large 60 Hz earth currents would induce significant fields and currents in a cow through magnetic induction.

These calculations show that the magnetic fields resulting from earth currents are not likely to be responsible for any observed adverse dairy cow health and production outcomes, at least through a Faraday induction mechanism. In addition, the magnetic field produced by earth current is

Box C



Estimate of currents induced in a cow by a uniform ac magnetic field:

Consider the simple cow model shown above. Impose a uniform ac magnetic field (**B**) perpendicular to the circuit loop of radius (r). Calculate the induced internal electric field (**E**) and current density (**J**) at radius r due to a time-varying magnetic field, $B = B_o e^{j\omega t}$.

Faraday's law of induction: $\oint \mathbf{E} \cdot d\mathbf{l} = -d\phi/dt$ where the left side of the equation is the line integral of the electric field vector (E) around the path (here a circle of radius r) enclosing a magnetic flux density given by $\phi = \iint \mathbf{B} \cdot d\mathbf{s}$, the surface integral of the magnetic field across the disc of radius r. Then, $2\pi r E = -j\omega B_o \pi r^2$, so $|E| = \omega B_o r/2$ and $|J| = \sigma E = \sigma \omega B_o r/2$.

Example: f = 60 Hz, r = 0.40 m, $B_o = 10^{-7}$ Tesla (1mG), $\sigma = 0.5$ S/m.
Then $|E| = 2\pi(60)(10^{-7})(.40)/2 = 7.5 \cdot 10^{-6}$ V/m.
$|J| = (.5)(7.5 \cdot 10^{-6}) = 3.75 \cdot 10^{-6}$ A/m^2

likely to be insignificant compared to the field from all other sources in and near a barn (e.g., wiring, fluorescent light fixtures, milking equipment, grounding conductors, distribution lines, etc.).

On the other hand, magnetic field effects due to Faraday induction could be problematic under scenarios where currents have frequency components much higher than 60 Hz. Faraday's law requires that the electric field induced in a conducting medium is proportional to the rate of change of magnetic flux density; faster changes in the field produce larger internal electric fields. Perhaps currents with frequency components much higher than 60 Hz might induce a problematic current in a cow. For example, lightning results in a large, rapidly changing current flow to earth. Also, a phase-to-neutral or ground fault on the distribution system is another source of rapid change in current flow, the on- and off-set of which have transient characteristics. A large, fast, earth current transient passing near a cow would induce a voltage transient directly into the cow which is much larger than that induced by normal, steady state 60 Hz currents. Induced current from an earth current transient may even exceed the current due to the associated contact voltage at some very high frequency. This is because magnetic induction is proportional to frequency while current due to contact voltage depends only on contact resistance which is independent of frequency. Whether these induced transients have enough energy to affect a cow has not been determined. However, it is likely that lightning strikes and distribution faults occur only infrequently.

In addition, magnetic fields from *ground* currents (rather than earth currents) might be problematic under certain circumstances. Cows are confined in a barn such that their heads are close to ground current in waterlines, stanchions and other metalwork. The magnetic field from this current is not reduced by that from a parallel return current as it is in most wiring. As an example, if 1 amp flows in a water line, it produces a magnetic field of 20 milligauss 10 cm away, a realistic distance to the head of a cow. It would therefore be desirable to extend future measurements to document localized magnetic fields due to ground current in dairy barns.

<u>Non-Faraday Alternating Magnetic Field Effects</u>. Mechanisms other than Faraday induction have been proposed in the published literature to explain observed biological effects attributable to alternating magnetic fields. Among these are several studies which have shown physiological and behavioral effects that depend upon the simultaneous presence of dc (static) magnetic fields and particular amplitudes of an alternating field, generally chosen to be above 100 milligauss in laboratory studies. The magnitude of the dc field generally determines particular frequencies ("resonances") at which systems respond. For example, it has been reported (Thomas et al, 1986) that sharp changes in rat behavior accompany a 30 minute exposure to a 271 mG static magnetic field combined with a parallel 60 Hz magnetic field of 369 mG peak magnitude. The theoretical explanation of these experimental results is unsettled at the present time and is an area of active research. Other research has established the effect of relatively large (at least several Gauss) static and time-varying magnetic fields on chemical (including biochemical) reactions involving free radicals. The magnetic field levels that have been studied in all these effects are much greater than the 0.1 to 1 milligauss 60 Hz magnetic field intensities measured thus far on

impacted Minnesota farms.

D. Internal Body Electric Fields Due to Small Contact Voltages

Voltages associated with earth and ground currents between contact points to animals produce internal electric fields which cause the flow of body currents. Different types of physiological effects may be produced depending upon the magnitude and frequency of such currents and the duration of animal exposure to the responsible voltages (e.g., seconds, days, weeks or years).

One existing body of literature (Lefcourt, 1991; Reinemann et al, 1995) supports the conclusion that at 60 Hz a behavioral response is produced in cows only by currents larger than 1 mA; a moderate behavioral response occurs at levels of 3 mA to 6 mA, above which it may become severe. Some research indicates that production problems due to animal behavioral effects occur at 4 mA and changes in animals (possibly leading to decreased milk production) have been observed at the 6 mA level and above. Research involving exposure of cows to contact voltages of less than 0.5 V (corresponding to 1 mA or more for a 500 ohm cow) for up to 30 days at a time is reported to have shown no significant behavioral effects. Accordingly, many Minnesota utilities will attempt to mitigate stray voltage problems at a level of 0.5 V or above.

A separate body of literature on biological effects of electric and magnetic fields (see representative citations below) compares specific biochemical responses to the strength of the internal electric field in various living systems. It is worth noting that comparable studies involving long-term (i.e., longer than one month) exposure to continuous voltages of less than 0.5 V have not been reported for dairy cows. Research in this area may be desirable because conductive contact with stray voltages smaller than 0.5V can produce electric fields inside cows which are larger than the internal electric fields shown to be physiologically significant in other animals (mostly rodents and small primates).

A relatively small, steady state, 60 Hz stray voltage can result in a larger internal electric field in a cow than that which is associated with biological effects in other species. For example, bone formation in the isolated ulna of the turkey is associated with an internal electric field of approximately 10^{-3} V/m at 15 Hz and 75 Hz (McLeod et al, 1992). In cerebrospinal fluid of the pigtailed macaque, a decrease in metabolites of dopamine and serotonin was associated with an internal electric field of $2\cdot10^{-4}$ V/m at 60 Hz (Wolpaw et al, 1989). In rats an apparently decreased level of testosterone and phase shifts in plasma hormone levels between exposed and sham were associated with an internal electric field of $5.6\cdot10^{-4}$ V/m at 60 Hz (Free et al. 1981). Further, various government standards for exposure to external 60 Hz electric fields are consistent with the internal field strengths cited above. For example, the American Council of Government and Industrial Hygienists limits occupational exposure to 41.7 kV/m. This corresponds to an internal field strength of $4.17\cdot10^{-3}$ V/m in man, assuming an attenuation of 10^{-7}. The International Non-Ionizing Radiation Committee of the International Radiation Protection Association limits continuous population exposure to 5 kV/m. This corresponds to an internal field strength of $5\cdot10^{-4}$ V/m. Both of the above cited standards are based on probable thresholds for biological effects on the basis of well established models for electrical effects on cells[9].

In a cow these levels of internal electric field could result from exposure to stray voltage levels lower than the 0.5 V and above currently believed to be associated with potential problems. For example, average internal electric fields from 10^{-3} to 10^{-2} V/m would be created in the head of a cow by voltages of 0.007 V to 0.07 V applied between mouth and all hooves. Comparable average internal fields would be produced in the body of a cow by voltages of 0.24 to 2.4 V applied between front and rear hooves, and these internal fields would be produced in leg muscle tissue by voltages of approximately 0.002 V to 0.02 V (See Box D).

The electric field exposure studies cited above are specific for laboratory animals. It is important to emphasize here that a biological response to an electric field exposure that is observed in birds, primates or rodents in the lab may not necessarily be the same as that for dairy cattle in conductive contact with voltage on a farm. Further, in the absence of findings of poor health and demonstrable gross or microscopic lesions, alterations in hormone or metabolite concentrations in extracellular fluids are not necessarily indicators of a pathological condition. It should also be stressed that the exposures used in these electric field experiments were *continuous* and *long-term* whereas typical cow contact exposures to voltage on a water cup represented in Example 1, Box D are *momentary* and *intermittent*. Also, the step voltage range of 0.24 to 2.4 V calculated for the path from mouth to all hooves in Example 2, Box D, is significantly larger than typical step voltages found in dairy barns and very much larger than average step voltages of mV/m

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Box D

Stray voltages which produce internal electric fields at biological effects levels:

Biological effects have been reported to occur at internal electric field levels down to 10^{-2} - 10^{-3} V/m and below (in species other than cows). To calculate stray voltage levels which result in similar internal field levels in a cow, apply Ohm's law: $V = IR$ where (V) is the stray voltage, (I) is the current through the cow and (R) is the path resistance. Ohm's law at a point is: $E = J/\sigma$ where (E) is the internal electric field at a point in a cow, (σ) is the conductivity and (J) is the current density there. To combine these relations, use: $J = I/A$ where (A) is the cross sectional area of the current path. Then: $V = JAR = \sigma ARE$.

Example 1: Path from mouth to all hooves, internal field in the head.
A = head cross-sectional area≈ 20 x 20 cm = 0.04 m^2.
R≈ 350 ohm, σ≈ 0.5 S/m. Then V = 7 E.
For E = (10^{-3} to 10^{-2} V/m), V = (0.007 to 0.07 V).

Example 2: Path from front to rear hooves, internal field in the body.
A = rump cross-sectional area ≈ 80 x 80 cm = 0.64 m^2.
R ≈ 750 ohm, σ≈ 0.5 S/m. Then V = 240 E.
For E = (10^{-3} to 10^{-2} V/m), V = (0.24 to 2.4 V).

Example 3: Path from front to rear hooves, internal field in the leg muscle tissue.
A = muscle cross-sectional area of two legs (front or rear) = 0.5 x (10 cm x 10 cm) = 0.005 m^2. R = 750 ohm,
σ≈ 0.5 S/m. Then V = 1.875E.
For E = (10^{-3} to 10^{-2} V/m), V ≈ (0.002 to 0.02 V).

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[9] Sheppard AR. Epidemiologic and laboratory research on the potential human health effects from exposure to power frequency electric and magnetic fields, a background paper for Minnesota Environmental Quality Board, 658 Cedar St., St. Paul MN 55155. (1993)

expected to be associated with earth current (see Section VI. A). On the other hand, as shown in Example 3, Box D, relatively small voltages of 2 mV to 20 mV applied between the cow's front and rear hooves, are more likely to be typical of levels found in dairy barns. These voltages could result in electric field levels in leg muscle tissue which are associated with biological effects, particularly considering that the exposure is relatively continuous for a cow confined in a stall.

There is a possibility that cattle may be affected in some way when chronically exposed to low voltages, but there is no evidence for or against such a finding. Currently, the likelihood that the calculated internal currents and electric fields would be a significant factor in impairment of dairy cow health and milk production is unknown.

Box D shows the range of stray voltage values that would be associated with internal electric fields of 10^{-3} to 10^{-2} V/m under two common exposure scenarios, voltage between mouth and all hooves, and between front and rear hooves. These levels of stray voltage result in larger internal electric fields than exposure to the 60 Hz magnetic fields measured thus far in dairy barns. As described previously, an 0.7 milligauss 60 Hz magnetic field would result in an internal electric field of $7.5 \cdot 10^{-6}$ V/m in a cow (see Box C). This is two to three orders of magnitude smaller than the internal electric field range due to stray voltage considered above. Under the 60 Hz, steady state scenario where the effect is restricted to conduction and Faraday induction, it may be that if earth current has a direct effect on a cow, it is through a long-term exposure to the accompanying voltage and not the magnetic field. However, if direct magnetic field interactions or some other identifiable physical process is involved as previously discussed, the above comparison may not apply.

E. Indirect Mechanisms

Some conceivable mechanisms of indirect interaction between earth/ground currents and dairy cows have been discussed by the Science Advisors; however, insufficient information is available to evaluate the applicability of any of them. Among these mechanisms is a possible effect of earth current on ground water chemistry whereby earth current, after partial ac to dc rectification and concentration at farm wells, could lead to pollution of the herd's water supply. Rectification of earth currents has been observed at strong discontinuities of soil electrical characteristics such as can occur at the border of a large deposit of extraneous material (Frohlich, 1988). Contamination might also result from acceleration of corrosion of water pipes and consequent introduction of impurities into water. A second mechanism involves piezoelectric properties of mineral crystals in the earth and concrete where a large ac electric field in the earth could possibly cause vibration in the floor to which cattle may be sensitive.. In addition, some reports have claimed that the physical properties of water can be altered by dc magnetic fields, but these changes are reported to occur at field strengths much greater than those normally found on dairy farms.

It also should be noted that ground water conditions may influence the farm electrical condition.

Most dairy farms in Minnesota are located on landscapes that contain ions dissolved in ground water. Any increase in ground water during wetter periods will result in enhanced electrical conduction near the soil surface. Potential electrical problems related to earth current will be amplified during high water periods. Therefore, improved drainage near barns could decrease the likelihood of problems due to earth current, if indeed such problems exist.

F. Summary

In a dairy barn, stray voltage, ground current and earth current are all present. While they are distinct quantities, they are all related to ac voltages on the neutral conductors of electrical distribution systems. *Neutral voltages* (neutral-to-earth voltages or NEV's) arise because conductors that carry neutral current have some electrical resistance. Primary neutral voltages on the distribution system access the secondary neutral on the farm because the primary and secondary neutral conductors are normally connected at the transformer serving the farm. Voltage on the secondary neutral is also caused by electrical use on the farm.

Neutral-to-earth voltages are of concern to some dairy farmers because the National Electric Code (NEC) requires that the secondary neutral conductor be connected to the metal water line (a very good ground connection) near the point of entrance to the barn. This practice results in voltage to which cows are exposed. The secondary neutral provides a voltage source and the water line an electrical path for *ground current*, the current which flows between the electrical neutral system and earth along a metallic path. In a stanchion or tie-stall barn, ground current flows along the waterline, through the metalwork of the stalls to which the water line is bolted, and then to the earth through the concrete in the floor, among other parallel paths.

Neutral voltages result in *stray voltages* in the stall. Between the barn electrical service entrance and some point on the earth's surface, the voltage falls depending on the resistances of path segments. The resistance between the water line and the floor in a stall results in a stray voltage to which a cow may be exposed. This stray voltage is referred to as a cow contact voltage because it is that voltage between the cow's nose (i.e., while drinking) and hooves. The voltage drop or step potential across the floor is also a cow contact stray voltage, that between the cow's front and rear hooves.

Once ground current leaves its metal pathway and enters the earth, it becomes *earth current*. Like ground current, earth current can be associated with cow contact stray voltages. Technically, it is earth current and *not* ground current that is associated with step potentials in stalls, since ground current becomes earth current when it leaves the metal stall pipes and flows in the concrete. It should be recognized that earth current in a stall consists of current flowing from near sources (e.g., stall pipes) as well as from distant sources (i.e., all other connections of neutral systems to earth). Because current diffuses within a short distance once it enters the nearly limitless conductor of the earth, its associated step voltages also become very small within a short distance. Thus it is more likely that step voltages in a stall are associated with earth current originating *in the stall* rather than from sources more distant unless these sources are very strong.

In the foregoing discussion of basic physical mechanisms, a small number of scenarios were identified through which electrical parameters could conceivably be affecting dairy cows:

1) Pulsed electric fields from sources such as cow trainers may be locally large enough at the cow's back to be sensed by cows.

2) Magnetic fields from ac ground current on water lines in the barn may be large enough at the head of a cow to induce biological effects.

3) Exposure of cows to ac magnetic fields from all sources in the barn combined with particular levels of the geomagnetic field may conceivably produce biological effects.

4) Current transients may affect a cow through the associated transient stray voltage or through magnetic induction.

5) *Continuous* or frequently repeated contact of confined cows to sources of low level stray voltage may result in internal electric fields at levels high enough to produce biological effects.

All of the above scenarios can be due to common stray voltage sources rather than earth currents from distant sources. This is because, in a tie stall barn or a stanchion barn, there is a direct metal path from the farm's neutral to the cow through the waterline and stall metalwork. Thus it is more likely that, on truly and effectively isolated farms, these scenarios would be due to on-farm stray voltage sources or off-farm sources other than the primary distribution line leading to the farm. Currents of low intensity may not produce an easily observed acute behavioral response such as tail switching or weight shifts. However, over longer periods of time, small currents may produce other significant but less readily detected responses such as changes in social/herd behavior, in stress-related hormone concentrations, or in immune response. The latter responses may indicate that possible harm is being done to a cow. Whether the levels of the electrical parameters identified in scenarios (#1) through (#5) above can have a pathological effect on dairy cows is unknown.

VII. RESEARCH PLAN

A. Research Justification

The primary question raised in the legislation authorizing the activities of the Science Advisors is whether currents in the earth adversely impact dairy cows. The information presented to date by individual dairy farmers and TERF is consistent with the claim that cows on some Minnesota dairy farms have persistent and unresolved behavior (e.g., unwillingness to enter barn, refusal to eat or drink in the stall), milk production (e.g., production levels that are erratic, low compared to state averages or low compared to farmers' expectations; incomplete milk out) and/or health (e.g., persistent mastitis and leg sores) problems. There also is evidence that such unresolved problems exist in other states. In their December 1994 report to the Science Advisors, TERF proposes that these problems are the result of earth currents which arise from the utility practice of bonding the distribution system's primary neutral to the earth. However, neither the TERF report, nor any other information or research available to date demonstrate a clear relationship between currents in the earth and the reported problems.

It is already well-established in the scientific literature that intermittent cow contact voltages of one-half volt or higher can induce many of the problems cited by dairy operators who have reported their concerns to the Science Advisors or filed complaints to the Minnesota Public Utilities Commission. In addition, as pointed out in Section VI. of this report, there are several possible mechanisms other than exposure to cow contact voltages of one-half volt or higher through which electricity might affect dairy cows. While all of these scenarios can be due to common stray voltage sources, earth current from distant sources cannot be excluded. There also are a variety of non-electrical factors (e.g., pathogenic bacteria and viruses, nutritional deficiencies, metabolic diseases, milking equipment, etc.) which have been thoroughly documented in the scientific literature to cause some of these same problems in dairy cows. Further, the reported problems could result from a combination of electrical and non-electrical stressors.

When multiple parameters in the dairy farm environment might be affecting the cows, it is very difficult and may be impossible to determine the specific contribution of any one factor without examining all of them. Since there has been no uniform and systematic effort to study possible effects on dairy cows of electrical parameters other than conventional stray voltage, conclusions cannot be drawn about their relative contribution to the problems cited by concerned dairy operators. The *only* way to prove or disprove possible contributions of these other electrical parameters to persistent and unresolved dairy herd behavior, health and production problems is to conduct targeted research.

B. Overview of the Research Plan

The research plan proposed here includes both field and laboratory studies. It is designed to address two primary goals:

(1) clarifying the exact nature and scope of the persistent and unresolved behavior, health and milk production problems reported by dairy farmers who are concerned about currents resulting from the practice of bonding the primary electric distribution system to the earth, and

(2) expanding the base of scientific information on whether and, if so, how man-made or natural sources of electricity can contribute to the reported problems.

Field or "on-farm" studies are an integral component because they can provide information on the nature, prevalence and geographic distribution of the problem in the context of the environment in which it occurs -- some aspects of which cannot be duplicated reliably in the laboratory. In addition, if sample sizes are large enough, field studies can provide valuable information on "normal" and "exceptional" conditions and measurements for various electrical parameters on and off the dairy farm. Such data are essential for evaluating the on-farm significance of the threshold levels of any effects revealed independently by laboratory studies. A secondary but very important outcome of field studies is that some of the information gained along the way can be useful to the individuals, in this case dairy farmers, who are encountering the problems under study.

Laboratory investigations are an essential component of the plan because they allow comprehensive evaluation of accurately specified parameters and are useful in determining threshold levels at which electrical effects can be measured. Such studies constitute an approach to rigorously demonstrating the "negative hypothesis" that specific electrical parameters and sources *do not* cause measurable effects in cows. In the case where the presence or magnitude of a particular electrical parameter is found to be associated with a specific adverse effect(s), laboratory research is the principal approach that can confirm the mechanism. Knowing the mechanism is a powerful measure for developing effective mitigation strategies.

The field and laboratory studies outlined below are complementary. Each would serve to inform the other throughout the term of the initiative, which could extend up to four or five years depending on the findings acquired each year. Year I of the research plan includes background/exploratory studies that are needed to fill in some of the current gaps in knowledge about the nature and scope of the reported behavior, production and health problems at issue here. Also included in Year I are strategies for developing electrical measurement protocols, equipping a research laboratory, and developing at least one model for cow behavioral response for use in studies planned for later years. During Year II, pilot/preliminary studies would be conducted in order to test and refine the field measurement protocols and the laboratory behavioral response model developed in Year I, and to incorporate that information into the planning of definitive studies to be initiated in Year III. The definitive study phase would likely extend from Years III through V, and would address directly the question of whether electrical parameters other than those already known to affect dairy cow behavior, health and production are associated with some of the problems reported by Minnesota dairy operators. At the end of each year of the initiative, results of the studies performed to date would be assessed, and decisions would be made about whether, or to what extent, the next phase of the research plan should be undertaken.

Specific objectives and plans for each year of the initiative are as follows:

1. Objectives and Work Plan--Year I:

Three areas of research would be initiated in Year I: (a) surveys of dairy farmers and veterinarians/farm advisors and assessment of Dairy Herd Improvement Association (DHIA) records related to milk production parameters, (b) development of measurement protocols for electrical and related parameters not typically measured on dairy farms and assessment/refinement of available protocols for conventional on- and off-farm electrical measurements, and (c) establishment of a laboratory equipped to conduct rigorous studies of effects of steady state and transient electrical parameters and development of at least one less subjective and more quantitative model of cow behavioral response to environmental stressors.

a. Surveys and analysis of DHIA records. To date there has been no uniform and systematic attempt to collect information and documentation on the persistent, unresolved health and milk production problems reported by some dairy farmers to be associated with the utility practice of bonding the electric distribution system's primary neutral to the earth. Resolution of this issue is further complicated by the fact that the signs of poor health and production reported by these farmers are known to be associated with a variety of factors, some electrical and some non-electrical. When the potential causes are as multi-varied as the observed effects, it is difficult to establish causal relationships. The availability of resources to conduct research on this issue and the types of studies that can be carried out successfully will depend, in part, on obtaining more information on the true nature and scope of these unresolved problems on dairy farms in Minnesota and elsewhere. Thus several surveys are planned to provide more information on these issues and, to the extent possible, document the level of association between farmers' perceptions of problems and any relevant records maintained on their herds.

One survey would be directed toward farmers. An effort would be made to reach all dairy farmers in Minnesota, and possibly several other states (see Section E. below, "Interstate Collaborations"), via dairy producer associations and farm organizations, the popular press, farm journals, etc. The survey would include, among other things, self-reporting on the types of signs that have been ascribed by some farmers to earth currents and related parameters, but without any reference to electricity. Another survey would assess the prevalence and distribution of signs of unresolved health and production problems on these farms as ascribed by veterinarians and other farm advisors. Whenever possible, attempts would be made to acquire information pertaining to farms that are no longer in business.

Both the survey of farmers and the survey of veterinarians and farm advisors would be designed to help better define "the problem." That is, they would provide a more precise definition of the clusters of health, production and behavior abnormalities believed by some farmers to be associated with electricity. The surveys also may serve to identify possible associations between reported problems and the geographic location of a farm and other factors that might be unique to such farms and thus important to the design of future research. Finally, the surveys may help identify farms that could serve as cases for the field studies referred to in Years II and III of this plan.

Computer analysis of Dairy Herd Improvement Association (DHIA) records would be conducted to assess general trends and the degree of variability in milk production and associated parameters (e.g., milk fat, somatic cell counts (SCC), etc.) in Minnesota as well as the degree of variability between farmers' perceptions of health and productivity changes and the available DHIA records for their herds. Records on milk production and related parameters are maintained by DHIA and are reliable resources for retrospective analysis of the kinds of data needed to document the problems reported by dairy farmers.[10] A random sample of Minnesota dairy farmers would be asked for permission to access their DHIA records through local processing centers. The milk production and reproductive records of willing participants would be analyzed both individually and collectively. Respondents would be classified into the following groups:

(1) productivity has steadily improved;
(2) productivity has neither improved or declined;
(3) productivity has gradually declined; and
(4) measures indicate erratic or aberrant productivity.

This DHIA analysis would be used for several purposes: (1) to estimate the overall variability in productivity measures (e.g., milk production in pounds/cow/day, average days in milk, SCC, percent butterfat, percent protein, etc.) in DHIA herds over the last several years; (2) to identify possible "problem" herds (i.e., those showing a gradual decline or erratic or aberrant productivity) and "non-problem" or "control" herds (i.e., those showing steady or steadily improved productivity); (3) to estimate the prevalence of problem herds among DHIA

[10]Note: Concerns can be raised about the extent to which DHIA provides a representative sample of dairy farms in Minnesota. Further, a large fraction of the herds owned by dairy operators who have filed complaints with the Minnesota Public Utilities Commission are not enrolled in DHIA. Their farms would not be identified under this protocol. It is also important to note that some farmers with concerns about adverse electrical effects on their herds do not report persistent problems in SCC and milk production. However, the majority of the concerned farmers do report large changes in these parameters and thus it is important to gain documentation for them, to whatever extent is possible.

membership and (4) to determine the geographic distribution of problem herds in the DHIA sample. At present, the "normal" or baseline measures of Minnesota dairy herd production parameters are not available in a form that can be used for comparison with the data reported by farmers in the TERF report and elsewhere. The DHIA analysis could reveal, for example, when monthly milk production trends were low over the last several years. Further, when the results of the DHIA analysis for individual farms are compared to data from the surveys of the farm owners, it would be possible to estimate the level of association between farmers' perceptions and actual data on milk production parameters. This is particularly important because although farmers should never be expected to maintain comprehensive data on all of the signs of interest here, a substantial investment in research cannot be fully justified or correctly targeted without some reliable way to further validate farmers' perceptions of the nature of the unresolved problems with their herds. Finally, all of the outcomes of the DHIA records analysis would be important to the final design and implementation of the "case/control" study to be initiated in subsequent years.

b. Development of measurement protocols for electrical and related parameters not typically measured on dairy farms and assessment/refinement of existing protocols for electrical parameters typically included in the assessment of on- and off-farm electrical problems. This component of the Year I research plan is directed at developing and selecting measurement protocols. These protocols would be used in subsequent years to fully characterize the electrical environment on farms, first as part of the pilot field (case/control) study described under the Year II Work Plan and later as part of the longer-term field studies described in the Work Plans for subsequent years. Electrical parameters for which protocols should be developed or selected include, but are not necessarily restricted to, the following: electrical map on and near the farm, including type of neutral isolation, if any and diurnal variation of total power consumption and current used by particular loads; neutral-to-earth potentials, including cow contact voltages; electrical parameters associated with the milking system; ground rod and ground rod-to-earth resistances on and near the farm; establishment of ground current paths; total earth current (e.g., magnitude, direction, source impedance, frequency composition and modulation, variation with time, and localization across the barn, near wells, primary and secondary grounds, etc.); earth surface potential differences; cow trainer and fencer characteristics; magnetic field near metal structures, including frequency composition; and DC magnetic field inside the barn, and at various positions; electrical currents inside animals due to external sources.

Additional parameters that can be related to or affected by electrical conditions, also would be characterized. Examples of these include wiring code compliance of the farm electrical system; soil resistivity inside and outside the barn and during different seasons (in view of variation with soil moisture); location of water table during different seasons; water characteristics (e.g., electrical resistivity, ion content during different seasons, and well depth); area map of relevant parameters (e.g., pipelines, pumping stations, electrical substations, electrical lines within a selected distance from the farm, etc.); construction of the barn as it affects electrical and magnetic environments (e.g., metal vs. wood); ventilation in the barn; type of lighting (fluorescent or incandescent) and on-off cycles; and extent of electrical homogeneity of concrete barn floors.

c. Establishment of a laboratory facility and *initiation* of preliminary studies to develop improved dairy cow behavioral and physiological response indicators. Year I would set the stage for laboratory work that would be carried out over the next several years. A laboratory facility would be designed and equipped to carry out rigorous experimental studies on exposures of 8 or more dairy cows to steady state and transient voltages and fields from a variety of different sources and under multiple conditions that model the ones cows are exposed to in dairy barns, particularly those operated by farmers who have reported the types of problems of interest here. Facilities somewhat similar to those proposed here already exist at research institutions in Michigan, Minnesota, New York, Wisconsin and other states and have been used for stray voltage research over the last decade. However, the proposed studies would require some modifications of the facilities and approaches published thus far.

In addition to equipping a research facility, work would be *initiated* toward the development of less subjective and more quantitative dairy cow behavioral response indicators and more reliable physiological response indicators needed for the laboratory studies proposed in Years II and beyond in this plan. Improved response indicators are needed for several reasons. For instance, chronic (e.g., one or more months) exposure of cows to certain electrical stimuli, such as the relatively low intensity step voltage between the front and rear hooves, may cause apparently subtle changes that could eventually manifest as health and production problems. Such responses would be difficult or impossible to detect with the laboratory models used by researchers at the University of Wisconsin or Cornell University that monitor immediate behavioral responses (e.g., shifting of body weight, "dancing") to electrical stimuli (e.g., steady state or transient voltages on a drinking cup) delivered intermittently, and usually over a relatively short period of time (hours or days). Further, while immediate behavioral responses such as the shifting of the cow's body weight are presently thought to be among the most sensitive indicators of stress and can be related to the observations reported by farmers, they are more subjective and difficult for different observers to score uniformly, especially over long periods of time.

In addition, the research published on stray voltage effects on cows during the 1980's and through the present time is limited in the area of reliable physiological response indicators, and in general, it cannot be used to arrive at definitive conclusions. Newly developed or improved analytical methods have become available in recent years for more accurately monitoring changes in concentrations of a number of hormones that may be responsive to environmental stressors. Physiological response indicators are especially needed for studies proposed in Year III on effects of electrical stimuli, particularly when the stimuli are of low magnitude, but are applied either continuously or intermittently over a long period of time (e.g., 4-6 weeks or more).

Year I research in the laboratory would likely focus on the development of less subjective, more quantitative models for cow behavioral responses to short-term (i.e., ranging from one or several seconds or minutes up to 24 hours), intermittent and continuous exposures to electrical parameters. One well-developed model for measuring an immediate stress response in the cow which may be applicable to this area of research is the evaluation of cyclic contraction patterns in two forestomach compartments, the reticulum and the rumen. These gastric contractions have been well-characterized, can be readily detected and recorded and are continuously present in healthy, undisturbed cows. A reduction in the frequency or magnitude of pressure events or an alteration in the rhythmic pattern of contractions could be used as an indicator of a disturbing or painful electrical stimulus. Painful, frightening or other stressful stimuli such as infectious diseases, metabolic diseases and digestive upsets are known to inhibit normal contraction patterns.

This gastric motility or some other quantitative model would be developed in the laboratory by a qualified researcher and tested during Year I of this plan for its applicability, first using known non-electrical stressors (e.g., duodenal infusion, autonomic drugs) and then an established electrical stressor (i.e., stray voltage at levels known to produce behavioral responses in most cows). The tests would involve a minimum of 8 cows and would require up to 4 weeks per exposure condition.

2. Objectives and Work Plan–Year II:

The focus of the Year II plan would be on pilot/preliminary studies aimed at testing and refining the measurement protocols, the laboratory facility, and the cow behavioral response model developed in Year I, and to incorporate that information into the planning of definitive studies to be initiated in Year III.

a. Pilot field ("case/control") study. Approximately 10 farms would be investigated in depth by a skilled research team (not including staff from state agencies or utilities serving Minnesota dairy farms) in a pilot "case/control" study. The study would include a total of 5 "case" farms initially identified from the survey of the farmers and preliminarily confirmed by the survey of veterinarians/farm advisors and possibly DHIA records as having persistent and unresolved health and production problems and 5 "control" farms without such problems as identified from the same sources. The pilot study would accomplish three major goals: (1) It would serve as a testing ground for electrical measurement protocols developed in Phase I. (2) It would function as a pilot to demonstrate the feasibility of conducting an expanded study in Year III to identify possible associations between certain electrical or non-electrical risk factors and the observed health and production problems. (3) It would allow preliminary assessment of the feasibility of reporting the findings of the investigatory team to the dairy operators participating in the research and coordinating follow-up assistance to those who are interested in finding remedies to any problems that are identified.

A standardized questionnaire and measurement protocol manual would be developed at the end of Year I and piloted in this study. These materials must be appropriately pre-tested so they can be used by one or more investigative teams. Data would be gathered on the electric and associated parameters listed under Year I of the work plan, using the measurements selected or developed during that phase of the research. In addition, data would be collected on other, non-electrical parameters which have been well-documented in the scientific literature to be associated with the types of adverse outcomes attributed to electrical effects by some farmers. Among these are stall type and size, nutrition, mastitis control program, immunization schedule, and milking procedures. Finally, documentation of the reported problems on "affected" or case farms would be sought, including average herd milk production, somatic cell count (SCC), water consumption, abscesses and lesions, mortality of calves, heifers and cows, reproduction and aberrant behaviors.

The research team(s) would consist of a suitably trained electrician, an electrical engineer, a veterinarian and an animal scientist proficient in dairy nutrition and management. Each team would be trained to evaluate a single farm in two to three days, with repeat visits as necessary to address seasonal variations in certain measures and other appropriate follow-up activities. Data collected would include, but not necessarily be limited to the lists of electrical and non-electrical measures described under the Year I study plan.

The pilot case/control study of 10 farms would be carried out only if enough farms (e.g., at least 30 and preferably 50) with unresolved health and behavior problems are identified by the surveys and the DHIA records analysis to justify an expanded case/control study beginning in Year III. At the completion of the pilot study, researchers would arrive at one of the following conclusions:

a. Sufficient knowledge has been gained to properly design and conduct an expanded, more definitive case/control study to reveal any statistically significant correlations between measures of animal health and productivity and specific, measurable electrical parameters.

b. Evidence of strong associations between animal health and production measures and a specific risk factor(s) is sufficient to convince researchers that steps should be taken immediately to reduce the risk factor(s) on all affected farms. In this case, an expanded study may be difficult to justify, or it would have to be re-targeted to identifying farms affected by the identified risk factor(s).

c. Insufficient herd-to-herd variation in health and production outcome measures; inability to make meaningful, accurate, reliable and repeatable electrical measurements across farms; or inability to adequately define a "problem" herd would make it difficult to proceed to an expanded case/control study.

In addition to informing the design of the definitive case control study described under the Year III Work Plan, this pilot study would provide some useful information for the laboratory studies proposed for Year III (e.g., preliminary ranges for certain on-farm electric measurements).

Information gleaned from the pilot case/control study, and later the expanded case/control study, cannot be of value to farmers collectively until the data gathering phases are completed and the results are analyzed. However, immediate feedback to individual farmers on the findings from data collection performed on their farms would be feasible. Informal contacts with several Minnesota professional associations representing farmers and dairy operators suggest that farmers would be supportive of an effort to implement some type of information feedback mechanism to be undertaken in parallel with the field research. A program could be piloted in Year II to report back investigation findings to individual farmer-participants, on a confidential basis, and to coordinate follow-up visits and cooperation with the serving veterinarian and other farm advisors, as needed. (See also Year III Work Plan for more details on potential applications of this concept.)

b. Laboratory studies. The laboratory component of Year II of the research plan would focus on identification and application of reliable indicators of physiological responses in dairy cows and determining thresholds for behavioral and physiological responses of dairy cows to intermittent and continuous, but short-term (e.g., ranging from several minutes to approximately 24 hours) exposures to steady state and transient voltages and magnetic fields.

Increasingly sensitive techniques for serological analysis have continued to be developed over the last 5-10 years, yet these have only been applied to studies aimed at evaluating hormonal changes in cows in response to short- or long-term exposures to electrical stimuli. In the studies initiated in Year II, stress-related hormones, such as the catecholamines and adrenocorticosteroids, and other hormones that may indicate an adverse impact on health and milk production in the cow would be assessed.

The studies proposed in Year II must be undertaken for several reasons. Physiological response studies performed to date using rodents and primates have only limited application to dairy cows. Reports of studies on responses to electrical stimuli as determined by changes in blood levels of stress-related hormones in laboratory animals (e.g., rats, mice and monkeys) also are conflicting. Laboratory animals do not necessarily serve as reliable models for predicting physiological responses to environmental stressors in cows. For example, anatomical and physiological differences are too great to allow transfer of results from rodents or primates to cows. Without a better understanding of the possible relationships between specific electrical parameters and physiological responses in dairy cows, it is unlikely that there will ever be a resolution of the question of what electrical parameters and conditions, other than relatively high levels of stray voltage, are critical.

A primary reason for undertaking studies to establish threshold behavioral responses of cows to electrical parameters is that few guidelines are available from studies published to date. The only scientifically-derived guidelines available were developed from experiments with intermittent contact exposures to relatively high levels of stray voltage, such as those which occur while the cow drinks out of a metal water cup. Guidelines for transient voltages are incomplete and no guidelines have been developed for magnetic fields or for continuous exposure to lower levels of stray voltage. One important outcome of knowing the true threshold levels for any effects of these parameters, is that dairy operators, utility companies, regulators, farm advisors, veterinarians and others can work together more effectively towards appropriate solutions.

3. Objectives and Work Plan–Years III-V:

Year III of the research plan marks the definitive phase which addresses the question of whether electrical parameters other than those already known to affect dairy cow behavior, health and production are associated with some of the problems reported by Minnesota dairy operators.

a. Expanded field ("case/control") studies. There are two key reasons for conducting a large scale, case/control study. First, it would demonstrate whether an association exists between the presence/magnitude of a specific electrical parameter and specific problematic health and production outcomes. Second, it would provide a large database on "normal" and "abnormal" measures of important electrical and non-electrical parameters on Minnesota farms with and without persistent, unresolved health and production problems. Taken collectively, this information would be extremely valuable to farmers, utilities, regulatory agencies, farm advisors and the dairy industry. Such a database is not presently available in Minnesota or any other state. Further, the data collected on individual farms could be of significant value to the dairy operator, particularly one with unresolved health and production problems.

Measurement protocols tested and refined in the Year II pilot study would be applied to larger samples of case and control farms, ideally at least 50 of each type. Control farms would be selected from the same herd size strata and the same geographic areas as case farms. As currently envisioned, the study protocol would take two years to complete on 100 farms. Final analysis of the full complement of data collected on these farms could not be conducted or reported on until enough farms are studied (probably at the end of Year IV of this plan) to reveal any statistically significant relationships. Data would be analyzed using appropriate multivariate statistical techniques (e.g., logistic regression) to compare exposures (both electrical and non-electrical) between case and control farms, adjusting for the presence of potentially confounding variables and effects of modifiers.

At the beginning of Year III it would be appropriate to evaluate the level of farmers' interest in the program piloted during Year II for reporting back to and advising them, confidentially, on any actual or potential problems found during data collection on their farms. If the pilot reporting program is well-received, it would be more fully developed and continued in Year III. Significant input would be solicited from dairy and farm organizations on what type of format would be most useful for reporting findings and advice to farmers, and on the types of follow-up assistance needed. The involvement of veterinarian(s) and farm advisor(s) that serve the participating dairy farmers also would be solicited.

If dairy operators do want ongoing access to a trained investigative team once the data collection phase of the case/control study is complete, then one could be established for that purpose. There are a variety of approaches that could be used to operate and support such a team. Whatever the mechanism, an ongoing dairy farm investigatory team might serve some or all of the following roles:

- Educate utilities, farmers, local veterinarians and others on the need for working together to solve problems.
- Encourage a greater mutual respect and trust among utilities, farmers and farmers' advisors.
- Continue to improve procedures for on-farm assessment of electric and non-electric stressors.
- Provide appropriate technical expertise to define electrical and non-electrical stressors.
- Provide advice to farmers and utilities on methods that may be used to correct problems.
- Monitor success of corrective actions taken by farmers and others serving farmers.

Some type of advisory mechanism involving technical experts and stakeholders also could be instituted to oversee and monitor the performance of any ongoing, investigatory team that is established once the "formal" field research is complete. An advisory committee could help maintain the accountability of the team by ensuring that feedback is received from the farmers and others who use the team's services and that it is integrated into the team's investigative and reporting processes on an ongoing basis.

b. Laboratory studies. After the response indicators and threshold studies are completed during Years I and II, it would be possible to initiate more definitive studies of cause and effect in the laboratory.

Several areas of laboratory research would be initiated in Year III, and extended as necessary into subsequent years with priorities depending on any relevant results of the Year II pilot case/control study and research going on elsewhere independent of this plan. Current priorities for definitive laboratory studies include examination of behavioral and physiological effects of longer-term (i.e., at least 4-6 weeks) and continuous (e.g., front-to-rear hooves) or intermittent cow contact (e.g., metal drinking cup, stanchion or tie chain) exposure to low level voltages: short- and longer-term exposure to AC magnetic field levels such as those that might be associated with sources of ground currents in the dairy barn, with and without combined DC magnetic fields; and short-term and long-term exposures, both intermittent and continuous, to current and voltage transients.

The individual studies would involve an assessment of various observable behaviors (e.g., standing and lying time) during exposure and sham exposure conditions in concert with the less subjective, more quantitative measure developed in Year I and II. Water consumption and milk production would be measured routinely. In addition, peripheral blood levels of various hormones (e.g., the catecholamine, adrenocorticosteroid and others) that may indicate an adverse effect on health or milk production, and if so, what the potential mechanism of interaction might be.

The proposed laboratory studies are warranted for many reasons. First, many of the previous studies of electrical effects on dairy cows suffer from a poorly defined outcomes strategy. That is, no matter how well-defined the conditions under which the electric stimuli are applied and measured, the effects that may result are so often characterized in such subjective, non-quantitative ways (e.g., tail switching, weight shifting) that it is impossible to draw definitive conclusions about outcomes. These observables are important for *identifying* possible stressors in the field, but they are of limited value in trying to *explain* such problems.

Not only are the outcomes of some of the previous work subject to criticism, but so are the manner in which the electrical stimuli were applied. Very little work has been done with exposure of dairy cows to uniform magnetic fields, and few, if any, definitive conclusions can be drawn. For instance, establishing a current source in the vicinity of a cow to generate a magnetic field is of dubious value if one cannot characterize precisely the field thus produced, or define the specific aspect of a potential magnetic field interaction that is being probed. Studies also must take into account that in addition to intensity, magnetic fields exhibit vector, or directional qualities, gradients, frequency, and different response possibilities when used in conjunction with static magnetic fields.

In the stray voltage area, very little is known about effects on cows of voltages below 0.5 volts (producing internal currents below 1 milliamp). From laboratory experiments with small animals (e.g., rats and mice), it is known that currents well below 1 milliamp, when induced continuously, or intermittently over periods of weeks or months, can affect the neuroendocrine system. In general terms, more work also needs to be done to determine whether some parts of the cow's body (e.g., the head/brain) are more susceptible to electric exposure effects than others.

Another limitation in many of the published studies in the broad area of stray voltage is lack of proper controls. Research conducted under the program proposed here would utilize both positive and negative controls to validate each assay and to firmly establish the magnitude of responses.

Finally, while some laboratory work on threshold levels of transient voltages on dairy cows has been conducted, it is by no means exhaustive. For example, work in the late 1980's by Gustafson et. al. at the University of Minnesota was with 60 Hz signals with duration from one cycle to one second. More recent studies by Reinemann et. al., at the University of Wisconsin have determined cow responses for frequencies of 60, 500, 6,000 and 50,000 Hz. Intermittent exposure (i.e., via contact with the water cup while drinking) to 60 Hz, 1 cycle transients for 21 days at or above the response level for each cow did not reveal any effects on all parameters measured. These studies reveal that wave shape (or frequency content) as well as duration of transients determine nerve stimulation as evidenced by an obvious, immediate behavior response. Yet apparently nothing is known about possible effects of frequent application of transients that are below the nerve stimulation level. More information also is needed on the characteristics of transients encountered on rural distribution systems and on farms. Preliminary indications from measurements taken in Minnesota and Wisconsin suggest that laboratory studies conducted to date may not adequately model the complexity of actual on- and off-farm transients. Thus more studies are needed on the high frequency transients to further define the response ranges in which to investigate.

C. Budget Summary:

1. Year I:

a. Survey research and analysis of DHIA records. $75,000.

b. Development of new measurement protocols for electrical parameters not typically tested on and off farms and assessment/refinement of protocols more typically used. $80,000.

c. Equipping a laboratory for rigorous studies of possible electrical effects on dairy cows and development of a behavioral response indicator. $100,000.

d. Associated staff and Science Advisors' support costs. $125,000.

Total Year I Estimated Budget: $380,000

2. Year II:

a. Pilot field (case/control) studies. $85,000

b. Laboratory research. $100,000

c. Associated staff and Science Advisors' support costs. $125,000.

Total Year II Estimated Budget: $310,000

3. Years III - V:

a. Expanded field (case/control) studies. $230,000/year.

b. Coordination of program to confidentially report results of individual farm investigations to participating dairy operators. $35,000/year.

c. Laboratory studies. $100,000/year.

d. Associated staff and Science Advisors support costs. $125,000/year.

Total Years III-V Estimated Budgets: $490,000/year

D. Possible Funding Sources

The authorizing legislation charges the Science Advisors with identifying possible funding sources *other than* additional assessments of electric utilities by the Minnesota Public Utilities Commission. A preliminary assessment of possible private, state and federal funding sources is reported here. The likelihood of receiving funds for one or more of the components of this research plan from any of these sources has not been determined. More time will be required to fully assess the possibilities summarized below.

1. Private:

The tailored collaboration program of the Electric Power Research Institute (EPRI) is used by coalitions (often regional) of electric utilities affiliated with EPRI to address problems of special interest to them. Through this program, a percentage of the annual contribution to EPRI paid by member utilities is directed to a specific research initiative. This could prove to be a relatively likely source of funds particularly if EPRI would agree to collaborate with the Science Advisors who would be monitoring and overseeing peer review of the research (see Section F., "Leadership, Personnel and Related Issues," below).

The National Rural Electric Cooperative Association (NRECA) funds some research, and supported some of the early stray voltage work conducted at the University of Minnesota. Although some of the work proposed in this plan may be eligible, the problems to be addressed would likely have to be shown to be of interest nationally.

Dairy-related businesses and corporations and groups representing them also should be contacted as possible funding sources. While these industries have not been involved previously in any substantial way in the funding of research on effects of electrical parameters on dairy cows, it is at least important to inform them of this plan and related research going on elsewhere. Significant funding may be possible from this sector if a coalition of businesses and corporations with an interest in the affected dairy farms could be developed.

Coalitions of farmers and farm and dairy professional associations could be organized to contribute funds to such research. The likelihood of this strategy will depend on how these groups view the importance of such research relative to other compelling needs that require fiscal resources.

2. State:

The Legislative Commission on Minnesota Resources (LCMR) funds environment-related research projects within Minnesota on a competitive basis. While the most recent program announcement (December 1995) suggests that most of the studies proposed in this research plan would be only borderline eligible, submission of a preliminary proposal should nevertheless be attempted.

General funds from the Minnesota Legislature also could be appropriated if the Legislature finds such research to be warranted, either through the Minnesota Department of Agriculture and/or the Minnesota Public Utilities Commission. Since this is an agricultural issue as well as an electric issue, it is appropriate that both agencies be involved.

Aside from these options, coalitions of states might be able to fund some of the proposed studies with appropriated or assessed funds such as those currently supporting the work of the Science Advisors to the Minnesota Public Utilities Commission. This kind of approach is more likely to occur in later years of the initiative, once the proposed research is more widely known and preliminary studies have been performed. (See also Section E., "Interstate Collaborations.")

The legislation authorizing the work of the Science Advisors also authorized the Minnesota Public Utilities Commission to assess up to $150,000 for any research recommended by the Science Advisors through June 30, 1996. However, during the 1995 legislative session, the Minnesota Legislature amended the original legislation such that these funds also can be applied to the general costs associated with the ongoing work of the Science Advisors. These funds have not been expended to date. Approximately $80,000 additional dollars remain in the budget (to date) from the originally authorized assessment for staff, administrative and other costs related to the Science Advisors' activities. The Science Advisors cannot undertake any work beyond June 30, 1996, nor could there be any further assessments of utilities for such activities unless the authorizing legislation is amended and extended.

3. **Federal:**

U.S. Department of Agriculture (USDA), the U.S. Department of Energy (DOE), the National Institute of Environmental Health Sciences(NIEHS), and perhaps the National Science Foundation are the federal agencies, if any, that would be likely to fund research in this area.. The agency with the most funds available for research grants on the possible effects of electric and magnetic fields is the EMF Biological Mechanisms Research Program at DOE; however, most of these funds are targeted for more basic research, and research proposals geared specifically to dairy animals probably would not be competitive. The joint NIEHS/DOE Electromagnetic Fields Research and Public Information Dissemination Program also should be contacted. USDA animal health research grants might be explored for some of the studies proposed here, particularly those related to stray voltage which is a well-established problem nationally. In general, federal funds for research have decreased, and programs even remotely relevant to the research proposed here are set aside for very specific research questions.

Other possible opportunities may be found through the Small Business and Industry Research (SBIR) programs sponsored by each of the federal research agencies. Each agency sets aside a small percentage of funds for this program. Initial SBIR grants are in the $50,000 range and are awarded to small businesses for the early stages of new product development and related business growth activities. It is worth exploring this option, possibly as a collaborative project with one or several of the small, private companies set up in recent years to develop apparatus and techniques for the study of electromagnetic fields and their possible effects on living systems. This may be particularly relevant for the proposed laboratory studies and the development and testing of new field measurement protocols for certain electrical parameters.

E. Interstate Collaborations

The Science Advisors recommend that research collaborations be undertaken with agencies and/or research institutions from other states whenever feasible. Regional or multi-state collaborations are not only a cost-efficient approach to research, but they have a greater potential for bringing about a more rapid resolution of the problems described in this report. A first step might be to identify other states that would be willing to distribute and analyze the farmer and veterinary surveys developed in this plan. The Wisconsin Public Service Commission already has expressed an interest in such a collaboration. Until the true scope and nature of unresolved stray voltage and related problems becomes better defined on regional and national scales, it will be very difficult to obtain research funding from national sources or to develop regional funding coalitions.

To date, most of the Science Advisors' discussions with other states have focused on Wisconsin, a close neighbor of Minnesota and a state with the most significant and documented experience in investigations of the effects of stray voltage and related electrical parameters on dairy herds. Staff from the Minnesota Public Utilities Commission have been following the work of a Wisconsin steering committee (consisting of representatives of Wisconsin agencies, farm groups, utility representatives, etc.) charged with making recommendations to the Wisconsin Public Service Commission on research that should be done on possible effects of electrical parameters other than stray voltage as it is understood conventionally. In addition, several of the individual Science Advisors are very familiar with stray voltage and related investigations and research underway in other states including Michigan, Connecticut, New York and Vermont.

F. Leadership, Personnel and Related Issues

The legislation authorizing the current Science Advisors to the Minnesota Public Utilities Commission calls for the Science Advisors to monitor, oversee the peer review of, and report on any research that is carried out. This general model for an independent scientific advisory committee should be continued beyond June 1996, the end of the term of the current legislation, and until the proposed research is completed. In addition, staff from the Public Utilities Commission should continue to provide the necessary support, as the Commission deems appropriate, to the work of the Science Advisors. A staff person(s) also should be designated by the Minnesota Department of Agriculture to support the work of the Science Advisors, as the Department deems appropriate. The work of the Science Advisors and implementation of the overall research plan, including research administration, fund raising and input from relevant state agencies, other groups and organizations with an interest in this issue, and other states should continue to be coordinated by a scientist-liaison with the assistance of others, as needed, with skills in these areas.

All of the research conducted under this plan would be done by scientists and other appropriate personnel who are contracted to carry out specific studies. Basically, candidates for leadership of the individual studies would be identified through a request-for-proposals process. (In some cases, multiple studies in the plan might be contracted to a single project leader.) Proposals would be reviewed by the Science Advisors, who also would seek advice from other scientists with special or relevant expertise, as necessary. The most technically qualified contractors would be selected. Once completed, the results of the research would be peer-reviewed by the Science Advisors and other technical experts; then reported to the Public Utilities Commission. As appropriate, the research results also would be submitted for publication in peer-reviewed scientific journals.

Much of the research included in this plan, particularly the field studies, will require some cooperation and assistance from electric utility personnel. In addition, successful implementation of the survey and field study components, and development of the program to report out useful information and suggestions to the owners of the farms involved in the field (case/control) studies, will require the support of dairy producer and farm organizations, dairy industry groups, veterinary associations and others. While none of these organizations should be involved directly in the scientific design or actual conduct of the research proposed herein, many have a stake in the outcomes and should be apprised of any findings on a regular basis and given frequent opportunities to provide appropriate input into the overall process of the initiative.

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Appendix A. TERF Report

Under the same legislation that established the Science Advisors, the Minnesota Department of Public Service was authorized to contract with a dairy producer organization to assemble information and data to assist the Science Advisors in their task of assessing possible earth current effects. The contract was awarded to The Electromagnetics Research Foundation (TERF) and required the following information: a) data on electrical measurements made at individual farmsteads; b) data on dairy herd health, behavior and production on these farms; c) statistical correlations between these two types of data; d) proposed models explaining the impact of currents in the earth on livestock; and e) a bibliography of research on electrical phenomena and livestock production, health and behavior.

The December 1994 TERF report, entitled Dairy Farm Stray Voltage, has the following components: an overview of the nature of milk production and health problems on dairy farms that report unsolved stray voltage problems; stray voltage measurement and mitigation; case summaries for 75 dairy farms (presumably in Minnesota and possibly in other states -- other locations were not identified) that report stray voltage problems, including amplified case studies for 8 Minnesota farms (i.e. case studies that include more raw data and historical information); recommendations on needed research; and a literature review and bibliography.

Overview. The report provides a substantial amount of anecdotal information on the nature of the animal (and some human) health problems that some dairy operators believe are associated with effects of currents in the earth and/or stray voltage and related parameters. The electrical and non-electrical information provided for the 75 dairy farms (locations unknown) profiled in the report help to illuminate the complexity of the milk production, animal health (and to a lesser extent human health) and related problems reported by dairy farmers. Arguments are offered to support the contention that laboratory research cannot always model the complexities of the dairy farm environment, and that this should be taken into account in designing any research on possible causes of adverse effects.

Measurement and mitigation. The TERF report does not attempt to characterize earth currents, even though they are the electrical parameter most relevant to the Science Advisors' charge. A more concerted and rigorous effort at characterizing earth currents--both in the literature review section and in the case studies--would have strengthened the report. In addition, detailed descriptions of more widely accepted measurement techniques such as those involving the surface potentials associated with earth currents would have been more useful in this regard than references to dowsing and ley lines which have no established scientific basis or quantitative relation to earth currents.

The TERF report makes the case that some dairy operations continue to experience stray voltage-like signs (e.g., unusual behaviors such as not entering the barn and tail switching, reduced water intake, etc.) even after utility mitigation techniques have reduced measurable stray voltage to well below the presently accepted level of concern (i.e., 0.5 volts). The authors propose an association between these signs and earth currents without adequate documentation. While the report provides anecdotal evidence that biologically-related problems exist on the case study farms, it does not provide any reliable or clear evidence that electrical parameters associated with earth currents (i.e., magnetic fields, electric fields, voltages) are involved.

Case study analysis. The Science Advisors thoroughly reviewed the case study information provided in the TERF report, with particular attention to the 8 amplified case studies since these included substantial amounts of raw data and information on some potentially significant historical events that might serve as the basis for some analysis. This type of information is useful in that it focuses attention on problems and their possible explanations. However, there are inherent limitations of information presented in this way that make it nearly impossible ever to use it to draw conclusions about cause-and-effect relationships. One limitation is that much of the information appears to have been recorded retrospectively, often from memory; many pertinent events may not have been recalled, recorded and reported. In addition, the methodology of data recording is unknown, and may vary greatly among farms affecting both the quality and consistency of the data. Most importantly, with respect to the demonstration of cause-and-effect, concurrent controls or comparisons are not presented, indeed they are often not possible under dairy farm conditions. Examples A and B at the end of this section are included here as illustrations of the types of data provided in the TERF report case studies and the problems inherent in trying to analyze such data. These cases represent Case 113 and 158, respectively, in the TERF report. They were selected as being typical of the 8 amplified case studies.

The primary source of the data presented in the 75 case studies in the TERF report is a questionnaire sent by TERF to dairy farmers. This survey is of limited value because its format may have biased answers by the use of leading and subjective questions, the emphasis on electrical issues and the implied association between electrical parameters and health problems. All of the animal behavior, milk production and health problems listed in the questionnaire could be signs of electrical or non-electrical stressors or both.

The report's summary of the survey results identifies a number of production, behavior and health patterns that are common on farms where stray voltage or earth current problems have been reported, yet it fails to demonstrate that electrical parameters are associated with these patterns. The data in the report's amplified case studies could be more helpful in showing trends (e.g., changes in water consumption, somatic cell counts, etc.) than the data given in the remainder of the case studies, but none of these data lead to unambiguous conclusions about electrical or other possible causes. Since only information on farms with concerns about stray voltage and earth currents was reported and not data from a large random sample of Minnesota dairy farms, the results cannot be extrapolated to give an estimate of the total number of affected farms in Minnesota. Further, because general locations of farms were not given, potential associations between reported problems and geographic locations cannot be determined.

Possible non-electrical causes of reduced milk production or adverse health effects are not assessed in the TERF report. This poses a serious problem for the case study analysis because any electrical factor needs to be examined in the context of possible non-electrical factors (e.g., type of animal housing, time in and out of the barn, ventilation, nutrition, water sources, disease, genetics, weather, etc.) operating in the farm environment. The nature and magnitude of cattle responses to electric stressors are also affected by both the general health status of the cattle and non-electrical stressors in the environment. Significant cause and effect relationships can only be established through analyses (statistical and otherwise) of the multitude of factors operating in the farm environment.

TERF recommendations on needed research. The TERF report recommends research based on a raised barn approach in which test animals are housed in a facility off the ground and insulated from it. The report indicates that this recommendation is based on the preliminary results of such experiments conducted by farmers. As described, "the mobile experimental barn (MEB) would . . . test the effect of housing and milking a set of eight cows in a more or less earth EM field-isolated facility."

There are some serious problems with this experimental approach as it is outlined in the TERF report. For instance, the design aims to isolate the facility electrically. Yet while the proposed electrical insulation in the flooring could provide isolation from earth current step potentials, it would not be effective in shielding from external magnetic fields. Electric fields associated with earth currents are negligible (see section on "Mechanisms"). Another serious problem with the MEB approach is the lack of experimental controls. The Science Advisors observed two MEB facilities during the farm site visits. In those cases, there were other variables associated with moving cows to an elevated facility that may affect milk production, water intake and somatic cell counts. In addition to elevating the cows, changes occurred in the ventilation of the facility, the type of overhead cover, lighting, proximity to other cows in the herd, the milking routine, the watering devices used, the type of bedding and the milking machine equipment. Further, if earth currents were to affect dairy herd health indirectly (e.g., by inducing adverse chemical changes in the drinking water), these effects would not be detected by the MEB approach. Under such circumstances, it cannot be determined if any changes in addition to or other than cow elevation impacted the outcomes reported by the farmers. TERF recommends that future research focus on an MEB study. They propose using eight cows, yet a much larger number would be needed to yield statistically significant results. The physical basis of the experiment needs to be clarified, and a detailed plan for the use of experimental controls would be required to justify this type of research. (See also Example C at the end of this section for additional analysis of the basic MEB approach as exemplified on one Minnesota dairy farm.)

Literature review and bibliography. The TERF report's literature review and analysis addresses a number of areas with excessive reference to biological effects of electric and magnetic fields in pre-1980 literature which was often based on poorly controlled experiments. Some citations dated before 1970 are no longer considered valid. References to microwave and radio-frequency effects are interesting but were not linked to earth current impacts on livestock. The literature review focusses selectively on studies that suggest adverse health effects of low intensity fields while ignoring those which provide evidence to the contrary. Several recent and comprehensive reviews of the biological effects of electromagnetic fields are not included. Further, the report does not distinguish among peer-reviewed and non-peer-reviewed literature, including the popular press; most of the report relies on non-peer reviewed reports. Another concern about the TERF report is that most of the models and theories presented are either outdated, known to be invalid, or based on questionable hypotheses or interpretations that are not supported by the scientific literature.

Summary. Overall, the TERF report presents detailed anecdotal evidence that health and production problems occur on some dairy farms. The electrical data are weak in that little indication is given of who made the measurements, how they were made, when they were made, or for how long a time period. A rigorous statistical correlation between such electrical data and herd health and production problems is not made and is not possible. In addition, the reported health problems of dairy herds and farm animals are not documented by veterinary reports or other supporting data. The proposed research involving a raised barn reflects poor experimental design. The literature on which much of the report is based is generally outdated and often not clearly relevant. The TERF report frequently only represents one viewpoint when the published scientific literature clearly offers more than one. By focusing on only one point of view (e.g., that currents in the earth negatively impact dairy cows), the TERF report is an advocacy document, not a scientific analysis. It does not provide adequate information for the Science Advisors to assess possible effects of earth or ground currents on dairy herd health and production.

Example A: Case 113[1]

Overview:

Case 113 is one of the 75 case descriptions presented in the TERF report and is also one of the 8 amplified cases containing production and other historical records. The case summary contains a case description, a chronology of events of interest from 1983-1994, and data sets and graphs for monthly rolling herd average (RHA), milk production and somatic cell count (SCC). The case history includes observations on cattle behavior (e.g., cows reluctant to enter barn and/or stalls, dancing, kicking, nose pressing), production (e.g., , incomplete and or slow milkout, poor milk production, breed back difficulties, high SCC, etc.), health (e.g., mastitis, swollen legs/joints, poor hair coat, hoof stress rings, legs numb, etc.), calf problems (e.g., tongue rolling), pet problems (e.g., dog avoids barn), and human health problems (e.g., tingling/numbness, vision, breathing, fatigue, irritability, etc.). As in most of the case descriptions presented in the TERF report, these signs or observations are simply listed. The TERF report concludes that the serious behavioral, health and production problems in Case 113 are characteristic of stray voltage, specifically earth current, and that, "since AC currents are not present and cannot directly cause the effects noted in the barn . . . it is only logical to conclude that the DC potentials are playing an important role in the effects of the cattle."

Reported Results:

Rolling Herd Average: Figure 1 shows monthly rolling herd average data. (Note: Points not shown in the plot were missing in the data record.) Analysis of possible associations with electrical events will be given relative only to the milk production data.

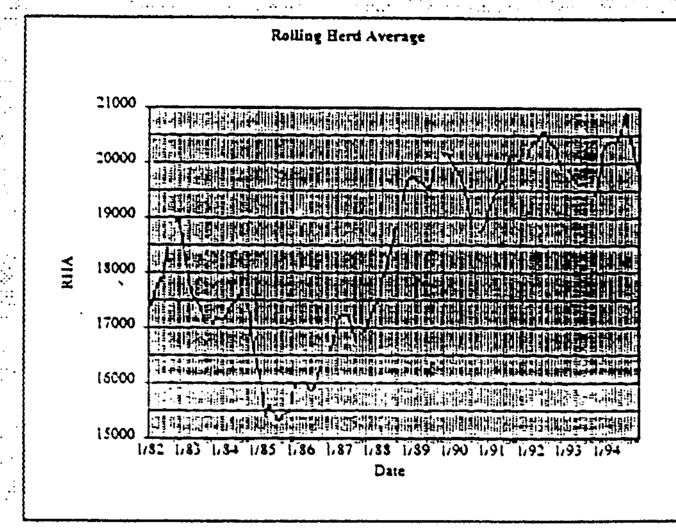

Figure 1

Milk Production: Figure 2 shows monthly milk production data annotated with reported historical events, primarily stray voltage mitigation procedures. According to the case description, after installation of an isolation transformer in November 1981, there was an increase of 2,000 pounds in milk production and a complete turn around in cow behavior, as well as a lowering of SCC, although these changes lasted for only 13 months, until January 1983. This corresponds to the first peak in the milk production data in Figure 2. The decline continued until June 1985 when it

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[1] Source: Report of The Electromagnetics Research Foundation (TERF) submitted to the Science Advisors by the Minnesota Department of Public Service.

reached a low of about 50 lb/cow/day. The case study indicates that testing at that time did not reveal "AC shock potentials." Minimal gains in production apparently prompted installation of an electronic grounding system in June 1986. Thereafter, milk production rose to more than 62 lb/cow/day where it remained through 1994. A spark gap isolator was used for more than a year, then removed in 1990 coincident with a brief downward trend in milk production. Milk production has remained above 62 lb/cow/day since late 1988. Although this is not necessarily a low value, it is apparent that the dairy operator believes his herd should be producing higher. It seems that the beginning of a downward trend in production in 1994 prompted the dairy operator to investigate earth currents as a continuation of his concern about stray voltage.

Somatic Cell Counts (SCC): Figure 3a is a plot produced from the somatic cell count data provided in the case study. Long-term trends are revealed in Figure 3b using a statistical technique in which each data point is plotted as an average of some number of neighboring points, in this case ten. (The averaging routine takes averages of the previous five points and the following five points and uses that average value and plots it in place of the actual data. In cases where there are not previous or following data points, the technique uses only those points which are available.) SCC data are not available to reveal conditions before and after installation of an isolation transformer in November 1981. The SCC data that are provided begin in mid-1983. There is an SCC peak around 1985, as depicted in Figure 3b, when milk

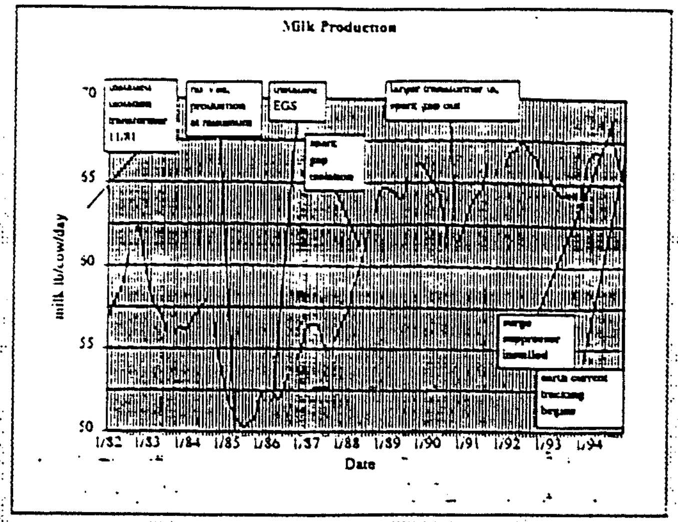

Figure 2

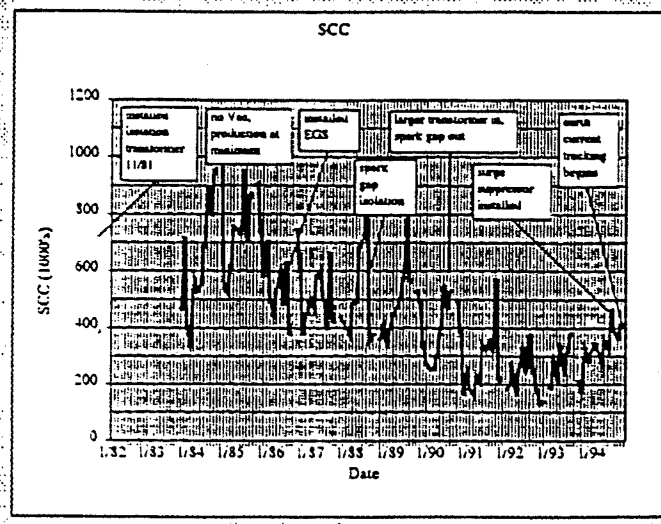

Figure 3a

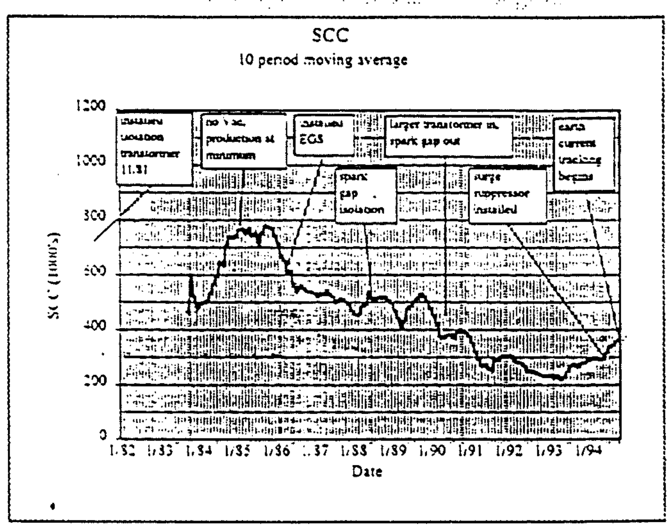

Figure 3b

production values were lowest as described above. Figure 3a indicates that subsequent stray voltage mitigation measures (i.e., installation of an electronic grounding system, spark gap isolator installation, then removal, surge suppressor installation) were attempted coincident with short term peaks in SCC.

Science Advisors' Analysis:

The information provided in Case 113 is insufficient to make causal associations between the occurrence of adverse behavior and health signs and any particular electrical phenomena such as earth currents or DC potentials. In the case study section entitled "General Information, Farm Characteristics," the presence of numerous ponds, saturated soil, bonded metalwork in the barn and a grounded steel barn are cited. In the section on "Electrical Effects," the history notes groups of light bulb failures ("explosions"), shocks from water lines or faucets, telephone noise and accelerated corrosion of buried pipes. Possible significance of this information is left undeveloped. Saturated soil can have both electrical and non-electrical significance as can corrosion of buried pipes. Telephone problems, shocks from faucets and light bulb failures (explosions) deserve further investigation. However, it is not clear how this data supports the conclusion that DC potentials are playing an important role. It is stated that "DC potential difference on the order of 0.5 volts could exist between one end or (sic) the urine stream and the other which could cause a sufficient current flow through the cow to produce discomfort." The phrase "could exist" implies speculation since no other information is provided such as: On what kind of measurement this observation is based? Were the measurements taken during problem times? Were the measurements different when problems were not being experienced? and, How do similar measurements compare on other farms? It is not possible to analyze data presented in this way. New electric services were installed which, it is claimed, produced effects on livestock including increased mastitis, kicking off milkers, cows unwilling to enter barn/stalls, breeding problems and swollen joints as well as some human health problems. The installation dates of the new electrical services were not reported. Additional services in the area (especially in areas served by single phase power) are claimed to cause additional AC earth current in the vicinity, but nothing is presented to substantiate such a claim on this farm. Upgrading of primary and secondary grounds is described, and it is stated that installation of an isolation transformer in November 1981 preceded a temporary increase in milk production and a lowering of SCC, but the case data presented did not go back this far.

Clearly the dairy operator in Case 113 has consistently and carefully monitored changes on his farm and has taken prompt and aggressive action to mitigate stray voltage problems. It is unlikely, given the number of mitigative devices installed, that standard stray voltage is any longer a problem on this farm, although the case study gives no indication of whether the farm was isolated from the primary neutral again after removal of the spark gap in 1990 nor if the EGS system is still in use. Milk production was at a satisfactory level (65 lb/cow/day), but falling, at the end of the data record provided for this case (late 1994). The SCC was just over 350,000, substantially lower than during much of the previous 10 years, but rising. The case study concludes: "All measurements indicate that, except for the AC coming directly through the earth, AC currents are not present and cannot directly cause the effects noted in the barn. Therefore, it is only logical to conclude that the DC potentials present in the barn are playing an important role in the effects on the cattle." In order to assess a possible role of DC voltages, it would be necessary to include much more detailed measurement information on cow contact DC voltages than can be found in the description of Case 113. The conclusion that DC potentials are the cause of the problem is partially based on an absence of measured AC potentials. This can only be valid if all other causes of the problem also have been eliminated.

Example B: TERF Report Case 158[2]

Overview:

Case 158 is representative of the 75 case descriptions presented in the TERF report and is one of the 8 amplified case studies that contain raw data and historical information on changes related to the electrical distribution system or other events. Included in the case summary are a case description, data set and graphs of rolling herd averages, somatic cell counts (SCC), milk production, and a parameter referred to as "MGT." Historical notes are given for the period from 1976 to 1995. Problem signs listed in the case history are in the areas of cattle behavior (e.g., poor water consumption, dancing, kicking, nose pressing, etc.), health (e.g., mastitis, swollen legs and joints, poor hair coat, etc.), production (e.g., uneven or incomplete milkout, poor milk production, etc.), and human health (e.g., flu, headaches, numbness and tingling). The case also provides general information on electrical parameters and measurements on the farm. For instance, the case has entries such as "maximum primary neutral-to-earth voltage: 13 VAC." Corrective changes also are indicated in the case description: "Replaced wires that showed current on outside. Immediate positive response that lasted a month then gradually disappeared..."

Reported Results:

Rolling Herd Average (RHA): Figure 1 is a graph developed to illustrate the raw data presented under Case 158 of the TERF report. It summarizes monthly RHA's from 1966 to 1994, and indicates specific events noted in the case history. There is an upward trend in RHA from 1966 to 1976, at which time an underground phone system was installed for areas in proximity to the farm. Behavior problems were reported to have begun at that time and were followed by a drop in RHA. Historical notes indicate that the distribution system was contributing 1.7 V to the secondary NEV at the barn. Testing, inspection, bonding and grounding were done in February 1979, then further testing in November 1979 was followed by isolation of the farm. After only a small improvement in RHA, the barn was rewired (May 1981). These electrical improvements led to little change in RHA

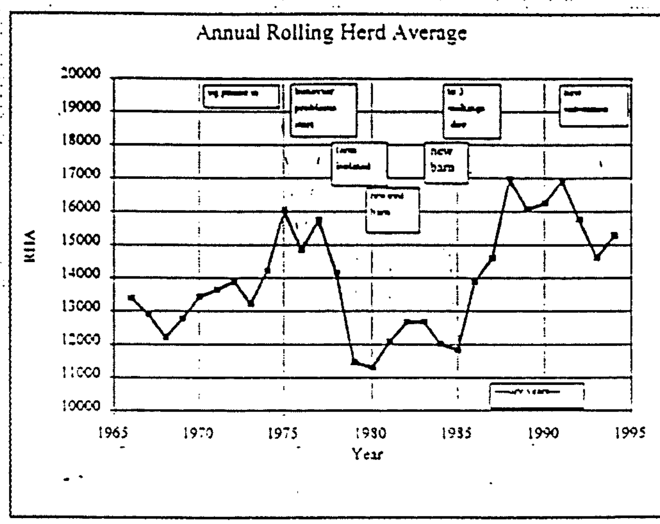

Figure 1

[2] Source: Report of The Electromagnetics Research Foundation (TERF) submitted to the Science Advisors by the Minnesota Department of Public Service.

until a new barn with an equipotential plane was built in 1985. This, followed by a change to three milkings per day one year later, marked the beginning of a rapid recovery of RHA until 1991.

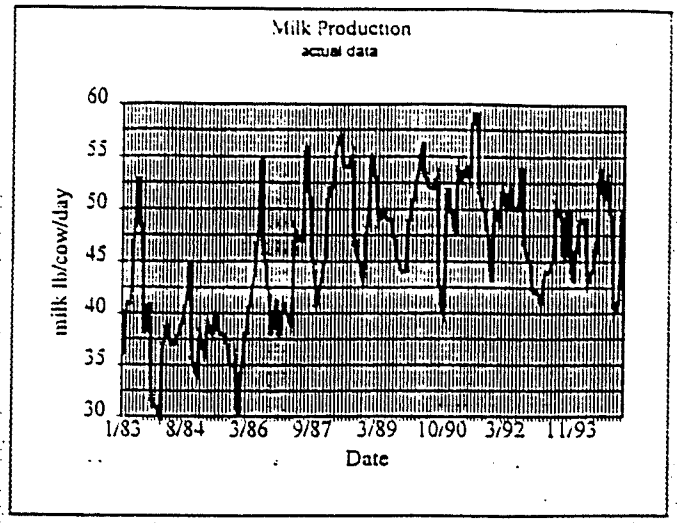

Figure 2a

Milk Production: Twelve years of milk production data were presented for Case 158 in units of lb/cow/day averages calculated monthly. The raw data are depicted in Figure 2a in summary form. Seasonal variations in the data make it difficult to observe long term trends in graphic form, so a 10-period moving average was calculated using the raw data provided in the TERF report (Figure 2b). Long-term trends are revealed in Figure 3b using a statistical technique in which each data point is plotted as an average of some number of neighboring points, in this case ten. (The averaging routine takes averages of the previous five points and the following five points and uses that average value and plots it in place of the actual data. In cases where there are no previous or following data points, the technique uses only those points which are available.) Production is lowest in 1984-1985 (between 35-37 lb/cow/day), begins to increase in 1986, peaking in late 1988 at over 50 lb/cow/day, and leveling out in that range with some variation until a decline begins in 1991. Milk production was at approximately 47 lb/cow/day in 1994, at the end of the data record.

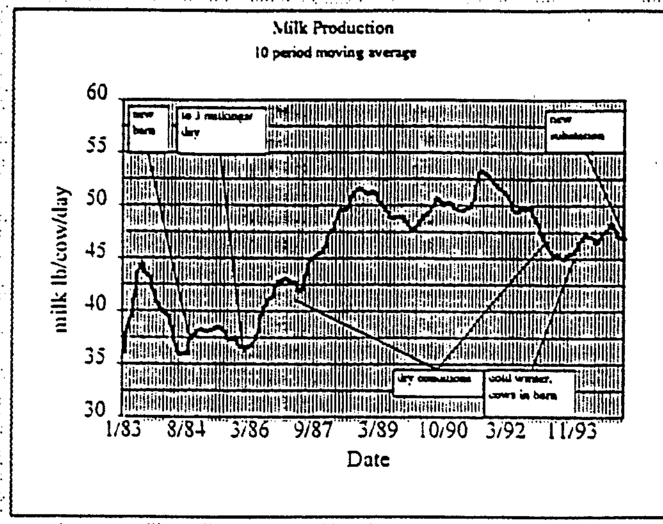

Figure 2b

Somatic Cell Counts (SCC): Five and one-half years of SCC data are included in the amplified case data in the TERF report. Monthly averages are summarized in Figure 3a, which is a graphic depiction of the raw data provided in the TERF report. Large variations in this data make trends indistinct. Again, using a 10-period moving average technique to plot the data, long-term variations are more clearly revealed (Figure 3b).

<u>Science Advisors' Analysis</u>:

The increase in milk production in 1986 seems to be more consistent with the change to three milkings per day than with the construction of a new barn. The production peak also is consistent with the hypothesis that drier conditions (and presumably less earth current) result in more milk. The potential significance of constructing a new substation 7 miles away in January 1995 cannot be evaluated because herd data are not provided after that date. The SCC data reveal no obvious trends which indicate an effect due to dry conditions existing from 1987 to 1992. The largest SCC's occurred in the Winter of 1993-94, when the cows were confined to the barn due to an "extraordinary cold winter." Weather or confinement could have contributed to the rise in SCC in 1993-1994, although the upward trend in SCC began during the previous winter. It is not clear that any of the SCC trends are associated with the events reported to have taken place during the time period of interest (see historical notations in Figure 3b).There is no indication how the primary neutral voltage of 13 V was documented: who, when, where or what measurement protocol. No indication is given as to what is meant by "Replaced wires that showed current on outside."

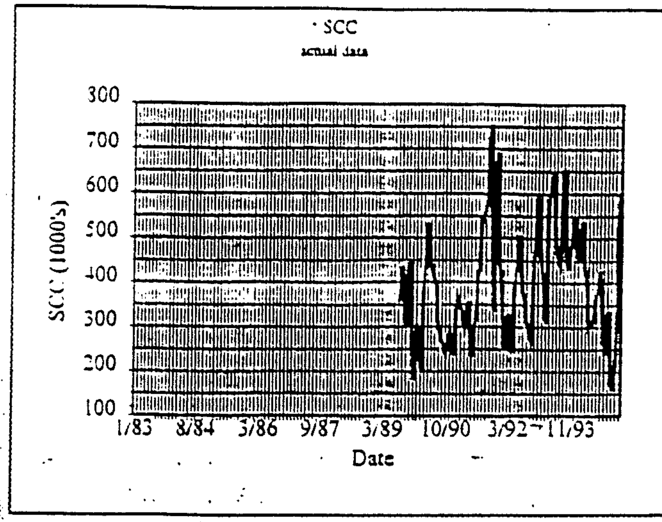

Figure 3a

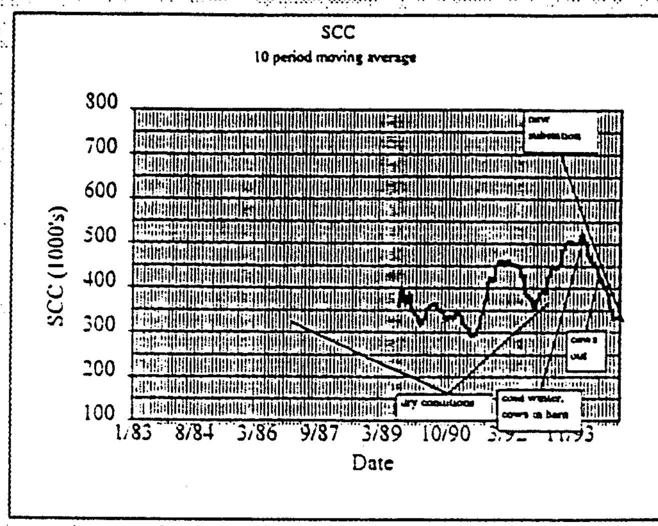

Figure 3b

Overall, an analysis of this case study reveals no clear associations between earth current and herd performance and health. The case description indicates that stray voltage was a problem in the late 1970's and that apparently the utility system was contributing to it (e.g., after measuring the neutral-to-earth voltage the utility decided to isolate the farm). Isolation of the farm from the primary neutral, construction of a new barn with an equipotential plane and a more intensive milking schedule are all factors which could account for the changes seen in production. Events such as "occasional shocks from water lines or faucets" can be important clues in diagnosing a situation. Transient events from both on-farm and off-farm sources have been detected this way. However, more information as to when (e.g., historical time frame, time of day, etc.) and where (e.g., barn, house, etc.) are necessary to eliminate other causes such as simple electrostatic discharges. In addition, the last historical note reads "January 1995, mild warm winter. Meter reads 1,000 kilowatt hours per month increase over previous winter which was considerably colder." More information is needed to analyze these observations. Increases in power consumption can be attributed to changes in user practices, ground faults, meter calibration and power quality.

In general, the data presented in Case 158 present several potentially important clues to explain the swing in production from about 1979 to 1987, but no connection is made to earth currents or how some of the observations might be a result of earth currents. It is not clear how this case is intended to support an earth current theory.

Example C: The Elevated Cow Test[3]

Overview:

In June 1995, a dairy farmer from Battle Lake Minnesota presented information to the Science Advisors concerning a test he conducted on his farm. During the previous April and May he compared data on somatic cell counts (SCC), water consumption and milk production for two cows elevated off the ground in a truck bed to data for the same two cows while they were in the barn before and after the test. The cows were selected for this test as representative of the herd average for milk production. The farmer presented graphs of daily SCC and milk weights for each cow and a graph of daily average water intake per cow per day over the 40-day test period. He reported that when the cows were elevated in the truck bed, water consumption and milk production were higher and individual SCC's were lower than before or after elevation. He attributed these beneficial changes to removing the cows from some aspect of the electrical environment in the barn. Specifically, he related the observed effects to electric or magnetic fields associated with earth current or ground current, and indicated that he did not believe cow contact potentials were involved.

Reported Results:

Water consumption: During the first twelve days in the barn, average water consumption for the two cows was 17.5 gal/cow/day. Over the 20 days the cows spent in the truck, average intake was 25.6 gal/cow/day, a 46% increase. For the last 8 days when the cows were put back in the barn, intake fell 40% to an average of 18.3 gal/cow/day. A graph of the data indicates a noticeable increase while the cows were elevated, though the immediate change on day 12 (first day of elevation) is less dramatic than that on day 32 (20th day of elevation). The cows were given well water to drink from a barrel in both situations.

Milk production: Milk production for both cows was higher while in the truck than in the barn. The cow named "Lucky" produced 14% more milk in the truck than before in the barn, then decreased 14% again when returned to the barn. "Flower" produced 11% more milk in the truck than before, then decreased 8% when returned to the barn. The cows were "bucket-milked" using a vacuum extension in the truck; they were milked into a pipeline as usual in the barn.

SCC: Average counts for both cows were lower when on the truck compared to before and after. Even though there is some large variability in the data, especially when counts are high, the data indicate an apparent difference. The SCC for "Flower" dropped quickly upon being placed in the truck, but showed a much smaller increase upon return to the barn. "Lucky" showed a minor

[3] Source: Information for this example was derived from a transcript of the June 29, 1995 meeting of the Science Advisors at the Minnesota Public Utilities Commission, 121 7th Place East, Suite 350, St. Paul, MN 55101-2147.

decrease in SCC going into the truck and a much larger increase upon return to the barn.

Science Advisors' Analysis:

The data were interpreted by the farmer to support the idea that cows housed in an elevated truck bed outside of the barn drink significantly more water, exhibit greater milk production, and have lower SCC than cows housed inside the barn as a result of eliminating the effects of harmful electrical conditions in the barn. From the information presented, however, it is possible that factors other than electricity were contributors to the observed changes. The environment in the truck was certainly dramatically different from that in the barn, not necessarily better or worse, just different. First, the cows were removed from an established relationship with the rest of the herd. Additional uncontrolled and undocumented factors were the housing climate and ventilation (e.g., temperature, humidity, wind, solar radiation), which were markedly different in the barn compared to the truck and would be likely contributors to the observed changes in water intake. Further, the difference in milking equipment used in the barn and the truck may have contributed to the change as well. Although efforts were made by the farmer to minimize differences in feeding or milking practices, these too may have contributed to the observed effects. Stall size and bedding also were different inside the barn and in the truck; both are known to affect cow comfort, incidence of injuries to legs and trauma to udders and teats.

Care needs to be taken in the analysis of the significance of recorded changes in water consumption data as well. For instance, it is expected that cows will drink more water out of a bucket than they will from a water cup in their stall. In addition, there is a well-established formula for calculating how much water a cow should be drinking under various circumstances. In order to determine expected water consumption, it is necessary to know the amount of dry matter intake in the cow's diet, the ambient temperature, the milk production of the cow, and the sodium content of the cow's diet. Since not all of this information was provided by the farmer who carried out this experiment, expected water consumption values for the cows involved cannot be estimated.

There almost certainly were differences between the electrical environment in the barn and that in the truck, and these differences may have contributed to the observed changes. However, this cannot be established definitively because electrical quantities were not documented during the test. The wooden truck bed and insulation between the wheels and the ground would result in lower cow contact voltages compared to those in the barn. However, the farmer's hypothesis involved fields, not voltages. A wooden truck box would do very little to shield cows or remove them from magnetic fields due to earth current. The most significant source of field changes in this case would be the magnetic fields associated with ground current flowing in the water line and other barn metalwork and with fluorescent lights and other electrical devices in the barn. Waterline ground current in the barn may be partially attributable to off-farm earth current. However, it is well understood that the farm's secondary neutral-to-earth voltages also cause waterline ground currents. It is unlikely that diffuse earth currents with unknown (in this case) associated voltages could cause more waterline ground current than would be supplied by normal secondary neutral voltages. Generally, the electrical exposures from which cows were removed during this test are more likely to be caused by ordinary voltages and currents in the stall due to secondary neutral-to-earth voltage than those due to earth current from distant sources.

Cows were simultaneously subjected to a number of changes in the course of this test: removal from the barn; elevation above ground level; removal/isolation from the rest of the herd; caretaker routine; stall size; type of bedding and flooring; milking routine; and milking equipment. Alterations in milk production and SCC could result from any one or a number of combinations of these changes. The experiment does not provide convincing evidence that elevation above ground level or elimination of harmful electrical events is responsible for the outcome. Before an attempt is made to redo this experiment, it would be useful to come to some understanding regarding the sources of the electrical exposures that are removed by elevating cows outside. Finally, these electrical quantities, if large enough to affect cows, must be measured, not only in the barn and the truck, but outside and off the truck, before, after and during the test if earth current or any other electrical parameter is to be a part of the working hypothesis.

Appendix B. Lusty Farm Study

A month-long study was conducted during March and April, 1993 on the David and Sue Ann Lusty farm, Miltona, Minnesota, under the auspices of the Minnesota Environmental Quality Board (MEQB). The study was designed to evaluate observations by a number of dairy farmers that disconnecting primary neutral grounds on and near their farms had immediate and significant positive benefits in terms of herd health and production. During the study on the Lusty farm, two of the distribution system's ground rods were disconnected and reconnected successively for approximately 1 week intervals to determine whether this had any effect on the barn's electrical environment or on the health and production of the cows. The ground connection was performed blind in that only the MEQB consultant knew whether the switch was open or closed. After the study was completed, the data were distributed to and analyzed by several reviewers, including TERF, the Minnesota Inter Utility Stray Voltage Task Force (MIUSVTF), and an MEQB consultant.

The Science Advisors reviewed the written reports and heard presentations by the MEQB, the utilities, TERF, the veterinarian who collected data on the Lusty farm, and the MEQB consultant who carried out the electrical measurements. Some of the data from the study also were reviewed. A number of conclusions can be drawn from this information.

There are some drawbacks to the type of protocol used in the Lusty farm study (i.e., the herd is used as its own control through on/off grounding switch-overs). First, the controls are not concurrent. This makes evaluation of the results difficult because the herds themselves change over time (e.g., lactation cycles vary within a herd and must be taken into account in data analysis). Indeed the study documentation shows that five animals calved near the beginning of the study and were added to the herd. Animals that have recently calved are toward the upper range of their milk production, so the net effect is to raise milk production per cow. This could have inadvertently been attributed to interruption of the grounding. In addition, it is well-documented that water consumption should increase in this group.

One behavioral parameter, tail switching during milking, appeared to increase when the ground rods were connected. This is the only observation that would support the grounding hypothesis. The on-off periods also should have been continued longer, at least two weeks or longer each, to allow investigation of sustained changes attributable or not to grounds connection/ disconnection.

There was significant disagreement on the planning and design of the Lusty farm study and on data interpretation among the farmers and utilities who participated. This is reflected in the fact that the conclusions in the reports written by each of these groups differed. In the report TERF prepared on the Lusty farm study and in public comments made by Mr. Lusty to the Science Advisors, the claim was made that the primary ground current on the Lusty farm was reduced just before the study began and throughout its course, from a reported normal level of about 150 milliamps (mA) to the reported unusually low level of 30-40 mA. The claimed primary ground current values immediately or shortly before and after the study were never independently confirmed; however the 30–40 mA measurement was confirmed throughout the study. If this contention had been documented, it would have invalidated the study. Nevertheless, the very existence of such a serious claim compromises the perceived credibility of the study.

Both farmers and utilities potentially have important roles to play in on-farm studies of effects of electrical parameters on animal behavior, health and welfare. Farmers are deeply aware of the normal status of conditions on the farm and have information that should be taken into account in on-farm research design. By the same token, the utilities have expertise in the electric distribution system and thus experience and knowledge that also must be considered in designing studies. Indeed, any changes to the primary distribution system can only be made by the serving utility and must follow existing guidelines and regulations. However, the lack of consensus on study conditions and results among the different stakeholders involved in the Lusty farm study illustrate the problems that can ensue when parties with vested interests become deeply involved in the design and analysis of a scientific research project. In general, data collection, processing, storing and analysis during scientific experiments should be carried out by trained scientists with the necessary expertise and without vested interests. It would have been prudent to involve a scientific advisory group in the planning and analysis phases of the Lusty farm study to avoid some of the problems (i.e., multiple interpretations of the same data, lack of consensus on findings) that arose under the exclusive guidance of a steering committee of parties with vested interests.

Studies like the one on the Lusty farm are potentially very useful in determining an association between a specific factor (e.g., current flowing into the earth at a primary ground rod) and a particular outcome (e.g., reduced milk production). The Lusty study failed to provide evidence that earth currents have adverse effects on dairy production or animal health. However, the study was designed to measure possible effects of current flowing into the ground at the ground rod, which is itself just one contributor to the total current in the earth. The results of the Lusty study may be useful in designing a more comprehensive study of possible earth current effects.

Appendix C. Visits to Minnesota Dairy Farms

The authorizing legislation specified that the Science Advisors make on-site visits to farms with formal and informal complaints concerning stray voltage and use of the earth as a conductor of electricity. Accordingly, on April 19 - 21, 1995, the Science Advisors visited six farms in the vicinity of Alexandria, Minnesota. The nine Science Advisors were divided into two groups in such a way that their scientific disciplines (e.g., veterinary medicine, physics, electrical engineering, epidemiology) were represented on each farm. They were given a briefing book that contained for each farm a list of participants, an agenda, a summary of the dairy operator's claims as presented to the PUC under the formal or informal complaint process, and a map of the distribution system in and around the farm.

Farm site visits lasted from one to four hours. Dairy operators demonstrated why they believed earth currents, ground currents and/or other electrical factors were affecting their herds. Serving utility personnel were on hand at most of the farms to demonstrate methods of stray voltage measurement and mitigation, to make grounding changes to facilitate farm demonstrations, and to answer questions about the primary distribution system.

The intent of these visits was to become familiar with the facilities and overall environments on these farms, meet the dairy operators, and observe demonstrations by the dairy operators and the serving utilities. The Science Advisors are not charged with investigating specific claims and thus the site visits were not intended to be investigations. Any thorough investigation would require much more time than was spent on each farm during these site visits.

After the visits, the Science Advisors met to discuss their observations and any conclusions they had with respect to (1) the distribution system and stray voltage, (2) earth and ground currents, (3) non-electrical parameters, and (4) other issues on each farm. These observations and conclusions are summarized below:

1. <u>The Distribution System/Stray Voltage</u>

All six farms were reported to have low cow contact voltages by conventional stray voltage standards (i.e., well below the 0.5 volt generally considered to warrant mitigation) and are isolated from the primary neutral system. None of the farms had operating electronic grounding systems. A majority were served by single-phase lines. Potential electrical problems were observed on or near some of the farms, including substandard wire sizes, cow trainer installation errors, missing isolator ground, temporary fourth-wire installation, old primary phase insulators, trees too near the phase wire, spliced primary ground wires, improper fencer installation, corroded wiring in barn, use of isolation devices that may pass transients, and others. Some of the non-standard wiring practices could pose safety problems. In observing the measuring technique used by utility personnel during the visits to Minnesota dairy farms, it was noted that the quality of the ground connections, whether on the primary or secondary side, was generally inconsistent, with ground rod/earth resistances often varying from site to site by as much as a factor of ten.

2. Earth Currents, Ground Currents and Related Issues

A number of demonstrations were conducted by farmers that were intended to show the presence of and/or changes in earth currents. Dairy operators typically measured earth currents by measuring current in wires between two grounds. Current measured in this way ranged up to 1 mA between reference grounds while disconnecting and reconnecting primary grounds. Current measured between distribution grounds and reference grounds was often higher than this due to neutral-to-earth voltages present on the neutral conductors. Dairy operators maintained that these measurements change when changes are made to the amount of current entering the earth at primary or secondary grounds. AC magnetic fields were not detectable away from expected sources, including over paths of earth current identified by farmers using the dowsing technique.

Soil types on at least half the farms visited were associated with till on rolling glacial terrain. Abundant surface water and a likelihood of high mineral content are prevalent on all farms, conditions that are conducive to the flow of earth current.

3. Non-Electrical Parameters

Signs of poor health and low milk production were reported by dairy operators and/or observed by the Science Advisors during the site visits. However, time and other constraints prevented the Science Advisors from considering possible causative factors or assessing their relative importance on these particular farms. Among the non-electrical factors that may be important, in general, to improved herd health and production are: housing, nutrition, genetics, cow comfort, reproductive status, milking procedures and equipment, infectious diseases, water quality, water availability, rearing of calves, stanchion, stall design, bedding and drainage of excess water near the barn. Successful evaluation and elimination of potentially harmful non-electrical factors typically requires regular, extensive and long-term study followed by implementation of appropriate remedies.

4. Other Issues

Several of the dairy operators conducted "ley line" demonstrations using "dowsing rods." These metal rods are purported to cross in the hands of an individual (dowser) who is standing over the path of an earth current. The dowsing rods were observed to cross in certain areas in the hands of some individuals. However, no conclusions can be drawn from these demonstrations because there is no established scientific evidence indicating a relationship between dowsing and ley lines and/or earth current.

Appendix D. Stray Voltage and Ground Current Investigations in Wisconsin and Related Activities

The authorizing legislation specified that the Science Advisors are to review existing information, including information from other states, and monitor ongoing research into the use of the earth for carrying current and its effects on animal health and production. Among the states, Wisconsin probably has been the most active in the area of stray voltage and ground current investigation. In addition, since Wisconsin is a close neighbor of Minnesota, efforts there have been the Science Advisors' primary focus of attention to date.

The Science Advisors have reviewed documents on stray voltage and ground currents proceedings under the Wisconsin Public Service Commission's (PSC) Docket 05-EI-106 (deals with traditional aspects of stray voltage) and Docket 05-EI-108 (addresses more recent and controversial aspects of stray voltage such as magnetic field effects, ground currents, transients and dc currents/voltages). The Wisconsin PSC is in the process of deciding a course of action as to needed research in these areas.

On February 27 - 28, 1995, the Science Advisors heard presentations from key participants in Wisconsin stray voltage data collection and research: Mr. Dan Dasho, Stray Voltage Program Manager for the Wisconsin PSC, and Dr. Douglas Reinemann, Professor of Agricultural Engineering, University of Wisconsin, Madison.

According to Mr. Dasho, the Wisconsin PSC has been involved in stray voltage issues since about 1980. A Stray Voltage Analysis Team (SVAT) was formed in 1989 to investigate individual cases in a multidisciplinary format. To date 110 farms have been studied. Wisconsin has defined stray voltage, based on expert testimony, as that voltage which would produce a current of 1 mA through a cow (as measured from water line to floor through a 500 ohm resistor), the "level of concern requiring action." This corresponds to 0.5 volts. The PSC recognizes stray voltage mitigation as an ongoing process because of the complexity of the electrical circuit and the variability in electrical parameters involved.

Mr. Dasho also presented some information relevant to earth currents. On Wisconsin farms, the median magnetic field level from all sources is between 0.6 and 0.7 milligauss as measured at 0, 3 and 6 feet above the floor. A typical step potential measured between front and rear hooves is less than 0.05 volts. He reported that commonly measured step potentials are 10 to 100 times smaller than those between metal and floor, the cow contact points most likely to be associated with traditional stray voltage problems. Mr. Dasho noted that earth current is related to stray voltage through the front-to-rear hoof step potential, and that some farmers who do not accept proposed SVAT solutions attribute their problems to earth currents. He concluded that stray voltage problems are reported more frequently in winter, partly because cows are in the barn and are observed more frequently. Problems occur under both wet and dry conditions, he indicated.

Mr. Dasho reported that the PSC participated in an experiment in which three to five amps of ac current was injected into the earth between ground rods using a portable generator. The magnetic field in the area between them was at background levels. This result, coupled with low level magnetic field measurements on problem farms in Wisconsin, led Mr. Dasho to speculate that magnetic fields are unlikely to be an important causative agent of herd health problems.

Dr. Reinemann has conducted a series of studies to test sensitivity of cows to various electrical parameters. He presented information on recent experiments to test the sensitivity of cows to transient voltages and magnetic fields. His protocol employs a set of four test stalls which are electrically isolated from their surroundings. Reinforcing grids in the floor provide a means to simulate earth current with no attendant step potential. Stalls are suspended on load cells (electronic devices that detect weight shift) which allow automatic measurement and recording of cow reaction to electrical stimuli. Cow reactions are also observed and video-recorded during exposures.

Upon exposing 24 cows to a number of transient voltage waveforms, a wide, normally distributed range of sensitivity was observed. The range over which cows responded to currents produced by transient voltages was as follows: 2.6 milliamp to 8.9 milliamp for 5 cycle 83 millisecond (ms) transient, 1.4 milliamp to 9.9 milliamp for 1 cycle 16 ms transient, 4.4 milliamp to 25 milliamp for 1 cycle 2 ms transient. Generally, larger magnitudes were needed to elicit a response to faster transients.

Reinemann and colleagues also tested sensitivity of cows to magnetic fields on the assumption that this parameter is one possible mechanism of interaction between earth current and the cow. Current was passed through the floor grid at a fundamental frequency of 60 Hz with 2nd and 3rd harmonics and random noise components. The largest magnetic field thus produced was 40 milligauss just above the stall floor. In another exposure, current was passed through a wire coil around the cow's neck to simulate ground currents in stanchions and water lines. The maximum field thus produced was 4 gauss at a fundamental frequency of 60 Hz with 2nd and 3rd harmonics and random noise components. Another exposure was performed using only random frequency noise. All three exposures were pulsed one second on and one second off for 30 seconds. No response was observed for dairy cows exposed to these short duration but very high level magnetic fields. Dr. Reinemann indicated that studies on longer-term (2-3 weeks) exposure to transient voltages are underway in his laboratory and that existing test equipment would allow for studies of long-term exposure to magnetic fields.

Appendix E. PUC Report on the Use of the Earth as a Conductor of Electric Current by Electric Distribution Facilities in Minnesota

The authorizing legislation requires that the Public Utilities Commission determine the age and condition of electric distribution facilities in the state and further that the Science Advisors use this and other information to determine the extent to which these facilities use the earth as a conductor of electric current. A 1995 PUC staff report and analysis is available which addresses only the question of the extent to which the utilities use the earth as a conductor of current. The PUC report summarizes data from distribution systems of 48 utilities that provide electricity to rural Minnesota and provides a statistical description of the degree to which the earth is used as a conductor of return current back to the substation. The extent to which the utilities use the earth as a conductor of electric current is as follows: approximately 25 percent of the return current flows in the earth for 3-phase line systems (i.e., average of 4.21 amp), approximately 50 percent for 2-phase line systems (i.e., average of 5.05 amp), and approximately 60 percent for 1-phase line systems (i.e., average of 2.87 amp). As other PUC reports on the survey of electric distribution facilities become available, the Science Advisors will review them in so far as they are relevant to their charge.

Appendix F. Public Comments

The Science Advisors have reviewed responses to a September 1994 public notice published by the PUC requesting written comments on scientific facts or questions that should be considered in making a preliminary determination on the need for further research on stray voltage and earth current issues[4]. Comments were submitted by a broad range of interested parties, including individual scientists involved in related research, individual electric utilities, veterinary practitioners and dairy management specialists, utility and dairy operator group representatives. In addition, the Science Advisors have considered public testimony provided at each of their public meetings.

This process yielded many resources, including important literature references, historical perspectives on stray voltage and related problems, and information on related activities in other states. Concerned farmers described the nature of the outcomes they associate with earth and ground current problems, detailing the types of adverse behavioral and health effects they observe with dairy cattle and farm animals as well as with the people living on the farms. Some of the observed effects were reported to occur immediately upon a change in the electrical environment, while others were said to occur two, three or more weeks after the change. Many of the farmers requested that any proposed research address both of these situations.

Utility representatives shared information on how they conduct stray voltage measurements, their perspectives on mitigation procedures, etc. This group and others in the scientific community stressed the importance of evaluating all potential affecters, including non-electrical parameters, in determining the cause of the dairy herd behavior, milk production and health problems reported by concerned dairy operators.

[4] Technical comments submitted to the Science Advisors in response to the public notice have been compiled and are available through the PUC.