STATE OF MINNESOTA
PUBLIC UTILITIES COMMISSION

10 - 0564

MEMORANDUM

TO: Interested Parties

FROM: Patricia J. Hoben, Ph.D.
Research Director and Liaison to the Science Advisors

DATE: August 5, 1998

SUBJECT: Final Report of the Science Advisors

Attached for your information is a copy of the final report of the Science Advisors to the Minnesota Public Utilities Commission. The report describes the results of the field study carried out in the summer of 1997 and expectations for laboratory research initiated recently. The science advisors also offer final conclusions and recommendations in their report, based on all of the sources of information they assessed since their appointment in December 1994.

The Science Advisors give three findings in their report, which are quoted below:

- "We have not found credible scientific evidence to verify the specific claim that currents in the earth or associated electrical parameters such as voltages, magnetic fields and electric fields, are causes of poor health and milk production in dairy herds."

- "At the present time, there is no basis for altering the PUC-approved standards by which electric utilities distribute power onto or in the vicinity of individual dairy farms."

- "There are many well-documented non-electrical factors that are known and accepted by the scientific community, and by most farmers as well, to cause dairy cow health and production problems. Among the most noteworthy factors are poor nutrition, poor cow comfort and hygiene, and low or no use of vaccinations and related preventive veterinary practices. These factors should always be addressed by those who want to improve performance of dairy herds."

Additional details on the findings and recommendations are given on pages 37-39 of the report. Please contact Mr. Burl Haar if you have any questions pertaining to the Commission's action on this report. You may contact me directly if you have any questions regarding the report or want additional details on the research addressed in the report. Riley Hendrickson and I both can be reached at The Bakken Library and Museum, (612) 927-6508.

Attachments

CONSULTANTS' REPORT

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

Research Findings and Recommendations Regarding Claims of Possible Effects of Currents in the Earth on Dairy Cow Health and Milk Production

July 31,1998

Minnesota Public Utilities Commission
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[1] Alex Furo, Electrical Engineer and Consultant, was a Science Advisor from December 1994 until April 1998.

All findings and recommendations in this report are those of the Science Advisors who worked under contract to the Minnesota Public Utilities Commission, and do not necessarily reflect the views of the Commission.

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I. INTRODUCTION

This is the final report of the Science Advisors to the Minnesota Public Utilities Commission (PUC). We are a multidisciplinary group with expertise in the fields of agricultural engineering, animal physiology, biochemistry, electrical engineering, electrochemistry, epidemiology, physics, soil science and veterinary science. The Minnesota Legislature authorized the PUC to establish a committee of science advisors in response to claims by some dairy farmers that electric currents in the earth from electric utility distribution systems are somehow responsible for problems with animal behavior, health and production problems of dairy cows. These claims were advocated by The Electromagnetic Research Foundation (TERF), a group consisting mainly of dairy farmers from Minnesota and Wisconsin. While TERF produced a report including anecdotal evidence, they did not propose a specific mechanism for how currents in the earth might interact directly with dairy cows to cause the problems with dairy production (TERF, 1994). It is important to note that the issues associated with currents in the earth from grounded electric distribution systems are quite different from concerns raised in the 1970's about Minnesota's DC power line and from ongoing controversies related to low frequency fields from overhead AC power lines.

On November 23, 1994 the PUC authorized us to carry out the following tasks:

(1) Review any evidence that might support the proposal that earth currents adversely affect dairy herd health and production.
(2) Determine whether further research in this area is warranted.
(3) Oversee any research proposed to resolve questions related to possible earth current effects.
(4) Provide recommendations to the PUC based on available evidence and the results of any research conducted with funds appropriated under the legislation.

We issued a Progress Report in January 1996 (Minnesota PUC, 1996) in which numerous electrical and related technical terms were defined[2], information from interested parties was reviewed, possible mechanisms of earth and ground current interaction with dairy cattle were hypothesized, and a research plan to address unanswered questions was proposed. We noted then that currents in the earth can only interact with dairy cows through their associated electric fields, magnetic fields and voltages, and that these parameters should be the focus of our analysis, rather than earth currents per se. The Commission approved our research plan in February 1996 and the Minnesota Legislature appropriated additional funding for some of the proposed work in April 1996 and again in April 1997.

This report is based on all of the reviews and analyses we conducted and upon the results of the dairy farm field study for which we served as advisors. Our overall conclusions and recommendations are given in Section V. Section II describes a survey

[2] The "Definitions" section of the 1996 Progress Report is included as Appendix A of this report.

of Minnesota and Wisconsin dairy operators that was designed to obtain information on the specific types of herd health and production problems and to assess the extent to which owners of dairy herds attribute such problems to stray voltage or other causes. Section III describes the results of a field study to assess possible associations between selected electrical and non-electrical parameters and the presence or absence of persistent problems associated with dairy cow health and milk production. Section IV describes laboratory research at the University of Wisconsin that is being funded by the PUC. Detailed descriptions of the field study protocols and the laboratory research design also are appended to this report.

II. MAIL AND TELEPHONE SURVEYS OF MINNESOTA AND WISCONSIN DAIRY FARMERS

Dairy herd owners in Minnesota and Wisconsin were surveyed in late November 1996 in a collaborative effort involving the Agricultural Statistics Services of Minnesota and Wisconsin, the University of Minnesota, the University of Wisconsin, the Department of Public Service of Wisconsin, the Minnesota Public Utilities Commission, the Minnesota Department of Agriculture, the Wisconsin Department of Agriculture, Trade and Consumer Protection, and various organizations representing dairy farmers and electric utilities in the two states. The objectives of the survey were: (1) to collect more comprehensive and valid information than had previously been available on the general health and milk production status of Minnesota and Wisconsin dairy herds and (2) to learn more about perceptions of dairy operators about electrical and non-electrical causes of persistent problems associated with health and production.

A. Mail Survey

The most comprehensive database on dairy herd operations is maintained by the National Agricultural Statistics Service of the U.S. Department of Agriculture. The PUC contracted with the Minnesota Agricultural Statistics Services to conduct mail and telephone surveys using the dairy operator listings in Minnesota and Wisconsin. At the time of the survey (November 1996), there were about 11,000 dairy operations in Minnesota and 25,000 dairy operations in Wisconsin.

Surveys were mailed to a random sample of 2,500 dairy operators, 1,250 from each state's database. Post card reminders and follow-up telephone calls were used to encourage response. Thirty percent (752) of the surveys were completed and returned. The purpose of selecting a random sample of dairy operators was to obtain results that would be representative of the entire population of Minnesota and Wisconsin dairy operations. The random selection method and the number of completed surveys obtained from the initial mailing suggests that the results are representative of the opinions and perceptions of herd owners in the two states.

The results of the mail surveys are as follows:

1. <u>General Herd Information</u>

Responses from dairy herd owners in Minnesota and Wisconsin were similar for almost every parameter addressed in the survey; thus all response data could be averaged for the two states. The average reported herd size (milking and dry cows) was 56, with a range of 10 to 385. Average daily milk production at the time the survey was taken was 52 pounds/cow/day for cows in milk and 42 pounds/cow/day when dry cows were included. From the dairy owners rough estimates, average annual mortality and culling rates for adult cows were calculated at 4.3 percent and 20.6 percent, respectively.

2. <u>Clinical Signs of Herd Health Problems</u>

Herd owners were asked how often each of 22 clinical signs of health or production problems were observed in their herds over the last 12 months. Respondents reported poor heat (estrus) expression, poor conception rate, and mastitis as the most frequently observed signs. Some of the least frequently observed signs were unhealed sores on cows' legs and bodies and various behavioral patterns (e.g., unusual behavior at the drinking cup, nose pressing, and excessive kicking).

Ten percent of all herd owners at the time of the survey thought that cows in their herds have persistent health and/or production problems. These dairy herds tended to have lower milk production rolling herd averages, higher somatic cell counts, and more frequent adverse clinical signs than herds for which no such problems were reported.

3. <u>Perceived Causes of Herd Health and Production Problems</u>

Herd owners were asked their opinions regarding importance of each of 26 factors in causing problems with animal health and/or production problems in their herds. Factors rated as most significant (top one-third) were forage quality, fresh cow performance, cow comfort, heat detection, and animal housing or environment. Factors rated as least significant (bottom one-third), were soil type, quality of outside experts' advice, stray voltage and other electrical phenomena, and chemical contamination of feed or water.

B. Telephone Survey

Each of the herd owners who had completed and returned a mailed survey was contacted by telephone to obtain more detailed information concerning their experience with on-farm investigations of stray voltage and related electrical phenomena. Ninety percent of those who completed and returned the mailed survey also participated in the telephone survey.

Principal findings:

- Thirty percent of the dairy herd owners reported that *at some time* they had a problem with herd health and/or production which they thought was caused mainly by stray voltage or some other electrical phenomena.
- Sixty percent of all dairy herd owners reported that their farms had been tested at least once for stray voltage; 15 percent reported testing for other electrical phenomena, such as magnetic fields, electric fields, EMF, ground currents or earth currents. Of these respondents, about one-half reported that the persons who conducted the tests informed them of stray voltage or other electrical conditions that should be corrected; eighty-seven percent of those with problematic conditions reported that corrective steps had been taken.
- Sixty percent of dairy operators reported that stray voltage testing was performed by employees of electric utilities. Thirty percent of dairy operators reported that electricians conducted such tests. Milk processing field representatives and dairy farm owners were also reported to have conducted stray voltage tests in 10-20 percent of the cases.
- Eighty-seven percent of dairy herd owners in Minnesota and Wisconsin who reported that electrical phenomena were investigated, also reported they were satisfied with both the investigations and attempts to correct stray voltage or other electrical conditions.
- Eight of the 679 owners in Minnesota and Wisconsin who both returned a completed mail survey and answered questions in the telephone survey, indicated that their herds presently had persistent problems with health and production *and* that they think uncorrected stray voltage or related electrical conditions are having negative effects on the health and production of their dairy herds.

C. Conclusions

The results reported here place dairy farmers' perceptions about stray voltage and related electrical conditions into context with the variety of non-electrical factors that have long been known to be associated with poor herd health and low milk production. From their answers to several of the questions in both the mail and follow up telephone surveys, it is clear that most owners of dairy herds in Minnesota and Wisconsin are much less concerned about stray voltage and other electrical conditions as the source of their unresolved health and production problems than claimed by TERF (TERF, 1994) and by individual dairy farmers who reported to us in public hearings during meetings at the PUC. Most dairy farmers who have had potentially problematic electrical conditions on their farms appear to follow up on them and are generally satisfied with the corrections recommended by electric utility representatives or other farm consultants.

The survey forms used and additional details on findings from the mail and telephone surveys are included in Appendix B.

III. COMPARATIVE FIELD STUDY OF HIGH HEALTH AND PRODUCTIVITY (HHP) AND LOW HEALTH AND PRODUCTIVITY (LHP) DAIRY HERDS ON MINNESOTA DAIRY FARMS

A. Overview

The focus of our charge as advisors to the PUC was to examine the effects, if any, of currents in the earth and related parameters on dairy cows. However, such a mandate could not be fulfilled without also assessing non-electrical factors. It has long been known that certain non-electrical factors can significantly increase problems with cow health and production. Of all the complaints brought to our attention by the PUC or directly by farmers where electric currents in the earth were said to be involved, none showed convincing evidence that non-electrical factors could be ruled out.

In addition, there is little information on the electrical conditions on farms *that do not have* persistent problems with health and production. Further, we could not find any study in which electrical measurement protocols had been used uniformly such that results could be compared from farm to farm. For these reasons, we designed a small field study to assess the effects of both electrical and non-electrical factors on the health and productivity of dairy herds. The study included two different kinds of dairy operations, those with persistent and unresolved health and productivity problems and those without such problems.

The primary objectives of the field study were:

(1) To test the feasibility of implementing protocols in relatively short visits to dairy farms that would measure electrical factors, inspect electrical wiring conditions, and assess herd health and productivity.

(2) To determine whether it is possible in a small field study to document associations among specific electrical or non-electrical factors and the health and productivity of dairy herds.

(3) To assess the need for and approach to a larger scale study of potential factors that contribute to poor health and production of dairy herds.

The study did not evaluate on-farm or off-farm sources of electric and magnetic fields and voltages since the first step should be to establish whether the fields or voltages associated with earth and ground currents interact with the cow in the barn to induce health and production problems. Only if such an effect is found would it be appropriate to examine the sources and undertake some kind of mitigation.

The field study was carried out under contract to the PUC by Dr. Ashley Robinson and Dr. Will Marsh, both with the Department of Clinical and Population Sciences at the College of Veterinary Medicine, University of Minnesota, at the time of the study.

Dr. Robinson was selected for his expertise in veterinary epidemiology; Dr. Marsh was selected for his expertise in agricultural statistics.

B. Selection of Study Farms for Evaluation

Several approaches to the selection of farms for the field study were considered. One was to select farms directly from the Dairy Herd Improvement Association (DHIA) database, with one group at the high end of production and the other at the low end. This option was not selected because of concerns that the DHIA database may not represent all types of dairy operations in Minnesota. Also, many of the farmers who have raised concerns about earth currents are not members of DHIA. A second option was to survey veterinarians and ask them to identify dairy operations that seem to meet a pre-established set of conditions. This option was not chosen because of potential concerns about bias of the veterinarians and the fact that, in many cases, the serving veterinarians may not visit the farms regularly. The third option, which was chosen by the study directors, was to use responses of dairy herd owners to the mailed surveys since herd owners maintain the most comprehensive information pertaining to their herds.

Several conditions were established for a dairy operation to be a candidate for the field study. The herd owner must have (a) provided a completed response to the mailed survey (367 Minnesota dairy herd operators returned completed surveys); (b) responded to the follow up telephone survey questions (331 Minnesota dairy herd operators responded to the telephone survey); (c) had more than 30 cows in his or her herd; (d) reported conditions for the herd that placed it in either the "high health and productivity" or "low health and productivity" categories within the total population of respondents; and (e) expressed a willingness to cooperate with the on-farm study (over 95 percent of those who could be reached and who met criteria (a-d) agreed to cooperate).

Farms were chosen that were at the two extremes in health and productivity of the available population since such differences between the two groups would be most likely to reveal any meaningful associations between electrical or non-electrical factors. *Our aim was to identify at least 10 farms of each type, since samples of this size – if different enough in type -- may be large enough to provide statistically significant associations, yet small enough to be carried out in a single season by a single research team.*

The high health and productivity (HHP) herds and low health and productivity herds (LHP) were defined as follows: HHP herds were defined as those reported by the owners to have 3 or more of the following conditions: a rolling herd average of 18,000 or above pounds of milk/cow/year; somatic cell counts (SCC) below 250,000 in the last month recorded; cow mortality rates of 0 percent; cow culling rates of 11 percent or lower; and an average score of 1.4 or below on a scale of 1-5 that ranks severity of each of 26 clinical signs characterizing the herd. Low health and productivity (LHP) herds were defined as those with 3 or more of the following conditions as reported by the owners: a rolling herd average of 16,000 pounds/cow/year or less; an SCC of 350,000 or above in the last month recorded; a mortality rate of 6.8 percent or higher; a cull rate of 29 percent or higher; and an average score of 2.1 or higher on a scale of 1-5 that ranks severity of each of 26 clinical signs characterizing the herd.

Individual survey responses from the 331 Minnesota dairy operators who completed both the mail and telephone surveys were reviewed to determine which ones met at least 3 of the 5 criteria for HHP or LHP herds. These subgroups were contacted in March and April 1997 to determine whether they would participate in an on-farm field study. The telephone interviews were used to ascertain whether the circumstances on the dairy farm were still the same as reported in the previous November. If so, a visit was scheduled to the farm where one member of the research team met with the owners and reviewed milk production and other records to confirm the information provided in the surveys. Afterward, a total of 15 owners of potentially LHP herds and 14 owners of potentially HHP herds agreed to participate in the field study. Only 9 HHP herds and 10 LHP herds were finally chosen because the others were either borderline in meeting some of the criteria, or lived in geographic regions already represented in the study sample.

C. Field Study Process

The field study was conducted by a research team under contract to the PUC. The team consisted of a veterinarian, a specialist in electrical measurements, an electrical inspector, and two research assistants. One research assistant was responsible for pre-visit interviews and collection of available farm records. The other assisted both the veterinarian and the electrical measurement specialist. Three detailed protocols for the 3-4 day site visits by the team are given in Appendix C: one for the evaluation of herd health, production and management; one for inspection of the farm wiring; and another for measurements of the electrical environment. The protocols were developed with our advice as well as input of staff from the PUC, the Public Service Commission of Wisconsin, the Minnesota Department of Agriculture, and the Wisconsin Department of Agriculture, Trade and Consumer Protection; and representatives of special interest groups including various farm and dairy producer organizations, electric utilities, research universities and others. The field study data was analyzed by Dr. Marsh, with assistance from Ms. Doris Mold, also of the College of Veterinary Medicine of the University of Minnesota, and members of the field study research team.

The protocols were tested on two farms before the study of the selected 19 farms began. Data from these two farms were not included in the final analysis. The farm visits were conducted from early June through early October 1997. *Members of the 4-person team (i.e., the veterinarian, the electrical inspector, the electrical measurements specialist and the field research assistant) were not made aware of whether a dairy operation was classified in the LHP or HHP herd category, with one exception. After the field data had been collected, the data were analyzed using number designations for* *the farms and not the owners name. This "blind" study approach was used to preclude bias in data collection and the analysis.*

D. Field Study Results: Confirmation that HHP and LHP Herds are Different

The 19 study farms were widely distributed throughout the state of Minnesota in a pattern that aligns with the known geographic distribution of dairy farms. The farms were concentrated around a line beginning in West-Central Minnesota, roughly following Interstate 94 from Fergus Falls to the Twin Cities, with the line then continuing into the south-east corner of the state. The herds of the 19 study farms ranged from 30 to 125 dairy cows; this range is similar to the herd size distribution of the 10,400 Minnesota dairy operations registered in the database of the Minnesota Agricultural Statistics Service at the time of the surveys were conducted. Further, of the 19 study farms, 17 had stanchion and/or tie stall facilities and 2 were parlor facilities. This proportion (9:1) of stanchion and tie stall facilities relative to parlor facilities corresponds to that reported by the total group of respondents to the mailed survey.

The first step in the analysis of results from the field study was to confirm that the two study populations -- HHP and LHP herds -- were indeed different. Since the study farms were selected initially using only data from the survey responses of dairy herd owners, it was necessary to obtain data from owner records, creamery receipts and owner interviews to document that the information on the surveys was valid and up to date.

In this and subsequent analyses, mean values for a variety of descriptive and outcome parameters were derived for each group of herds, HHP and LHP, and then compared. The "P value" for each comparison was determined. The P value is a measure of the statistical association between two measurable parameters. The statistical significance of any correlation analysis increases with the size of the sample. In a small sample such as the 19 or fewer dairy herds in this study, P values can best serve as a statistical tool for establishing a ranking among factors that may be of interest when comparing HHP with LHP herds. The lower the P value, the greater the probability that a real association exists. In this study, where the purpose is to identify specific factors that may be associated with certain outcomes, those factors with the lowest P values are of greatest interest.

1. <u>Herd Data</u>

Average rolling herd milk production and somatic cell counts (SCC) were obtained from up to two years of records on the 19 study herds. The mean rolling herd average for all farms was 56 pounds per cow per year, with a minimum of 25.7 pounds per cow per year and a maximum of 78.7 pound per cow per year for the 2-year period ending in October 1997. The rolling herd average for HHP herds was 67.2 pounds per cow per year and for the LHP herds was 45.9 pounds per cow per year ($P = 0.0006$). The mean SCC was lower for HHP herds than LHP herds (319,000 vs. 413,000; P = 0.0994). The mean bacteria count was also lower for the HHP herds: 28,000 vs. 9,000 (P = 0.0896). The owners also were asked to confirm the presence or absence of some of the 26 clinical signs they had reported in the mailed survey. Some of these parameters were later evaluated quantitatively as part of the veterinary protocol during the visit by the research team.

The other 3 parameters that were used initially to identify HHP and LHP herds from the dairy operators' survey data (i.e., annual mortality rate, annual culling rate and average score for clinical signs) were confirmed in interviews with the dairy operator by a member of the research team. However, the differences among the two groups of herds were not very significant. Rough estimates of the mortality rates and culling rates were based on discussions with the owner. According to these estimates, the mean annual culling rate for HHP herds was 34.5 percent and that for LHP herds was 28.3 percent (P = 0.33). HHP herds had an estimated annual death rate of 3.7 percent while the rate in LHP herds was 5.9 percent (P = 0.32).

2. Individual Cow Data

Further characterization of the differences among the two types of herds at the individual cow level was carried out as part of the study protocol. The veterinarian examined a total of 965 adult cows in the 19 herds. Cows in HHP herds were found to be taller (56.26 inches vs. 54.95 inches; P = less than 0.0001), heavier (1,359 vs. 1,305 pounds; P = less than 0.0001) and to have higher body condition scores (3.25 vs. 3.10; P = less than 0.0001) than their counterparts in LHP herds. Cows in the HHP herds were younger (4.23 vs. 4.69 years; P = 0.001), likely due to a younger age at first breeding (14.8 vs. 16.2 months; P = 0.0038), and had shorter inter-calving intervals as indicated by the lower average days in milk (177.6 vs. 196.1; P = 0.0510) at the time of farm visits. There was no difference in lactation number of cows in HHP and LHP herds (2.56 vs. 2.43; P = 0.2881). Individual cow data, although useful for confirming differences among HHP and LHP herds, was not used in subsequent analyses of risk factor associations because statistically, it is not appropriate to compare herd data (19 data points) with individual cow data (over 900 data points).

3. Findings

The above data show that the two groups of field study herds -- HHP and LHP -- are most clearly distinguished by the measure of pounds of milk produced/cow/day. This is also the most commonly used parameter to characterize overall herd performance in most research. The difference between HHP and LHP herds in mean somatic cell counts is also convincing given the low sample size. The other herd level data collected show various degrees of statistical differences among the two herds. There are also some very significant differences among the two types of herds when data on the individual cow level is used (e.g., height, weight, body condition etc.). After all the data are considered, there are, indeed, significant differences between HHP and LHP herds.

E. Field Study Results: Analysis of Non-Electrical Parameters

1. Background

Some of the main outcomes cited by farmers who are concerned about possible effects of earth current are reduced milk production, increased somatic cell counts, reduced water consumption and hocks that are swollen or have sores and abrasions. However, there are known causes for these adverse health and production outcomes that are not electrical. These risk factors are described below.

Among the main risk factors for lowered milk production are poor nutrition, high environmental temperature, infectious diseases, milking machine defects and improper handling of cows by those who care for them. Water intake is also important in dairy cows and is primarily determined by 4 factors: dry matter intake, milk production, ambient temperature and sodium intake. Exceptions occur when cows are not able to swallow water because of some physical disability or when the cow cannot reach a water source. Over a period of several days, a cow must consume enough water either through drinking or in forages to maintain a balance in body constituents. A change in water intake can occur whenever one or more of the four major determinants of water needs is altered.

An elevated somatic cell count (SCC) in milk indicates that the mammary gland has an inflammatory condition and is shedding more cells than normal in the milk. Inflammation of the mammary gland can be caused by many factors such as traumatic injury or bacteria that originate in the environment or come from another cow through contamination of milking machine equipment, defective milking equipment or improper milking techniques. Improper nutrition can also lead to deficiencies in the immune system which are often associated with high SCC. In addition, poor environmental conditions such as dirty stalls and muddy pastures can produce high levels of contamination in the teat openings.

A lack of cow comfort and rumen acidosis are the primary causes of swollen hocks, abscesses, sore feet and nose bleeding. Small stalls and little or no bedding commonly cause increased standing time and sore feet and swollen hocks. Rumen acidosis typically results from feeding high carbohydrate rations that, in addition to the signs listed above, increase the production of lactic acid, cause a metabolic acidosis, and reduce rumen motility, feed intake and milk production.

The veterinary management protocol for the study focused on three main types of non-electrical risk factors which have been well-characterized in previous research: (1) nutrition, as measured by dry matter intake, net energy, crude protein and fiber; (2) overall cow comfort, which takes into account size and cleanliness of stalls, bedding levels and types, and ventilation; and (3) vaccination and related disease prevention practices.

2. Findings

Table I summarizes the data collected from the 19 herds on the key risk factors addressed in the veterinary evaluation protocol. The results of statistical analyses comparing these factors among the HHP and LHP herds are summarized in Section III, J.

Table I: Non-Electrical Risk Factor Findings - Range and Mean Values for the 19 Study Herds

Non-Electrical Factor	Range	Mean Value
Nutrition (percent of NRC[3] Recommendation)		
Dry Matter Intake	77.8 to 106.4 percent	97.3 percent
Net Energy	77.3 to 108.3 percent	97.3 percent
Crude Protein	61.5 to 121.4 percent	97.4 percent
Fiber	98.8 to 182.9 percent	124.1 percent
Cow Comfort[4]		
Comfort Score - Cows	1 to 4	2.61
Comfort Score - Heifers	1 to 5	2.96
Rubber Mats	5 of 17 stanchion and tie stall barns	
Stall Size[5]		
Width	40 to 54 inches	47.7 inches
Length	56 to 92 inches	69.2 inches
Vaccinations		
Cows	0 to 8	4.4
Heifers	0 to 8	4.3
(13 types possible)		

[3] NRC: National Research Council

[4] Cow comfort ratings were performed by the veterinarian on the research team using the following scoring system: 1 = clean, dry, well-bedded; good ventilation. 3 = adequate cleanliness, mostly dry, with some stale air. 5 = dirty, wet, with little or no bedding and stagnant air.

[5] Recommended stall sizes (Hurnink, 1990) are at least 40 inches wide and 54 inches long for a 1300 pound cow and 43 inches wide and 56 inches long for a 1500 pound cow.

F. Field Study Results: Electrical Measurements

In our 1996 Progress Report we identified five possible mechanisms by which the various electrical parameters associated with the electrical distribution system that supplies power to dairy farms could conceivably affect dairy cows' behavior, health or milk production (Minnesota PUC, 1996). The purpose of this section is to evaluate these hypotheses with the information now available.

The hypotheses are:

1. *AC Voltage*: Continuous or frequently repeated contact of confined cows to sources of low level stray voltage may result in electric fields inside the cow at levels high enough to produce biological effects without producing observable or measurable behavior modifications.

2. *Transient Voltage*: Current transients may affect a cow through the associated transient stray voltage or through magnetic induction. Examples include 60 Hz transients from motor starting events, and high frequency transients from electrical switching events and from malfunctioning cow trainers and electric fences. The sources of these transients can originate on or off the farm.

3. *AC Magnetic Fields*: 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.

4. *Interaction of AC and DC Magnetic Fields*: 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.

5. *Pulsed Electric Fields*: Pulsed electric fields from sources such as cow trainers may be locally large enough at the cow's back to be sensed by cows.

In the following sub-sections the rationale for each of these hypotheses and is given together with the range of values obtained for each electrical measurement made across the 19 herds. Our conclusions from the electrical measurements and inspection components of the field study are also given. Measures for HHP and LHP herds are compared in Section III, J.

1. <u>AC Voltage</u>

Rationale: This mechanism was proposed because internal body electric fields of 0.01 volt/meter to 0.01 volt/meter have been shown to produce physiological responses in other animals, mostly rodents and small primates. Studies have indicated that internal electric fields within this range are associated with a change in bone formation in the isolated turkey ulna, a decrease in concentrations of metabolites of dopamine and serotonin in cerebrospinal fluid of macaques, and decreases in testosterone concentrations in rats. Effects such as these can be either adverse, beneficial or neutral, and may be reversible. They are not necessarily applicable to dairy cow health or milk production. However, field strengths in the range of 0.001 volts/meter to 0.01 volts/meter could be induced in the head of a cow (depending on cow and contact electrical resistance), if the cow were exposed to 0.007 to 0.07 volts between water cup and rear hoof. Further, we estimated that a front-to-rear hoof step potential exposure of 0.002 to 0.02 volts would produce such field strengths in the cow's leg muscle tissue.

Results from the 1997 Field Study: The average exposure from water cup to rear hoof was 0.041 volts over 12 hours, 0.051 volts during a high electrical use hour, and 0.026 volts during a low electrical use hour. The average step potential in the stall was 0.006 volt over twelve hours, 0.008 volts during a high electrical use hour, and 0.005 volts during a low electrical use hour. The highest one-hour average cow contact voltage measured on the water line on a single study farm was 0.209 volts. This voltage is less than the 0.5 volts or higher necessary to initiate a behavioral response in dairy cows as presently established in the stray voltage literature. The highest step potential in a study barn stall was 0.047 volts, measured as a one-hour average. The step potentials measured in all of the study farm stalls were 10 to 100 times lower than the established threshold to initiate an observable behavioral response in dairy cows.

However, the measured voltages are high enough to support the low level voltage hypothesis. Twelve of the 17 stanchion and tie stall farms had water cup voltages higher than 0.007 volts (corresponding to an estimated internal electric field on the order of 0.001 volts/meter) as a 12-hour average. Five of 17 farms had water cup to rear hoof voltages higher than 0.07 volts (corresponding to an estimated internal electric field of 0.01 volts/meter). Considering the threshold range for step potentials as defined by the low level voltage hypothesis, the lower end of the estimated range of values for leg muscle tissue (0.002 volts) was exceeded as a 12-hour average on 14 of 17 farms; the higher end of the estimated range (0.02 volts) was exceeded on only one farm. Only the front to rear hoof step potentials measured in the study results in the continuous and longer term exposure required to satisfy the low level voltage hypothesis.

Measured AC earth current densities on 19 dairy farms included the range from 21 to 1139 microamps/meter^2 in the barnyards and from 2 to 184 microamps/meter^2 in the field away from the barn. The AC magnetic fields which result from these earth currents are too low to be measured, and are very much lower than those levels currently of concern in published reports. Therefore, if earth currents induce any kind of physiological response, it must be through the associated step potential across the ground. Measured open circuit step potentials (for a step of 1.5 meters) on these 19 farms ranged from 0.001 to 0.052 volts in the barnyard and from 0.0001 to 0.012 volts in the field. These voltages were all substantially lower when measured across a 500 ohm resistor similar to the electrical resistance of a cow.

These values were measured during a single season. Step potentials vary with soil resistivity which may change with soil moisture and temperature throughout the year. To examine this possibility, a long-term step potential measurement series was carried out at a rural residential site, the characteristics of which insured an adequate test of seasonal variations in earth current. Open circuit step potentials were measured infrequently (every one or two weeks) over a period of 17 months. No discernable pattern related to seasonal changes was evident in the data.

2. Transient Voltage

Rationale: In addition to steady state voltages, cows are exposed to transient voltages. The limited amount of research published on this topic suggests that overt behavioral and some physiological responses to transient voltages are similar to responses to 60 Hertz (Hz) voltages when comparisons are made based on total energy. Thus, since transient voltages have both a magnitude and duration, the shorter the transient duration, the higher must be the voltage to elicit the same behavioral response. Transient voltages found in the barn can be classified as either "60 Hz transients" due to high starting currents drawn by electric motors or "high frequency (HF) transients" which are usually caused by nearby electrical switching events and by malfunctioning electric fence and cow trainer systems.

Results from the 1997 Field Study: Transient voltages between cow contact points were measured using an impedance model of a cow which allowed simultaneous measurement of high and low frequency voltages (Aneshansley et al., 1995), (Stringfellow, et al., 1996). The largest 60 Hz transient voltage occurring between cow contacts on any of the 17 stanchion and tie stall barns in the study was 2.603 volts rms (between water line and rear hoof). This is marginally larger than the single-cycle voltage necessary to cause a behavioral response in 1% of the cows in a herd in another published study (Reinemann et al., 1996). The second-largest 60 Hz transient measured on any farm was 1.533 volts on the water line of another farm. Low frequency step potential transients were usually much smaller than those occurring on the water line. The largest 60 Hz step potential transient detected on any of the farms was 0.148 volts (the largest of seven similar events occurring on this farm in 12 hours).

High frequency (20 kHz to 10 MHz) transient voltages also were detected between cow contacts and recorded. They typically lasted from a few to a few hundred microseconds. Long transients often were composed of several shorter transients and were due to switch contact points bouncing upon closure. The largest water line to rear hoof HF transient had a peak voltage of 1.9 volts. High frequency step potential transients were detected on only two farms: On one farm they were shown to be caused by lightning, and were as large as 0.7 volts peak. On the other farm they were shown to be caused by a faulty cow trainer where the high voltage wire was in contact with barn metalwork; these were as large as 0.9 volts. High frequency transients were detected between the milk line and rear hoof on a number of farms. The largest high frequency transient on a milk line had a peak voltage of 2.48 volts.

In addition, high frequency transient voltages that exceed the 4 volt threshold of the equipment used in the study were measured on the barn neutral bus and referenced to a near (<20 foot) ground stake. On some farms, almost no high frequency transients above the 4 volt threshold were recorded on the neutral, while others had hundreds during a 12-hour period. On three farms, equipment caused neutral high frequency transients to occur every half cycle. These were traced to a kitchen range in two cases, a solid state motor controller for a barn fan, and a countertop air ionizer/purifier. The most common sources of high frequency transients found on farm neutrals, however, were electric fence and cow trainer systems. High frequency transients caused by these devices were detected on the secondary neutral of 14 of the 17 stall barns studied, although they were not always large enough to be recorded (i.e., above the 4 volt threshold) or observed between cow contact points (0.5 volt threshold). These transient voltages were caused by one or more of the following: (1) an energizer grounded to or near the electrical ground on 14 farms, (2) a high voltage wire in contact with barn metalwork or ground on five farms, and (3) a faulty energizer unit on four farms. While sources of transient voltages other than those from electric fences and cow trainers were not characterized in every case, it is well known that they are attenuated with distance due to reactive components in the circuit impedance. Therefore, high frequency transients are usually, but not exclusively, caused by nearby sources.

3. <u>AC Magnetic Fields</u>

Rationale: Cows are confined in stanchion or tie stall barns such that they are close to ground current on water lines, stanchions and other metalwork. The magnetic fields from these currents are not reduced by those from parallel return currents as with most modern electrical wiring. Localized magnetic fields due to ground currents in dairy barns could thus be problematic if they were much larger than about 10 milligauss.

A wide range of magnetic field exposure intensities has been studied in the laboratory. From the data in the literature, there is a general scientific consensus that fields of 1000 milligauss and above produce physiological responses in exposed animals. These effects may or may not adversely affect the health of these animals. Effects in animals below 10 milligauss have not been reported. Only a very few animal studies have been performed using field intensities between 10 and 100 milligauss. Most studies in this range showed no effects. Some studies in the 10 to 100 milligauss range have shown both a reduction in the hormone melatonin in rats and changes in the development of chick embryos, but such changes have not been reported in studies involving humans. Four independent laboratories have found effects in cellular systems (e.g., effects in growth of breast cancer cells in culture) at levels as low as 12 milligauss. Physiological effects have been reported in laboratory studies where animals were exposed to fields between 100 and 500 milligauss. However, results of these studies are mixed; some report field-associated effects and some do not. Effects in animals exposed in this higher range generally have not been independently replicated. In contrast to laboratory animal experiments, evidence in isolated cell systems suggests statistically significant effects with exposures above 100 milligauss. In light of the laboratory study results, data from epidemiological studies are perplexing in that associations between exposures to magnetic fields and adverse health effects in humans have been reported in a fairly large number of studies at levels below 10 milligauss, but above approximately 2 or 3 milligauss. However, firm connections have not been established between such field levels and effects, primarily due to imprecision in assessments of exposure levels. In most human epidemiological studies, it has been difficult to establish both the duration and the intensity of exposure of individuals.

Results from the 1997 Field Study: In each of the 17 stanchion and tie stall barns studied, the 60 Hz magnetic flux density was measured at the cow's head, at the top of the back closest to the overhead water line, and at the base of the tail of each cow. The barn was surveyed during a milking period when barn neutral voltages and ground currents were highest. The barn was also surveyed during an electrically quiet period. Data show that the average exposure of dairy cows in this study was at a fraction of one milligauss. Rarely did exposures exceed several milligauss. The largest single measurement of magnetic flux density on the 17 farms was 9.56 milligauss at the back of a cow; this was caused by an electrical appliance (cow trainer energizer) and disappeared within 1 meter (<0.04 milligauss at the tail of the same cow). These data illustrate that the AC magnetic flux density is commonly highest at the back of each cow (averages across all stalls and farms during milking were 0.44 milligauss at the head, 0.68 milligauss at the back, and 0.59 milligauss at the tail). This is due to proximity of the cow's back to ground current carried by the water line or metal vacuum line to which the barn neutral is bonded.

4. <u>Interaction of AC and DC Magnetic Fields</u>

Rationale: Mechanisms other than Faraday induction have been proposed in the published literature to explain effects attributable to alternating magnetic fields. Several laboratory studies have shown physiological effects that depend upon the simultaneous presence of a DC (static) magnetic field and an AC (alternating) magnetic field of at least one tenth the magnitude of the static field, or about 50 milligauss. Other, more recent studies have indicated effects on cell cultures at 12 milligauss. In addition, laboratory studies are underway to confirm isolated reports that ac magnetic fields at or below 1 milligauss may affect biological systems in the presence of a dc magnetic field.

The magnitude of the DC field determines particular frequencies ("ion cyclotron resonances") at which systems respond. Responses have, for example, been observed in solutions of amino acids. Possible mechanisms to explain these experimental results comprise an active area of research. Other research has established the effect of relatively large, at least 500 milligauss, static and time varying fields on chemical and biochemical reactions involving free radicals.

Results from the 1997 Field Study: Magnetic fields were examined in detail for one short time period in one stall for each of the 19 of the farms in the field study. Both ac and dc magnetic flux densities were determined for multiple points in the stalls of stanchion or tie stall barns and parlor barns. Then cyclotron resonance conditions for six biologically important ions at 60 Hz were evaluated at each grid point. Resonance (or near resonance) conditions were observed for one or more of the ions to some degree on each farm. The ions K^+ and Mg^{2+} scored the highest when summed across all farms, then, in descending order Cl^-, H^+, Li^+, and Ca^{2+}. However, the single highest alternating magnetic flux density recorded during these measurements was 9.24 milligauss, which is still lower than the lowest field level (12 milligauss) at which physiological effects have been demonstrated in laboratory cell cultures.

5. Pulsed Electric Fields from Cow Trainers

Rationale: Exposure to electric fields in air has been shown to affect biological systems only at magnitudes of several kilovolts/meter. Such fields are found, for example, between a high voltage transmission line and the earth. In a dairy barn, the only source of large electric fields is the cow trainer system. The currents induced in a cow from such high frequency pulsed fields may be strong enough to be sensed. Sensations might be expected with pulsed electric fields larger than 5 to 10 kilovolt/meter.

Results from the 1997 Field Study: For each barn in the field study the peak pulsed electric field was approximated by dividing the cow trainer peak voltage by the average height of the trainer bar above the cows' backs. Average heights of trainer bars ranged from 6.4 centimeters (cm) to 11.2 cm with a mean of 8.1 cm. Peak output voltage ranged from 0.88 kilovolts to 3.0 kilovolts with a mean of 2.0 kilovolts. The calculated average peak electric field varied from 13.9 kilovolts/meter to 43.3 kilovolts/meter with a mean of 25.3 kilovolts/meter. The cow might be able to sense the field at these levels. These field values should be considered to be only representative; higher or lower fields exist as the bar height above the cow changes, as it does often during the day for all cows with normal movements in their stall.

Charge transfer via high frequency conduction is likely to exceed that due to pulsed electric field induction. As noted above, pulses from cow trainer or electric fence were found on the barn neutrals of 14 of the 17 study farms. We estimated that a cow trainer could induce a current in the cow of 0.5 amperes with a duration of resistance x capacitance = 3 nanoseconds, equivalent to a charge transfer of 0.0015 microcoulombs. For comparison, if voltage pulses of 0.1 volt appeared for 100 microseconds between cow contacts, this would result in a charge transfer by conduction of Q = volts x time/resistance = 0.033 microcoulombs, assuming a cow impedance of 300 ohm at a frequency on the order of $1/(100 \cdot 10^{-6}) = 10$ kilohertz. This 'conducted' charge resulting from a nominal, negligible cow contact transient of 0.1 volts is approximately 20 times the estimated charge transferred via electric field induction.

G. Field Study Results: Electrical Inspection

Farm wiring was inspected to identify conditions that could cause or contribute to the voltage, magnetic field and electric field levels measured in the study. Electrical systems on the farms were evaluated with respect to requirements of the National Electrical Code (NEC) as they apply to secondary grounded-neutral electrical systems. The properties of interest were those that may affect (1) neutral-to-earth voltage, (2) voltage relative to earth on equipment connected to equipment grounding conductors, and (3) flow of load current through any path external to the intended circuit conductors.

The electrical inspection of the farms included a preliminary inspection of the premises, a survey of the barn and associated equipment for hazardous electrical conditions, an inspection of the barn and associated equipment for conditions that would produce stray voltages and magnetic fields, a check of the secondary distribution system neutrals and grounding on the farm, an evaluation of the approximate farm grounding impedance and the primary neutral impedance, and a check for grounding of submersible water pumps and well casings. Observations noted during these inspections follow:

1. Hazardous Electrical Conditions

Six farms had line connections supplying main circuit breakers that were severely overheating and in danger of imminent failure. Every farm had one or more pieces of equipment that were not grounded. All but two dairy barns had one or more ungrounded units; some had several. Thirteen had one or more buildings that did not have a grounding electrode as required by the NEC. Interior water piping systems were generally not bonded to the electrical systems except through inadvertent connections at equipment such as water heaters. Some enclosures of service entrances were not bonded (grounded), raising the shock hazard. A number of barns had "temporary" or other makeshift wiring such as extension cords. One farm lacked any connection between the neutral and ground, a condition which could potentially elevate the farm grounding system to 120 V. Many older buildings were served through original, often bare conductors or conductors with badly deteriorated outer jackets.

2. Stray Voltage and Magnetic Field Conditions

The neutral-to-earth voltage in several barns could have been substantially reduced by balancing 120 volt loads such as light and fan circuits. One farm had an isolation device at the barn service entrance that was ineffective because of a previously undiscovered bypass in a wiring circuit in the barn. One farm had a bad neutral connection resulting in 5 volts on the neutral to outbuildings and a cattle waterer. Another neutral connection on this farm was warm and would fail eventually. Another farm supplied power to a cattle shed through substandard wiring resulting in 2 volts on the neutral with a 10 ampere load. One farm had an open neutral in the feeder to a machine shed. Two farms had high resistance barn neutrals resulting in elevated neutral-to-earth voltages. In at least three barns, 120 volt loads were improperly supplied from 240 volt circuits that did not contain a neutral, but an equipment ground was present. This produced a flow of current on the grounding conductor that caused elevated ac magnetic fields. Eight barns had more than one service (an accepted practice), resulting in at least one case where interconnections raised the magnetic field level in the barn by 1 to 3 milligauss. Several failing conductor connections occurred because oxide inhibitor was not used when terminating aluminum conductors.

3. Farm Grounding Impedance and Primary Neutral Impedance

Farm grounding impedances ranged from 0.2 to 2.6 ohm with an average of 1.1 ohm. Primary neutral impedances ranged from 0.2 to 1.0 ohm with an average of 0.48 ohm.

4. Grounding of Submersible Water Pumps and Well Casings

Few submersible pumps or well casings were grounded according to NEC requirementa. Where grounds were used, grounding impedances were generally about 5 ohm.

H. General Conclusions: Electrical Inspection

The field study indicates that farm wiring is likely to result in hazardous conditions on many Minnesota farms. In many cases farm wiring resulted in elevated neutral-to-earth voltages in the barn. These hazardous conditions appear to be caused by the following factors:

- A substantial amount of wiring was done by the owner, operator, or other persons without electrical training.
- Many code violations were present in work done by electrical contractors.
- Electrical inspectors failed to note or did not require correction of some code violations.
- The wiring in general was not properly maintained or replaced when it became defective.

This situation could be improved by providing information to the users, improving the training of electricians, and by more effective administration of electrical inspection statutes in the state. Also, a re-inspection program, if implemented, could be effective.

I. General Conclusions: Electrical Measurements

The 1997 field study was one vehicle for examining whether certain electrical parameters can be found to be within the range needed for any of the five hypotheses cited above to be relevant. We have used this examination for setting priorities for further research. For each of the five electrical hypotheses posed in our 1996 progress report, we conclude the following:

1. <u>AC Voltage</u>

The range of average front to rear hoof step potentials of dairy cows in stalls on the 17 farms where the measurement was made was 0.001 volts to 0.047 volts. Using data from published studies on animals other than dairy cows, we have estimated that voltages as low as 0.002 volts could conceivably cause internal electric fields in the cow that are high enough to produce a physiological response. If a physiological response is to occur in dairy cows, it is more likely to be produced by step potential exposures in the stalls rather than outside because (1) step potentials in the stall are larger than outside and (2) step potentials in the stall last longer because of long periods of cow confinement.

No one has proposed a specific physiological response in dairy cows that are exposed to low level voltages (i.e., 1-100 millivolts range). It is not possible to extrapolate directly the research findings from other animal species directly to dairy cows. The various types of physiological responses (e.g., circulating hormones or their metabolites) to electric and magnetic field exposures that have been shown in the published literature to occur in various animals other than dairy cows, are neither equivalent to nor indicative of pathological effects that cause poor health and production in dairy cows. Since it is not possible to extrapolate to dairy cows, we recommend further studies that specifically examine exposure of dairy cows to step potentials lower than those threshold levels already known to elicit behavioral responses.

2. <u>Transient Voltage</u>

Measured magnitudes of transient voltages are lower than would be necessary to elicit a behavioral response in dairy cows according to the most recent laboratory research. Further, data from the field study demonstrate that transient voltages in a dairy barn are most often from nearby sources, a finding which supports previous research.

3. <u>AC Magnetic Fields</u>

Adverse physiological or biological effects of ac magnetic fields at levels in the range of those found in the field study have not been documented in the laboratory (Reinemann et al., 1996; and Burchard et al., 1996). As noted in Section III F. 3., laboratory research on other animals has demonstrated effects caused by ac magnetic fields, but these results involve field strengths generally well above the 10 milligauss measured in this study. No AC magnetic fields were detected away from outside distribution lines; thus, there were no measurable ac magnetic fields associated with electric currents in the earth. These findings indicate that, at this time, further research on effects of AC magnetic fields on dairy cows is not a priority.

4. Interaction of AC and DC Magnetic Fields

Some magnetic resonance conditions were found in the test stall at each of the farms studied. However, even the largest, single ac magnetic flux density measured in the field study was not as large as those used in published laboratory studies where effects have been observed. Because of this large difference, the likelihood is low that cyclotron or ion parametric resonance has affects cows under normal circumstances. Thus, further research on the interaction of AC and DC magnetic fields in dairy cows is not a priority at the present time.

5. Pulsed Electric Fields from Cow Trainers

There does not seem to be a practical need to further study pulses of electric fields from cow trainers. As more farmers expand herd size and adopt loose housing for dairy cattle, the need for these devices will be reduced. The likelihood of electrical problems associated with improperly installed or malfunctioning cow trainer systems is high, and the pulsed electric fields from normally operating cow trainers may be large enough to be sensed by the cow. If trainers are perceived to cause problems, farmers can work to improve installation practices or discontinue using them altogether. There are many reasons why even the best installation and maintenance practices can lead to new problems over time. Intentionally shocking a cow when she arches her back has been judged not to be justifiable in Sweden.

The findings from the field study support placing the greatest priority on future research that addresses continuous or frequently repeated contact of confined cows to sources of low level voltage which may produce internal electric fields at levels high enough to produce physiological responses. The range of step potentials measured in the test stall on the 17 farms was 1 to 47 millivolts. The prediction in the original hypothesis was that physiological responses might be induced with exposures as low as 2 millivolts. A laboratory investigation of the low voltage hypothesis is warranted and has already been initiated (see Section IV). If additional research funds were to become available, then basic research in the area of magnetic field effects (beneficial, adverse or neutral) would also be useful, particularly because the threshold magnitude of magnetic fields exposure expected to elicit some type of response decreases as more studies are undertaken at progressively lower exposures (i.e., into the 10 milligauss range).

6. Conclusions Regarding Sources of Earth Currents

As noted in section III-A an extensive evaluation of the relative importance of on-farm and off-farm sources of earth currents and related step potentials or magnetic fields was not an objective of the field study, because it was to be established first whether such potentials or fields at the small expected amplitudes could be related to milk production or animal health. Furthermore, the measurements necessary to establish conclusively the sources of currents on the farm would have made the measurement protocol prohibitively time consuming and expensive. However, in view of concerns about earth currents expressed by some farmers and the field study results concerning step potentials and soil resistivity, it is still useful to extract from the available field study data all possible information about source location.

If the source of step potentials is in the barn, one would expect that step potentials should fall off with distance from the barn. Indeed, on most of the study farms step potentials in the stalls were higher than they were in the barnyard and much higher than in the field. All exceptions were in the five barns where rubber mats were used which imposed a high resistance between the floor and the resistor that simulated the animal and across which the step potential was measured. Furthermore, the step potential was always larger in the barnyard than in the field, often by an order of magnitude. The only exceptions were two farms, one where a transmission line was located at 0.1 mile from the farm (potential in the field $\approx$ 1/2 potential in yard) and the other where a combination of increasing soil resistivity with distance and nearness to a distribution line over part of the measurement path led to about equal step potentials in the field and barn yard. These data can suggest that cumulative background earth current density due to off-farm sources is relatively small unless these sources are close to the farm or are extremely strong compared to earth currents from sources such as ground current flowing to earth on stall pipes. It is well known that step potentials decline as one moves away from ground rods or other grounding electrodes. However, it must be pointed out that multiple grounds, connected directly (or indirectly, i.e. through a short earth path when "isolation" is used) to a primary neutral can also concentrate current from distant sources when the potential difference between this neutral and the distant source is large enough. The reason for this is that a potential difference between a single "point" (the farm) and a distant distributed source will lead to current concentration at that point. Thus, while data from the field study suggest that in most farms the predominant source of earth current was local, a firm exclusion of distant sources would have required additional measurements. Current from distant sources can also access the farm through the primary/secondary neutral bond on farms that are not isolated.

J. Statistical Analysis of Possible Associations between HHP or LHP Herds and Selected Electrical and Non-Electrical Factors

1. Background

The goal of the field study was to collect data that could be correlated with herds in the HHP and LHP categories. The average values of data measured in each group for a specific factor provide an initial indicator of a possible association between the factor and high or low health and productivity. A factor or variable that shows a possible association may or may not be a cause of the outcomes that characterize the LHP and HHP herds. The P value for comparing averages indicates the statistical significance that can be attached to the differences in averages. Low P values indicate a high statistical significance for an association, high P values indicate a low statistical significance. In addition to the statistical comparison of averages of factors for LHP and HHP herds, all factors measured for each of the 19 herds in the field study were combined in a single data set and assessed by a second statistical procedure called Pearson correlation coefficient analysis.

By using these two statistical methods - comparison of averages and correlation coefficient analysis - the relative significance of all the possible risk factors can be assessed. For example, if a comparison of average values for a particular measurement shows a significant difference between LHP and HHP herds, such as P = 0.04, the degree of significance is strengthened if the correlation coefficient analysis also gives a low P value (e.g., P = 0.05). When the P values are low for both statistical tests, it is more likely that the data will continue to show the same trend even if more data points (i.e., larger sample size) are added. If the P value for the correlation coefficient analysis of a particular variable plotted against pounds of milk/cow/day proves instead to be relatively high (e.g., 0.2 or higher), this indicates that there may be some spurious or "outlier" data points that account for the observed "significant" difference in the comparison of averages between LHP and HHP herds.[6]

2. Findings

The results of the statistical analyses are given in Table II. This table shows that HHP herds were offered more high-energy feed (i.e., dry matter intake and net energy in feedstuffs were greater), were provided with greater cow comfort (i.e., overall scores were higher and cows had longer stalls) and were more likely to have a vaccination program. In addition, HHP cows were exposed to lower maximum voltages between the milk line and cow hoofs, lower average step potentials, lower soil resistivity in the field, and higher magnetic fields. The Pearson correlation coefficient analysis showed that net energy in feedstuffs, cow vaccination score, cow comfort score and dry matter intake were strongly correlated with milk production. Less strongly correlated with milk production were: soil resistivity in the field and average step potential during low electrical use. Factors that did not correlate well with milk production were: soil

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[6] The Pearson correlation coefficient analysis was performed to estimate the strength and direction of linear associations between pounds of milk/cow/day in the herd and all other variables in turn. The different variables tested could have a positive or a negative correlation coefficient, "rho," between -1 and +1 ("+" rho values indicate that the factor increases with milk/cow/day; "-" rho values indicate that the factor decreases with milk/cow/day). The correlation coefficient analysis also yields a P value. This P value tests strength of association of the factor with milk/cow/day. It tests the probability that this association is unlikely to have occurred by chance. A high P value indicates that the association is likely to have occurred by chance. Rho is a measure of the strength of the association between the factor and milk/cow/day. If the factor increases by a certain number of units, then milk production should likewise increase. Rho values closest to +/- 1.0 indicate the strongest associations between the factor and milk/cow/day.

resistivity in the barnyard, maximum voltages between the milk line and the cow's hoofs, cow comfort scores for calves, magnetic fields, and average voltages between the milk line and cow's hoofs during low electrical use.

The data indicate that good nutrition, cow comfort and a vaccination program are significant factors associated with higher health and productivity. Soil resistivity in the barnyard was not well correlated with milk production. Soil resisitivity in the field, while correlated with milk production, may be related to the amount of water, electrolytes, soil fertility and nutritional quality of forages grown in the field, may vary greatly, and from a practical standpoint, may not be easily controlled. Higher soil resistivity also leads to greater dispersion of the earth portion of the unbalanced current underneath the neutral wire of a distribution line (Pender, 1936).

Amounts of feed offered daily to lactating cows varied between 52.0 and 93.6 pounds on an as-fed basis, which corresponds to a range of 36.6 to 53.7 pounds per cow per day on a dry matter basis. On average, cows in HHP herds were given the opportunity to consume more dry matter per head per day than cows in LHP herds (48.8 vs. 44.3 pounds, $P=0.049$). Rations for HHP herds contained more net energy for lactation (36.9 vs. 31.6 percent, $P = 0.0059$) and crude protein (7.8 percent vs. 7.0 percent, $P = 0.1994$).

When compared to published National Research Council standards, rations fed to cows in HHP herds met or exceeded requirements for dry matter intake, net energy for lactation, and crude protein. Conversely, the amount of dry matter offered to cows in LHP herds averaged 2.75 pounds per head per day below NRC recommendations. Consequently, rations for LHP herds contained insufficient energy to support a desirable level of milk production while maintaining body conditions. In order to meet NRC requirements, cows in the LHP herds would, on average, need to be fed 5.7 percent more dry matter, 5.9 percent more crude protein and 7.8 percent more energy per day than was offered to them to adequately meet the nutritional demands of their level of milk production at the time of the site visits. Based on the Acid Detergent Assay (see protocol in Appendix C 3), the amount of fiber in rations fed to lactating cows in all herds studied was well in excess of NRC requirements.

Cows are effectively insulated from milk line voltages because of the high resistance of plastic milk hoses and the air pockets in the milk stream during milking. Cows otherwise do not make contact with the milk line. The maximum voltages between milk line and hoofs measured in the field study represent one 60 Hz transient voltage on each farm, and are too low to produce a behavioral reaction according to the most recent research measuring performance of dairy cows while subjected to these types of transient voltages (Reinemann, 1997). Step potentials were well documented in the test stall in each dairy barn. They were 4.2 times higher on average on LHP farms than HHP farms, indicating a possible electrical association. However, the step potential values from measurements made on cows in the HHP herds could have been lower than those for LHP herds simply because of the insulation provided by rubber mats used in the stalls (i.e., 5 of the 8 HHP herds housed in stanchion or tie stall barns used rubber mats in the cows' stalls; 0 of the 9 LHP herds used rubber mats).

Table II: Low Health and Productivity (LHP) and High Health and Productivity (HHP) Herds Compared by Average (Mean) Scores for Various Factors[7]

	Discrimination Between LHP and HHP Herds			Correlation with Milk/Cow/Day	
Risk Factor	**LHP Herds (Avg.)**	**HHP Herds (Avg.)**	**P value**[8]	**Correlation Coefficient (rho)**	**P value**
Use of mats in stalls (17 stanchion and tie stall barns only)	0 of 9	5 of 8	0.0048	Not done	Not Done
Net energy in feed stuffs (percentage)	31.6	36.9	0.0059	0.635	0.0047
Cow vaccination score (13 types of vaccinations possible)	3.1	5.9	0.0109	0.722	0.0005
Comfort score - cows[9]	3.1	2.1	0.0134	-0.772	0.0002
Maximum AC voltage between milk line and cow hoofs	0.63	0.25	0.0334	-0.175	0.4869
Stall length (inches)	64.0	73.7	0.0446	0.452	0.1209
Dry matter intake (pounds/cow/day)	44.3	48.8	0.0490	0.564	0.0147
Soil resistivity in barnyard (ohm-cm)	8960.4	2962.0	0.0506	-0.233	0.3381
Comfort score - calves	3.3	2.4	0.0543	-0.219	0.3832
Soil resistivity in the field (ohm-cm)	9726.4	2830.0	0.0670	-0.474	0.0406
Average step potential, low electrical use (volt)	0.0070	0.00167	0.0727	-0.471	0.0418
Comfort score - heifers	1.2	2.4	0.0778	-0.348	0.1714
Magnetic field at the cow's back during milking (milligauss)	0.26	1.24	0.0779	0.299	0.2437
Average AC volts between milk line and cow hoofs, low electrical use	0.0662	0.0282	0.0832	-0.195	0.4380

[7] Data is ordered from lowest P value for the comparison of averages to highest P value. Nineteen herds were included for all herd parameters except those indicated.

[8] P value calculations were based on a two-sample "T" test for all variables except for use of mats in stalls, for which a chi square test for independent variables was employed.

[9] Cow comfort ratings were performed by the veterinarian on the research team using the following scoring system: 1 = clean, dry, well-bedded; good ventilation. 3 = adequate cleanliness, mostly dry, with some stale air. 5 = dirty, wet, with little or no bedding and stagnant air.

K. Field Study Conclusions

1. Characteristics of HHP and LHP Herds

The average milk production (pounds/cow/day) for a two-year period prior to the study was the major difference between HHP and LHP herds. In addition, the herds differed in cow height, weight, body condition, age, calving intervals, etc. Some of these factors used to differentiate among the two productivity groups may themselves influence herd productivity (e.g., average size and weight of cows).

2. Influence of Electrical and Non-Electrical Factors

There is convincing evidence that several of the non-electrical risk factors measured are associated with the LHP herds. The risk factors found to be of greatest importance in LHP herds were lower standards for nutrition, cow comfort and the use of vaccinations to prevent infectious disease. There is a lower association with both step potential during low electrical use times and soil resistivity in the field. Step potentials were in the range of those predicted by the low level voltage hypothesis to induce some kind of physiological response. The use of rubber mats likely contributed to lower step potentials on 5 of the HHP farms; nevertheless, there was a difference between HHP and LHP herds.

3. Complexities of Possible Influences

The field study provides further documentation of how the dairy farm environment represents an extremely complex web of potentially interacting variables that can positively or negatively impact overall productivity. Some of the factors identified with low or high health and productivity in the field study could be possible causes of the conditions. Alternatively, they may be confounders of other factors or indirect effectors (e.g., smaller cows have smaller rumens and smaller appetites which can, in turn impact production of milk; soil resistivity in the field can impact feed and thus affect overall nutrition and milk production.). It is important to note, however, that we cannot make definitive statements from this field study about possible "causes" of herd health and productivity problems. This would require conducting experiments that control for one variable at a time. By the same token, a positive result in a controlled laboratory experiment may not necessarily reflect what actually would occur in an on-farm context where the single variable under study would never exist independently of all others.

4. Assessment of Need for a Larger Study

One purpose of the pilot field study was to determine whether a larger scale study (e.g., 50 or more farms) is feasible and warranted. Such a large study is neither practical nor warranted. While there were only 19 herds in this field study, it was possible to identify variables that associate clearly with HHP and LHP herds. Data from this study can be used effectively to prioritize which electrical variables should be included in any future field or laboratory studies. The low level step potential hypothesis is supported by the data in the field study and this is being pursued in the laboratory (see Section IV). Scaling up the field study to 50 or 100 herds may be prohibitively expensive (at least $500,000); further, statistics from the 19 farm study indicate that more data is unlikely to change the present findings, especially for the non-electrical and electrical factors that show major differences between LHP and HHP herds. In addition, it is desirable to conduct the study in a single season so that seasonal variations would be excluded. In order to conduct a larger study in a single season, multiple research teams would be required; however, such multiple teams would reduce the uniformity of the approach.

5. Choice of Farms

In the design phase of the field study, there were suggestions that the study sample should include more of the 1.2 percent of dairy operators who reported that persistent health and production problems on their farms were caused by stray voltage or related electrical conditions. In fact one such respondent was selected in the initial screening. This dairy owner's herd did meet the study criteria and was included among the 19 farms in the study. We concluded that the perceptions of farmers about the possibility of electrical causes of problems with herd health and production are not sufficiently objective to use as a basis for farm selection. Further, we concluded that a more objective basis for choosing farms was needed, and that it should be based on well-documented outcomes rather than qualitative perceptions of causes. Thus the two groups of study farms in the field study were identified on the basis of outcomes such as milk production.

6. Applications of the Field Study

In addition to future research possibilities, the results of this study can guide individual dairy farmers to prioritize those factors most strongly associated with herd health and production problems on the typical dairy farm. Further, the protocols that were developed in the study can be used to evaluate the factors that are of greatest potential concern. Brief, confidential reports were developed and provided to individual study participants. The veterinarian, the specialist in electrical measurements, and the electrical inspector who collected data on the farms prepared these reports. Dairy operators reported that these summaries were very helpful. The protocols developed for this study and the approach to reporting could easily be adapted for use in investigations by others who want to assist dairy operators.

IV. LABORATORY STUDIES IN PROGRESS

The combined electrical data from the field study indicated that while none of the five electrical hypotheses can be ruled out, only one of them is a priority for research at this time. The hypothesis states that, *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*. A laboratory study to test this hypothesis under controlled conditions was proposed by a team led by Dr. Douglas Reinemann, Associate Professor in the Department of Biological Systems Engineering at the University of Wisconsin, Madison. The PUC contracted with Dr. Reinemann and his colleagues to conduct the laboratory study. The research was initiated in May 1998.

The laboratory study has four major objectives:

1) Investigate immune function response to continuously applied, low-level voltage. The presumed pathway of exposure is hoof-hoof step potential.
2) Compare dairy cow sensitivity to voltage applied hoof-hoof with muzzle-hoof pathways.
3) Investigate the relationship between behavioral responses previously observed and other physiological methods of quantifying stressors.
4) Compare responses to low voltage exposure and responses to other stressors.

Three experiments will be conducted to meet these objectives. Two types of voltage and current exposures will be performed as described below. Short-term exposure (from 1 to 10 minutes) will be used for Parts I and II and objectives 2, 3, and 4. Longer-term (2-week) continuous exposure will be used for Part III and objective 1.

A. Part I: Short-Term Exposure, Hoof-to-Hoof Sensitivity Testing, and Comparison of Behavioral to Physiological Responses

Previous methods have relied primarily upon behavioral response as an indication of the sensitivity threshold to electrical exposure. Behavioral responses have also been used by several other researchers to measure the threshold response to voltage exposure. As stated in our 1996 report, "less subjective and more quantitative dairy cow behavioral response indicators and more reliable physiological response indicators are desired in further laboratory studies." Recent studies indicate that behavior and performance are reliable indicators of stress (Hicks et. al., 1998; Turner et. al., 1998). These reports provide evidence that behavioral, endocrine and immune system studies combined with studies on performance criteria, such as fertility, reproduction, weight of newborns, dry matter intake, weight gain, feed conversion, body condition, and milk production are required to fully assess potential harmful impacts of stressors.

Little work has been done to document hoof-hoof exposures, yet this is a common exposure pathway in the field. Short-term experiments involving acute exposures will be performed to establish the relationship between sensitivity to hoof-hoof and muzzle-hoof pathways.

Four cows each will be tested using the muzzle-hoof pathway and the hoof-hoof pathway. The following day each cow will be tested using the alternate pathway. These tests will establish the threshold behavioral response level for each cow.

The test cows will then be exposed to the hoof-hoof pathway for at least 3 days. Blood samples will be drawn at 15-minute intervals for 1 hour before testing. The main physiological measures will be endocrine response. Each cow will then be exposed to current equal to 50%, 75% and 100% of the sensitivity threshold determined in the first part of the experiment. If no behavioral response is found a fourth level of 150% of the sensitivity threshold will be applied. These voltage exposures will be applied for 5-minute intervals once every hour. Blood sampling will continue at 15-minute intervals throughout the testing and for an additional hour after the last exposure.

B. Part II. Comparison of Treatments Applied during Milking

The treatments for these experiments will be applied in one of the milking stalls during milking. Treatments will be applied over 4 consecutive days using a Latin square design with 8 cows per experiment and 2 cows per treatment group.

The frequency of behaviors such as hoof lifting and kicking during milking have been suggested as measures of cow discomfort during milking. These are likely to be sensitive measures for hoof-to-hoof voltage exposure. The milk letdown reflex is influenced by stresses experienced during milking. Discomfort during milking may decrease both the peak and average milk flow rate during milking, increase the time taken to remove the milk and increase the amount of milk remaining in the udder after machine milking.

The results of these experiments should provide valuable information on the relative effects of voltage exposure and other common stressors in the animal environment such as sub-optimal milking machine performance.

C. Part III: Longer-Term Continuous Exposure to Sub-Acute Voltages.

The primary objective of these experiments will be to measure immune and endocrine system responses to continuously applied hoof-to-hoof voltage exposure below the sensitivity threshold of individual cows. The treatments will be applied continuously for a period of 2 weeks. The cows will be exposed to voltage whenever they are in the housing area. The level of voltage exposure will be 1/2 to 1 volt (1 - 2 milliamp). The low level voltage will be cycled on and off on a 10 minute intervals as biological effects previously observed appear to be most pronounced when the exposure is changing with time.

D. Research Schedule

The experimental apparatus has already been assembled and tested. Progress reports will be issued to the Minnesota PUC throughout the study. Experiments will be repeated until a significant response is documented, until there is sufficient statistical evidence to conclude a negative result, or until the end of the contract period (June 30, 1999), whichever comes first. Thus, some experiments may be repeated more or less than others and there may not be time and resources to complete the full schedule. It is estimated that three replicates will be required for each experiment. Dr. Reinemann will forward a final report summarizing all of the experiments completed to the PUC by June 30, 1999.

Peer review will be provided by three scientists throughout the course of this research. The review will consist of a site visit to the laboratory in early fall 1998, review of Dr. Reinemann's mid-term report on research progress, and technical review of draft publications as they become available. The study reports and peer reviews will be forwarded to the PUC upon completion.

V. FINDINGS AND RECOMMENDATIONS TO THE MINNESOTA PUBLIC UTILITIES COMMISSION

The findings and recommendations given below take into account our review and analysis of many different sources of information acquired by or provided to us over the four years of our term as advisors to the Minnesota Public Utilities Commission. The primary information sources we have used include:

- Research studies published in the peer-reviewed literature.
- Oral and written reports by concerned dairy farmers.
- Oral and written reports by electric utility company representatives.
- Oral and written reports by other citizens or scientists.
- Information provided by government agency staff with responsibility for matters pertaining to stray voltage and/or dairy cow health and production in Minnesota and Wisconsin.
- Information provided by groups that represent large numbers of dairy farmers such as the Minnesota Farmers Union and the Minnesota Milk Producers Association.
- The 1994 report of The Electromagnetics Research Foundation (TERF) written under contract to the Minnesota Department of Public Service with funds provided under the same legislation that authorized our own work.
- Site visits to Minnesota dairy farms with persistent, unresolved herd behavior, health and/or milk production problems.
- Results of the mailed and telephone surveys of Minnesota and Wisconsin dairy farmers.
- Results of the field study described in this report.

A. General Findings

Based on our analysis of information from the above sources, we have reached the following conclusions:

1. *We have not found credible scientific evidence to verify the specific claim that currents in the earth or associated electrical parameters such as voltages, magnetic fields and electric fields, are causes of poor health and milk production in dairy herds.*

2. *At the present time, there is no basis for altering the PUC-approved standards by which electric utilities distribute power onto or in the vicinity of individual dairy farms.*

3. *There are many well-documented non-electrical factors that are known and accepted by the scientific community, and by most farmers as well, to cause dairy cow health and production problems. Among the most noteworthy stressors are poor nutrition, poor cow comfort and hygiene, and low or no use of vaccinations and related preventive veterinary practices. Those who want to improve performance of dairy herds should always address these factors.*

At the present time, there is only one electrical condition that is well documented in the peer-reviewed, published literature to influence adversely cow behavior, health or milk production under specific circumstances. That is cow contact stray voltage. The 19-farm field study did find significant differences between high and low producing herds in the levels of electrical step potentials and soil resistivity in the field. Findings from epidemiological studies (i.e., those that employ field data to examine risks associated with specific factors) and laboratory research are important in uncovering and exploring new ideas about possible biological or physiological effects resulting from the various electrical parameters associated with electric distribution systems. In studies where effects have been established, they have either been potentially adverse, potentially beneficial or potentially neutral to the cell, animal or human system under study. Indeed the scope and direction of current research in this area is in flux and we encourage additional basic research.

There has been some confusion among the general public, politicians and government decision makers about the relationships between currents in the earth and their possible effects on dairy cows versus the possible effects of overhead AC power lines or the high voltage DC power line built in Minnesota and widely debated in the late 1970's. Our analysis has focused only on the question of currents in the earth arising from the grounded AC electric distribution system. This report excludes other types of electrical power distribution systems, such as the DC power line. The 60 Hz magnetic fields that arise from overhead powerlines were recently addressed in the report of an advisory committee to the National Institute of Environmental Health Sciences (NIEHS) that met in June 1998. The NIEHS committee found a *possible* relationship between low frequency magnetic fields from overhead ac power lines and certain forms of cancer in humans. However, the NIEHS committee findings should not be used to draw conclusions about possible effects on dairy cows from currents in the earth from electric distribution systems.

It is important to note here that there is a difference between what is conceivable or possible and what is likely or probable. For example, the NIEHS committee concluded that there is a "possible" not a "probable" association between the presence of 60 Hz magnetic fields of 2-3 milligauss or higher and childhood leukemia. In the 19-farm field study described in this report, the average AC magnetic fields measured inside the dairy barns were on the order of 0.5 milligauss. Thus *with the present body of evidence, it is our best judgement that magnetic fields from earth currents or any other contributory sources in the dairy barn are not of sufficient levels to cause any health or production problems in dairy cows.*

B. Recommendations

- The Minnesota Public Utilities Commission should advise the Minnesota Departments of Agriculture and Public Service, the Minnesota Board on Electricity, the University of Minnesota, and other agencies with appropriate missions on the need to support training of dairy farmers, utility electric engineers, government agency staff, electrical inspectors, veterinarians, insurers, milk processors and other consultants to dairy farmers. This training should address the importance of collaboration, discussion and evaluation by consultants with varying expertise in simultaneously assessing the potential for both electrical and non-electrical causes of health and production problems.

- The protocols developed for the field study and appended to this report should be given to the Minnesota Department of Agriculture so they can make them available for use by the dairy diagnostic team grants program in the state of Minnesota, as needed.

- Depending on the results of the research on low level step potentials that is now underway in Dr. Reinemann's laboratory, the Minnesota Public Utilities Commission should encourage investigators, including Dr. Reinemann, to pursue additional funds for extending that research, as appropriate.

- Although research on low level step potentials is the priority at this time, if more funds become available for research, attention should be paid to possible effects of magnetic fields on farm animals.

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VIII. APPENDICES

A. Definitions[1]

B. Survey Instruments

C. Field Study Protocols

1. Electrical Measurements Protocol

2. Electrical Inspection Protocol

3. Veterinary Evaluation Protocol

D. Laboratory Research Proposal

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[1] Minnesota Public Utilities Commission. Progress report of the science advisors: proposed research for evaluating possible electrical causes of poor health and production in dairy cows. Minnesota Public Utilities Commission, 121 7th Place E, Ste. 350, St. Paul, MN 55101. January (1996).

Appendix A: 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").

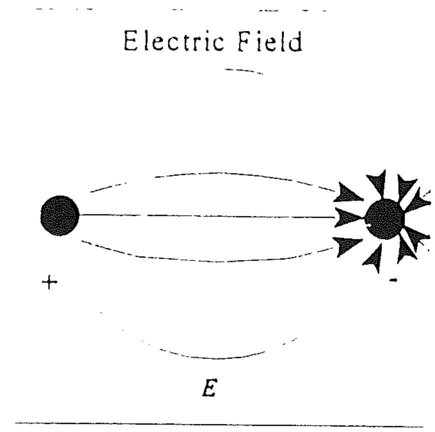
1. **Stray voltage** is the difference in voltage measured between two surfaces that may be contacted simultaneously by a person or animal (typically less than 10 volts). Sources of ac stray voltage are neutral-to-earth voltages resulting from normal current flow on a resistive neutral system. Stray 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.

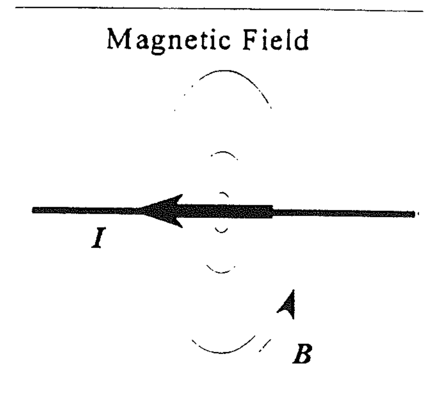
3. **Step potential/voltage** is the voltage between two points on the earth separated

[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.

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.



Appendix B: Survey Instruments

PLEASE CHECK ALL THAT APPLY TO YOUR OPERATION

- ☐ Stanchions (101)
- ☐ Tie stalls (102)
- ☐ Loose housing (103)
- ☐ Free stalls (104)
- ☐ Flat parlor (105)
- ☐ Elevated (herringbone or parallel) parlor (106)
- ☐ DHIA membership (107)
- ☐ Regular veterinary herd health visits (108)
- ☐ Feed / dairy consultant used (109)
- ☐ Forage testing (110)
- ☐ Own computer used in business (111)
- ☐ Computerized dairy records (Scout, DairyChHAMP, etc.) (112)
- ☐ Computerized farm records (113)
- ☐ Electronic information service (CTN, (Internet, etc.) (114)
- ☐ Manual farm business records (115)
- ☐ Farm busin./enterprise analysis (116)

1. Today's date (month/day/year): _____/_____/_____ (117)

2. Your position (check one): (118)

   1. ☐ Owner
   2. ☐ Manager
   3. ☐ Employee

3. Location of dairy herd:

   State ____________________ (119)

   County ____________________ (120)

   Township ____________________ (121)

4. How many dairy cows (dry or in milk) were in the herd yesterday? __________ cows (122)

5. How many of those dairy cows were milked yesterday? __________ cows (123)

6. How much milk was produced yesterday? __________ lbs. (124)

7. What is the current rolling herd average for milk production (check one)? (125)

   1. ☐ Less than 14,000 lbs. 2. ☐ 14,000 - 15,999 lbs. 3. ☐ 16,000 - 17,999 lbs.

   4. ☐ 18,000 - 19,999 lbs. 5. ☐ 20,000 or more lbs. 6. ☐ Don't know

8. Please indicate your level of satisfaction with the herd's current milk production (circle a number between 1 and 5 on the scale below): (126)

   Extremely Dissatisfied 1 2 3 4 5 Extremely Satisfied

9. What was the bulk tank somatic cell count (SCC) on the latest report from your milk processor (check one)? (127)

   1. ☐ Less than 150,000 2. ☐ 150,000 - 249,999 3. ☐ 250,000 - 349,999

   4. ☐ 350,000 - 449,999 5. ☐ 450,000 or more

10. Please indicate your level of satisfaction with the herd's current somatic cell count (SCC) (circle a number between 1 and 5 on the scale below): (128)

    Extremely Dissatisfied 1 2 3 4 5 Extremely Satisfied

11. How many dairy cows (dry or in milk) were in the herd this time last year? __________ cows (129)

12. During the last 12 months, how many replacement milking animals (mature heifers or cows) were purchased? __________ head (130)

13. During the last 12 months, how many adult dairy cows died on the farm? __________ cows (131)

14. During the last 12 months, how many dairy cows were treated or culled for lameness (not including routine foot trimming)? __________ cows (132)

15. During the last 12 months, how many dairy cows were culled for all reasons? cows (133)

1. Have you ever had herd health and production problems that you thought were being caused mainly by stray voltage or other electrical phenomena?

   1. _____ Yes 2. _____ No 3. _____ Don't Know (201)

2. Has your farm ever been tested for stray voltage?

   1. _____ Yes 2. _____ No 3. _____ Don't Know (202)

3. Has your farm ever been tested for other electrical problems (for example: magnetic fields, electric fields, EMF, ground currents, earth currents)?

   1. _____ Yes 2. _____ No 3. _____ Don't Know (203)

[If respondent answers "Yes" to either question 2 or 3, then go on to question 4. If respondent answers "No" or "Don't Know" to both question 2 AND 3, then go directly to question 10.]

4. When was the most recent test for stray voltage or other electrical phenomena carried out?

   _____ (month) _____ (year) (204)

5. Over the last six years, how many different times have you had your farm tested for stray voltage or other electrical phenomena?

   _____ (number) (205)

6. Who among the following have been involved in conducting tests for stray voltage or other electrical phenomena on your farm? (Check all that apply.)

   1. ____ utility employee (206)
   2. ____ government employee or team (207)
   3. ____ electrician (208)
   4. ____ extension agent (209)
   5. ____ veterinarian (210)
   6. ____ private consultant (211)
   7. ____ yourself (212)
   8. ____ other (213) (for example: field man, other farmer, specify: ____________ (214))

7. Did any of the persons who conducted tests on your farm ever inform you that there were stray voltage or other electrical conditions on your farm that should be corrected?

   1. _____ Yes 2. _____ No 3. _____ Don't Know (215)

8. If yes to #7: Has anything ever been done to try to correct those condition(s)?

   1. _____ Yes 2. _____ No 3. _____ Don't Know (216)

   If no or Don't Know to #7: Were corrections made anyway?

   1. _____ Yes 2. _____ No 3. _____ Don't Know (217)

9. After all investigations and/or attempts to correct any stray voltage or other electrical conditions on your farm, are you satisfied with the results?

   1. _____ Yes 2. _____ No 3. _____ Don't Know (218)

10. At the present time, do you think uncorrected stray voltage or related electrical conditions are having negative effects on the health and/or production of your dairy herd?

    1. _____ Yes 2. _____ No 3. _____ Don't Know (219)

Dairy Farm Electrical Effects Research Program
Minnesota Public Utilities Commission:
Draft Electrical Measurements Protocol

I. Introduction

An on-farm case/control study was recommended by the Science Advisors to the Minnesota Public Utilities Commission[1] as one element of a field- and laboratory-based research program to expand the base of scientific information on whether and, if so, how man-made or natural sources of electricity can contribute to persistent and unresolved health and production problems in dairy herds. The Science Advisors' research plan outlines a case/control field study in which various electrical and non-electrical parameters would be examined on a sample of dairy farms, first in a pilot study of 20 farms, 10 with persistent and unresolved health and production problems and 10 without such problems. The pilot study would provide an opportunity to (1) test the feasibility of implementing informative electrical measurement, electrical inspection and dairy herd health and production evaluation protocols in relatively short visits to each study farm and (2) assess the need for a larger scale study of potential electrical risk factors. The Science Advisors recommended that if a larger scale study is indicated, a study of 50 or 100 farms would likely be sufficient to determine with some statistical certainty the relative contributions of various possible risk factors, electrical and non-electrical, that could be affecting the health and production of dairy cows.

For the pilot field study, candidate case and control farms will be identified through a mail/telephone survey of a random, statewide sample of dairy farmers and by follow-up site visits to confirm farmer's reports of health and production status of their dairy herds. Once the study sample of 20 farms is identified, the pilot field study would be conducted by a 3-member team consisting of an electrical engineer or electrical measurements specialist, an electrical inspector or contractor, and a veterinarian.

The Science Advisors, project staff and other experts have contributed to the development of an electrical measurements protocol which addresses stray voltage, ground currents, transients, earth currents and other electrical parameters that have been hypothesized to have the potential, under various circumstances, to impact animal health and/or production. The electrical measurements protocol is the subject of this document. The protocols for the on-farm electrical inspection and the dairy herd health and production evaluation, also to be implemented as part of the pilot field study, will be developed by contractors with the advice of the Science Advisors, the Research Director and other project staff and advisors.

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[1]Minnesota Public Utilities Commission. Progress Report of the Science Advisors: Proposed Research for Evaluating Possible Electrical Causes of Poor Health and Production in Dairy Cows. Minnesota PUC, 121 7th Place E, Suite 350, St. Paul MN 55101-2147. January (1996).

V. Measurement Strategy

A number of specific measurements/data were suggested by the Science Advisors which would be reasonable and useful for further refining the understanding of possible effects on dairy cattle of stray voltage, external current and other electrical scenarios. These can be grouped into the following categories:

General Information, including an area map describing the distribution system.

Electrical Environment, including neutral voltages, grounding resistances, cow contact voltages, transient voltages on distribution conductors and in the cow contact area, ac magnetic fields (especially near ground current paths), dc magnetic field in the barn and farmyard, farm electrical load, electrical characteristics of the milking system and cow trainer.

Earth Current Parameters, such as soil resistivity, location of water table, water ion content, earth surface (step) voltages and electrical homogeneity of the barn floor (See Section VII.D).

This parameter list is still under development; testing will likely indicate that some of these quantities should be eliminated, altered or replaced by others.

Because Wisconsin has made, and is making, measurements similar to some of the above and has proposed to carry out additional on-farm research, every effort will be made to coordinate measurement methodologies to the extent necessary to combine or compare future data sets.

VI. Measurement Methods

A. GENERAL INFORMATION

1. Area map (2-by-2 miles minimum). Provides locations of earth current sources and preferred paths.

Request a geographic map of the distribution feeder from the serving electric utility. Annotate, if necessary, with the following: location of test farm, conductor type and size, all capacitor banks on the circuit (including their status) and, out to ½ mile from the test farm, locations of other electrical services (including phase, type, size, neutral isolation), all primary grounds (and their resistances), distribution lines of other utilities, telephone lines, pipelines and all other known, large, buried conductors.

stronger source which should be identified if possible.

2. AC ground current and magnetic fields. Record the following quantities separately:

a) AC ground current on metal paths in barn. Possibly may cause locally high magnetic fields near cows (see Hypotheses II-2 and 3); also helps to locate sources of cow contact voltages.

Measure Iac using Swain ammeter (specified in Appendix A) in all grounding electrode conductors (to ground rod and water line, for example) from barn panel neutral bus. Measure Iac in metallic water line, vacuum line and/or milk line at each stall, noting stall where Iac is largest (probably nearest the barn panel).

b) AC magnetic field (Bac). Measurement would indicate ground current flow. If large enough, Bac could affect cow physiology (see Hypotheses II-2 and 3).

Using a Dexsil Magnum 310 milligauss meter (specified in Appendix A):

· Measure Bac in the barnyard noting minimum and maximum values and likely sources.
· Map Bac throughout barn during maximum and minimum electrical use. In stall barns record the value of Bac at approximately 1 m above floor at each stall (or every other stall in large barns) for the following locations: at cow's head, back, rear, and where current-carrying conductors pass closest to cow (if this is a distinctly different point).
· Map Bac (3-dimensions) in stall.
· Record a time series at normal location of cow's head in stall identified above (VII.B.2.a) during maximum electrical use (e.g., during milking).
· Determine 60 Hz harmonic content at same location during milking using milligauss meter with ac output (specified in Appendix A), digital storage oscilloscope, portable computer and harmonic analysis software.

c) DC magnetic field (Bdc). DC field strength appears to determine whether certain ac magnetic field frequencies result in biological effects (see Hypothesis II-3).

Using a Walker Scientific flux-gate magnetometer (specified in Appendix A):
· Measure Bdc outside at a few locations.
· Measure Bdc at a few locations in barn.
· Map Bdc (3-dimensions) in stall, coincident with Bac measurement above.
· Compare outside values with model (GEOMAG30/IGRF) predictions available from NOAA.

(described in the next paragraph). Low frequency transients may also be recorded between cow contacts across the hybrid impedance model (low frequency output) using a digital recording oscilloscope to record 60 Hz wavetrains using a sweep speed of 1 second or more.

•High Frequency Transients

- on barn wiring: Using a Dranetz 658 power analyzer (specified in Appendix A) according to manufacturer's recommendations, monitor power quality at the barn service panel using the following channel assignments:

· Channel A = Line voltage [Line 1] to [Neutral] (120 V)
· Channel B = Line voltage [Line 2] to [Neutral] (120 V)
· Channel C = Neutral voltage [Neutral] to [Near (6') Reference]
· Channel D = Neutral current

Format disks as IBM 9-sector, 720K disks (rather than using Dranetz format feature) to allow subsequent computer archiving of data. Use the following setup initially, then adjust items 3 through 7 to limit data capture to a rate such that most of one 24 hour period is recorded per disk:

1 Setup #	A	B	C	D
2 Range	VH	VH	VL	I30
3 Hi Lim	126	126	72.4	30.0
4 Lo Lim	114	114	00.0	00.0
5 Sens.	002	002	00.5	05.0
6 Imp.	0025	0025	002.5	002.5
7 Wave	010	010	02.0	3.0
8 Freq.	Sens:0.5	Range: 45-65 Hz		

Print out the following for each channel:

· RMS/Impulse Plot Summary (graph and text).
· Worst impulse events (positive and negative) singly and as multiple channel plots.
· Harmonic distortion analysis on initial waveforms, including the waveform, harmonic graph and harmonic table.
· Multiple channel plots of impulses which are coincident with transient events recorded at cow contact points (as follows).

-Transients at cow contacts: Using a Tektronix digital storage oscilloscope (specified in Appendix A), monitor high frequency transients between cow contacts in the test stall via 100' RG 58C/U coaxial cable using the first channel. Simultaneously monitor

AC current in the earth is accompanied by a step voltage and magnetic field at the surface. Earth current data are required to prove/disprove relevance to dairy herd health and production problems (see Hypotheses II-2, 3, 4 and 5).

1. Location of water table. Strongly affects soil resistivity. Seasonal variations may account for seasonal problems in herd. Map surface water on farm. Measure soil resistivity vs. depth using a soil resistivity meter and 4-point Schlumberger method, locate the depth of the resistivity discontinuity which indicates location of water table.

2. Soil resistivity. Earth current surface voltages are proportional to soil resistivity. Also, there are some reports indicating that earth current rectification may occur where soil resistivity changes abruptly.

Determine soil resistivity (ρ) on the farm. Compare between wet and dry conditions if testing schedule permits. Using a Vibroground soil resistivity meter (specified in Appendix A) and 4-point Wenner method with 5' electrode separation, map ρ around the barn. Combine resistivity and step voltage data (item 3 below) to determine earth current density around the perimeter of the barn. Note any apparent correlation with location of nearby grounding electrodes.

3. Step Voltage (V_s). Exposure to step voltage is the most likely way earth current might affect cows. V_s (across 500Ω) is the voltage which causes current to flow through cow.

· Using ground probes and Fluke multimeter (specified in Appendix A), map V_s (open circuit and across 500Ω) around perimeter of barn.

· Obtain continuous record of V_s (open circuit) at a point near barn. Drive three 2' ground rods in an L-configuration allowing determination of the N/S and E/W components of V_s. Convert each of the V_s components from Vac to Vdc using converters (specified in Appendix A). Record resulting dc signals using strip chart recorder. Determine source impedance between ground rods using a multimeter and 500 ohm and 1000 ohm shunt resistors.

· Using Tektronix digital storage oscilloscope, computer and Wavetek software, determine harmonic spectrum of surface potential.

4. Electrical homogeneity of concrete floor. Breaks may result in step potentials which are larger than otherwise.

Measure Idc with Fluke multimeter between electrodes 1m apart (attached to shoe heels) on barn floor and charged to 9 Vdc. Calculate nominal resistance of contacts plus concrete path. Map barn floor.

Tektronix THS-720 TekScope
Digital storage oscilloscope: battery- or line-powered, two-channel, autoranging, 100MHz bandwith, up to 500MS/s sample rate, 2500 point record length, separate digitizers for each channel, waveform averaging and enveloping with hardware peak detection, real-time digitizing with up to 5-times oversampling, independently isolated channels, cursors and 21 continuously updated automatic measurements, simultaneous oscilloscope and meter operation, advanced pulse and video trigger capability.

Vibroground 4-Point Soil Resistivity and Ground Resistance Tester
Measures soil resistivity from 0 to 1,915,000Ω. Accuracy not affected by earth's resistance and condition, polarization effects, stray AC and DC currents in the earth, or accuracy of meter. Measures soil resistivity using 4-point method, resistance to earth of man-made grounds using 3-point method, and circuit resistance using 2-point method.

Walker Scientific Portable Hand-held Fluxgate Magnetometer FGM-3D1
Single axis DC magnetic field instrument. Battery-powered, best resolution 0.01mG, +/- 0.5% absolute accuracy traceable to NIST, 3 FS ranges +/-(20, 200, 2000)mG, noise 0.5 gamma, wide bandwidth 100Hz, analog output +/-2V.

Waveform Manager Pro for Windows, Metratek
Software accessory for digital field service oscilloscopes. Transfers waveforms, data and setups between scope and computer. Here, used to transfer and store transient waveforms at capture, then reset scope trigger. Performs harmonic (and other) analyses on waveforms and provides full Windows support for report writing.

WaveRider Data Acquisition System, EGS, Inc.
Battery and line powered, eight differential inputs, detects and stores peak voltages per power cycle, sample rate > 35/cycle depending on # channels enabled, electrically isolated serial port to 1kV, average data collection rate 70 peaks/s, burst data capture rate one per channel per cycle at 480/s, internal buffer approx 13,000 peaks, channel full scales from 5V to 400V AC peak, channel input impedances from 17.7kΩ to 1.4MΩ, band pass -6dB (50% voltage for all channels.

Day 3

6 am	Conduct transient recording during milking on CC#2.
7	Record Bac time series in barn during maximum electrical use. Determine Bac harmonic spectrum.
8	Breakfast. Team discussion.
9	Check electrical homogeneity of barn floor.
11	Conduct transient recording during quiet time on CC#2.
12 pm	Read kW-hr meter. Lunch.
1	Measure CC#2 source impedance. Move to CC#3. Measure CC#3 source impedance. Conduct transient recording during quiet time on CC#3.
3	Map step voltages and soil resistivity around perimeter of barn.
5	Conduct transient recording during milking on CC#3.

Day 4

7 am	Breakfast.
8	Shut down all instrument systems and archive data files.
9	Disassemble monitoring systems. Map Bac and Bdc in stall. Pack trailer.
12 pm	Read kW-hr meter. Lunch. Team discussion.
1	Deliver trailer to next farm.
2	Travel.
6	Home.

V 60 Hz

Farm:

Vrms 12-Hour

Date	Time Per.	SN min	SN max	SN avg	CC point	CC min	CC max	CC avg	K=CC/SN
					#1				
					#2				
					#3				

LF trans. 12-Hour

Date	Time Per.	SN #	SN max	CC point	CC #	CC max
				#1		
				#2		
				#3		

Vrms High Electrical Use

Date	Time Per.	SN min	SN max	SN avg	CC point	CC min	CC max	CC avg	K=CC/SN
					#1				
					#2				
					#3				

LF trans. High Electrical Use

Date	Time Per.	SN #	SN max	CC point	CC #	CC max
				#1		
				#2		
				#3		

Vrms Low Electrical Use

Date	Time Per.	SN min	SN max	SN avg	CC point	CC min	CC max	CC avg	K=CC/SN
					#1				
					#2				
					#3				

LF trans. Low Electrical Use

Date	Time Per.	SN #	SN max	CC point	CC #	CC max
				#1		
				#2		
				#3		

Note: SN = Secondary Neutral, barn to Reference
CC#1 =
CC#2 =
CC#3 =

Farm:

Note:
CC#1 =
CC#2 =
CC#3 =

Cow Contact High Frequency Transients - 1

HF transient counts/30 min

High electrical use:

Date	Start Time	CC point	Trig. Lev.	# Trans.
		#1		
		#2		
		#3		

Low electrical use:

Date	Start Time	CC point	Trig. Lev.	# Trans.
		#1		
		#2		
		#3		

HF transient matches with transients on secondary neutral

CC #1

Date	File Name	Time	CC Dur	Vpk (CC)	Dranetz Disk Name Event #	SN Dur	Vpk (SN)	K=CC/SN

CC #2

Date	File Name	Time	CC Dur	Vpk (CC)	Dranetz Disk Name Event #	SN Dur	Vpk (SN)	K=CC/SN

CC #3

Date	File Name	Time	CC Dur	Vpk (CC)	Dranetz Disk Name Event #	SN Dur	Vpk (SN)	K=CC/SN

Magnetic - 1

Farm: Date: Start Time: End Time:

Bac barn, milking

Stall	Head	Back	Tail	Average	Stall	Head	Back	Tail	Average
Avg					Avg				

Sketch

Magnetic - 3

Farm: Date: Start Time:

Bac Time Series

Time	Bac	Time	Bac	Time	Bac
0:00		6		12	
0:10					
0:20					
0:30					
0:40					
0:50					
1		7		13	
2		8		14	
3		9		15	
4		10		16	
5		11		17	

Average

Earth - 1

Farm: Date: Start Time: End Time:

le in field

Position	R	Rho	Vo (n/s)	Vr (n/s)	Vo (e/w)	Vr (e/w)	Vo	Vr	Rsrc	phase 1=in,2=out dir	J microA/m	Position E m	Position N m

Earth - 3

Farm: Date: Start Time: End Time:

E homogeneity of barn floor

Stall	Gutter mA	R(Gutter)	Stall mA	R(Stall)	Stall	Gutter mA	R(Gutter)	Stall mA	R(Stall)
Avg					Avg			Avg	

Note: See sketch for Bac map of barn.

If you are concerned about the level listed above, you should report this value to your local electric utility company. They will schedule a stray voltage investigation for your farm and will help you determine the source. Stray voltage has many possible causes which are as likely to be on your farm as off. Stray voltage is a well-understood phenomenon and solutions should be available in all cases, often at little or no expense to you.

Transient Voltage

Transient voltages are very brief electrical events caused by switching, operation of electrical equipment (especially motors), lightning, or by electric cow trainers, fencers and crowd gates. These transient voltages may appear in the barn where cows can access them, just as for stray voltage. Not as much is known about the effects of transient voltages on cows as is known for steady voltages. The research that has been done to date has shown that behavioral responses to transients occur at higher levels than for steady voltages. Briefer transients require higher voltages to produce an effect, which most often is a behavioral response that indicates the cow has sensed and reacted to the transient.

The largest low-frequency transient voltage measured in the test stall was ________ volt measured between ____________ and the rear hoof across 500 ohm. It was probably caused by the start-up of an electric motor.

The largest high-frequency transient voltage measured in the test stall was ________ volt measured between ____________ and the rear hoof. Research indicates that these fast transients are most often caused by operation of a switch nearby. High frequency transients may also be caused by improperly grounded electric animal control equipment. The regularity of cow trainer transients on cow contacts is easily apparent and is rectified by improving the cow trainer ground. Cow trainer transients (<u>did</u>) (<u>did not</u>) appear at cow contact points in your barn.

Steady and transient voltages were also measured on the barn wiring at the circuit breaker panel. This data record will be used to determine the quality of your electric power and will help to identify sources of transient voltages in the stall.

Magnetic Fields

Magnetic fields are caused by the flow of electric current. Alternating current (ac) produces ac magnetic fields. These fields can be found everywhere to some degree, though they are larger near electrical devices and conductors. In the barn they are produced by florescent lights, wiring, motors and other electrical devices, and the flow of current on metal paths such as water lines, among other things. There is no evidence to date that indicates that ac magnetic fields have any negative effect on cows. Other research has indicated a possible effect on other biological species and material, and magnetic fields may be implicated in some human health concerns. The debate about these effects continues.

neutral conductor on your farm and the neutral conductor on the distribution line are each connected to earth with ground rods and other electrodes at many places. This is done to limit the voltage on the neutral side of wiring. By so doing, this practice also reduces stray voltage to a safe level. Grounding is a safety practice required by the National Electric Safety Code to reduce the impact of faults and lightning strikes on the distribution system. As a consequence, current flows in the earth from the ground rod back to the current source (your transformer on the farm or the electric distribution substation).

Current flowing in the earth cannot have an effect on a cow unless the step voltage between front and rear hooves is large enough (see discussion of ac voltage above). These voltages are believed to be small, or at least smaller than step voltages found in barn stalls due to stray voltage. For this reason, they have not been commonly measured. This lack of data is why our research involves earth current measurements.

Step voltages were measured around the perimeter of your barn. The largest step voltage found outside the barn was ________ volt as measured across 5 feet of earth using a 500 ohm resistor. This compares with ________ volt measured across 5 feet in the test stall, again using a 500 ohm resistor. These comparisons will be used to determine the relative importance of voltages related to earth current in the stray voltage picture.

Other earth current quantities were measured or determined. The soil resistivity was measured around the barn. A soil sample was collected to determine its type and conductivity (ability to conduct electric current). A soil profile is being developed for your geographic location, again to get a more complete understanding of currents in the earth.

Further Information

If you have questions about the above information, you may contact me at the following address:

Riley Hendrickson
MN Public Utilities Commission
121 7th Place East, Suite 350
St. Paul, MN 55101-2147

Data Privacy

This specific electrical data collected on your farm is being provided to you, the dairy operator, alone. No one else will be given this data without your written permission. The only data we will release from this research project will be statistical data that does not allow identification of individual test farms.

Appendix C2: Electrical Inspections Protocol

Dairy Farm Electrical Effects Research Program
Minnesota Public Utilities Commission
Electrical System Evaluation Protocol

I. Premises

For the purpose of this protocol, neutral-to-earth voltage (NEV) is the ac voltage measured between the grounded neutral conductor of an electrical system and the earth. Stray voltage is a small voltage between conductive surfaces subject to simultaneous contact by dairy cows.

The procedures described below will generally serve as means to evaluate conditions on the utility primary neutral and farm electrical system that may cause or contribute to stray voltage and electromagnetic fields. The values of stray voltage and electromagnetic fields that have been shown or alleged to affect dairy cows have been the subject of many published and sometimes conflicting reports, and are not addressed.

A. **Stray Voltage.** The predominant source of stray voltage is NEV on conductors which are connected to grounding electrodes at more than one point and interconnected with equipment grounding conductors. Less frequently, the source may be fault, leakage or capacitive current from energized conductors to equipment enclosures, or current flow between the earth and grounding electrodes. Possible sources of stray voltage include:

   1. Voltage drop in utility primary neutral conductors interconnected with the farm neutral system
   2. Voltage drop in secondary system neutral conductors on the supply side of points where they are bonded to equipment grounding conductors
   3. Voltage drop in secondary system neutral conductor connections on the supply side of points where the conductor is bonded to equipment grounding conductors
   4. Voltage drop in equipment grounding conductors due to current from conductor faults in the equipment to which the grounding conductor is connected
   5. Faults, insulation leakage, or capacitive coupling in ungrounded electrical equipment
   6. Improper use of equipment grounding conductors as a circuit conductor for utilization equipment, including the output circuits of equipment such as cow trainers, fencers, and milker pulsators, either directly, or through conductive interconnection with the electrical equipment
   7. Improper connection of equipment grounding conductors to grounded circuit conductors on the load side of the disconnecting means for a building or structure
   8. Voltage drop across the impedance associated with grounding electrodes due to earth current from faults in ungrounded equipment in contact with the earth, such as pumps
   9. Voltage drop across the impedance associated with grounding electrodes due to earth current between grounding electrodes resulting from an open-circuited neutral conductor in the supply circuit to a building with 120-volt load
   10. Voltage drop across the impedance associated with grounding electrodes where the electrode is inadvertently connected to an ungrounded circuit conductor, sometimes the result of improper installation or repair of two-wire feeders or services.

B. **Electromagnetic Fields.** Electromagnetic fields are generated by electromagnetic devices and currents whose instantaneous sum is zero in conductors enclosed in the same raceway or cable and are considered unavoidable without relocation of the offending equipment. Abnormal electromagnetic fields result where conductors of a circuit are not in close proximity, including cases where part

Most farm wiring systems will have Code violations or other defects. The inspector must therefore judge whether the defects observed pose an imminent hazard. Hazards may be corrected prior to the study only where it is clear that such changes will not affect the values to be studied. Where the electrical inspector, in consultation with other team members, determines that such conditions pose an undue risk, the farm should be dropped from the study. If a farm is dropped from the study, the reason shall be discussed with the owner/operator, followed by a written report to the owner/operator reaffirming that decision and the conditions that prompted it.

B. **Inspection and Testing Procedures.** Evaluation of the farm electrical system shall include visual inspection and test procedures to determine conditions that may cause or contribute to stray voltage or abnormally high electromagnetic fields, according to Part IV, below. Where the electrical measurements specialist identifies abnormal parameters, the electrical inspector shall perform any additional inspection services, when requested, to determine the cause. If hazardous conditions are found in the course of inspection and testing, the procedures of the last paragraph of Part III A, above, shall be followed.

C. **Inspection Findings Reported to Owner/Operator.** Although it is not an objective of this study to conduct a complete electrical safety inspection, as a service to the owner/operator, and to avoid possible liability claims, the inspector shall record and report to the owner/operator any observed National Electrical Code violations or system defects that, in his or her judgement, constitute significant risk of fire, shock, personal injury, or premature deterioration of components of the electrical system.

IV. Evaluation Procedures

A. **Documentation of Inspection Procedures.** All electrical inspections findings will be recorded on-site on the standardized electrical inspection forms devised to assure uniform procedures. The inspection record shall include:

1. Date, identifying information for the farm, and names of persons present
2. Name and address of serving electrical utility
3. A checklist of each item evaluated in the inspection
4. A description of any National Electrical Code or National Electrical Safety Code violations or other conditions that the inspector deems to be imminently hazardous or to actually or potentially contribute to stray voltage or electromagnetic fields, including Code references and Code edition where pertinent

B. **Site Electrical Plan.** As an aid to later analysis of the results an evaluation, a rough site plan (need not be to scale) with the following information shall be provided:

1. Identification of the northerly direction and orientation relative to public road
2. The location of poles for utility primary and secondary conductors and farm wiring system
3. The location of the utility distribution transformer
4. The location of the farm service equipment or service point
5. The relative location and identification of farm buildings and structures served with electrical power
6. Location and type of any passive or active primary isolation or neutral-to-earth voltage suppression devices
7. Routing of supply conductors for buildings or structures

structures

7. Impedance of grounding electrodes at the disconnecting means for structures

   A ground-rod resistance tester is the most convenient instrument for measuring electrode impedances if there are other grounding electrodes connected to the neutral system. Another method is to calculate the impedance from the measured grounding electrode current and the voltage between the grounding electrode and a remote reference ground, adding 120-volt load to obtain an accurately measurable voltage when necessary.

8. Grounding / bonding of neutral conductors and equipment grounding conductors at the disconnecting means for a structure

9. Proper grounding of conductive parts of electrical equipment, where required

   Grounding continuity may be conveniently checked by connecting a conductor to the grounding bus of the panelboard, extending it to the supplied equipment, and using an ohmmeter to measure the resistance between the conductor and the equipment enclosure.

10. Proper routing, sizing, and integrity of equipment grounding conductors

11. Installation of equipotential planes and bonding of metal equipment in confinement areas

    Due to the interconnection of many components with equipotential planes, in most cases it is impractical to accurately measure their impedance to ground. The effective grounding impedance of structures so equipped can be roughly determined by disconnecting the load in the building and testing with a ground-rod resistance tester on the neutral (or feeder grounding conductor, if present), or calculating it from the NEV and no-load neutral current.

12. Intentional or accidental grounding connections to circuit neutral conductors on the load side of the disconnecting means for structures

    Neutral grounding connections may be detected by the following methods:

    a. If the equipment is operating, check for current in the equipment grounding conductor, or place the ammeter jaws around both (or all three, if the circuit is three-phase) circuit conductors (but not the equipment grounding conductor) to check for residual current, which would indicate a fault.

    b. If the equipment is not energized, use an ohmmeter to check the resistance between a circuit conductor (on the load side of any controller or switch) and the equipment grounding conductor. The resistance should be at least several hundred thousand ohms. For 120-volt circuits, the neutral must be disconnected before performing this test.

13. Integrity of insulation of ungrounded circuit conductors

14. Correct polarity of two-wire circuits supplying structures - to assure that the ungrounded conductor is not erroneously connected to a grounding electrode

15. Grouping of conductors of the same circuit, including equipment grounding conductors

16. Current-carrying circuit conductors tapped from equipment grounding conductors

D. Summary Reports

A summary report of the conditions revealed by the electrical inspections shall be prepared upon completion of the project.

Appendix B. Proposed Farm Visit Schedule

Day 1

10:00 AM	Arrive. Conduct preliminary survey for unsafe conditions.
11:30	Begin inspection and testing of dairy barn and related facilities
12:30	Lunch break
1:30	Resume inspection and testing of dairy barn and related facilities
2:30	Begin inspect neutral/grounding system of other farm structures
6:00	End activities

Day 2

8:00 AM	Draw site plan
9:00	Perform load tests
10:00	Complete inspection reports - discuss results with other team members
11:30	Depart - unless other team members request further services

Dairy Barn and Associated Electrical Equipment

Building Power Source No. 1

☐ Overhead ☐ Underground

Drop or lateral phase conductors:

☐ Copper ☐ Aluminum

Size ______ Number per phase ____

Drop or lateral neutral conductor(s):

☐ Copper ☐ Aluminum ☐ ACSR

Size ______ Number per phase ____ Length, ft. ______

Entrance phase conductors (if applicable):

Wiring method:

☐ Non-metallic conduit ☐ Metal Conduit ☐ SE Cable

☐ Copper ☐ Aluminum

Size ______ Number per phase ____

Entrance neutral conductor(s) (if applicable):

☐ Copper ☐ Aluminum

Size ______ Number per phase ____ Length, ft. ______

Equipment grounding conductor (if any):

☐ Copper ☐ Aluminum

Size ______ Number per phase ____ Length, ft. ______

Main Disconnect:

☐ Fused switch ☐ Circuit Breaker

Rating in amperes __________

Building Power source No. 2:

☐ Overhead ☐ Underground

Drop or lateral phase conductors:

☐ Copper ☐ Aluminum

Size ______ Number per phase ____

Drop or lateral neutral conductor(s):

☐ Copper ☐ Aluminum ☐ ACSR

Size ______ Number per phase ____ Length, ft. ______

Entrance phase conductors (if applicable):

Wiring method:

☐ Non-metallic conduit ☐ Metal Conduit ☐ SE Cable

☐ Copper ☐ Aluminum

Size ______ Number per phase ____

Entrance neutral conductor(s) (if applicable):

☐ Copper ☐ Aluminum

Size ______ Number per phase ____ Length, ft. ______

Equipment grounding conductor (if any):

☐ Copper ☐ Aluminum

Size ______ Number per phase ____ Length, ft. ______

Main Disconnect (source 2 cont.):

☐ Fused switch ☐ Circuit Breaker

Rating in amperes __________

Source 1 neutral conductor impedances (ohms):

Drop or lateral:______ ohms (wire table values)

Entrance conductors (if any): ______ ohms (wire table)

Total neutral impedance ______ ohms (wire table)

Measured voltage drop at _____ amperes: _____ volts

Calculated neutral impedance: ______ ohms

Source 2 neutral conductor impedances (ohms):

Drop or lateral:______ ohms (wire table values)

Entrance conductors (if any): ______ ohms (wire table)

Total neutral impedance ______ ohms (wire table)

Measured voltage drop at _____ amperes: _____ volts

Calculated neutral impedance: ______ ohms

Underground metal water pipe present: ☐ Yes ☐ No

Other underground metal piping, etc. suitable for use as a grounding electrode: ____________________

Grounding electrodes employed / impedance in ohms:

	Source 1	Source 2
☐ Ground rod:	______	______
☐ Underground water piping:	______	______
☐ Well casing	______	______
☐ Building steel	______	______
☐ Reinforcing steel	______	______

Other ____________________

Non-electrical equipment bonded to service:

☐ Interior water piping ☐ Milk pipeline ☐ Vacuum line

☐ Building steel ☐ Stanchion/tie stalls metalwork

Other ____________________

Service bonding jumper installed? ☐ Yes ☐ No

Equipment grounding meets National Electrical Code (NEC) requirements? ☐ Yes ☐ No (see comments)

Equipotential plane installed? ☐ Yes ☐ No

Impedance _____ ohms

Neutral grounding connections or faults that violate NEC?

☐ No ☐ Yes (see comments)

Branch circuit and feeder overcurrent protection meets NEC requirements? ☐ Yes ☐ No (see comments)

Submersible pump(s) grounded? ("Yes" if checked)

☐ Pump ☐ Casing ☐ No submersible

Location ____________________ Ohms ______

Building and Electrical System Layout (not to scale)

Dairy Diagnostics & Assessments Research Program
Minnesota Public Utilities Commission:
Draft Report on Veterinary Farm Study Evaluation

I. Introduction

As part of the ongoing project established by the science advisors to the Minnesota Public Utilities Commission, a team of professionals was assembled. This team consisted of; an electrical inspector, an electrical engineer, and a veterinarian. The purpose of the team was to conduct field assessment and data collection on 20 dairy farms in the State of Minnesota.

In this particular draft, I, Robert J. Schell DVM will summarize the procedures and techniques utilized in the veterinary portion of the protocol of the on farm assessments.

II. Selection of Farms

Along with the potential 20 test farms, there were 2 additional "practice" farm sites selected for conducting protocol testing. These two farms were selected from knowledge of the individual dairymen and were not chosen at random for test procedures but rather as locations for trial runs of the protocols. The results were tabulated to ensure that spreadsheet formulas were correct. The data was not included with the test farms nor evaluated for statistical significance.

The actual test farms were selected from surveys conducted by the Minnesota Agriculture Statistics Service. The minimum number of milk cows had to fall in the 15th percentile of average dairy size in Minnesota. The farm had to milk at least 30 cows.

From this point farms were separated by the following categories:

1. Rolling herd average
2. Somatic Cell Count (SCC)
3. Mortality Rate
4. Cull Rate

Farms were assigned scores based on the above as follows:

1. Rolling herd average; poor-1 or 2, below 16,000 lbs/cow/yr
   good-4 or 5, above 18,000 lbs/cow/yr
2. Somatic Cell Count Score(SCC); poor-4 or 5, SCC 350,000 or >
   good-1 or 2, SCC below 250,000
3. Mortality Rate; poor-80th percentile on mortality rate of 6.8%
   good-20th percentile on mortality rate of 0%
4. Cull Rate; poor-80th percentile on culling rate 29%
   good-20th percentile on culling rate 11.1%

The mean clinical score were broke down as follows:

poor-80th percentile on signs score 2.09
good-20th percentile on signs score 1.36

- monthly protein percentage
- monthly somatic cell count (SCC)
- bacteria counts at the bulk tank

With the above data, time plots could be attained for the individual dairy and compared to its contemporaries.
The collection of this data was often the most difficult to obtain. Due to missing milk receipts and the reporting differences between milk procurement companies. This created a need for the data to be standardized.

The next data obtained from the farm visit was animal profiles. Each animal in the herd was profiled (up to 75 head per herd). The purpose of the profile was to determine if there were physical differences in the animals on a herd basis. Included in this analysis were the following traits.

- Cow ID
- Age
- Lactation number
- Days in milk
- Reproductive status (open, bred, or pregnant)
- If pregnant, days carrying calf
- Height
- Weight
- Body condition score (1-5, with 3 being average)
- Manure consistency score
- Lactating status (none, lactating, or dry)

With the accumulation of this data a herd profile could be calculated and this could be compared herd to herd. These indicators are very useful and used regularly in the field. In addition to these above, every lactating cow was tested with a procedure called the "California Mastitis Test". The test includes the collection of milk from each lactating quarter from the profiled cows. The quarters are sampled into a sample paddle with a uniform amount of milk from each quarter. A test detergent is added to each quarters' sample. A resulting change in color and consistency occurs when the SCC of the quarter is elevated. The quarters were scored 1 through 4, with a score of one showing no change in consistency and a light blue color. A score of four indicates a complete clumping or the production of a gel like mass and a deep purple color. The higher the score the higher the SCC. The purpose of this test was to assess if the SCC in the bulk tank was produced by a few cows with extremely high SCC or a high number of cows with a modest SCC. This information assisted in determining farm recommendations for herd problem work-ups or the removal or treatment of individual animals.

The above listed categories were collected for all of the cattle in the herd. Animals in the lactating stage, as well as, dry cows. Any animal who had not yet had her first calf was considered youngstock and data on these animals was collected in the following health survey. A similar type of accumulation of incidence with a slight variation in categories was used for data collection. The youngstock categories were as follows:

- calf scours (listed as a percentage of incidence in the herd in the last 12 months)
- pneumonia ("actual number of treated cases)
- parasites - internal (number of animals in groups that tested fecal positive for any internal parasites)
- parasites - external (number of animals treated for external parasites or mainly "lice")
- pinkeye
- ringworm infections
- warts
- lameness (foot, leg or hip injuries)
- abortions (again 1^{st}, 2^{nd}, or 3^{rd} trimester)

Accumulation of data on the youngstock was the most difficult because the records were the least accurate. Most farms in the study required that I rely upon the dairyman's recollection of incidence from the past twelve months. The ability to accurately recall the information varied by producer.

NUTRITION:

In the area of nutrition, each farms' lactating cow ration was defined and analyzed. All roughage's were analyzed for dry matter content using a digital gram scale and a food dehydrator. One hundred grams of each feedstuff were placed in the dehydrator and when a constant weight was achieved, the dry matter percentage was recorded. This process usually took approximately 24 hours. If the farmer was using a total mixed ration (TMR), this also was dehydrated to determine dry matter percentage. The dry matter percentages were used to calculate dry matter intake of each animal. The amount of feed fed each animal was weighed by ingredient and then multiplied by its dry matter percentage to give the actual dry matter intake. When this was calculated and all ingredients combined the total dry matter intake was calculated. I used a software program produced at Michigan State University called "Spartan Balancer" as a spreadsheet template and feedstuff library to put together the ration as it was being fed to the cattle. If the dairyman had not previously had his feedstuffs analyzed, a sample of the feed was submitted to an analysis lab. At the lab the results obtained were:

- Dry matter Percentage of the feedstuff
- Crude protein content
- NDF (neutral detergent fiber)
- ADF (acid detergent fiber)
- TDN (total digestible nutrients)
- Insoluble protein

It was also recorded if there was the need for a booster immunization (whether or not this was completed). Also where applicable, the timing of the vaccine was recorded, such as with killed vaccines. The date or dates of the annual vaccination or biannual was recorded. Other vaccines that were given at certain reproductive stages or as a continuous ongoing process where specific animals were vaccinated monthly or weekly were also noted.

The same criteria was used on the youngstock and the completion of the vaccination protocol was submitted. In the youngstock it was also identified if they were vaccinated against brucellosis or "bangs" disease. This is a common practice amongst dairymen.

ENVIRONMENT

The assessment of the environment begins with the basic measurements of the housing facilities of the milk cows. This includes the length, width, and height of the actual building in which the animals are housed. utilizing these dimensions the cubic footage of the building can be calculated. The purpose of the calculation is to determine two things, the amount of air that needs to be exchanged both summer and winter and to determine if the barns are physically large enough to adequately house the cattle in them. It is desirable to have 4 air exchanges per hour in the peak winter (cold)days and 30 air exchanges per hour in the summer. Exhaust fans are designed and calibrated in units called CFM or cubic feet per minute of air exchanged. The information on building dimensions and the calculations for CFM summer and winter are included in the spreadsheet.

The area measured next is probably the single most important to the cow, and that is the dimensions of her individual stall. The desired demensions in a tie or stanchion barn are 48 inches wide by 72 inches long. I laid out and reported an average stall size for the entire barn. In retrospect a grid should be made of the barn with the stall sizes listed individually, as in many barns the stall sizes varied. This was not a large issue in barns were cows had assigned stalls, but in the majority of the barns this was not the situation. A problem arises when a large cow ends up in a small stall. The outcome is reduced production. If a grid map were made and time permitting a correlation could be made between cow size, stall size, and production in these trial barns.

Animal comfort was analyzed next. This was done on each of the following areas;

- Milking cows
- Maternity pens
- Dry cows
- Springing Heifers
- Breeding age heifers
- 4-13 mo. old calves
- 0-4 mo. old calves

MILKING SYSTEM

Along with collecting data on the dairy cattle and their environment it is also necessary to check the equipment required to harvest milk from the cows. In using standard techniques adopted by the National Mastitis Council, the milking equipment analysis was added to the protocol.

In the analysis of the system various parameters were evaluated including;

- operating vacuum level (inches Hg)
- regulator function test
  - effective reserve with .6 inch vacuum drop
  - manual reserve with .6 inch vacuum drop
    - result equals % regulator function (>90% required to pass, effective reserve divided by manual reserve)
- milk machine drop off test (< .6" vacuum drop in line vacuum w/ 1 machine inserting maximum air)
- pulsator function test on each pulsator
- mono Vs. dual pulsation
- if dual pulsation, then front to rear or side to side
- pulsation rate (beats per minute)
- pulsation ratio, % of each beat in the milk phase Vs rest phase
- milk line size (inches)
- pulsation line size (inches)
- number units
- number of units per milker
- maximum number of milking units per milker
- milk line type; high line or low line

A number of these tests require special instruments to evaluate the milking equipment. A vacuum gauge along with a flow meter are required to conduct all of the regulator tests. A digimat 2000 was used for the pulsator function tests. This piece of equipment digitally measures all of the parameters that pertain to the pulsators (i.e. rate, ratio, all phase breakdowns and degree of fluctuations).

The purpose of testing the milking system was to identify if there was system variability and reasons to suggest limited milk production. In almost every installation we were able to identify some aspect of the milking system that was not operating up to manufacturers specifications.

LIVESTOCK INVENTORY

ADULT COWS (have had at least one calf)

subtotals

lactating	______
dry	______
other	______
total	0

YEARLINGS (> 12 mo. age and **not** calved)

total	0

YOUNGSTOCK (< 12mo age)

4 to 12 Mo.	______
< 4 Mo old	______
total	0

OTHER

steers	______
bulls	______
beef cattle	______
______	______
______	______
total	0

total	0

2 HEALTH PROBLEMS: PREVIOUS 12 MONTHS

COWS

OFF FEED/INDIGESTION	______
FATTY LIVER/COW SYNDROME	______
UDDER EDEMA	______
DISPLACED ABOMASUM (LDA & RDA)	______
MILK FEVER	______
KETOSIS	______
MASTITIS (CLINICAL)	______
MASTITIS (TREATED SUBCLINICAL)	______
RETAINED PLACENTA	______
METRITIS OR PYOMETRA	______
HARDWARE DISEASE	______
FAILURE TO CONCEIVE (BRED > 3 TIMES)	______
ASSISTED CALVINGS	______
LAME CATTLE/ FOOT PROBLEMS	______
HOCK INJURIES	______
CHRONIC SCOURS	______
PNEUMONIA	______
ABORTIONS:	
LESS THAN 3 MO PG	______
3 TO 6 MO PG	______
GREATER THAN 6 MO PG	______

3 COMMON HERD PRACTICES

COWS

A) DRY COW THERAPY PRACTICES

	Y	N
ALL		
NONE		
SELECTIVE		

PRODUCT USED:____________________

B) **TEAT DIPPING**

ALL		
NONE		
SELECTIVE		

PRE-DIP		
POST-DIP		

PRODUCT USED POST:________________

PRODUCT USED PRE:________________

C) DO YOU WEAR LATEX GLOVES AT MILKING?

DO ALL MILKERS?

4 OTHER HERD HEALTH PRACTICES

A. VETERINARY HERD HEALTH VISITS

	Y	N
weekly		
twice/mo		
monthly		
quarterly		
as neded		
other:__________________________		

B. CALF RAISING PRACTICES

colostrum at birth from dam		
colostrum at birth thawed from freezer		
nurse on cow w/ no help from dairyman		

milk replacer		
whole fresh milk		
whole discard milk		
% whole fresh______%discard_______milk rep______		

age at weaning

< 4 weeks		
4 - 6 weeks		
6 - 8 weeks		
8 - 10 weeks		
.> 10 weeks		

MILK RECEIPTS

MONTH	DATE month/year	days/mo	lb milk/mo	# cows milking per day	average # treated cows per day	lb milk/day	# milk/ cow/day
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							

NUTRITIONAL WORKSHEET

RATION GROUP: ____________ DATE: ____________

feedstuff	lbs. fed	% dry matter	lb. dry matter

comments: ____

FARM:

date	YOUNGSTOCK VACCINE	Y	N	BOOSTER Y OR N	MLV.KILLED	VACCINE USED
	BRUCELLOSIS (BANGS)					
	IBR					
	BVD					
	BRSV					
	LEPTO					
	PASTUERELLA					
	CLOSTIDIAL					
	ROTA VIRUS					
	CORONA VIRUS					

OTHER:

RUMEN pH READINGS

	ANIMAL ID	pH	DIM
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

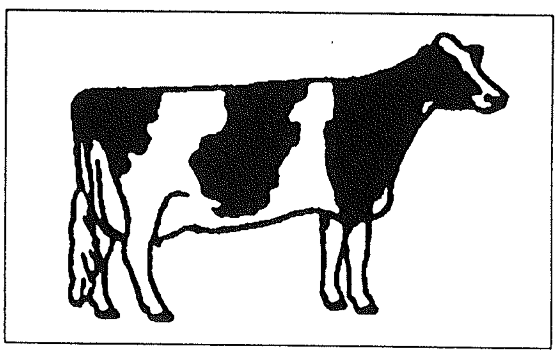
cow comfort continued:

day #	*time*	*# cows standing*	*total cows in barn*	*activity in barn ** see note*

** should be conducted at a time when there are no people in the barn

% of herd with hook bone lesions ☐

% of herd with pin bone injuries ☐



% of herd with hock injuries ☐

% of herd with knee injuries ☐

other: describe:______________________________

FARM·

LAB RESULTS

BULK TANK SAMPLE ANALYSIS

TYPE OF BACTERIA	YOUR HERD	NORMAL	MODERATE	HIGH	VERY HIGH
Strep. ag.		0-50	100-200	200-400	>400
Staph. aureus (coagulase pos.)		<50	50-150	150-250	>250
Non-Ag. Strep.		500-700	700-1200	1200-2000	>2000
Coliforms		<100	100-400	400-700	>700
Staph. epi (coagulase neg.)		<300	300-500	500-750	>750

FECAL EXAMINATIONS

sample source or animal #	coccidia pos/neg	other pos/neg	type other

OTHER LAB TEST

describe: type test & animal ID	result pos/neg/other

Appendix D: Laboratory Research Proposal

RESEARCH PROPOSAL

SUBMITTED TO THE MINNESOTA PUBLIC UTLITIES COMMISSION

BY Douglas J. Reinemann, Ph.D., Associate Professor, Biological Systems Engineering, University of Wisconsin-Madison

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Lewis G. Sheffield, Ph.D., Associate Professor, of Dairy Science, University of Wisconsin - Madison.

Jenks Britt, DVM, Associate Professor of Veterinary Medicine, University of Wisconsin-Madison

The proposed study has four major objectives:

- Investigate immune function response to continuously applied, low-level voltage. The highest priority question emerging from the science advisors report is the possible adverse effects of continuous exposure to low level voltage and current. The presumed pathway of exposure is hoof-hoof step potential.
- Compare dairy cow sensitivity to voltage applied hoof-hoof with muzzle-hoof pathways.
- Investigate the relationship between behavioral responses previously observed and other physiological methods of quantifying stressors.
- Compare responses to low voltage exposure to other acute stressors.

Three experiments are proposed to meet these objectives. Two types of voltage and current exposures would be performed. Short-term exposure (from 1 to 10 minutes) would be used for Parts I and II and objectives 2, 3, and 4. Longer-term (2-week) continuous exposure would be used for Part III and objective 1.

Part I. Short-term exposure, hoof-hoof sensitivity testing, and comparison of behavioral to physiological responses

Short-term acute exposure experiments will be performed to establish the relationship between sensitivity to hoof-hoof and muzzle-hoof pathways. There has been very little work done to document hoof-hoof exposures yet this is a common exposure pathway in the field. Previous methods have relied primarily upon behavioral response as an indication of the sensitivity threshold to electrical exposure. Behavioral responses have also been used several other researchers to measure the threshold response to voltage exposure. As stated in the science released in response to environmental stress.

All of the above assays are straightforward, and the necessary reagents for RIA and ELISA are readily available. These measures typically have coefficients of variation of 25-30%. For replication of 8-10 animals per treatment, this would correspond to detecting a 50-60% change in hormone concentration. The concentrations of the hormones measured typically double (or more) in response to stress, so the experiment should readily detect important differences.

These experiments will test whether direct physiological measures of stress occur at voltage and current levels below those at which behavioral responses can be measured. This would help to clarify the applicability of previously documented behavioral measures of response to voltage and current.

Part II. Comparison of treatments applied during milking

The treatments for these experiments will be applied in one of the milking stalls at the UW Dairy Cattle Research and Instruction facility during milking. Treatments will be applied over 4 consecutive days using a Latin square design with 8 cows per experiment and 2 cows per treatment group. The treatments applied will be:

Control
Hoof-hoof voltage exposure below sensitivity threshold
Milking machine induced stress
Combined low voltage and milking machine stress.

The response measures will be:

Hoof lifting during milking
Average and peak milk flow during milking
Pounds of milk yield
Milking time

Cows will be directed into one of the four milking stalls equipped with the experimental apparatus. Cows not involved with the experiment will be milked in the other 3 milking stalls during the experiment so that 'normal' milking routines will not be interrupted. The order in which cows enter the milking area will be recorded and the time taken for the cow to move from the entrance gate to the parlor into the milking stall will measured. Reluctance to enter the milking stall may provide a measure of carry over effects of treatments. The level of voltage exposure will be 1/2 to 1 volt (1 – 2 milliamp). This is below the level of concern established by previous research and adopted by the State of Wisconsin, Public Service Commision in their stray voltage rule.

Frequency of hoof lifting and kicking during milking have been suggested as measure of cow discomfort during milking. These are likely to be sensitive measures for hoof-hoof voltage exposure. The milk letdown reflex is influenced by stresses experienced during milking. Discomfort during milking may decrease both the peak and average milk flow rate during milking, increase the time taken to remove the milk and increase the amount of milk remaining in the udder after machine milking.

The results of these experiments would provide valuable information on the relative effects voltage exposure and other common stresses in the animal environment such as sub-optimal determined. Phytohemagglutanin and concanavalin A activate largely T lymphocytes, pokeweed mitogen T and B lymphocytes and S. aureus cells B lymphocytes. After 72 hours, 1 mCi 3H-thymidine will be added, cells incubated an additional 4 hours and cells harvested using a 96-well plate harvester. Incorporation of 3H-thymidine into DNA will then be used as an index of mitogenesis.

To assess immunoglobulin production (Lane et al., 1979), 3x106 cells will be suspended in 300 ml media. Cells will be treated with or without pokeweed mitogen for 5-10 days and immunoglobulin production assessed by ELISA, using antibodies against specific bovine immunoglobulins.

To assess oxidative burst (Trush et al., 1978), chemiluminescence in response to standard activators of macrophage and neutrophil function will be used. Leukocytes (106)will be placed in 0.5 ml phenol red free Dulbecco's Modified Eagle's Medium (DMEM) containing 100 mg/ml luminol. Baseline luminescence will be assessed after 10 minutes incubation. Next, 0 or 10 ng/ml phorbol myristate acetate (PMA) will be added, cells incubated 1 minute and light emission determined again. The difference will be used to estimate PMA-induced chemiluminescence. Specificity will be assessed by measuring superoxide production on randomly selected samples, using reduction of cytochrome c (Badwey et al., 1979) as well as phagocytosis and intracellular killing of opsonized S. aureus (Leijh et al., 1979).

These assays are rapid, relatively inexpensive, routine and provide important initial information on immune system function. Lymphocyte mitogenesis (blastogenesis) is a well-documented response to lectins, and is generally recognized as a useful measure of systemic immune function. Chemiluminescence is widely used as a measure of respiratory burst in phagocytic cells, a key event in phagocytosis and intracellular killing of bacteria. These two measures together will provide important measures of lymphocyte and phagocyte function in response to various treatments.

Obviously, the above measures are not exhaustive. In addition to the proposed measures, a variety of others, such as cytokine expression, response to in vivo antigen challenges or NK cell activity could also be measured. However, the proposed measures represent several of the major immunological processes, and are likely to be altered if systemic immune function is suppressed by the treatments. If these basic measures of immune function are altered, additional studies to determine the mechanisms of alteration in more detail could then be undertaken.

In a recently completed study (unpublished) we used the above measures of bovine immune function, and observed that error variation was 10-15% for most measures. Using 8-10 animals per treatment, this would allow us to detect differences of 15-20%, which is in the range considered physiologically relevant for these measures (see, for example, Kehrli et al., 1989a, b; Weigel et al., 1992).

Because samples cannot be stored for immunology measures, a technician must be available during the times when experiments are in progress. Samples for hormone assays can be stored prior to analysis. A full-time technician will collect samples and perform immediate immune function assays, as well as to perform hormone assays on stored samples when samples are not being collected. Additional hourly labor will e used to assist in sampling and reagent preparation.

ESTIMATED BUDGET

Lab Technician, 14 months	43,550
Research Assistant ½ time for 16 months	32,760
Hourly lab and technical assistance, 1/3 time, 16 months	17,740
Electrical monitoring and hardware, equipment and supplies	18,000
Lab Supplies, Immune and Endocrine Assay materials	19,700
Cow use fee 1500 cow-days	4,500
Travel	2,400
Office supplies, expenses and publishing costs	2,500
Danish Institute of Agricultural Science	
Scientist salary and office support 4.5 months	31,500
Travel	4,800
Total from Minnesota PUC	178,550