Dairy Cow Response to the Electrical Environment: A Summary of Research conducted at the University of Wisconsin-Madison

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Faculty at the University of Wisconsin-Madison have been involved in programs on the subject of stray voltage since the issue surfaced in the 1970s. Prior to 1990, this work consisted mainly of educational programs on stray voltage and various aspects of agricultural wiring practices. An extensive research program on dairy cow response to the electrical environment was initiated in the early 1990s and has continued to the present. This paper will summarize the rationale for and the results of these studies on animal response to various electrical exposures.

Wisconsin Department of Agriculture Sponsored Research

A research program was initiated at the request of the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) in 1991. These studies were funded by WDATCP. A citizen's advisory board to the WDATCP, composed of parties with concerns about stray voltage, established the priorities for this research. The highest priority at the time this research was initiated was dairy cow response to short duration or 'transient' voltages. The specific objectives of these studies were to:

- Develop experimental methods to quantify behavioral responses of dairy cows to electrical phenomena,
- Determine electrical phenomena, other than steady-state 60-Hz AC voltages that could affect dairy cows (primarily transient voltages and magnetic fields). This objective included characterization of how animals perceive and react to current flow and evaluation of short and long-term exposure to transients on animals,
- Develop predictive methods to relate responses measured in these studies to exposures previously reported and a wide variety of electrical stimuli,
- Advance the science of electrical measurements used to assess electrical environment of dairy cows, and
- Contribute to the stray voltage knowledge base by continuing research recommended in the USDA Handbook 696, "The Effects of Electrical Voltage/Current on Farm Animals" (5).

These studies were planned and conducted by a multi-disciplinary team of faculty from disciplines including:

- Agricultural and Biological Systems Engineering,
- Animal Behavior,
- Dairy Science,
- Electrical Engineering,
- Veterinary Science,
- Electropathology, and

- Biostatistics.

Staff from WDATCP and Public Service Commission of Wisconsin (PSCW), dairy farm operators, practicing veterinarians and researchers from other universities, also made significant contributions to experimental design and interpretation of data. These studies are reported in references (6)-(20). The major results and conclusions of these studies are summarized below.

Measuring Behavioral Responses

Experimental procedures were developed to measure and detect behavioral responses to applied current pulses by an animal behavior specialist. A number of suspected behaviors were monitored by human observers. Computer-based data acquisition equipment was also used to monitor animal activity. For studies in which current pulses were applied from muzzle to 4-hooves, facial activity was the most sensitive behavioral response followed by front hoof lifting. Human observers' measurements of hoof lifting agreed well with automated recording of animal motion. Tail motion showed no statistically significant response to the current stimulus.

Current Thresholds for Behavior Response

The distribution of responses at 60-Hz and higher frequencies showed remarkable agreement with other studies. This distribution of sensitivities to 60-Hz current agrees well with several other studies performed by independent research groups and with differing approaches (5). The range of sensitivity to a single-cycle, 60-Hz, current pulse for 120 cows ranged from 2.8 to 19 mA (measured from zero to peak) with a median response threshold of 9.6 mA.

Cows were less sensitive (e.g., more current was required to elicit a response) to shorter duration or higher frequency waveforms over the frequency range from 60-Hz to 50,000 Hz. The median for a sensitivity single-cycle, 50-kHz pulse increased to 1308 mA (measured from zero to peak). The waveform and number of cycles of the stimulus for high frequency pulses also affected sensitivity. The current thresholds established in the UW studies agree well with neuro-electric models and the large body of research on human sensitivity to short duration voltage and current (1, 4) as well as other studies done on dairy cows. These relationships were observed and documented in humans as early as 1901 and have been repeated in numerous controlled experiments since that time.

Cows did not respond to magnetic fields of up to 4 Gauss produced by current flow in metal structures. This result agrees with the bio-electric studies (2, 4) in which it was concluded that environmental fields encountered on the farmstead are far too small to be responsible for nerve stimulation of farm animals.

Aversion to Current

Further studies were conducted to determine the level of current, relative to the behavioral reaction threshold, required to affect cows' feed and water intake and milk production. The groups were monitored for a 14-day pretreatment period followed by a 21-day treatment during which a single-cycle, 60-Hz transient current was applied to water bowls once every second, and a 14-day post treatment period. Exposure levels were set relative to the sensitivity of individual animals to short duration exposure to take into account the wide range of sensitivities among cows. The exposure levels ranged from 7 to 20 mA (measured from zero to peak). Feed and water intake, milk production, Somatic Cell Count (SCC), blood composition, and activity level were monitored during the experiment.

Average changes in feed and water intake and milk production during the 21 day Treatment period were not significant when compared with the 14-day pre-treatment period. No change in Somatic Cell Count (SCC) or linear score were found for the animals at the highest exposure level. Animals showed an acclimation to the transient current exposure with avoidance behaviors most prominent immediately after exposure and reduced avoidance response with increasing exposure time.

Significant reductions in water and feed intake, and milk production were measured on the first three days of exposure for cows exposed to 150% of their reaction threshold current level. The exposure levels for these cows ranged from 11 to 20 mA. The current level required to elicit this short term reduction in water and feed intake and milk production was thus considerably higher than that to produce a behavioral response.

Behavioral effects, as indicated by delay to drink and gross observation, were apparent during the first day of exposure at levels lower than those required to cause measurable changes in daily total water and feed intake or milk production. On average, an increase in the reaction threshold (cows became less sensitive) was observed between pretreatment and posttreatment periods. This confirms results of previous studies and field observations noting rapid acclimation to voltages as well as changes in animal behaviors with no measurable decline in water or feed intake or milk production.

Short-term aversion to water was also observed in a second study when a single-cycle 6000 Hz current pulse (ranging from 60 to 150 mA zero-peak current) was applied to the water bowl. Reduced water consumption was again observed for current exposure levels 150% of the behavioral response threshold.

Predictability of aversive response was improved over previous studies by taking into account individual animal sensitivity. This result clarifies previous experiments in which animals had to be removed from experimental trials because of dramatic response. More consistency in behaviors was observed, and greater response was obtained when using a multiplicative current exposure scheme (150% of behavioral response threshold), than with an additive scheme (1.5 or 3 mA + behavioral response threshold). The responses were all explainable by avoidance of water bowls associated with the presence of an annoying stimulus rather than direct physiological effects. Cows in these experiments were exposed to the transient current whenever they attempted to drink. In practice, transient events are not typically present every time an animal attempts to eat or drink.

A subsequent study investigated aversive response of a continuously-applied stimulus to intermittently-applied stimulus. A continuously applied current pulse at 150% of the behavioral reaction threshold of each cow produced the expected short-term reduction in water consumption, while the intermittently applied pulse at the same current level did not result in reduced water intake. In order for current exposure to affect cows, the applied current must first be of sufficient level to cause avoidance behavior. In addition, these events must also occur often enough to cause animals to avoid water and/or feed.

Other Results and Conclusions

The relationship between cow impedance and cow sensitivity was also examined in these studies. There was a trend for more sensitive cows to have higher resistance. Thus using the minimum threshold current for the population of cows combined with the minimum impedance from that same population will result in an overly conservative estimation of the minimum threshold contact voltage for that population. Measurement of cow contact voltage and current using a 500-Ohm shunt resistor have been shown in our laboratory studies as well as field studies (21) to be a conservative estimate (worst case) of the current likely to flow though a cow.

This combined body of research indicates that the response levels presented in the USDA handbook (1) are conservative in that the responses cited (e.g., perception only at 1 - 2 mA rms) will only occur for a small percentage of cows. The vast majority of cows will not perceive currents of this level and will show no harmful effects. There was no evidence from these studies that there was any direct physiological effect of voltage/current exposures below the levels at which a behavioral response can be documented nor at levels at which aversion to water and/or feed are first observed. The short term decrease in water and feed intake that has been documented are consistent with aversive response to an unpleasant stimulus.

Minnesota Public Utilities Commission Sponsored Research

A second research program was initiated at the request of the Science Advisors to the Minnesota Public Utilities Commission. These Science Advisors were assembled to assess the possible effects of current in the earth on dairy cow health and milk production. The specific questions addressed in this research were developed by the team of Science Advisors. This research was funded by the Minnesota State Legislature. A study was designed to investigate a hypothesis developed by the Science Advisors related to the possible effects of current flowing in the earth on the health of dairy cows. Stress hormones and immune function response of dairy cows exposed to low-level step potentials were examined. These experiments were designed, carried out and analyzed by a multi-disciplinary team of scientists from the US and Denmark from disciplines including:

- Biological Systems Engineering
- Animal Health and Welfare
- Bovine Immunology
- Bovine Endocrinology
- Bio-Statistics

The results of these studies are reported in references 16-20. A summary of the methods, major results and conclusions of these studies follows.

A series of experiments was performed to measure behavioral responses and changes in blood cortisol concentration of cows exposed to 60-Hz electrical current applied from front to rear hooves. The types of behavioral responses for hoof-hoof exposure differed somewhat from the muzzle-hoof exposures previously studied. Increased activity level as measured by electronic load cells was not a consistent indicator of response to current, whereas a flinch or startle response was a consistent and repeatable behavioral indicator. Cows responded at lower current levels to the one-front to two-rear-hoof pathway than to muzzle to 4-hooves pathway. Cortisol levels did not increase in response to short-term current exposure at levels up to 150% of the behavioral reaction threshold. Cortisol concentrations were found, however, to increase in response to hoof trimming. These results confirm several previous studies indicating that behavioral changes are a more sensitive indicator of response to short-term electrical current exposure than blood cortisol levels.

Milking performance of cows subjected to electrical current during milking and two common milking machine problems were documented. The first experiment used 32 cows in a 2x2 factorial design with exposure to 1 mA (60-Hz rms) of electrical current from front to back hooves during milking and a pulsation failure (no massage phase) as treatments. A second experiment used 16 cows in a 2x2 factorial design with exposure to 1 mA (60-Hz rms) of electrical current from front to back hooves during milking and excessively aged milking machine liners as treatments. The response measures for both experiments were milk yield, average milk flow rate, maximum milk flow rate, cow activity, and strip yield.

The main effect of current exposure was not statistically significant for any of the response variables. The main effect of pulsation failure was significant for cow activity (5.8 fewer weight shifts during a milking). The main effect of aged liners was significant for milk yield (2.2 kg increase), average flow rate (0.3 kg/min reduction), maximum flow rate (1.2 kg/min reduction), and liner slips (26 more per milking). The significance of some interactive effects appeared to indicate that current exposure had a mitigating effect on the changes caused by the milking machine problems. These interactions were not consistent across experiments, however, and in some cases were highly influenced by a few observations. This study adds further evidence to the body of literature showing that exposure to low-level step potential resulting in <1 mA rms of 60-Hz electrical current during milking is not a cause of cow discomfort or poor milking performance.

A third series of experiments were performed in which twelve mid-lactation dairy cattle were subjected to intermittent low electrical currents (approximately 1 mA of current) from front to rear of stall for a period of 14 days. An additional 12 cows were housed in identical stalls with no treatment. Electrical monitoring indicated that achieved current was within 10% of target. Feed intake, water intake, milk production and rectal temperature were monitored daily and were unaffected by treatment. Behavioral measurements, including percentage of time lying and time to reenter stalls after milking, were unaffected by treatment. Immune function was assessed by analyzing blood samples taken twice a week for thirteen different response variables. The measures for lymphocyte blastogenesis (concanavalin A and phytohemagglutanin mitogens), and oxidative burst (PMA-induced chemiluminescence) were chosen a priori as the best indicators of immune function response. Immunoglobulin production, interleukin-1 and interleukin-2 were also assessed.

Chemiluminescence, lymphocyte blastogenesis and serum IgG antibody titers were unaffected by current exposure. Serum IgA was increased ($P=0.015$) in the treated group. No other treatment or treatment x time interactions were significant at the typical level of $P<0.05$. However, serum interleukin-1 levels tended to increase following current exposure ($P=0.097$), while there was a tendency for interleukin-2 levels to decline ($P=0.107$). These results suggest little impact of 1 mA of current for up to two weeks on immune function in dairy cattle. Although possible effects on IL1, IL2 and IgA concentrations were observed, these effects were not large enough to suggest major alterations in immune function by electric currents.

Wisconsin State Legislature Sponsored Research

A third research project was initiated and funded by the Wisconsin Legislature in 2000 to address concerns of citizenry over the possible affects of electrical currents flowing in the earth. The two major objectives of this project are to:

- Determine the potential exposures of dairy cattle in Wisconsin to ground currents of 1 Hz to 1 kHz frequency, and
- Evaluate gene expression events in circulating leukocytes of cows exposed to the identified electrical phenomena.

These experiments were designed by faculty from

- Civil and Environmental Engineering,
- Dairy Science, and
- Biological Systems Engineering.

Remote-Reference Magnetotelluric (RRMT) Geophysical Method

The electrical resistivity of the ground can be determined from taking the square of the ratio between orthogonal components of the electric and magnetic fields:

$$\rho_a = \frac{0.2}{f}\left|\frac{Ex}{Hy}\right|^2.$$

The fields being measured in this case are the electric and magnetic fields that are generated by interactions of charged particles streaming out of the sun with the Earth's magnetic field. The fields propagate downward from the ionosphere and interact with the earth. This method held much promise for geological studies as well as mineral and oil exploration.

Early studies ran into problems. Signals that are generated locally by man-made sources or by nearby lightning storms are noise in the signal we are trying to measure, and sometimes this "noise" is much stronger than the signal. The net effect of this noise is to 'bias' the measured apparent resistivities, i.e. produce erroneous results. Because this was such a problem, MT methods were not used up until the mid 1970s.

In the early to mid 1970s, it was realized that the signals we are interested in can be correlated over large distances while man made signals do not correlate over those same distances as they tend to die off rather quickly. Thus a method was developed where the fields collected a few to many miles apart are correlated to determine the coherent signal. These coherent signals are then used to produce the apparent resistivity estimates. However, at the same time we can determine the non-coherent signal, or noise, at each site. This is especially true if one of the sites is in a 'quiet' area that is far from power lines, and other electrical devices.

This remote reference technique will be applied to this study, where four systems will be making simultaneous measurements on the farm, while a fifth station located some distance away provides the quiet measurements. This will allow us to determine the noise present at each measurement location at the farms, which, since we are measuring the electric fields in the ground, can be correlated to stray-ground voltages. In addition, the set up will allow us to have the farmer turn off and on different parts of his system to see how the earth currents change due to different activities.

The fields are fairly simple to measure. In the 1Hz to 10 kHz frequency band, electric field measurements are made by grounding a 10m to 100m long wire with low noise electrodes. The magnetic field measurements are made with induction coils. The acquisition system is a 24-bit system which allows for measurement of the electromagnetic fields over eight orders of magnitude. The system is synced to the global position system (GPS) such that multiple systems located tens to hundreds of kilometers apart can be recording simultaneously, and the data can later be correlated time-wise within the accuracy of the GPS clocks.

Gene Expression as a Measure of the Biological Consequences of Low Level Voltage Exposure

We plan to use gene expression to examine potential impacts of electrical exposures on the immune system of dairy cattle. The immune system is critical to maintaining health, and health effects are expected to be mediated by alterations in immune system function. Environmental factors, such as electrical exposure, signal the cow to turn on or off various genes. The genes themselves remain unchanged. However, the genes produce varying amounts of messenger RNA, in a process known as gene expression.

Changes in environment dramatically alter messenger RNA production. These changes are responsible for environment-induced alterations in function, such as sensitivity to disease. Therefore, a major part of this study will be to define the impact of electrical exposures on the messenger RNA produced in the immune system.

We will conduct controlled exposure studies in which effects of low level voltage/current exposure on the immune system will be evaluated in detail. Using new methods in biology, known as array hybridization, we will then assess the impact of electrical exposure on the messages produced in the immune system. This method will allow us to assess several thousand messages in a single sample. Unlike other studies, in which a relatively small number of measurements are conducted, this method allows us to assess essentially every messenger RNA produced in a tissue. This greatly reduces the chances of missing potentially important measures because they were not included in a study. Because message production in the immune system is a critical link between the environment and a cow's health, these measurements will provide critical information on the impact of electrical exposures on dairy cattle.

EPRI Sponsored Studies

Reading of electric meters by direct observation entails considerable expense and inconvenience and presents an opportunity for human error. Electric utilities are adopting various remote meter reading technologies, such as radio transmission, telephone transmission, or using the powerlines to carry a signal to and from the meter. Power line signals can be encoded in a number of formats. Some types of powerline communication devices superimpose short duration voltage/current pulses on the underlying sinusoidal 60-Hz power waveform. These voltage pulses appear on the primary neutral.

This study examined the sensitivity of dairy cattle to electrical transients similar to those produced by automatic meter reading devices. Several different pulse waveforms were studied, encompassing the range of waveforms that might be encountered in practice. Behavioral reaction thresholds were determined for cows using the muzzle-hooves exposure pathway. We found that there was no interaction between the high frequencies generated by the automatic meter reading devices and the underlying 60-Hz signal. We also found that cows were less sensitive to the signaling pulses than they were to 60-Hz current, and that they became progressively less sensitive as the duration of the signaling pulse was shortened. These results compared well with previously validated neuro-electric models.

Inter-Agency Cooperative Efforts

The animal research summarized above is part of the inter-agency cooperation on electrical issues on farms in Wisconsin. UW faculty have worked with personnel from the Rural Electric Power Services Program (formerly Stray Voltage Program) jointly administered by the Wisconsin Department of Agriculture, Trade and Consumer Protection and the Pubic Service Commission of Wisconsin on analysis of field data, development of measurement techniques, and educational programs. Publications resulting from these activities are cited in references 21-31.

References

1. Reilly, J.P., 1992. Electrical Stimulation and Electropathology. Cambridge University Press, Cambridge. 504 pp.
2. Reilly, J. P., 1995. Nerve Stimulation of Cows and Other Farm Animals by Time Varying Magnetic Fields. Transactions of the ASAE 38(5):148
3. Reilly, J.P., 1994. Transient Current Effects in Stray Voltage Exposure: Biophysical Principles and Mechanisms. ASAE paper number 94-3594, written for presentation at the ASAE, Winter Meeting, Atlanta, Georgia, 13 Dec.-16 Dec.
4. Reilly, J.P. 1998. Applied Bioelectricity: from Electrical Stimulation to Electro-pathology. Springer Verlag, New York 563 pp.

5. USDA, 1991. Agriculture Handbook No. 696. Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems. A. Lefcourt, Editor, U.S. Government Printing Office.

UW Animal Research

6. Reinemann, D.J., L.E. Stetson, J.P. Reilly, N. K. Laughlin, 1999. Sensitivity of Dairy Cows to Short Duration Currents. Transactions of the ASAE Vol. 42, No. 1, pp. 215-222.
7. Reinemann, D.J., L.E. Stetson, N. Laughlin, 1995. Response of dairy cattle to transient voltages and magnetic fields. IEEE Transactions on Industry Applications, Vol. 31, No. 4, pp. 708-714, July/August,
8. Reinemann, D.J., L.E. Stetson, S.D. LeMire, and J.W. Patoch, 1997. Comparison of dairy cow aversion to continuous and intermittent current. ASAE Paper No. 97-3018, Written for presentation at the 1997 International Meeting sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, Minneapolis, MN, August 10-14, 1997.
9. LeMire, S.D., D.J. Reinemann, P.J. Gaffney, 1997. Dairy cattle drinking behavior and stray voltage exposure. ASAE Paper No. 974012, Written for presentation at the 1997 ASAE annual International Meeting sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, Minneapolis Minnesota, August 10-14, 1997.
10. Reinemann, D.J., L.E. Stetson, J.P. Reilly, N.K. Laughlin, S. McGuirk, S.D. LeMire, 1996. Dairy Cow Sensitivity and Aversion to Short Duration Transient Currents. Paper No. 963087, Written for presentation at the 1996 International Meeting sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, Phoenix, Arizona, USA, 14-18 July 1996.
11. LeMire, S.D., and D.J. Reinemann, 1996. Sample Size Calculations for Stray Voltage Milk Reduction Studies. Paper No. 963086, Written for presentation at the 1996 International Meeting sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, Phoenix, Arizona, USA, 14-18 July 1996.
12. Reinemann, D.J., L.E. Stetson, N.K. Laughlin, 1995. Water, Feed and Milk Production Response of Dairy Cattle Exposed to Transient Currents. Paper No. 953276, Written for Presentation at the 1995 International Meeting Sponsored by the American Society of Agricultural Engineers, June 18-23, 1995, Chicago, Illinois.
13. Reinemann, D.J., L.E. Stetson, N. Laughlin, 1994. Effects of Frequency and Duration on the Sensitivity of Dairy Cows to Transient Voltages, ASAE Paper No. 943597, presented at the International Winter Meeting of the American Society of Agricultural Engineers, Atlanta, Georgia, December 13-16, 1994.
14. Reinemann, D.J., L.E. Stetson, N. Laughlin, 1994. Response of Dairy Cattle to Transient Voltages and Magnetic Fields. Proceedings of the Institute of Electrical

and Electronics Engineers, Rural Electric Power Conference. April 1994, Colorado Springs, Colorado.

15. Reinemann, D.J., N. Laughlin, L.E. Stetson, D. Ament, J.E. VanOver, and D.J. Sweet, 1993. Dairy Cattle Response to Electrical Environment: Test Equipment and Procedures, ASAE technical paper No. 933025, Presented at the 1993 summer meeting of the American Society of Agricultural Engineers, Spokane, Washington.

16. Reinemann, D.J., M.D. Rasmussen, L.G. Sheffield, M.C. Wiltbank and S.D. LeMire, 1999. Dairy Cow Response to Electrical Environment Part I. Comparison of Behavioral to Physiological Responses, and, Part II. Comparison of Treatments Applied during Milking. Report to the Minnesota Public Utilities Commission, June 30, 1999.

17. Reinemann, D.J., M.D. Rasmussen, L.G. Sheffield, M.C. Wiltbank and S.D. LeMire, 1999. Dairy Cow Response to Electrical Environment, Final Report, Part III. Immune Function Response to Low-Level Electrical Current Exposure. Report to the Minnesota Public Utilities Commission, June 30, 1999.

18. Reinemann, D.J., S.D. LeMire, M.D. Rasmusssen, M.C. Wiltbank, L.G. Sheffield, 1999. Comparison of Behavioral and Physiological Response to Electric Shock in Lactating Dairy Cows. ASAE Paper No. 993154, Written for Presentation at the 1999 ASAE/CSAE International Meeting, Toronto, Ontario, Canada, July 18-21.

19. Reinemann, D.J., M.C. Wiltbank, L.G. Sheffield, M.D. Rasmussen and S.D. LeMire, 2003. Comparison of Behavioral and Physiological Response to Electric Shock in Lactating Dairy Cows. Transactions of the ASAE, In PressReinemann, D.J., M.D. Rasmussen and S.D. LeMire, 2002. Milking Performance Of Dairy Cows Subjected To Electrical Current And Induced Milking Machine Problems. Transactions of ASAE**.**

20. Sheffield, L.G., DJ Reinemann, MD Rasmussen, MC Wiltbank and SD LeMire, 2003. Immune Function Response to Low-Level Electrical Current Exposure. J. Dairy Sci**. I**n Press.

Wisconsin State Agency Collaborations

21. Cook, M.A., D.M. Dasho, R. Reines, W.K. Dick, D.J. Reinemann, J. Ryder, D.F. Winter, 1994. Effects of Source Resistance on Cow Contact Voltage Measurement. ASAE paper No. 943601, presented at the International Winter Meeting of the American Society of Agricultural Engineers, Atlanta, Georgia, December 13-16, 1994.

22. Cook, M.A, D.M. Dasho, W.K. Dick, D.J. Reinemann, and D.F. Winter, 1994. Distinguishing Stray Voltage Contributions from "On-Farm" and "Off-Farm" Sources. ASAE paper No. 943065, Presented at the 1994 International Summer Meeting of the American Society of Agricultural Engineers, Kansas City, Missouri, June 20 - 22, 1994

23. Cook, Mark A., Daniel M. Dasho, Douglas J. Reinemann, and LaVerne E. Stetson. 1995. "Electrical Service to Agricultural Buildings: Four-Wire and Three-Wire

Systems." Microfiche no. 95-3623 in ASAE, Annual Meeting (Chicago, IL, 18 June-23 June).

24. Cook, M.A., D.M. Dasho, R.S. Reines, and D.J. Reinemann, 1996. Relationships Between Secondary Neutral and Cow Contact Voltages. Paper No. 963072. Written for Presentation at the 1996 International Meeting Sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, July 14-18, 1996, Phoenix, AZ USA

25. Cook, M.A., D.M. Dasho, R. Reines, D.J. Reinemann, and L.E. Stetson, 1995. Electrical Service to Agricultural Buildings: Four-wire and Three-wire Systems. Paper No. 953623 Written for Presentation at the 1995 International Meeting Sponsored by the American Society of Agricultural Engineers, June 18 23, 1995, Chicago, Illinois

26. Dasho, D.M., M.A. Cook, R.S. Reines, and D.J. Reinemann, 1994. Characteristics of Cow Contact Voltage Transients. Paper No. 943602, presented at the International Winter Meeting of the American Society of Agricultural Engineers, Atlanta, Georgia, December 13-16, 1994

27. Dasho, D.M., M.A. Cook, R. Reines, and D.J. Reinemann, 1995. Stray Voltage: the Wisconsin Experience. Paper No.953625. Written for Presentation at the 1995 International Meeting Sponsored by the American Society of Agricultural Engineers, June 18 23, 1995, Chicago, Illinois

28. Dasho, D.M., M.A. Cook, R.S. Reines, and D.J. Reinemann, 1996. Magnetic Field Measurements on Wisconsin Dairy Farms. Paper No. 963071. Written for Presentation at the 1996 International Meeting Sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, July 14-18, 1996, Phoenix, AZ USA

29. Kasper, R.A., and D.J. Reinemann, 1996. Bibliographic Development On Electrical Phenomena Impacting Agricultural Operations, Paper No.963083, Written for presentation at the 1996 International Meeting sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, Phoenix, Arizona, USA, 14-18 July 1996.

30. Kasper, R.A., D.M. Dasho, M.A. Cook, J. Martens, J.W. Patoch, and D.J. Reinemann, 1996. Stray Voltage Training Model. Paper No.963075, Written for presentation at the 1996 International Meeting sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, Phoenix, Arizona, USA, 14-18 July 1996.

31. Reines, R.S., M. A. Cook, D.M. Dasho, and D.J. Reinemann, 1998. Putting stray voltage in perspective: the Wisconsin experience revisited. ASAE Paper No. 983004, Written for presentation at the 1998 ASAE annual International Meeting, Orlando Florida July 12-15, 1998