

# Review of Literature on the Effect of the Electrical Environment on Farm Animals

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This document presents review of published literature relating to stray voltage and other forms of electrical exposure on farm animals. Farm animal exposures and their effects are the main focus of the review; however, some studies on human exposure are also included, insofar as they help explain physiological responses of animals. Studies on the effects of electrical exposure on cows began over 40 years ago while studies on humans date back more than 100 years. These studies by hundreds of independent research groups in many countries have given us a very good understanding of the way that electricity affects living organisms and the levels of electrical exposure that can be problematic to farm animals.

The published literature can be divided into several broad categories (with page numbers indicating the start of each section):

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Current exposure studies can be further divided in to exposures leading to nerve stimulation producing sensation or muscle contraction, and potential behavioral modification, and exposures that do not produce sensation but may produce some other physiological response. Studies of a number of therapeutic current exposures techniques have been included.

Exposures to electric and magnetic fields (EMF) do not produce nerve stimulation or sensation at the levels encountered by farm animals. The exposure mechanisms are, furthermore different than for the contact current mechanism. Studies EMF exposures have therefore been presented as a separate category. There are many more studies and publications on the mechanics the electrical transmission, distribution, and end use wiring systems and their influence on exposure levels and appropriate measurement techniques for various electrical aspects of the electrical environment that are not presented in this review.

The studies within each category are arranged chronologically so that the reader can follow the development of the research through time. Each major study effort may be represented by numerous publications some peer reviewed (**in bold**) and some not. Many early studies raise questions or pose speculations that have been answered in later studies. The author's abstracts are included in their entirety when they exist. Some publications that do not have abstracts have been summarized and some comments have been added in *italics* for clarification.

The state of Wisconsin has established **1-volt** in cow contact locations (or 2 milliamps of 60 Hz current flowing through a cow) as its regulatory standard. I think it will be clear to the reader that this vast body of research clearly supports this as a safe exposure limit. This 1-volt standard is meant to apply to steady 60 Hz rms voltages and currents measured in cow contact locations. The voltage and current exposure produced by 'ground currents' are typically 100 to 1000 times lower than this level.

I would like to acknowledge Roger Kasper for laying the foundation for this review and his employer, the Wisconsin Department of Agriculture, Trade and Consumer Protection for supporting this work. I would also like to acknowledge the efforts of the Electric Power Research Institute to update and summarize this vast body of literature.

## Major Review Publications

### Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems.

Lefcourt A.M. (ed.). 1991. USDA Handbook 696, U.S. Dept. of Agriculture, Washington, D.C., USA. This handbook is an excellent review of the sources of “stray voltage”, measurement and diagnostic techniques, research on sensitivity of dairy cows and responses to current exposure and mitigation methods. This comprehensive review is the consensus opinion of 15 scientists recognized as credible researchers and reviewers of scientific literature who were active in farm electric issues at the time of this publication. From the Preface:

*There were two primary reasons for publishing this handbook. First, we as scientists were distressed that our research results were being misinterpreted and misconstrued in media and in courtrooms. Second, we were disheartened by the animosity that sometimes arose among livestock farmers, dairy equipment manufacturers and public utility companies because of lack of understanding of the causes and effects of stray voltage on farms. To eliminate any and all potential for even the appearance of bias, we decided to accept no industry funding whatsoever. The USDA was chosen as a publisher because it represents an unbiased source of funds to pay for publication ...and because federal publications are 1. Understood by the general population to be unbiased and 2. Normally viewed as expert testimony in legal proceedings. Each contributor signed a notice acknowledging that the manuscript was factually correct and a faithful representation.*

The final recommendations of this group of experts include the following:

*Recommendations are expressed in terms of voltages (Vac as rms values) because voltage is the easiest and most commonly made measurement. However, as discussed throughout this handbook, animals respond to the electrical current generated by a voltage and not to the voltage directly. To relate voltage measurements to current, the worst case (500 Ohms) and more realistic (1000 Ohms) impedances were used. In any case, when a voltage is detected, it must be confirmed that the measured voltage has a low source impedance, i.e. that the voltage can deliver a current of sufficient magnitude to exceed level of concern. We suggest that contact voltage in excess of 2 to 4 V on farms are excessive and recommend their reduction. We recommend a range of action levels from 2 to 4 V to be as conservative as possible and to account for indirect losses due to problems resulting from inappropriate response of farmers to changes in animal behavior. Only under the most unusual circumstance can a cow detect voltage less than 0.5 to 1.0 V. Thus attempts to reduce cow contact voltages to below 0.5 to 1.0 V are unwarranted, and totally unnecessary. It is hoped that his handbook will help people to ask the right questions and to make informed decisions.*

The authors of this publication issued a statement of clarification in 2000 indicating the need for a comprehensive educational program to improve knowledge if its findings as the results of research were still being ignored or misinterpreted.

### A Review Of Stray Voltage Research: Effects on Livestock. R.J. Fick and T.C. Surbrook, 1996.

**Michigan State University.** This publication provides a useful summary the various experiments involving farm animals exposed to electrical current covering the period from 1962 until 1996.

Electrical and Biological Effect of Transmission Lines: A Review. J. M. Lee, 1996. Bonneville Power Administration. This publication provides an excellent overview of research on human, animal and plant exposure to EMF, the electrical fundamentals of EMF production in AC and DC transmission lines and an introduction to the biological foundation for EMF affects on plants and animals.

**Applied Bioelectricity: from Electrical Stimulation to Electropathology. J.P Reilly, 1998, Springer Verlag.** The 1998 text is updated from a 1992 text (Electrical Stimulation and Electropathology; J. P. Reilly, 1992. Cambridge University Press) and is the definitive reference on the biomechanics of nerve stimulation and resulting pathologies. This text summarizes the vast body of research on electrical stimulation over more than 100 years of investigation. Electrical properties of human and animal tissues are described. The use of electrical stimulation for beneficial medical purposes is covered as well as 'pathological' exposures that may result in injury, death or other undesirable conditions. The final chapter is a particularly useful discussion of standards for electrical exposure (both applied current and electric and magnetic fields) and the biological rationale for these standards. While the main subject of the book is human exposures there is also a chapter on animal exposures. It has been shown that the broad body of research on nerve excitation in humans also applies to nerve excitation in animals.

**Research Findings and Recommendations Regarding Claims of Possible Effects of Currents in the Earth on Dairy Cow Health and Milk Production: Final report of the science advisors to the Minnesota Public Utilities Commission.** Staehle, R.W., Anderson, L.E., Dzuik, H.E., Hird, D., Liboff, A.R., Polk, C., Richardson J.L., Stetson, L.E. Hoben, P.J., Hendrickson, R.C., 1998. Minnesota Public Utilities Commission, St. Paul, Minnesota, USA. This final Report of the Science Advisors to the Minnesota Public Utilities Commission, summarizes the results of a 4 year study by eight national experts on the possible influence of currents in the earth on dairy cow health and milk production. The study included an extensive literature review of the mechanism by which electricity affects living organisms. The study includes an opinion survey in Minnesota and Wisconsin which indicated that the vast majority of farmers are not concerned about the effects of the electrical environment on their cows. Detailed electrical measurements were done on 19 farms to estimate exposure levels to contact voltage, electric and magnetic fields. The report also gives the rationale for laboratory studies to investigate cause and affect relationships between low-level contact current exposure and immune function of dairy cows. The fundamental conclusion of these science advisors was "*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.*"

Stray Voltage and Dairy Farms: Proceedings of the 2003 NRAES. This document provides a comprehensive update to the 1991 USDA handbook 696 (see below) on research and field studies on stray voltage and other electrical exposures. Specific papers related to animal exposure and effects are listed separately in the following sections. Research and field studies have further confirmed and amplified the results and recommendations of the 1991 USDA handbook.

COMAR Technical Information Statement: The IEEE Exposure Limits for Radiofrequency and Microwave Energy. M.C. Ziskin. IEEE Engineering in Medicine And Biology, March/April 2005. The IEEE standard represents a consensus of scientific opinion about safe levels of exposure to RF energy, and its scientific rationale is consistent with conclusions of numerous expert groups and health agencies throughout the world. Nevertheless, laypeople often have questions about the adequacy of the standard or the process by which it was developed. This Technical Information Statement discusses the development and rationale for exposure limits for RF energy. The review process examined only studies that met selection criteria that included adequate dosimetry and experimental design, and independent confirmation of reported effects. Studies that were not published in the peer reviewed scientific literature, and those that were inadequately described to permit critical analysis, were excluded from consideration. Based on its review, the subcommittee concluded that disruption of food motivated learned behavior in laboratory animals is the most sensitive biological response that is both well confirmed and predictive of hazard. This effect, known as behavioral disruption, has been observed in laboratory animals ranging from rodents to monkeys. Some laypeople have expressed concern about the adequacy of the standard or of the process by which it was developed. Some of these concerns are addressed below.

Concern 1. The IEEE standards setting process for RF energy is captive of industry and represents only industry viewpoints. The IEEE exposure limits are developed through an open process, which helps to ensure a level of transparency and documentation that is unique in RF exposure limits. The standard was drafted by a 125-member subcommittee of the main committee, whose members were broadly distributed as to their place of employment and specialty. This committee represented a very broad range of expertise, including physicians, basic scientists, and engineers. Only a minority of its members were from industry; the largest group of members was from academia.

Concern 2. The standard ignores effects of long term exposure and “nonthermal” effects. The IEEE and other exposure limits are designed to protect against identified hazards of RF energy. During each revision of the standard, ICES and earlier committees failed to find credible evidence of cumulative effects due to chronic exposure, including cancer, or other hazardous effects from low-level exposure.

Concern 3. Other countries have lower limits than the IEEE/ANSI standards, and offer higher protection to their citizens. The exposure limits for RF energy vary widely in different countries. However, the guidelines of the great majority of countries are similar to those of IEEE or the closely similar guidelines of ICNIRP. A few countries have chosen much lower limits, in part due to differences in philosophy in setting limits. IEEE and most other Western exposure limits are designed on the basis of identified thresholds for hazards of RF fields and thus are science-based. Switzerland, Italy, and a few other countries have adopted “precautionary” exposure limits for RF energy. These are not based on identified hazards, but reflect the desire to set exposure limits as low as economically and technically practical, to guard against the possibility of an as-yet unidentified hazard of RF exposure at low levels. Western health agencies have been uniformly unable to identify any health hazard at exposure levels below IEEE or ICNIRP exposure guidelines.

IEEE or the generally similar guidelines of ICNIRP, offer a high level of protection against all identified hazards of RF energy and should serve as models throughout the world. The standards are living documents and will be revised as more scientific data become available.

**Merck Veterinary Manual, 2005. Merck & Co. Inc., Whitehouse Station, NJ, USA.** The Merck Veterinary Manual (MVM) has served veterinarians and other animal health professionals as a concise and reliable animal health reference for over 45 years. Since its introduction, the MVM has been eagerly adopted by the veterinary profession as a practical and comprehensive resource worldwide. The following summarizes the entry “Stray Voltage in Animal Housing”:

The term stray voltage has been used for the past 30 years or more to describe a special case of voltage developed on the grounded neutral system of a farm. If this voltage reaches sufficient levels, animals coming into contact with grounded devices may receive a mild electrical shock that can cause a behavioral response. At voltage levels that are just perceptible to the animal, behaviors indicative of perception such as flinches may result with little change in normal routines...

Studies by numerous independent research groups in several countries are in agreement that the most sensitive cows (less than 1 percent) begin to react to 60 Hz electrical current of 2 milliamps (measured as the Root Mean Square average or rms) applied from muzzle to hooves or from hoof to hoof. This corresponds to a contact voltage level of about 1 volt (60 Hz, rms). As the voltage and current is increased, a larger percentage of cows will react with behavioral responses will become more pronounced. Numerous studies have documented avoidance behaviors at levels above the first reaction threshold. The median avoidance threshold for 60 Hz current flowing through a cow is about 8 milliamps (4 to 8 volts rms). This response assumes that the cow comes into contact with objects that have different voltages and that this voltage causes sufficient current to flow through the cow. Even when the threshold is exceeded not all the animals respond behaviorally all the time, nor with the same signs but as the voltage increases, signs in the herd are more widespread and uniform.

In most situations cows are less sensitive to current and more sensitive to voltage than people are. While the resistance of cow and human tissues is similar, the contact resistance is generally lower for

cows than for humans, particularly if cows are in a wet environment. The resistance of a cow's body plus the contact resistance with the floor is commonly estimated as 500 Ohms. This is a reasonable value for a cow standing on a wet floor. Cows standing on a dry surface will typically produce 1000 Ohm resistance or higher. Cows standing or lying on dry bedding will have a resistance many times higher than this. The resistance of a human can be as low as 1000 ohms for wet hand - foot contact to higher than 10,000 ohms for dry hand - foot contact. The contact voltage to produce sensation can therefore be higher for humans than for cows, depending on the conditions of the contact points.

The scientific evidence strongly suggests there is no relationship between behavioral responses to stray voltage and physiologic or hormonal responses. There is no apparent relationship among behavioral modifications, milk production and animal health. The only studies which have documented adverse effects of voltage and current on cows had BOTH sufficient current applied to cause aversion AND forced exposures, (animals could not eat or drink without being exposed to voltage/current). It is typical for voltage levels to vary considerably at different locations on a farm. Decreased water and/or feed intake or undesired behaviors will result only if current levels are sufficient to produce aversion at locations that are critical to critical daily animal activity. These locations include feeders, waterers and milking areas. Controlled research has shown that if an aversive voltage was administered to a water bowl once per second, water intake was reduced. However, when the same voltage was applied once every 10 minutes and once per day, no reduction in water intake was observed. If an aversive current occurs only a few times per day, it is not likely to have an adverse effect on cow behavior. The more often an aversive voltage occurs in areas critical to cows' normal feeding, drinking or resting, the more likely it is to affect cows.

Clinical Findings: No one sign is pathognomonic; a wide variety of signs has been reported in cows exposed to different levels of voltage. Documented signs are behavioral changes and decreased drinks of water per day and length of time per drink. The amount of water consumed may not be affected even when behavioral modification occurs.

Intermittent periods of poor performance, poor milk letdown and incomplete or uneven milk-out, abnormal behavior during milking, increased milking time, refusal of feed or water, increased somatic cell counts in milk, and increased mastitis are signs often attributed by farmers to stray voltage; however, none of these signs were evident in numerous controlled studies. These signs are often caused by other factors, such as abusive cow handling, faulty milking machine, poor milking techniques and hygiene, and nutritional deficiencies. Therefore, animal behavior or other symptoms cannot be used to diagnose stray voltage problems. The only way to determine if stray voltage is a potential cause of abnormal behaviors or poor performance is to perform electrical testing discussed below. A thorough investigation of the entire production unit should be conducted to determine other sources of problems.

Diagnosis: For confirmation, a potential of 2-4 volt (60 Hz, rms) must be measured between two points that a cow might contact, and some cows should exhibit signs of exposure. Voltage levels may need to be monitored at different times of the day and on different days because the threshold level may be exceeded intermittently. When exposure during milking is suspected, measurements should be made with all electrical milking equipment turned on (both 110 and 220 volt). Although levels of exposure up to 2-4 volts AC are not thought to be detrimental, farms on which lower levels have been detected should be monitored to ensure that higher levels do not occur intermittently. Point-to-point or cow-contact measurement is the best indication of the exposure levels. Point-to-point refers to measurements made between two contact points that the cow might touch simultaneously.

The voltmeter should have high input impedance with full scale reading of 2-5 volts in 0.1 volt increments. All voltage readings should be made with a 500-1,000 ohm resistor across the two measuring leads to the cow contact points in addition to open circuit measurements. Readings without the use of a shunt resistor are meaningless. If more than 1 volt 60 Hz rms is detected at the cow contact points it is advisable to have a qualified electrician and/or the local power supplier evaluate the situation.

Point-to-reference ground measurements can be useful for diagnostic purposes. Cow contact measurements are typically  $\frac{1}{2}$  to  $\frac{1}{3}$  of point to reference voltage and current levels. A reference ground is established with a 4 ft (1.3 m) copper-clad rod driven into the ground 25 ft (8.5 m) from any grounding rods or electrical equipment. The other contact point is typically the secondary neutral buss in the service entrance panel to the barn or some other part of the grounded neutral system. Long, insulated meter leads (6-10 ft [2-3 m]) facilitate taking measurements on the farm and will give a reasonable estimate of 60 Hz electrical events, but will introduced considerable noise to higher frequency measurements.

Recent research has investigated the effects of high frequency or short duration transient voltages on cows. The main sources of these transient voltages on a farm are improperly installed electric fences and switching of electrical devices on that farm. The very high frequency switching transient pulses decay very quickly and do not travel far from their source. Exceptions to this are electric fences, which produce a very powerful electric impulse designed to control animals. This type of pulse is designed to produce aversion but not cause harm to the animal. Improper installation of these devices can cause these pulses to appear in unintended areas on the farm. More voltage and current is required to perceive an electrical pulse, as the duration of the pulse gets shorter. The measurement of high frequency events requires proper equipment and careful measurement technique. Further details on sensitivity levels and measurement techniques are available through the electric power supplier

Prevention and Control: Most on-farm sources of stray voltage are due to wiring systems that do not meet the wiring codes and standards. Deficiencies may include loose or corroded connections, ground faults (shorts), undersized wiring, or damaged wiring (by animals, accidents, or moisture). An electrician should examine the system and repair any defects. Voltage produced by non-faulty 240-volt equipment usually indicates the distribution system as the source and is the responsibility of the utility company to examine and correct.

Cows have been shown to resume normal behaviors within 1 day of removal of adverse voltage/current levels. Conditions produced by abnormal behaviors may take longer to be resolved but should be within 1 month.

Electrical systems should comply with wiring codes and standards at all times to protect both animals and people. Whenever suggestive signs cannot be attributed to other causes, measurements should be taken to determine if a voltage potential exists, and the results recorded for future comparisons. A review of EMF and other electrical exposures by national experts concluded that there was no evidence to suggest that they are harmful to cows at the typical exposure levels found on farms.

## **Current Exposure: Dairy Cows**

1. Phillips, D. S. M. 1962. Production of Cows May Be Affected by Small Electric Shocks From Milking Plants. *New Zealand Journal of Agriculture* 105.  
Abstract: This is the first published study of stray voltage on dairy farms. A limited study of milking plants in New Zealand showed that voltages ranged from zero to as much as 20 volts with most between 3 and 10 volts (60 Hz rms). Voltage levels varied considerably with time. The most important sources of voltage were: unbalanced loads (resulting in high neutral current) and the resistance of the neutral between the shed and transformer (secondary neutral voltage drop). A series of experiments were carried out to establish the lowest level of contact voltage at which there was a response. Voltage was applied to the teat-to-rear hooves pathway. Certain cows were more susceptible to "shocks" than others. Cracked skin reduced the minimum response level. Cows receiving these low voltages gave no outward signs of discomfort. Exposure of 3 volts applied during milking appeared to reduce milk yield on the more susceptible cows. After a series of experiments it was decided that 3 volts would be a likely minimum level for response.
2. Woolford, M. W. 1972. Small voltage in milking plants. *Proceedings of the 2nd Seminar on Farm Machinery and Equipment*. New Zealand Department of Agriculture.  
Abstract: Observations were made of cows when current was applied from front to rear hooves and between a wetted flank and 4-hooves. Behavioral responses were observed when currents reached 3 to 8 mA. Behaviors were judged to be uncomfortable for currents of 4.5 to 12 mA, or 150% of the behavioral response thresholds.
3. Craine, L. B. 1975. Effects on mammals of grounded neutral voltage from distribution power lines. *IEEE Rural Electric Power Conference* 75-303-3-1A.  
Abstract: A group of 70 heifers were allowed the choice between three different waterers with 0, 3, 6 and 8 volts (60Hz rms) applied. *Water consumption and current through cows was measured although the author provided no statistical analysis of the data.* The waterer nearest the cows was reported to have the highest water consumption, regardless of the voltage application. The water consumption at the 3 and 6-volt waterers was reported to be about 20% and 66% lower than the waterer with no voltage applied. In a second experiment 30 heifers were divided into two groups: a control with no voltage exposure and a treatment group. Treatments applied to a waterer in an ascending series from 1.85 to 8 volts (60Hz rms) for 5 days with 2-day recovery periods. No suppression in water intake was reported for the lowest exposure level while suppression was reported at the 4, 6 and 7-volt treatment levels. Cows resumed normal drinking during the 2-day recovery period. The gallons per drink were reported to have increased at all treatment levels. The 8-volt treatment was discontinued after 1 day because many cows refused to drink. A single Jersey cow subjected to increasing AC current applied between a woven copper bridle and 4-hooves exhibited discomfort when 4 to 6 mA of current was applied.
4. Whittlestone, W. G., M. M. Mullord, R. Kilgour, and L. R. Cate. 1975. Electric shocks during machine milking. *New Zealand Veterinary Journal*, 23.  
Abstract: An operant conditioning system has been developed using two manipulanda with the animals being reinforced on a variable ratio with a mean of 25. Reinforcement was provided by feeding crushed barley. The experimental animals were dry, non-pregnant Jersey cows. One of the manipulanda turned on an electric current applied to the teats, the rump or the flank; the other turned the current off. Using a step-wise increase in current in the range 0 to 10 mA, the threshold at which the cow desisted from using the manipulandum that maintained the shock and resorted to the other for its food, was determined. This averaged approximately 7 mA for one teat, 6 mA for the rump, and 4 mA for the chest area. A similar threshold was obtained for the udder when all four teats were

connected to the current source, the total current being of the order of 6 mA.

5. Henke-Drenkard, D. V., R. C. Gorewit, N. R. Scott, and D. M. Skyer. 1982. Sensitivity of cows to transient electrical current. *ASAE Annual International Meeting Technical Paper* No. 82-3029. Abstract: Four levels of electrical current were applied to cows under controlled conditions. Behavioral responses as an indication of sensitivity to current were noted. Endocrine responses were determined but were not found to be more sensitive indicators of sensitivity threshold to current than was behavior.
6. Lefcourt, A. M. 1982. Behavioral responses of dairy cows subjected to Controlled Voltages. *Journal of Dairy Science* 65(4)672-674. Abstract: A simple technique for establishing voltage across individual cows was developed. Five cows were exposed to an ascending current series (0.25 V steps to 1V and 1V steps to 5V) through EKG patches applied to shaved areas on the front and rear legs. By this technique behavioral responses to graded voltages applied across each cow, resistance of each cow, and current passing through each cow that resulted in a mild (flinched, became vocal, or showed any behavioral change in at least two of four or more repeated tests) or distinct (startle response or raised a leg consistently in repeated trials) behavioral response were noted. Most cows showed a mild behavioral response to a current of about 3 mA (which normally corresponded to a voltage across the cow of 0.7 V, 60 Hz rms). One cow responded to a current of less than 1 mA (which corresponded to a voltage across the cow of less than 0.2 V). This technique represents a good stimulus paradigm for investigating effects of stray voltage. Cow resistance varied from 250 to 405 Ohms using this pathway. Mild/distinct responses for each cow were 2.8/3.9; 2.8/4.1; 2.3/3.4; 3.8/5.1; 0.7/1.0 mA rms.
7. Lefcourt A.M., and Akers R.M. 1982. Endocrine responses of cows subjected to controlled voltages during milking. *Journal of Dairy Science (Abstract)* 65, Suppl. 1. Abstract: Cows were subjected to 5 mA (60 Hz rms) of current starting 10 minutes before beginning milking continuously for 20 minutes or intermittently 5 of every 30 seconds. Neither treatment appeared to have an effect on norepinephrine. The continuous treatment had a variable effect on milk yield, milking time and hormonal responses, some cows seemed to adapt and some cows seemed to enjoy the stimulation. Cow subjected to intermittent current showed decreased milk yield and milking time
8. Norell, R. J., R. J. Gustafson, and R. D. Appleman. 1982. Behavioral studies of dairy cattle sensitivity to electrical currents. *ASAE Annual International Meeting Technical Paper* No. 82-3530.
9. Gustafson, R. J., G. S. Christiansen, and R. D. Appleman. 1983. Electrical resistance of milking system components. *Transactions of the ASAE* 26(4). Abstract: The electrical resistance of two components of a milking system were measured for configurations simulating both high and low milk pipelines. Resistance of the milkhose from the milk receiver to the machine claw during milking was found to be inversely proportional to the milk flow rate. Minimum values measured were 79.9 and 30.3 kOhm for high and low lines respectively. On the average, the minimum value was 3.7 times a theoretical full hose value. Minimum resistance from the claw through the cow to the floor was 3 kOhm Estimated voltages across this system required to obtain perception level currents through the cow would be in the range of 50 Vac for the high line and 25 Vac for the low line.
10. Lefcourt, A. M., R. M. Akers, and S. Kahl. 1983. Correlation of Indices of Stress with Level of Electrical Shock for Cows. *Journal of Dairy Science (Abstract)* 66, Suppl 1, P219. Abstract: Electrical shock is commonly used as a paradigm of stress. Cows have a higher tolerance to electric shock than other species. To test this tolerance, seven lactating cows were shocked biweekly for 10s: 0, 2.5, 5.0, 7.5, 10, then 12.5 mA, 60 Hz. At lower mA, cows became tense and showed

limited movement. As mA increased, cows became more agitated. The experiment was terminated because of the severity of behavioral responses. Heart rate immediately after shock increased with mA and was significantly different from baseline at 10 mA (+17 beats/min.) and 12.5 mA (+30 beats/min.). Prolactin and glucocorticoids were unaffected by shock; however, both increased pronouncedly following a single recannulation prior to blood sampling. Norepinephrine was unaffected by shock or recannulation. Epinephrine doubled in two exceptional cows at 10 mA. The two exceptional cows showed consistent glucocorticoid responses, had consistently elevated baseline heart rates and prolactin, and were the only cows not shocked at 12.5 mA due to severe behavioral responses. The dramatic behavioral responses displayed by cows subjected to electrical shock were not correlated with significant or prolonged physiological responses. This dichotomy, although probably exaggerated in cows, suggests that shock may not be a good paradigm of "stress".

11. Norell, R. J., R. D. Appleman, and R. J. Gustafson. 1983. Electrical Sensitivity of Dairy Cattle. *NMC: National Mastitis Council, Proceedings 22nd Annual Meeting*.  
Abstract: Recent research at the University of Minnesota was designed to determine the: 1) Resistance of different pathways through the cow's body, 2) current required to affect the cow, and 3) current necessary for the cow to detect a voltage. Significant variation in resistance was found both among pathways through the cow and among cows. The lowest resistance appeared to be the mouth-all hooves pathway, a pathway likely to be common in milking parlors. Ten percent of the population is expected to have a resistance of less than 250 ohms, 25 percent less than 300 ohms, and about half the cows less than 360 ohms. Combining the pathway resistance data and cow sensitivity data results in an indication of the voltage drop across the pathway necessary for a response. Assuming that current sensitivity is not a function of pathway resistance, Figure 3 plots the voltage versus percent response rate by population percentiles for the mouth - all hooves shocks. For example, at 1.5 volts mouth - all hooves, 90% of the population would respond nearly 30% of the time, 50% would respond 50% of the time and 10% would respond over 90% of the time.
12. Norell, R. J., R. J. Gustafson, R. D. Appleman, and J. B. Overmier. 1983. Behavioral studies of dairy cattle sensitivity to electrical currents. *Transactions of the ASAE* 26(5).  
Abstract: Electrical resistance data were collected for 8 pathways through dairy cows. Significant variation in resistance was found between pathways through individual cows and between cows. The mean path resistances ranged from 359 ohms for a mouth-all hooves pathway to 738 ohms for a front-rear hooves pathway. The distribution for the mouth-all hooves pathway showed 25% of the population below 302 ohms and 75% below 441 ohms. Three experiments assessing animal sensitivity to current based on behavioural indicators were performed. No suppression of a learned response to obtain food was found up to 6.0 mA front-rear hooves shock. However, muzzle-all hooves shocks as low as 1.0 mA suppressed plate pressing behavior. A specific avoidance response to a mouth-all hooves shock was exhibited 13.8% of the time at 1.0 mA and 92.3% at 4.0 mA, while a learned escape response to a front-rear hooves shock above a normal activity level occurred between 2.0 and 3.0 mA.
13. Gorewit, R. C., N. R. Scott, and D. V. Henke-Drenkard. 1984. Effects of electrical current on milk production and animal health. *ASAE Annual International Meeting Technical Paper* No. 84-3502.  
Abstract: Effects of transient electrical current on animal behavior, physiological responses, and milk production are presented. Cows exhibit behavioral response between 2 and 4 mA. Current applications up to 8 mA applied between the udder and four hooves do not cause significant reductions in milk production or adversely affect milk composition. Hormone responses were minimal.
14. Norell, R. J. 1984. Dairy Cattle Sensitivity to Electrical Shocks as Determined with Behavioral Indices. Dissertation, University of Minnesota, St. Paul MN.  
Abstract: Electrical resistance differed between 8 body pathways in 28 Holstein-Friesian cows given

electric shock; e.g. the measured resistance of a mouth/all hooves pathway (359 ohm, with 20% below 302 ohm) was only 40% that of the highest resistance pathway (teat/front hooves). In 4 behavioral trials feeding was affected 13.8% of the time in cows given 1 mA by the mouth/all hooves route; 92.3% of the time when the current was raised to 4 mA. Cows responded to front/rear hooves shocks >2 mA; normal movement towards a parlor stall was inhibited by such a shock at 4 mA but not at 2.66 or 1.33 mA. Milking performance and parlor entry order were not affected by treatment. Given normal resistance, therefore, shock responses in cows can be expected to start occurring at about 0.36 V.

15. Appleman, R. D., and R. J. Gustafson. 1985. Behavioral Experiments Quantifying Animal Sensitivity to AC and DC Currents. *ASAE, Stray Voltage: Proceedings of the National Stray Voltage Symposium* .  
Abstract: Cow responses to various electrical current applications were analyzed to determine; 1) Aversion to learned response - determining current levels that alter a learned response such as food acquiring response. 2) Learned escape response - determining current level applications required for an animal to exhibit an escape response (front hoof pick-up would terminate the shock). 3) Grid crossing response - determining cow reactions when stepping from one grid to another of different voltage potential between the prep stall and milking stall. The study concluded that: 1) Suppression currents (current levels causing aversion responses) were consistently between 3.0 and 4.5 mA for two groups studied. However, a suppression threshold cannot be clearly defined from the study. 2) Learned escape response rates exceeded 90% at current levels over 4.0 mA. 3) While cows expressed inhibited grid crossing behavior, milk yield and machine on-time ratios were not significantly influenced by grid crossing experiments. Further research needs were also defined in this study; 1) Is there a carry-over effect on cattle after long-term exposure to stray voltage? 2) To what extent do cattle habituate or become sensitized to electrical shock? 3) Do "sensitive" cows have conditions that cause them to exhibit lower resistance and greater sensitivity to current ? 4) How frequently and to what extent do stray voltages affect other species of farm animals?
16. Appleman R.D., and Gustafson R.J. 1985. Source of stray voltage and effect on cow health and performance. *Journal of Dairy Science* 68(6)554-1567.  
Abstract: This review of literature summarizes off-farm and on-farm causes of stray voltages, tabulates electrical resistance of different parts of the cow's body, considers behavioral, endocrine and milk-yield responses to stray voltages and suggests methods for correcting stray voltage problems. As far as the effect of stray voltage on cows is concerned the authors conclude that the primary effect is behavior modification which then affects performance, rather than physiological modification. *The authors state that, based on research done to that point, less than 10% of cows are thought to perceive contact voltages below 0.35 V (60 Hz rms) (subsequent research on large sample sizes has refined this estimate), behavioral modification may occur above 0.7 V (60 Hz rms) and endocrine response above 3 V or 8 mA (60 Hz rms).* As a goal, a maximum neutral voltage of 0.35 V is suggested, although it is stated that problems are minimal in herds where neutral-earth voltage at full load remains below 0.7 V.
17. Gorewit R.C., D. V. Henke-Drenkard, and N. R. Scott. 1985. Physiological effects of electrical current on dairy cows. *ASAE, Stray Voltage: Proceedings of the National Stray Voltage Symposium* ASAE Publication 3-85.
18. Gorewit, R. C., N. R. Scott, and C. S. Czarniecki. 1985. Responses of dairy cows to alternating electrical current administered semirandomly in a nonavoidance environment. *Journal of Dairy Science* 68(3)718-725.  
Abstract: In four 96-h periods 8 pregnant Holstein-Friesian cows in wk 16-20 of lactation were in treatment or control groups. Each period was divided into 4 sub-periods of 24 h during which cows on treatment were given shocks of 4 mA at 30 s intervals during 5 min in every 4 h, via subdermal

electrodes on the spine. The treatment and control cows were alternated in consecutive periods. Milk yield was slightly but not significantly decreased by the shock treatment (down 0.16 kg/milking), but milk composition, and feed and water intake were not affected. Milk somatic cell count tended to increase during treatment, but again the increase was not significant. Behavioural responses were greatest on first exposure, but cows became accustomed to shocks within 24 h.

19. Gustafson, R. J., T. M. Brennan, and R. D. Appleman. 1985. Behavioral studies of dairy cow sensitivity to AC and DC electric currents. *Transactions of the ASAE* 28(5).  
Abstract: Dairy cow behavioral responses to alternating and direct current were examined for three body pathways: mouth-to-all hooves, front-to-rear hooves, and body-to-all hooves. For mouth-to-all hooves and front-to-rear hooves pathways, response frequency functions were obtained over a range of 0-5mA AC and 0-6 mA DC. At significant levels of response, a higher DC than AC current was needed to obtain the same response. At a 50% response rate, a 34% higher DC current than AC was needed for the front-to-rear path and 22% higher for mouth-to-all hooves. Front-to-rear hooves response rate became statistically significant above 2.0 mA AC and 1.0 mA DC. Mouth-to-all hooves response rate became significant above 2 mA AC and 4 mA DC. Response rate for a body-to-all hooves pathway with currents from 0 - 7.5 mA AC and 0-9 mA DC were inconclusive. No reliable response pattern was obtained for this body pathway.
20. Henke-Drenkard, D. V., R. C. Gorewit, N. R. Scott, and R. Sagi. 1985. Milk production, health, behavior, and endocrine responses of cows exposed to electrical current during milking. *Journal of Dairy Science* 68(10)2694-2702.  
Abstract: Six cows were exposed during milkings to electrical current to assess its effects on behavior, health, milking performance, and endocrine responses. Three treatments (0, 4, and 8 mA) were applied in a changeover design over three consecutive 1-wk periods. A cow received the same current treatment during 14 consecutive milkings, beginning with the evening milking (d 1) and ending with the morning milking (d 8). Treatments began 5 min. before milking and continued until milking unit removal. Treatments consisted of 60 Hz square wave current of 5-s duration applied every 30 s from udder to hooves. Milk accumulation curves provided information about milk yields, milking times, peak milk flow rates, and times of peak milk flow. Residual milk yields also were measured. Milk was analyzed for protein, fat, and somatic cells. Blood samples from 60 min before to 60 min after treatment were collected, and oxytocin, prolactin, and cortisol concentrations were measured. Behavioral responses to current decreased with time. Changes of milking performance and milk composition were not significant. Changes of milking related cortisol responses during 8-mA current stimulation were significant. Oxytocin release was delayed during 8-mA treatments. Current treatments did not affect prolactin.
21. Lefcourt, A. M. 1985. Physiological stress response to electric shock. *ASAE, Stray Voltage: Proceedings of the National Stray Voltage Symposium* ASAE publication No. 3-85.
22. Lefcourt A.M., Akers R.M., Miller R.H., and Weinland B. 1985. Effects of intermittent electrical shock on responses related to milk ejection. *Journal of Dairy Science* 68(2)391-401.  
Abstract: Groups of 7 and 6 cows respectively were subjected to 3.6 mA or 6.0 mA intermittent electric shock (5 s on, 25 s off) over 7 days at a.m. and p.m. milking, beginning as cows underwent 1 min preparation for milking. Milk yield, milking time and Wisconsin Mastitis Test scores were not affected by shock on comparing these variables with values obtained 5 days pre- and post-shock; maximum rate of milk flow increased slightly. The number of behavioral responses (e.g. lifting of legs) increased significantly. Heart rate increased by 3 beats/min in response to the initial shock. Milking-induced prolactin release appeared to be potentiated, with peak concentration and area under prolactin response curves increased similarly in both groups. Time to peak oxytocin response was significantly longer in the 3.6 mA group, however, oxytocin responses were otherwise unaffected. All measured variables showed significant differences between a.m. and p.m. milkings. Results

suggest that milk yield will not be adversely affected in the short term in cows subjected to stray voltage, but behavioral responses may present problems.

23. White, S. S., J. R. Bolton, and D. M. Fraser. 1985. Use of electro-acupuncture as an analgesic for laparotomies in two dairy cows. *Australian Veterinary Journal* 62(2).  
Abstract: Electro-acupuncture was used as the sole analgesic for standing laparotomies of 2 Friesian cows. Needles placed in the lumbosacral space, and second lumbar interspinous space and high in the lumbar fossa were stimulated with AC current at 15 to 28 Hz. The analgesia produced was similar to that of a paralumbar nerve block. In cow 1 and estimated output of 121 mV rms produce satisfactory analgesia. Cow 2 had no satisfactory analgesia after 20 Min so the frequency was increased to 28 Hz and the output adjusted to an estimate 160 mV rms. Satisfactory analgesia was produce after a further 30 min. Electro-acupuncture stimulation was applied for a duration of 3 h in cow 1 and 2 h in cow 2. The satisfactory use indicates that electro-acupuncture may be a realistic alternative to local anesthetic agents.
24. Brennan, T. M., and R. J. Gustafson. 1986. Behavioral Study of Dairy Cow Sensitivity to Short AC Currents. *ASAE Regional Meeting Technical Paper* No. NCR-86-202.
25. Gorewit, R. C., and N. R. Scott. 1986. Cardiovascular responses of cows given electrical current during milking. *Journal of Dairy Science* 69(4)1122-1127.  
Abstract: Six Holstein cows in late lactation were used to determine effects of 4-mA square wave alternating current on mammary gland blood flow rate, heart rate, and blood pressure. Current to the lumbar-sacral region of the cows' back was applied 10 s prior to udder massage and throughout milking. Heart rate was measured from systolic pulses (beats/min.) off strip chart recordings. Blood pressure determinations were made from carotid arterial cannulae. A single rise in blood flowrate occurred during milkings without current. Mammary blood flow increased (30% with respect to rest) without 40 s of milking. Heart rate and blood pressure did not change significantly. An abrupt increase in mammary blood flow rate, heart rate, and blood pressure was seen immediately upon current application prior to milking. Mammary blood flow rate increased 50%, heart rate 25 beats/min, and blood pressure 33 mmHg. The response latency was approximately 60 s. A second rise in mammary blood flow (31%) was milking induced, occurring within 42 s of milking machine attachment. Milk yield was not influenced by current. Our data suggest that 4-mA of alternating current, applied prior to and throughout milking, causes an immediate elevation in mammary blood flow rate, heart rate, and blood pressure of cows. Cardiovascular responses are short-lived. Current given throughout milking does not influence normal physiological changes in mammary blood flow during milking.
26. Lefcourt, A. M., S. Kahl, and R. M. Akers. 1986. Correlation of Indices of Stress with Intensity of Electrical Shock for Cows. *Journal of Dairy Science* 69(3)833-842.  
Abstract: Electrical shock is commonly used as a paradigm of stress. Cows have a higher tolerance to electric shock than other species. To test this tolerance, seven lactating cows were shocked biweekly for 10s: 0, 2.5, 5.0, 7.5, 10, then 12.5 mA, 60 Hz. At lower mA, cows became tense and showed limited movement. As mA increased, cows became more agitated. The experiment was terminated because of the severity of behavioral responses. Heart rate immediately after shock increased with mA and was significantly different from baseline at 10 mA (+17 beats/min.) and 12.5 mA (+30 beats/min.). Prolactin and glucocorticoids were unaffected by shock; however, both increased pronouncedly following a single recannulation prior to blood sampling. Norepinephrine was unaffected by shock or recannulation. Epinephrine doubled in two exceptional cows at 10 mA. The two exceptional cows showed consistent glucocorticoid responses, had consistently elevated baseline heart rates and prolactin, and were the only cows not shocked at 12.5 mA due to severe behavioral responses. The dramatic behavioral responses displayed by cows subjected to electrical shock were not correlated with significant or prolonged physiological responses. This dichotomy, although

probably exaggerated in cows, suggests that shock may not be a good paradigm of "stress".

27. Pascoe, P. J., and W. N. McDonell. 1986. The noxious effects of electro-immobilization in adult Holstein cows: a pilot study. *Canadian Journal of Veterinary Research* 50(2).
28. Aneshansley D.J., Gorewit R.C., Ludington D.C., Pellerin R.A., Xin Z., and Zhao X. 1987. Effects of neutral-to-earth voltage on behavior, production and water intake in dairy cattle. *ASAE Annual International Meeting Technical Paper* no. 87-3034.  
Abstract: Heifers and cows were exposed to five voltages (0-4 V) while drinking. Exposure was continuous for 21 days. No significant difference in water consumption, feed intake, milk production or concentration of fat or protein in the milk was found, though significant changes in drinking behavior (number of drinks/d and duration of drink) were noted.
29. Aneshansley D.J., Gorewit R.C., Pellerin R.A., Ludington D.C., and Price L.R. 1987. AC voltages on milking units: effects on behavior and production. *Journal of Dairy Science (Abstract)* 70(S1).  
Abstract: Eight cows were exposed to 0, 4, 8 and 16 Vrms applied through electrodes at the distal end of the inflations. Each cow received all treatments in a random design on four consecutive milkings over two days. Milk production, residual milk, machine-on time, milk composition, behavioral response and current (temporal pattern during milking and maximum value) were measured. Cows were monitored for two weeks prior to treatment to obtain normal production values. No significant difference was found between these values and treatments. Behavioral responses (kicking machines off and "dancing") were observed with 8 and 16 volts and only when these voltages produced currents in excess of 8-10 mA. Current appeared to increase with milk flow.
30. Cloud, H. A., R. D. Appleman, and R. J. Gustafson. 1987. Stray voltage problems with dairy cows. Rev. 1987. *University of Minnesota Extension Service, NCR Publication 125*.  
Abstract: There are three general classifications of symptoms, related to 1) behavior modification 2) milking characteristics and 3) production performance. It must be remembered, however, that many factors other than stray voltage may cause herd behavior or health and production problems. Both controlled research and observation on problem farms clearly shows that animals subjected to stray voltages are likely to exhibit a change in behavior. Generally speaking, higher voltages are required to limit water or feed consumption than to alter the other behavioral characteristics discussed previously. Poor milk letdown, incomplete milkout and increased milking time are common symptoms expressed by dairy farmers having stray voltage problems. Researches haven't been successful in identifying any significant hormonal changes. However, researchers have demonstrated that the milking machine hose, even under high flow rates, is not a likely pathway for electrical currents to the cow. If the stray voltage problem is severe enough to affect cows' behavior milkout may be influenced. Mastitis infections aren't directly caused by stray voltages. However, if cows behavior is modified, and if the milking routine is altered because of the cow's behavior, what may result is a less satisfactory milking performance, increased somatic cell counts, and more clinical mastitis. If cows drink less water, consume less food or become more mastitic, they are likely to produce less milk. Whether or not milk production will be adversely affected by stray voltage depends on the extent to which the cows' behavior is altered and how management compensates. The failure of controlled research to find a direct physiological effect in animals subjected to stray voltages, and the absence of documented case studies demonstrating a marked improvement in these traits upon correction of an existing problem leads to the conclusion that there is no direct and causal relationship.
31. Currence H.D., Steevens B.J., Winter D.F., Dick W.K., and Krause G.F. 1987. Dairy cow and human sensitivity to 60 hertz currents. *ASAE Annual International Meeting Technical Paper* no. 87-3036.  
Abstract: The effect of length of duration of electrical current which lactating dairy cows responded was studied and the residual effect of previous shock was evaluated. Significantly higher currents

were required for 1 cycle current duration than for 10 and 100 cycle durations. Similar studies were conducted using humans.

32. Gorewit R.C., Zhao X., Aneshansley D.J., Ludington D.C., Pellerin R.A., and Xin Z. 1987. Effects of neutral-to-earth voltage on animal health and reproduction in cattle. *ASAE Annual International Meeting Technical Paper* no. 87-3035.  
Abstract: Currents of 0.5, 1, 2 and 4 V were applied to the drinking cups of 28 lactating Holstein dairy cattle for a 21-day period. These voltage levels, applied in this fashion, did not influence significantly animal health or reproductive performance.
33. Aneshansley D.J., Gorewit R.C., Price L.R., and Czarniecki C.S. 1988. Effects of discontinuous voltages applied to waterers. *ASAE Annual International Meeting Technical Paper* no. 88-3523.  
Abstract: Holstein cows were exposed to a fixed voltage, 5V or 8V, 1 sec. pulses applied 50% of the time, or to 8-V, 1 sec. pulses applied randomly. No significant changes in average water intake, milk production, milk quality or somatic cell counts were found. Significant changes in average drinking patterns did occur and some individual animals did show significant changes.
34. Aneshansley, D. J., R. C. Gorewit, Price L.R., D. C. Ludington, and Pellerin R.A. 1988. Stray-voltage: Effects on machine milking . *NRAES Milking Systems and Milking Management Symposium Proceedings Handbook* No. 26.
35. Gorewit R.C., Aneshansley D.J., Ludington D.C., and Pellerin R.A. 1988. Delays in drinking due to AC voltages. *ASAE Annual International Meeting Technical Paper* no. 88-3524.  
Abstract: The ability of cows and heifers to adapt to voltages >2 V at their water source was investigated. Voltages of 3, 4, 5 and 6 V at 60 Hz were applied between the water bowl and a metal mat under the rear hooves during drinking. All the cows drank within 36 h of voltage application but 4 heifers did not drink at the 5 and 6 V treatments. The time required to drink 1 gallon of water after voltage application increased with voltage, and delays in drinking at the 5 and 6 V treatments reduced milk production in the short term (1 d). Milk production recovered within 2 d even during continued exposure to the voltage.
36. Gustafson R.J., Sun Z.Y., and Brennan T.M. 1988. Dairy cow sensitivity to short duration electrical currents. *ASAE Annual International Meeting Technical Paper* no. 88-3522.  
Abstract: For cow sensitivity to short duration monophasic electric currents, it was found that current level increase for shorter time periods. Two expressions were developed to describe that data collected. A neuroelectric model, based on a form used to describe cell stimulation, is not fully satisfactory for the data collected. Further study over expanded time, current range and with large cow numbers is needed in this area. Based on the available data, a statistical expression developed which can be used to describe the strength/duration relationship for times ranging from 0.1 to 300 mS is  $I_s = 11.02 \times t^{(-0.16)} [=]$  (mA) t is duration of stimulation in mS. The resistance of the mouth-to-all hooves pathway is not constant. The resistance decreases exponentially as the current increases. This should be taken into consideration by the further studies in estimating cow body pathway resistance.
37. Krisch Zehl, C. 1988. Influence of acupuncture and electro-acupuncture on plasma-LH [luteinizing hormone] and progesterone concentrations in cattle.: Einfluss von Akupunktur und Elektroakupunktur auf die LH- und Progesteronkonzentrationen beim Rind. *Muenchen Univ. (Germany, F.R.). Tieraerztliche Fakultaet. Inaugural-Diss. (Dr. Med. Vet.)*.
38. Reese N.D., Surbrook T.C., and Li C.M. 1988. Defining circuit parameters in the animal neutral-to-earth voltage path. *ASAE Annual International Meeting Technical Paper* no. 88-3525.  
Abstract: Circuit impedances in the animal neutral-to-earth voltage path were examined theoretically

and practically to determine representative values. Predicted values are compared with actual field measurements, and the measurements themselves described and discussed in detail. The circuit path is viewed as a collection of discrete impedances and each is examined for normal ranges and variations, rather than as a whole as in previous studies. Contact resistance between hoof and floor, and via the milk stream and clawpiece assembly, was not an important part of the neutral-to-earth voltage path through the animal.

39. Gorewit R.C., Aneshansley D.J., Ludington D.C., Pellerin R.A., and Zhao X. 1989. AC voltages on water bowls: effects on lactating Holsteins. *Journal of Dairy Science* 72(8)2184-2192.  
Abstract: Water intake, milk yield, feed consumption and milk composition of lactating cows were monitored before, during, and after 21-day exposures to voltage. 15 first parity and 15 multiparous cows were divided equally among 5 treatments (0, 0.5, 1, 2, and 4 V) in which voltages were applied continuously between water bowls and metal floor mats. Initial application caused delays in drinking, which increased with voltage. Two animals receiving 4 V did not drink for 36 h, at which time their voltages were disconnected. All other animals drank within 36 h and showed no significant long-term difference in the monitored parameters. Drinking behaviour in the presence of voltage was investigated further by exposing 44 first parity and 40 multiparous cows to voltage (3, 4, 5, or 6 V) for 2 days. Four first parity cows receiving 5 or 6 V did not drink for 36 h while all other animals did. Delays in resumption of drinking increased with voltage. In total, all 42 animals exposed to 3 V or less adapted within 36 h, as did 60 of the 66 Holsteins (91%) exposed to 4 to 6 V.
40. Aneshansley, D. J., and C. S. Czarniecki. 1990. Complex electrical impedance of cows: measurement and significance. *ASAE Annual International Meeting Technical Paper* no. 90-3509.  
Abstract: Complex impedances were measured in Holstein cows (1st through 4th lactation) between 10 and 100,000 Hz. A circuit model developed for humans appears to be appropriate for cows. Currents delivered at frequencies about 1,000 Hz were well above perception levels at 60 Hz but caused no behavioral responses.
41. Aneshansley, D. J., L. R. Price, R. C. Gorewit, and C. S. Czarniecki. 1990. Cow sensitivity to currents during milk ejection. *ASAE Annual International Meeting Technical Paper* no. 90-3505.  
Abstract: AC currents were delivered to cows (1st - 5th parity) through the milk during milking. Undesired behaviors occurred at currents greater than 5mA for 1st parity cows and at more than 8 mA for other cows. Currents caused no changes in milk production, milk quality or levels of cortisol.
42. ———. 1990. Milk production with voltage exposure during entire lactation. *ASAE Annual International Meeting Technical Paper* no. 90-3502.  
Abstract: Three groups of 10 Holsteins (2nd-5th lactation) were exposed to voltage (1,2 or 4 V) at waterers over their full lactation. A fourth group received no voltage. No significant reductions in milk production, milk quality, or water intake was found when comparing "no-voltage" cows to cows that received voltage.
43. Currence H.D., Steevens B.J., Winter D.F., Dick W.K., and Krause G.F. 1990. Dairy cow and human sensitivity to short duration 60 Hertz currents. *Applied Engineering in Agriculture* 6(3).  
Abstract: The effect of length of duration of 60 Hz, sinusoidal electric current (1, 10 and 100 cycles) on the current magnitude to which lactating dairy cows responded was studied and the residual effect of previous shock was evaluated. Significantly higher currents were required for the 1 cycle current duration than for 10 and 100 cycle durations. Results of a study to determine human response to currents of similar durations are also reported. *Current was applied to twenty-four dairy cows from one front to one rear hoof of dairy cows while trained observers indicated behavioral responses. The average response for all cows was 3.6 mA (60 Hz rms) for multiple cycle events and ranged from 2.2 mA (60 Hz rms) for the most sensitive cow to 5.4 mA (60 Hz rms) for the least sensitive cow. The average response for all cows was 5.5 mA (60 Hz rms) for single cycle event and ranged from*

3.2 mA (60 Hz rms) for the most sensitive cow to 8.8 mA (60 Hz rms) for the least sensitive cow. The current levels for dairy cow response were almost an order of magnitude higher than for humans.

44. Cutshaw, J. L., J. F. Hunter, and G. L. Williams . 1990. Transcutaneous Electrical Nerve Stimulation of the Teat Does Not Activate Neuronal Pathways that Suppress Gonadotropin Release in Cows. *Journal of Animal Science* 68(S1).  
Abstract: The objective of this study was to determine if a non-specific, but complete, activation of continuous neuroreceptors in the teat through chronic transcutaneous electrical nerve stimulation would prevent the post-weaning rise in luteinizing hormone (LH) secretion. Twenty postpartum (PP) suckled cows were randomly assigned to 1 of 4 groups (n=5) at calving: 1) suckled (S), 2) weaned (W), 3) electrical stimulation of the teat (ESTT), and 4) electrical stimulation of the tail (ESTL). All cows were ovariectomized on day 5 PP and two 70 x 5.65 mm estradiol 17beta implants were placed SC to provide a tonic level of estrogen stimulation (2.6 pg/ml  $\pm$  10). Calves from W, ESTT and ESTL were temporarily weaned on day 17-21 PP (day 0) and returned to cows after 4 d. Cows were control-suckled (S) or electrically stimulated (ESTT and ESTL) for 10 min every 6 hr. for the 4-day weaned period. Stimulation provided a continuous current alternating between 2.00 and 2.75 mA every 1.33 seconds. Between day 0 and 2, luteinizing hormone (LH) pulse frequency (pulses/6 h) increased ( $P < 0.006$ ) in W, ESTT and ESTL (4.6 $\pm$ 1.0, 5.6 $\pm$ 1.0, 4.4 $\pm$ 0.9, respectfully) and was greater ( $P < 0.003$ ) than S (0.4 $\pm$ 0.4) on days 2 and 4. Frequency of LH pulses in W, ESST and ESTL on day 10 had diminished to between 0 and 1.2 pulses/6 h and was not different than S. LH pulses amplitude in W, ESSTT and ESTL (1.4 $\pm$ 0.4, 1.7 $\pm$ 0.5, 1.2 $\pm$ 0.4, respectfully) was greater ( $P < 0.003$ ) than S (0.09 $\pm$ 0.09), on day 2, but did not differ on day 4 and 10. Mean concentrations of LH (ng/ml) were greater ( $P < 0.001$ ) in W, ESTT and ESTL (1.39 $\pm$ 0.2, 1.68 $\pm$ 0.2 and 1.07 $\pm$ 0.2, respectfully) than S (0.72 $\pm$ 0.05) on days 2 and 4, but not on day 10. Electrical stimulation of the teat does not suppress the rise in gonadotropin secretion following acute weaning, but return of the suckling calf effects a potent reversal of this response in ovariectomized females.
45. Gorewit, R. C., L. R. Price, D. J Aneshansley, and C. S. Czarniecki. 1990. Holsteins' reproductive performance during long-term voltage exposure. *ASAE Annual International Meeting Technical Paper* no. 90-3503.  
Abstract: AC voltages (1, 2 or 4 Vrms) were applied to waterers of lactating cows for a complete lactation. These voltages did not influence animal health or reproductive performance.
46. Hultgren, J. 1990. Small electric currents affecting farm animals and man: a review with special reference to stray voltage. II. Physiological effects and the concept of stress. *Veterinary Research Communications* 14(4).  
Abstract: The literature on the influence of small, steady electric currents on animal health, especially cardiovascular and endocrinological functions and milk let-down, and the effects on milk production is reviewed, with special reference to the problem of stray voltage. Direct physiological effects in cows may occur above 4 mA. How the long-term effects may contrast with the acute effects is not known. Habituation may occur. The altered behaviour and physiological changes due to exposure to stray voltage may be termed a stress response. The type of stress most likely to be encountered is chronic. Whether or not stress occurs depends on the timing and context of exposure and on individual cognition. Hence stray voltage may threaten farm animal health and production wherever modern animal housing is applied.
47. Hultgren J. 1990. Small electric currents affecting farm animals and man: a review with special reference to stray voltage. I. Electric properties of the body and the problem of stray voltage. *Veterinary Research Communications* 14(4).  
Abstract: The literature on the electrical properties of the body and sensitivity to steady electric current in humans and farm animals is reviewed and the problem of stray voltage is examined. Stray

voltage poses a problem to animal health and protection in cattle and pigs and possibly also in other animals. Dairy cattle can perceive alternating currents exceeding 1 mA between the mouth and all four hooves. Behavioural effects in cows usually occur above 3 mA. In practice, the major influence on dairy cows appears to be behavioural. In experimental research on sensitivity to electric current, the effects studied should be related primarily to the actual current densities or electric fields in the affected tissues rather than to the total voltages applied. Under normal conditions, herdsmen are less likely to be affected by stray voltage than their animals.

48. Price, L. R., D. J. Aneshansley, R. C. Gorewit, and C. S. Czarniecki. 1990. Voltages Applied to Waterers During a Full Lactation: Effects on Milk Yield, Composition and Quality. *Journal of Dairy Science (Abstract)* 73(S1).  
Abstract: Four groups of 10 Holstein cows were exposed to 0, 1, 2 or 4 V over an entire lactation. Each group was housed in a free stall environment with bunk feed and water ad lib. Voltages (a.c., 60 Hz) were applied between waterers and a metal grid. Animals could not drink without having their front hooves on the metal grid. Individual records were maintained for milk wt, milk fat, protein and somatic cell counts. Av. actual (16,121; 18,799; 15,296 and 17,030 for 0-4 V respectively) and mature-equivalent (17,200; 20,462; 16,111 and 19,645 for 0 to 4 V respectively) milk wt for 305 days showed no significant differences between no voltage and voltage groups ( $P>0.06$ ,  $P>0.50$  and  $P>0.14$  for no voltage compared with 1-4 volts respectively). Average actual milk yields for 305 days in the previous lactations were 17,672; 17,997; 16,930 and 17,363 for 0-4 V groups respectively. Somatic cell counts, milk fat and protein showed no significant differences between no voltage and voltage groups (for all variables  $P>0.39$ ,  $P>0.78$ ,  $P>0.70$  for no voltage compared with 1-4 V respectively).
49. Aneshansley, D. J., and R. C. Gorewit. 1991. Effects of Electrical Voltage/Current on Farm Animals: Physiological and Behavioral Effects. *USDA Handbook 696, U.S. Dept. of Agriculture, Washington, D.C., USA*.  
Abstract: Current level is of critical importance because animals respond to the current passing through their bodies, and not directly to the voltage that generated the current. During electrical contact, it is actually the total series impedance that limits the current cow or human receive and not just the body impedance. The total series impedance is the sum of source, path, contact and body impedances. The minim current needed to cause cows to lift their legs or open their mouths more often than the do normally can be as low as 0.5 mA to as much as 5 mA. Older recommendation for tolerable levels of cow contact voltages (0.5 V (1980) and 0.7 V (1987)) were based on the lowest values for perceive currents an low values for body, contact, path and source impedances. These past voltage recommendations need to be reviewed in light of recent research which indicates that when currents are below 6 mA for a short term (21 days), production, reproduction, and animal health are not affected: nor is there a sufficient effect on the levels of hormones naturally released during milking or in response to stress. Some moderate behavioral changes are evident, however, at currents between 3 and 6 mA. When currents above 7 mA are delivered through the milk, milking machines are kicked off. Although there is no conclusive evidence, it appears that behavioral changes which might require additional labor could occur at voltages as low as 1.5 V (3 mA). However, it also appears that the large majority of cows probably do not demonstrate problem behaviors until voltages are about 3 or 4 V. Theses voltage estimates are based on total impedances of 500 or 1,000 ohms. Direct economic effects have been show at voltage of 4 V and above, but only in a small percentage of cases where animals refused to drink for 36 hours (6 of 90 animals). For these six animals, production dropped rapidly during this period and significant health problems would have occurred if the animals had not been given alternate sources of water. Experiments involving long-term exposures of cows to voltage also indicate that cows acclimate physiologically and behaviorally to constant and intermittent currents below 6 mA. Base on current research cow contact voltages form low impedance sources should be kept less than 2 to 4 V. Cow contact voltages between 1 and 4 V from low impedance sources may cause behavioral effects resulting in

increased labor costs and/or inappropriate response of farmers to the changes in behavior. These possible increased costs have to be balance against the cost of reducing voltage in the range of 1 to 4V. Once cow contact voltage reaches 1.0V, a program of routine monitoring should be initiated to ensure that the voltages do not increase significantly. Attempts have been made to link stray voltage/current problems with herd health problems. Cows normally experience various health problems, including mastitis. Mastitis, or infection of the mammary gland, is a fact of life in the dairy industry. Animal susceptibility and treatment as well as milking ad hygiene practices are directly related to problems with mastitis. Electrical current cannot directly cause infections. It can affect the etiology of mastitis only indirectly e.g. when a milking machine kicked off by a cow is reattached without first being cleaned. It should be emphasized that factors such as mistreatment of cows, milking machine problems, disease, poor sanitation, and nutritional disorders can cause cows to exhibit all the symptoms that have been reported to occur on farms reporting stray voltage.

50. Lefcourt, A. M. 1991. Annotated Summary and Recommendations: Effects of Electrical Voltage/Current on Farm Animals. *USDA Handbook 696, U.S. Dept. of Agriculture, Washington, D.C., USA.*

Abstract: This handbook is an excellent review of the sources of “stray voltage”, measurement and diagnostic techniques, research on sensitivity of dairy cows and responses to current exposure and mitigation methods. This comprehensive review is the consensus opinion of 15 scientists recognized as credible researchers and viewers of scientific literature who were active in farm electric issues at the time of this publication. From the Preface: There were two primary reasons for publishing this handbook. First, we as scientists were distressed that our research results were being misinterpreted and misconstrued in media and in courtrooms. Second, we were disheartened by the animosity that sometimes arose among livestock farmers, dairy equipment manufacturers and public utility companies because of lack of understanding of the causes and effects of stray voltage on farms. To eliminate any and all potential for even the appearance of bias, we decided to accept no industry funding whatsoever. The USDA was chosen as a publisher because it represents an unbiased source of funds to pay for publication ...and because federal publications are 1/understood by the general population to be unbiased and 2/ normally viewed as expert testimony in legal proceedings. Each contributor signed a notice acknowledging that the manuscript was factually correct and a faithful representation.

The final recommendations of this group of experts include the following: Recommendations are expressed in terms of voltages (Vac as rms values) because voltage is the easiest and most commonly made measurement. However, as discussed throughout this handbook, animals respond to the electrical current generated by a voltage and not to the voltage directly. To relate voltage measurements to current, the worst case (500 Ohms) and more realistic (1000 Ohms) impedances were used. In any case, when a voltage is detected, it must be confirmed that the measured voltage has a low source impedance, i.e. that the voltage can deliver a current of sufficient magnitude to exceed level of concern. We suggest that contact voltage in excess of 2 to 4 V on farms are excessive and recommend their reduction. We recommend a range of action levels from 2 to 4 V to be as conservative as possible and to account for indirect losses use to problems resulting from inappropriate response of farmers to changes in animal behavior. Only under the most unusual circumstance can a cow detect voltage less than 0.5 to 1.0 V. Thus attempts to reduce cow contact voltages to below 0.5 to 1.0 V are unwarranted, and totally unnecessary. It is hoped that his handbook will help people to ask the ring questions and to make informed decisions.

*The authors of this publication issued a statement of clarification in 2000 indicating the need for a comprehensive educational program to improve knowledge if its findings as the results of research were still being ignored or misinterpreted.*

51. ———. 1991. Summary of USDA handbook on stray voltage/current. *ASAE Annual International Meeting Technical Paper* no. 90-3501.

Abstract: Summarized are the consensus opinions of the contributors including discussions on: 1)

history, 2) physical and electrical sources, 3) physiological and behavioral responses, 4) identification and detection, 5) mitigation, and 6) potential future research. The fundamental conclusion is that problem voltages can be reduced to acceptable levels; recommendations are made concerning action levels and mitigation techniques. Recommendations are expressed in terms of voltages ( $V_{ac}$  as rms values) because voltage is the easiest and most commonly made measurement. However, as discussed throughout this handbook, animals respond to the electrical current generated by a voltage and not to the voltage directly. To relate voltage measurements to current, the worst case (500 Ohms) and more realistic (1000 Ohms) impedances were used. In any case, when a voltage is detected, it must be confirmed that the measured voltage has a low source impedance, i.e. that the voltage can deliver a current of sufficient magnitude to exceed level of concern. We suggest that contact voltage in excess of 2 to 4 V on farms are excessive and recommend their reduction. We recommend a range of action levels from 2 to 4 V to be as conservative as possible and to account for indirect losses use to problems resulting from inappropriate response of farmers to changes in animal behavior. Only under the most unusual circumstance can a cow detect voltage less than 0.5 to 1.0 V. Thus attempts to reduce cow contact voltages to below 0.5 to 1.0 V are unwarranted, and totally unnecessary. It is hoped that this handbook will help people to ask the right questions and to make informed decisions.

52. Aneshansley D.J., Gorewit R.C., and Price L.R. 1992. Cow sensitivity to electricity during milking. *Journal of Dairy Science* 75(10)2733-2741.  
 Abstract: Alternating currents were delivered to lactating cattle through the milk during milking. Electrodes were placed at the top of each short milk tube and jointed for 1 electrical contact. A metal grid on which cows' rear hooves stood during milking was the 2nd contact. Constant voltages (0-16 V) applied to contacts showed 1st lactation cows to be more sensitive than multiple lactation cows. First lactation cows kicked milking machines at 8 V (currents >5 mA) and multiple lactation cows kicked at 16 V (currents >8 mA). At lower voltages, there were no consistent significant differences in milking duration, milk yield or composition for primary or residual milk. Application of constant currents of 5 mA for 1st lactation cows and 8 mA for multiple lactation cows produced no undesirable behaviour but did not result in some differences in production variables. Milking duration decreased during application of constant current to 1st lactation cows. Blood cortisol monitored in the multiple lactation cows during trial 2 showed a significant increase during milking but was equivalent or less during application of current. This study demonstrates that currents of 5 mA or less, delivered through the milk line, did not produce any direct economic effect. To produce this current, voltages on the milk pipe line would have to be >125 V (obvious human safety hazard) or in excess of 5 V on the claw of the milking clusters.
53. Gorewit R.C., Aneshansley D.J., and Price L.R. 1992. Effects of voltages on cows over a complete lactation. 1. Milk yield and composition. *Journal of Dairy Science* 75(10)2719-2725.  
 Abstract: The effect of long-term voltage exposure on milk yield and composition was assessed. 40 cows in 2nd-5th lactation were used. Four groups of 10 Holstein cows were exposed to either 0, 1, 2 or 4 V throughout an entire lactation. Each group was housed in a free-stall environment with trough feed and water provided for ad lib. intake. Voltages (a.c., 60 Hz) were applied between water bowls and a metal grid. Cows could not drink without placing their front hooves on the metal grid. Individual records were maintained for milk wt, milk fat, protein and somatic cell counts (SCC). Av. actual (7312, 8527, 6938 and 7725 kg for groups exposed to 0, 1, 2 or 4 V resp.) and mature-equivalent (7802, 9281, 7308 and 8911 kg for groups exposed to 0, 1, 2 or 4 V resp.) milk wt for 305 days showed no significant differences between groups exposed or unexposed to voltage. Av. actual milk yields for 305 days in the previous lactations were 8016, 8163, 7679 and 7876 kg for groups exposed to 0, 1, 2 or 4 V resp. SCC, milk fat and protein showed no significant differences between groups exposed or unexposed to voltage. Feed and water intakes were not affected by voltage.
54. ————. 1992. Effects of voltages on cows over a complete lactation. 2. Health and reproduction.

*Journal of Dairy Science* 75(10)2726-2732.

Abstract: For the effects of voltages on health and reproduction, 40 cows in 2nd-5th lactation were divided into 4 groups of 10. These included a control group that was not subjected to voltages and 3 treatment groups that were given either 1, 2 or 4 V at the water bowl. Cows in the treatment groups were exposed during the entire lactation to voltage whenever they drank. Voltages did not sufficiently affect milk yield. General health parameters studied were mastitis, hoof problems and changes in body wt. Reproductive and calving parameters examined were days to 1st breeding, days open, services per conception, response to PGF2alpha, calving intervals, visible abortion and calves born dead. Voltages did not significantly influence cow health or reproductive performance.

55. Gumprich, P. S. 1992. Stray voltage effects on dairy cattle. *Highlights of Agricultural and Food Research in Ontario* 15(3).

Abstract: A study was initiated at New Liskeard College of Agricultural Technology, Ontario, Canada, to measure the effects of typical levels of stray voltage (usually <10 V) on dairy cattle in a stanchion barn. The cows were included in the study from 2 wk post partum for 112 days. To simulate on-farm conditions, a continuous low-level voltage was interrupted by 2 periods of higher levels at 05.00-08.00 and 17.00-20.00 h, when higher loading occurs on most dairy farms. Three peak voltage levels were tested and milk production parameters measured for each. The peak and background levels were: (1) 1.0 and 0.30 V; (2) 2.5 and 0.75 V; and (3) 5.0 and 0.75 V. At level (1) cows receiving the voltage treatment had significantly higher milk fat percentage than cows in the control group (31.20 vs. 30.60 kg/cow per day). Milking time was longer for the experimental group at level (2) (8.5 vs. 8.3 min). There was a statistically significant ( $P<0.05$ ) residual effect on milk production 2 periods after the treatment at level (3). In addition, significantly less water ( $P<0.05$ ) was consumed by the treatment group (97.6 vs. 100.2 litres/cow per day). It was concluded that stray voltages up to 5.0 V in well managed tie-stall dairy operations were unlikely to cause observable changes in cow milk production or behaviour.

56. Gumprich, P. S., and L. Giesen. 1993. Stray voltage effect on somatic cell count of dairy cows. *NMC: National Mastitis Council, Proceedings* 32nd annual meeting .

Abstract: Three different levels of voltage were applied to 30 lactating cows in a switchback experimental design, from 1986 through 1990. The cows were exposed to a uniform voltage between the cow platform, waterbowls, and all metal stabling components. The parameters measured were: daily milk production, milking time, milk composition, water consumption, feed consumption, breeding and behavior. The results of these experiments indicate that stray voltages up to 5.0 volts in well managed tie-stall dairy operations are unlikely to cause any increase in somatic cell counts and/or clinical mastitis. Results suggest that any loss in production, or change in behavior of cows subjected to stray voltage of 5.0 volts or less, is likely due to factors other than stray voltage.

57. Reilly, J. P. 1994. Scales of Reaction to Electric-Shock: Thresholds and Biophysical Mechanisms. *Annals of the New York Academy of Sciences* 720.

Abstract: The author presents a summary of thresholds and biophysical mechanisms for reaction of cows to electric shock.

58. ———. 1994. Transient current effects in stray voltage exposure: biophysical principles and mechanisms. *ASAE Annual International Meeting Technical Paper* no. 94-3594.

Abstract: This paper reviews biophysical principles of electric shock, especially as related to stray voltage exposure. Experimental data from human and animal subjects are discussed. Particular attention is given to parameters of significance in electrical stimulation by transient electrical currents.

59. Reinemann, D. J., L. E. Stetson, and N. K. Laughlin. 1994. Effects of Frequency and Duration on the Sensitivity of Dairy Cows to Transient Voltages. *ASAE Annual International Meeting Technical*

Paper no. 94-3597.

Abstract: The reaction threshold of dairy cows was determined for sinusoidal transient voltages ranging in frequency from 60 Hz to 50,000 Hz and with single and multiple cycles. The behavioral responses indicative of reaction are discussed. Cows were less sensitive to higher frequency transient voltages. The distribution of sensitivities was normally distributed with the least sensitive cows responding at levels from 2 to 4 times that of the most sensitive cows. The minimum, average and maximum response levels for 60 Hz stimuli were 2.8, 7.4 and 11.9 mA, measured from zero to peak (corresponding to approximately 2, 5 and 8 mA rms).

60. ———. 1994. Response of dairy cattle to transient voltages and magnetic fields. *IEEE Rural Electric Power Conference* 38(C5).  
Abstract: A study of behavioral responses of dairy cattle to transient voltages and magnetic fields showed no response to magnetic fields up to 4 Gauss. Sensitivity to transient voltages decreased with decreasing phase duration.
61. Wohlt, J. E., and et al. 1994. Cortisol Increases in Plasma of Holstein Heifer Calves from Handling and Method of Electrical Dehorning. *Journal of Dairy Science* 77(12)3725-3729.  
Abstract: Changes in cortisol in plasma were used to assess stress when calves were restrained and then dehorned. Thirteen Holstein heifer calves between 3 and 4 wk of age were used over 4 d; each calf served as its own control. On d 1, 2, and 4, blood was sampled initially while calves were in a pen, 5 min after being placed in a restraint chute, and then at 5, 15, 30, and 45 min and 1, 2, 3, 4, 8, and 12 h after simulated or actual dehorning. On d 1, dehorning was simulated. On d 2 and 4, one horn bud of each calf was cauterized, respectively; sequence of horns (right, left) and dehorning instruments (conventional electrical, Buddex) were alternated for all calves. Day or previous dehorning procedures had no effect on initial concentrations of cortisol in plasma. However, after calves were placed in a chute, cortisol in plasma increased with each entrance. Cortisol in plasma peaked at 5 min posthandling (d 1, 11.3 ng/ml) or 15 min postdehorning (electrical, 21.9 ng/ml; BuddexTm, 20.7 ng/ml). These data suggest that both dehorning procedures resulted in similar rates of synthesis and secretion of cortisol.
62. Aneshansley, D. J., R. A. Pellerin, J. A. Throop, and D. C. Ludington. 1995. Holstein cow impedance from muzzle to front, rear and all hooves. *ASAE Annual International Meeting Technical Paper* no. 95-3621.
63. Reinemann, D. J., L. E. Stetson, and N. K. Laughlin. 1995. Response of Dairy Cattle to Transient Voltages and Magnetic Fields. *IEEE Transactions on Industry Applications* (4).  
Abstract: Stray voltages in dairy facilities have been studied since the 1970's. Previous research using steady-state ac and dc voltages has defined cow-contact voltage levels which may cause behavioral and associated production problems. This research was designed to address concerns over possible effects of transient voltages and magnetic fields on dairy cows. Dairy cow response to transient voltages and magnetic fields was measured. The waveforms of the transient voltages applied were: 5 cycles of 60-Hz ac with a total pulse time of 83 ms, 1 cycle of 60-Hz ac with a total pulse time of 16 ms, and 1 cycle of an ac square wave (spiking positive and negative) of 2-ms duration. Alternating magnetic fields were produced by passing 60-Hz ac fundamental frequency with 2nd and 3rd harmonic and random noise components in metal structures around the cows. The maximum magnetic field associated with this current flow was in excess of 4 G. A wide range of sensitivity to transient voltages was observed among cows. Response levels from 24 cows to each transient exposure were normally distributed. No responses to magnetic fields were observed.
64. ———. 1995. Water, Feed and Milk Production Response of Dairy Cattle Exposed to Transient Currents. *ASAE Annual International Meeting Technical Paper* no. 95-3276.  
Abstract: A study was conducted to determine the level of 60 Hz transient current, relative to the

short-term reaction threshold, required to affect feed and water intake, milk production and cow behavior. Long term 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 groups were monitored for a 14-day week Pretreatment period followed by a 21-day Treatment during which a 1 cycle 60 Hz transient current was applied to water bowls once every second, and a 14-day post Treatment period. Feed and water intake, milk production, Somatic Cell Count (SCC), blood composition and activity level, were monitored during the experiment. No changes in water, feed, or milk were found when entire 21 day Treatment period was compared with the 14-day Pre-treatment period. 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. Slight reductions during the first 3 days of exposure were noted in water and feed intake and milk production at the highest exposure levels (150% above the reaction threshold). The current level required to cause a short term reduction in water and feed intake and milk production was higher than that to produce a behavioral response.

65. Public Service Commission of Wisconsin. 1996. Findings of Fact, Conclusion of Law, and Order 05-E1-115. *PSCW Staff Report, Public Service Commission of Wisconsin* .  
Abstract: This order updates policies and procedures concerning stray voltage for electric distribution utilities in Wisconsin. It also addresses the appropriate level of concern, and mitigation factors.
66. Reinemann, D. J., L. E. Stetson, J. P. Reilly, N. K. Laughlin, S. McGuirk, and S. D LeMire. 1996. Dairy Cow Sensitivity and Aversion to Short Duration Transient Currents. *ASAE Annual International Meeting Technical Paper* no. 96-3087.  
Abstract: This paper summarizes relating to the sensitivity of dairy cows to a variety of transient current waveforms. The phase duration of stimuli ranged from 10 microseconds to 8.3 milliseconds (effective frequency from 50,000 to 60 Hz). Characterization of the effects of waveform (monophasic sinusoidal, monophasic exponential decay, biphasic and multiple cycles) transients are presented. Exposure pathways included: muzzle to four hooves, both a direct application to the nose and via water bowl exposure, teat to hooves via milking machines and via direct skin contact. The effects of hoof condition and hoof trimming were also studied. The sensitivities of over 120 cows were determined for a single cycle 60 Hz transient current. The relationship between sensitivity to transient current and aversion to water were examined for a 6,000 Hz transient current applied to a water bowl.
67. Aneshansley, D. J., L. H. Southwick, R. A. Pellerin, R. C. Gorewit, and J. A. Throop. 1997. Aversive Response of Dairy Cows to Voltages/Currents on Waterers at Frequencies of 60 Hz and Above. *ASAE Annual International Meeting Technical Paper* no. 97-3109.  
Abstract: In this experiment cows were exposed to AC currents of between 60 and 30,000 Hz watering stations. Researchers observed aversive response (removing the muzzle from the waterer) during exposures. Sensitivity was seen to decrease with increased frequency. DC offset voltage combined with 60 Hz AC current did not lead to increased AC sensitivity with DC bias increased to as high as 2 volts.
68. Gorewit, R. C., and D. J. Aneshansley . 1997. Effects of Steady State Voltages on Holstein Cows with Histories of Subclinical Mastitis. *ASAE Annual International Meeting Technical Paper* no. 93-7110.  
Abstract: This experiment aimed to determine whether steady-state voltages up to 4 V can exacerbate subclinical mastitis in cows that tested positive for the disease causing organisms. While animals did perceive the initial applications of voltage to water containers, leading to drinking delays with increased voltages, subclinical *Staphylococcus mastitis* did not become clinical when cows were exposed to 4 volts AC on drinking bowls. In addition, there was no discernible decrease in

milk production nor negative impacts on milk composition, blood chemistry or immune globulin status with exposure up to 4 V. *This experiment is an interesting replicate of earlier studies by the authors.*

69. LeMire, S. D., D. J. Reinemann, P. J. Gaffney, and R. Kasper. 1997. Dairy Cattle Drinking Behavior and Stray Voltage Exposure. *ASAE Annual International Meeting Technical Paper* no. 97-4012.  
Abstract: This study measured the average rate of arrival and the average length of contact of cows at water bowls over a one-day period of exposure to 60 Hz steady voltage that produced 1 mA of current through a 500 Ohm resistor using a standard stray voltage measurement contact. The results were compared to responses over a 24-hour period prior to introducing the electrical exposure. The study demonstrates a method for estimating the probability of dairy cow exposure to transient voltages. The method presented could be used to adjust exposure estimates for drinking behavior of cows under varying environmental and housing conditions. The nature of the distributions of cow contact times under those varied conditions require additional study.
70. Aneshansley, D. J., and R. C. Gorewit. 1999. Sensitivity of Holsteins to 60 Hz and Other Waveforms Present on Dairy Farms. *ASAE Annual International Meeting Technical Paper* no. 99-3152.  
Abstract: This study measured the current sensitivity of lactating cows. It was designed to quantify sensitivity to both short-term and steady-state electrical circumstances encountered on a typical dairy farm. It further quantified steady-state voltage sensitivity over a range of frequencies. The results were consistent with previous results, indicating that Holstein cows are sensitive to peak-to-peak currents rather than rms or peak values. *The behavioral reaction level of cows to transient and steady state currents with varying frequency, 3<sup>rd</sup> harmonic content and DC offset were documented and shown to agree with other studies.*
71. Gorewit, R. C., and D. J. Aneshansley. 1999. Effects of steady state voltages on mastitis. *ASAE Annual International Meeting Technical Paper* no. 99-3151.  
Abstract: Sixteen lactating Holstein cows were exposed to either 0, 1, 2 or 4 Volts RMS. Eight cows were receiving bST and eight cows were bST free. All cows were exposed to *Streptococcus uberis*, as a post teat dip after milking. Milk production, feed and water intake, somatic cell counts and milk fat and protein percentages were compared between treatments. Milk samples were aseptically collected and cultured for bacteria. Voltages did not significantly influence any of the variables studied. We conclude that steady state voltages of up to 4V, applied to water bowls, for: 7days, do not promote clinical mastitis in dairy cattle predisposed to mastitis during or after direct exposure of live bacteria to teat ends.
72. Reinemann, D. J., S. D. LeMire, M. D. Rasmussen, M. C. Wiltbank, and L. G. Sheffield. 1999. Comparison of Behavioral and Physiological Response to Electric Shock in Lactating Dairy Cows. *ASAE Annual International Meeting Technical Paper* no. 99-3154.  
Abstract: In this study, researchers measured behavioral and blood cortisol concentration responses of cows exposed to current applied from front to rear hooves. Increased activity level did not consistently correspond to current exposure while a startle response was a consistent indicator. Current applied from one front to two rear hooves elicited responses at lower current levels compared to those applied via a muzzle to four-hooves pathway. Cortisol levels did not increase in response to current levels up to 1.5 times higher than those that prompted behavioral responses, indicating that blood cortisol is not as good an indicator of current response as behavioral measures. The impacts of two common milking machine problems, pulsation failure (no massage phase) and excessively aged milking machine liners were compared to results following electrical current exposure applied during milking. Measures of milk yield, average milk flow rate, maximum milk flow rate, cow activity, and strip yield did not show significant changes with electrical current exposure; pulsation failure resulted in decreased cow activity. Aged liners affected milk yield

(increased), average flow rate (reduced), Maximum flow rate (reduced).

73. Reinemann, D. J., M. D. Rasmussen, M. C. Wiltbank, L. G. Sheffield, and S. D. LeMire. 1999. Comparison of Behavioral to Physiological Responses. *Dairy Cow Response to Electrical Environment: Final Report to the Minnesota Public Utilities Commission Part 1*.  
Abstract: A series of experiments were performed to measure behavioral and blood cortisol concentration responses of cows exposed to current applied from front to rear hooves. Increased activity level was not a consistent indicator of response to current, whereas a startle response (flinch) was a consistent and repeatable indicator. Cows responded at lower current levels to the 1-front to 2-rear hoof pathway than to muzzle to 4-hooves pathway. Cortisol levels did not increase in response to current exposure at levels up to 1.5 times the behavioral reaction level. Cortisol concentrations were found, however, to increase in response to hoof trimming. It appears for these results that behavioral changes are a more sensitive indicator of response to current than blood cortisol levels. This result agrees with several past studies.
74. ———. 1999. Comparison of Treatments Applied During Milking. *Dairy Cow Response to Electrical Environment: Final Report to the Minnesota Public Utilities Commission Part 2*.  
Abstract: Experiments were performed to compare milking performance of cows subjected to electrical exposure of one mA, rms of 60 Hz electrical current was applied from front to back hooves during milking. The milking machine problems created were either a pulsation failure (no massage phase) or excessively aged milking machine liners. The response measures included milk yield, average milk flow rate, maximum milk flow rate, cow activity, and strip yield (hand stripping yield). There was no statistically significant main effect on any of these variables for current exposure. Pulsation failure produced a significant decrease in cow activity (5.8 fewer weight shifts during milking). Aged liners produced a significant effect on milk yield (2.2 kg increase), average flow rate (0.77 kg/min reduction), maximum flow rate (1.2 kg/min reduction) and liner slips (21 more per milking).
75. Reinemann, D. J., L. G. Sheffield, LeMire S.D., M. D. Rasmussen, and M. C. Wiltbank. 1999. Immune Function Response to Low-Level Electrical Current Exposure. *Dairy Cow Response to Electrical Environment: Final Report to the Minnesota Public Utilities Commission Part 3*.  
Abstract: Twelve lactating Holstein cows, housed in a stanchion barn, were exposed to 1 mA of 60 Hz electrical current from front to rear hooves for two weeks. Twelve cows acted as controls. 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 phytohemagglutinin mitogens), and oxidative burst (PMA-induced chemiluminescence) were chosen "a priori" as the best indicators of immune function response. Immunoglobulin production and interleukin 1 and 2 were also assessed. There was no statistically significant difference between control and treatment cows for any of the main response variables. The difference between the control and treatment cows was statistically significant for one of the secondary response variables but did not appear to be consistent with other observations. Collectively, these results suggest that exposure to 1 mA of current for two weeks had no significant effect on the immune function of dairy cattle.
76. Reinemann D.J., Stetson L.E., Reilly J.P., and Laughlin N.K. 1999. Dairy cow sensitivity to short duration electrical currents. *Transactions of the ASAE* 42(1).  
Abstract: The results of 299 tests to determine the behavioural response threshold of dairy cows to a variety of short-duration or 'transient' electrical current waveforms via the muzzle to 4-hoof pathway are reported. The phase duration of stimuli tested ranged from 10  $\mu$ s to 8.3 ms. Phase duration is defined as the time between 2 consecutive zero crossing points of the waveform (e.g., 1/2 cycle of a sinusoidal waveform). The amplitude of the electrical currents, at a given phase duration, were increased in an ascending series. The lowest threshold current at which an observer could detect a

behavioural change was determined for individual cows. Various behaviours were quantified. Facial activity was the most sensitive behavioural response followed by front hoof lifting. Human observer measurements of hoof lifting agreed well with automated recording of animal motion. Tail motion showed no statistically significant response to the current stimulus. Cows were less sensitive (e.g., more current was required to elicit a response) to shorter duration or higher frequency waveforms. The strength-duration relationship observed for cows agreed well with neuro-electrical models previously verified by human response.

77. Aneshansley, D. J. 2003. Stray Voltage Research at Cornell University. *NRAES: Stray Voltage and Dairy Farms Conference Proceedings* .  
Abstract: In one experiment, voltages of 0, 0.5, 1, 2 and 4 V were applied to water bowls for 21 days. Two cows out of 6 did not drink for 36 hours for the 4V exposure. All of the other 28 cows drank normal amounts of water within 2 days. There was a relationship between the voltage level and delay to drink the first gallon of water. A second experiment applied 3, 4, 5 and 6 V to water bowls for 48 hours. Of the 84 cows, 2 heifers at the 5 V and 2 heifers at 6 V did not drink for 36 hours. Within 2 days those that drank were drinking amounts that were not significantly different from the time before voltage was placed on the water bowl. Again there was a typical dose response curve for voltage versus delay to drink the first gallon of water. Discontinuous voltages were applied between water bowls to rear hooves. Five temporal patterns were used to apply voltage of 5 and 8V 50% of the time. Drinking patterns were not consistent but there was no significant change in amount of water consumed. The effect of voltage exposure applied over a full lactation was studied using four groups of 10 cows each exposed to 0, 1, 2 or 4V applied from waterer to a metal grid (front hooves). Milk weights, SCC, milk fat, protein, feed consumption and water intake showed not significant differences between groups. Voltages did not significantly influence cow health or reproductive performance. First calf heifers kicked at milking machines where current applied to teats exceeded 5 to 12 mA while older cows kicked at milking machines at 8 to 18 mA. The average current required to cause cows to stop drinking ranges from 4.9 to 132 mA rms for steady 60 to 30k Hz currents and 38 to 80 mA for DC pulses from 0.4 to 0.1 ms in duration. For short bursts of 60 Hz lasting 30 cycles, 15 cycles and 6 cycles the average response level was 9.3, 9.7 and 10.7 mA rms respectively while the average response level for 60 Hz was 8.2 mA rms. When 180 Hz components were added to a 60 Hz waveform, a peak current metric explained responses better than an rms metric. Adding a DC bias of 0.5 to 2 V to 60 Hz waveform did not substantially change the response. Preliminary studies on the effect of 0, 1, 2 and 4 V applied between waterers and rear hooves on 16 animals with histories of sub-clinical mastitis and 16 animals challenged with an organism that could cause mastitis showed no significant results (milk production, feed consumption, milk fat and protein, SCC, blood chemistry, milk microbiology and serum cortisol).
78. Gustafson, R. J. 2003. Stray Voltage Overview. *NRAES: Stray Voltage and Dairy Farms Conference Proceedings* .  
Abstract: A large body of literature and experience in dealing with stray voltage problems in agriculture now exists. Based on field experience, early controlled experiments focused primarily on responses to 60 Hz current and path impedance. The early work was summarized by USDA 696. Behavioral observations were used extensively as an indicator of animal response. The relationship between endocrine response and behavior during electrical current exposure was also studied to some extent prior to 1990. A useful set of published reports by PSCW (1989) and more recently (1996) helped bring more consistency to testing done by multiple parties. A Wisconsin stray voltage analysis team (SVAT) jointly administered by PSCW and WDATCP while supporting stray voltage investigations in Wisconsin has collected considerable data from on-farm stray voltage since 1988. This useful data has been presented in publication for by Dasho et al (1995) and Reines et al. (1998). The definition of stray voltage in USDA 696 is still considered an accurate description of the stray voltage phenomena " ... A small voltage (less than 10 volts) measured between two points that can be simultaneously contacted by an animal...the source of voltage must be able to produce current flow

greater than the threshold current needed to elicit a response from an animal...” However, application of the definition requires understanding of both the voltage and the animal sensitivity. Work in this area did not cease with the publication of USDA 696. The companion papers for this proceedings will do a great deal to summarize updated knowledge...Expanded database on animal response to these electrical phenomena, including transients. A continuing challenge has been the incorrect application of the term stray voltage to other electrical phenomena such as electric field, magnetic fields and most recently, current flowing in the earth. Both the electrical phenomena and the physiological interactions with animals for EMF are different than those associated with stray voltage.

79. Reinemann, D. J. 2003. Dairy Cow Response to the Electrical Environment: A Summary of Research Conducted at the University of Wisconsin - Madison. *NRAES: Stray Voltage and Dairy Farms Conference Proceedings* .  
Abstract: 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.
80. Reinemann, D. J., M. D. Rasmussen, and S. D. LeMire. 2003. Milking Performance of Dairy Cows Subjected to Electrical Current and Induced Milking Machine Problems. *Transactions of the ASAE* 45(3).  
Abstract: 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 (rms, 60 Hz) 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 (rms, 60 Hz) 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 and in some cases were highly influenced by a few observations. Further investigation is warranted before drawing any firm conclusions regarding these interactive effects. This study adds further evidence to the body of literature showing that exposure to low-level step potential resulting in  $\leq 1$  mA rms of 60 Hz electrical current during milking is not a cause of cow discomfort or poor milking performance.
81. 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* 46(2).  
Abstract: A series of experiments were 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. Increased activity level 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 four-hooves pathway. Cortisol levels did not increase in response to short-term current exposure at levels up to

1.5 times the flinch reaction level. Cortisol concentrations were found, however, to increase in response to hoof trimming. These results indicate that behavioral changes are a more sensitive indicator of response to short-term electrical current exposure than blood cortisol levels.

82. Stetson, L. E. 2003. Minnesota Science Advisors Findings on the Effects of Ground Current on the Health and Productivity of Dairy Cows. *NRAES: Stray Voltage and Dairy Farms Conference Proceedings* .  
Abstract: I served as one of the members of the Science Advisors to the Minnesota Public Utilities Commission (PUC) from 1994-1998. The final report of the Science Advisors to the PUC in August of 1998 contained some findings and recommendations that should be shared with those who are interested in the electrical issues of ground currents affecting dairy animals. All findings and recommendations in the final 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. Each of the Science Advisors accepted the final report and recommendations. The findings and recommendations in the final report to the PUC are quoted here exactly as they were in the final Science Advisors Report. The remaining parts of this paper are excerpts from both the progress and final report or my explanation of the material in the final report.
83. Reinemann, D. J., L. E. Stetson, and S. D. LeMire. 2003. Comparison of dairy cow aversion to continuous versus intermittent voltage exposure. *Transactions of the ASAE*.  
Abstract: The results of studies comparing dairy cow response to steady-continuous, pulsed-continuous, pulsed-intermittent, and single exposure current applied to water bowls are presented. Aversion studies were performed in which the magnitude of applied current was set at a level having a fixed relationship to the sensitivity of individual animals. In the first experiment, response to a steady 60-Hz stimulus continuously applied to a water bowl (steady-continuous) was compared with response to a 10-cycle, 60-Hz stimulus pulsed once per second (pulsed-continuous). No differences between responses to these two treatments were evident. In the second experiment, response to pulsed-continuous stimulus, to a 10-cycle, 60-Hz stimulus applied to the water bowls once every 10 minutes (pulsed-intermittent), and to a single event of pulsed current (single-pulse) was compared to a control group receiving no current. Only the pulsed-continuous treatment produced a response significantly different from the control. The pulsed-continuous treatment increased the delay to drink and inhibited water consumption over both four and eight-hour intervals for current exposures ranging from 6 to 15 mA-peak. These effects were not observed for the pulsed-intermittent or single-pulse treatments.
84. Reinemann, DJ, LE Stetson, SD LeMire, 2004. Comparison of dairy cow aversion to continuous and intermittent current. **Transactions-of-the-ASAE**.  
Abstract: The results of studies comparing dairy cow response to steady-continuous, pulsed-continuous, pulsed-intermittent, and single-exposure current applied to water bowls are presented. Aversion studies were performed in which the magnitude of applied current was set at a level having a fixed relationship to the sensitivity of individual animals. In the first experiment, response to a steady 60 Hz stimulus continuously applied to a water bowl (steady-continuous) was compared with response to a 10-cycle 60 Hz stimulus pulsed once per second (pulsed-continuous). No differences between responses to these two treatments were evident. In the second experiment, responses to pulsed-continuous stimulus, to a 10-cycle 60 Hz stimulus applied to the water bowls once every 10 min (pulsed-intermittent), and to a single event of pulsed current (single-pulse) were compared to a control group receiving no current. Only the pulsed-continuous treatment produced a response significantly different from the control. The pulsed-continuous treatment increased the delay to drink and inhibited water consumption over both 4 and 8 h intervals for current exposures ranging from 6 to 15 mA peak. These effects were not observed for the pulsed-intermittent or single-pulse Treatments.

85. Reinemann, DJ, LE Stetson, NK Laughlin, 2005. Water, Feed and Milk Production Response of Dairy Cattle Exposed to Transient Currents. **Transactions of the ASAE** 48(1)385-392. ABSTRACT. A study was conducted to determine the level of 60 Hz transient current, relative to the short-term response threshold, required to affect feed and water intake, milk production, and cow behavior. Long-term 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 groups were monitored for a 14-day pretreatment period, a 21-day treatment during which one cycle of 60 Hz transient current was applied to water bowls once every second, and a 14-day post-treatment period. Water intake, feed consumption, and milk production were monitored during the experiment. No changes in the average water intake or milk production were attributable to current exposure for any exposure level. A slight reduction in feed intake was observed 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. Reductions in water intake, feed consumption, and milk production were apparent in the first several days of the exposure period but only at the highest exposure levels. The current level required to cause a short-term reduction in water and feed intake and milk production was higher than that required to produce a behavioral response.

## **Dairy Farm Field Studies**

1. Baird, C. R. 1978. A correlation study of incidence of mastitis and stray electrical currents in dairy barns. *ASAE Regional Meeting Technical Paper* no. NA 78-302.
2. Kirk J.H., Reese N.D., and Bartlett P.C. 1984. Stray voltage on Michigan dairy farms. *Journal of the American Veterinary Medical Association* 185(4).  
Abstract: Stray voltage investigations were performed on 59 Michigan dairy farms at the request of dairymen, veterinarians, and county extension agents. On 32 farms, sources of stray voltage were detected. When the voltage exceeded 1 volt alternating current, there were increased numbers of dairy cows that had abnormal behaviour in the milking facility and increased prevalence of clinical mastitis. Recovery from the stray voltage-induced abnormalities was related to the type of abnormality and the magnitude of the exposure voltage.
3. Thornton, E. 1984. A Study of stray Voltages on Alberta Dairy Farms. *ASAE Annual International Meeting Technical Paper* no. NR-84-309.  
Abstract: 11% of Alberta dairy farms with parlour milking systems have stray voltages over 1.0 v. Bad wiring is the most significant cause. There is no definite relationship between low levels of stray voltage, and with production.
4. Winter D.F., and Dick W.K. 1984. Field experience with the electronic grounding system for stray voltage reduction. *ASAE Annual International Meeting Technical Paper* no. 84-3503.  
Abstract: Field experiences at over 40 installations of an electronic grounding system are described. The theory of operation, installation procedure, measured reduction of stray voltage, and the improvements in dairy herd performance reported by the operators of these dairy facilities following the installation of the system are presented.
5. Appleman, R. D., Gustafson R.J., and Brennan T.M. 1987. Effect of Neutral Isolation in the Correction of Apparent Stray Voltage Problems Resulting From Off-Farm Sources on Milk Production and Herd Health. *Journal of Dairy Science (Abstract)* 70 Suppl. 1.  
Abstract: Of 3,396 dairy farms in a 10-county area, 399 (11.7%) installed neutral isolators by October 1986 to prevent primary system neutral voltages from accessing the dairy herd through the farm's secondary electrical grounded neutral system. Installation of these devices generally were limited to farms with voltages exceeding 1.0 V at the barn service neutral at milking time and to farms where screening tests determined that isolation would remove most of the voltage present. About 30% of these farms were enrolled in the DHI program for at least 2 years prior to and 6 months after isolation. Eighty-four farms had complete records available: 1) 12 month before; 2) 6 month before; 3) immediately preceding; 4) 6 months after; and 5) 12 months after neutral isolation was accomplished. Milk production averaged 6937, 6944, 6947, 7140, and 7268 kg annually per cow for the year ending in periods 1 to 5, respectively. Differences in average somatic cell count (SCC), percent cows positive to SCC, percent cows leaving herd, estrus detection index, conception rate, and expected calving interval between periods were small, inconsistent, and generally non-significant. With 57 cows per farm, gross income was increased \$5,000 annually. The cost of neutral isolators is about \$500.
6. Albright J.L., Dillon W.M., Sigler M.R., Wisker J.E., and Arnholt D.J. 1988. Dairy farm analysis of stray voltage problems in Indiana. *Journal of Dairy Science (Abstract)* 71 Suppl. 1.  
Abstract: Twenty Indiana dairy farms in 15 counties were checked for suspected stray voltage problems. Protocol as outlined in North Central Regional Extension Publication 125 was followed. Initial readings at the service panel averaged 0.43 volts. Tracing from a stray voltage recorder at 8 farms for 24+ hour surveillance were up to 1.4 volts. Following the installation of a Tingle Voltage Filter (TVF) on 6 farms, there was a 10-fold decrease from 0.43 to 0.4 volts. At this level the dairy

cows should no longer be at risk. Wide differences existed from farm to farm regarding dairy management expertise, and state of electrical wiring and grounding. Five of six TVF herds showed improvement in individual cow and group behavior. Test day results and milk production per cow/herd were inconclusive.

*There were no measurements of cow contact voltage. In addition the mitigation device will primarily reduce voltage contributions from utility sources. Any on farm sources would still exist but exposure levels and locations may have changed. As a result the exposure levels before and after modification of the electrical systems cannot be determined with any accuracy. As noted in the USDA handbook, this was an observational study with no controls farms or cows and the studies were not blind. The claims of changes in animal behavior must be made with caution and the previous and subsequent controlled research on voltage exposure levels that produce changes in animal behaviors are a better source of information on the subject*

7. Stanek, D. E. 1988. Stray voltage and animal behavior. *ASAE Annual International Meeting Technical Paper* no. 88-3521.  
Abstract: Stray voltage is the most financially debilitating, misunderstood, and frustrating problem livestock farmers in general are faced with. The one general statement that can be made as you read the case studies is that you only had to interview one dairyman who went through the problem. After you do nine more, a hundred more or any number, you will discover the data is almost identical, and without any distinct level of voltage that affects cows or does not affect cows. After three and one-half years, experience indicates that some animals subjected to one-tenth of a volt in the cow contact area may not reach their productive potential.
8. Hendrickson, S. R., T. J. Harvey, and A. N. Bringe. 1990. Occurrence of Neutral-to-Earth (N-E) voltage in the cow contact area and its relationship to milk production on randomly selected Wisconsin dairy farms: field survey. *ASAE Annual International Meeting Technical Paper* no. 90-3507.  
Abstract: Frequency, occurrence, and cause of N-E voltage in the cow contact area were monitored 4 times/year on 110 randomly selected Wisconsin dairy farms in the Wisconsin Public Service Corporation service territory. Dairy herd management practices were also analyzed and related to both production and N-E voltage findings.
9. ———. 1991. Occurrence of Neutral-to-Earth Voltage in the Cow Contact Area and Its Relationship to Milk Production on Randomly Selected Wisconsin Dairy Farms. *NMC: National Mastitis Council, Proceedings 30th Annual Meeting*.  
Abstract: Occurrence of neutral-to-earth voltage in the cow contact area by frequency, level, and cause was documented on 110 randomly selected dairy farms in the Wisconsin Public Service Corporation Service territory. Differences in selected management practices which may allow producers to limit the impact of neutral-to-earth voltage on milk production were also analyzed. Although 34% of the project farms had neutral-to-earth voltage levels equal to greater than 0.5 volts alternating current steady state voltage and/or 1 volt alternating current spike voltage in the cow contact area, it was found in all production groups (low, middle, and high). This suggests that rolling herd averages greater than 18,000 pounds of milk can be achieved despite the presence of voltage levels in the cow contact area of equal to or greater than 0.5 volts alternating current steady state and/or 1 volt alternating current spike voltage. High production group farms with neutral-to-earth voltage levels of concern also displayed a higher level of management intensity. This suggests that application of a variety of proven dairy herd management factors is key to achieving high levels of milk production with or without neutral-to-earth voltage levels of concern.
10. Stanek, D. E., and M. E. Monson. 1991. Animal sensitivity to low voltage/current levels. *ASAE Annual International Meeting Technical Paper* no. 91-4557.  
Abstract: Data concerning stray voltage/current through dairy cattle were collected. An Electronic

Grounding System was used to reduce both voltage and current to the lowest possible levels. This produced the optimum improvement in animal behaviour.

11. Southwick, L. H., D. J. Wilson, and P. M. Sears. 1992. Milk production, water consumption, and somatic cell count responses of cows subject to one or two volts of alternating current. *Journal of the American Veterinary Medical Association* 201(3)441-444.  
Abstract: A dairy farm located in central New York State was visited following complaints of electrical shock in the farmhouse shower and the milk house sink. As much as 2 volts AC of potential difference was measured between the waterline and the cow platform (cow-contact voltage). Voltage was coming from the primary neutral wire. The farm's electrical service was modified so that the farmstead could be connected or disconnected from the primary neutral wire at 2-week intervals for 12 weeks. When connected to the primary neutral wire, voltage between waterline and floor ranged between 0 and 1.8 volts, producing estimated current flow through cows of 3.6 to 4.9 mA when disconnected from primary neutral wire, voltage between waterline and floor was <0.1 volt. There was no difference in mean milk production, bulk tank milk somatic cell count, or water consumption among periods when cows were exposed or unexposed to voltage. Although not statistically significant the values for somatic cell count were lower and water consumption was higher when cows were exposed to voltage than when they were not.
12. Southwick, L.H., D. J. Wilson, and P. M. Sears. 1993. Stray Voltage on a Dairy Farm: A Case Study. *NMC: National Mastitis Council, Proceedings* 32nd Annual Meeting.  
Abstract: A dairy farm visited because of complaints of electrical shock in the farmhouse shower and the milkhouse sink was found to have 2 volts AC of potential difference measured between the water line and the cow platform (cow-contact voltage). Voltage was coming from the primary neutral wire. The farm's electrical service was modified so that the farmstead could be connected or disconnected from this primary neutral wire source at two week intervals for twelve weeks. When connected to the primary neutral wire, voltage produced an estimated current flow through cows in excess of criteria for stray voltage; when disconnected from primary neutral wire, voltage between waterline and floor was < 0.1 volt. There was no difference in mean milk production, bulk tank milk SCC, or water consumption among periods when cows were exposed or unexposed to voltage. Despite statistical nonsignificance, the values for SCC were lower and water consumption was higher when cows were exposed to voltage than when they were not. Dairy farmers are not completely confident and assured until they are satisfied that stray voltage will travel through the resistance of a cow at cow-contact points does not exist on their farm. However, disease or production problems on dairy farms require thorough investigation even when stray voltage is found.
13. Bodman, G. R. 1994. Ground Currents: A Cause of Undesirable Animal Performance? *ASAE Annual International Meeting Technical Paper* no. 94-3599.  
Abstract: Field investigations have revealed a number of instances where ground currents result in undesirable and adverse reactions in animals. A need exists to develop better test methods or to verify test methods currently being used. Work is also needed to assist in source identification and development of mitigation/control strategies. A need exists for investigators to include consideration of ground currents in their thinking when troubleshooting installations experiencing problems with livestock.
14. Cassel E.K., Vough L.R., Varner M.A., Eickelberger R.C., Manspeaker J.E., Stewart L.E., Douglass L.W., and Peters R.R. 1994. A demonstration project of interdisciplinary dairy herd extension advising funded by industry and users. 3. Impact on management practices. *Journal of Dairy Science* 77(8)2461-2476.  
Abstract: The objectives of this 24-herd, demonstration project of integrated problem solving and extension advising were (1) to evaluate milk production management practices, (2) to formulate recommendations for guiding producers to correct management deficiencies and (3) to measure the

rate of practice adoption. Management evaluations focused on herd nutrition and forage crops, mastitis control and milking equipment, reproduction, and herd health. 68 management practices or milking equipment components were evaluated on each farm. A total of 216 recommendations was made in nutrition and forage crops as follows: calf and heifer management, 89; forage crops, 73; dry cows, 26; lactating cows, 19; and general, 9. The least adopted suggestions for nutrition and crops were for forage crop management. A total of 283 recommendations was made in mastitis management of milking equipment as follows: milking practices, 90; milking equipment, 90; general mastitis control, 61; environment, 32; calf management, 9; and **stray voltage, 1**. Producers most resisted updating and maintaining milking equipment within the milking management area. Detection of oestrus was the focus of reproductive management advising. A total of 80 practices were recommended as follows: 1 person responsible, 24; specific location, 24; specific time, 24; and regular veterinary visits, 10. Designation of a specific site was the least adopted of these recommendations. Overall, 419 of 581, or 72%, of all recommendations were adopted.

15. Hartsell, D., and et al. 1994. The Effects of Ground Currents on Dairy Cows: A Case Study. *Bovine Practitioner* 28.

Abstract: In summary, these results are especially important since the majority of studies on stray voltage have concluded that there is not noticeable effects on cows' production, health, blood chemistry, SCC or water consumption when cows are exposed to shock currents as they touch the metal parts of the stall or waterer (Southwick et. al. 1992). In the work discussed in this paper the only change on the farm was the connecting of the electric utility grounds to their neutral. This was an electrical change that increased the electric current going into the ground on the farm by means of the primary neutral. The results included both observed and measured changes in health, blood chemistry, SCC and water consumption. New models are needed which can better match the behavior, health and production of the dairy cows to their electrical exposure. Simply an analysis of the information already generated would greatly assist in this process. It is hoped that this study will trigger new research and additional debate in connection with stray voltage and the effects of EM energy with a special consideration to the effects of the electricity that gets into the earth from the multitude of sources. The results of such research and debate could reveal significant effects for all living organisms that go far beyond what is known about the effects of electrical shock. An understanding of the effects discovered in this test could be the key to dealing with the many dairies in the country that are experiencing the erosion of their profits and health. If we ignore the canaries that stop singing, we can only blame ourselves for the inevitable results.

16. Dasho, D. M., M. A. Cook, R. S. Reines, and D. J. Reinemann. 1995. Stray Voltage: The Wisconsin Experience. *ASAE Annual International Meeting Technical Paper* no. 95-3625.

Abstract: This paper presents data from more than 1,000 stray voltage investigations conducted in Wisconsin by the Wisconsin Public Service Commissions Stray Voltage Analysis Team and investor owned utilities. More than 90% of by the farms in this data set had cow contact currents less than 2 mA and more than 70% had less than 1 mA. The low cow contact voltages are likely attributable to efforts by utilities in response to by the PSCW regulatory and educational efforts. Correlation was found between primary neutral voltage, secondary neutral voltage and cow contact current, as expected. There was no meaningful correlation between cow contact currents and either production or somatic cell count. The distribution of variables measured by the SVAT and IOU investigators compared well illustrating that consistent testing methods are being used. One goal of the PSCW was to develop and encourage consistent test procedures across the state. The data show that cow contact current is dependant on many physical factors stemming from both by the onfarm and offfarm electrical power systems. Specific measurement of cow contact current on each farm is required to determine the potential impact on cows on that farm. Because of the wide variation in the data, gross indicators, such as grounds per mile, secondary and primary neutral to reference voltages, etc., are not good predictors of cow contact currents. There are many confounding factors that may outweigh the impacts of stray voltage which makes it difficult to draw conclusions from

field studies about its effects on production and animal health. The implications for future research are that groupings of farms based on certain non-electrical parameters are important in attempting to draw correlations between cow contact currents and production and health variables.

17. Graham, M. 1996. Galvanic Skin Reflex as an Indication of Pain in Cows. *ASAE Annual International Meeting Technical Paper* no. 96-3088.  
Abstract: The galvanic skin reflex (GSR) has been measured in cows using electrocardiogram electrodes on the udder and a current of 5 microamperes to measure the skin resistance. Abrupt changes in the skin resistance were observed when a 0.02 milliamperes RMS current was injected into the claw while the cow was being milked.
18. Wilson D.J., Southwick L.H., and Kaeser D.R. 1996. Improvement in milk production and udder health following correction of stray voltage on computer feeders. *Agri Practice* 17(5-6)24-29.  
Abstract: Diagnosis and correction of stray voltage on farms was shown in this study on a 130-cow Holstein dairy farm in Ohio which had installed computerized grain feeders in 1986. Major production and disease losses (the latter due to mastitis) in dairy cattle were strongly associated with stray voltage, since cattle exposure to the voltage led to reduced consumption of concentrates. Improvement followed the elimination of stray voltage on the farm.
19. Graham, M. 1997. GSR in Cows in Response to Electrical Stimulation. *ASAE Annual International Meeting Technical Paper*.  
Abstract: Galvanic Skin Reflex (GSR) is a sudden change in skin resistance associated with increases in stress. Measurements of GSR were taken in cows exposed to currents of 1 mA RMS at 60 Hz for less than one second. Exposure was observed with udder and teat electrodes when current was injected into the teat and neck. Recommendations are offered for equipment used to take measurements and researchers are cautioned to precisely specify the piece of equipment used to avoid reporting apparently conflicting results.
20. ———. 1998. GSR Measurement of Accommodation to Repetitive Stress. *ASAE Annual International Meeting Technical Paper*.  
Abstract: This study measured galvanic skin reflex (GSR) of animals exposed to a series of identical electrical shocks. The responses decreased with successive tests. The larger electrical stress causes a larger first response, and greater proportional decreases with subsequent tests. GSR also indicates non-electrical stresses; thus, a cow that is uncomfortable for any of a number of reasons can show strong GSR readings. Tests have shown a particular sensitivity to waveforms that have a periodic character with a repetition rate on the order of one per second, similar to the frequency of milk machine pulsators, indicating that stray currents from the pulsator circuits are more problematic than previously thought.
21. Hendrickson R.C., and Patoch J.W. 1998. AC earth current on dairy farms. *ASAE Annual International Meeting Technical Paper* no. 98-3002.  
Abstract: Earth current from a.c. sources has been a topic of some interest in dairy states where claims have been made that earth current is associated with herd health and production problems. Mechanisms by which earth current could conceivably interact with a cow are outlined. A method of measurement of electrical parameters related to a.c. earth current is described. These include step potential, soil resistivity, and earth current density and direction. In 1997 measurements of these quantities were made on 19 dairy farms in Minnesota. These data are described as profiles from the barnyard into a field away from known earth current sources. Comparisons are drawn between step potentials in the barn, in the barnyard, and in the field. Results indicate that step potentials are smaller than those necessary to elicit a behavioral response in cows as presently established in stray voltage literature. Earth current density and step potentials are larger near the sources of earth current. They are usually largest in the barn, somewhat less in the barnyard and smaller by an order

of magnitude in the field. This indicates that cumulative background earth current density due to all distant sources is relatively small compared to earth current from local sources. Some exceptions are described.

22. Hendrickson, R. C., and J. W. Patoch. 1998. Electrical environment on 17 dairy farms. *ASAE Annual International Meeting Technical Paper* no. 98-3001.  
Abstract: In 1997, several electrical parameters were measured on 17 dairy farms with stall barns in Minnesota, USA. Some farms had reported herd health and production problems and some had not. The electrical measurements were designed to test 5 hypotheses which would explain how different electrical parameters on dairy farms might affect cow health and milk production. These hypotheses were based on biological outcomes beyond, but inclusive of, behavioral response and included possible effects of low level stray voltage, transient currents and voltages, electric fields from cow trainers, a.c. magnetic fields from current on water lines, and combinations of a.c. and d.c. magnetic fields. Measurements included 60 Hz stray and neutral voltages, low frequency (motor starting) transient voltages, high frequency transient voltages across a hybrid impedance cow model, cow contact source resistances, cow trainer electric fields, 60 Hz and d.c. magnetic flux density, and step potentials inside and outside the barn. These data are described statistically and indicate that measured voltage and field levels rarely, if ever, exceeded those levels necessary to initiate a behavioral response in dairy cows as presently established in the stray voltage literature. Continuous exposure to the low level step voltages found on most of the farms could produce electric fields in body tissue which are larger than those associated with biological effects in other species, though such effects have yet to be identified or demonstrated in dairy animals.
23. Reines R.S., Cook M.A., Dasho D.M., and Reinemann D.J. 1998. Putting stray voltage in perspective: the Wisconsin experience revisited. *ASAE Annual International Meeting Technical Paper* no. 98-3004.  
Abstract: Data from more than 2900 stray voltage investigations performed in Wisconsin (USA) are reported. Data includes electrical characteristics of both the distribution and on-farm wiring systems as well as rolling herd average milk production (RHA) and bulk tank average somatic cell counts (SCC). More than 85% of the first investigations reported maximum primary and secondary neutral-to-earth voltages  $< 2$  V rms. More than 90% of investigations reported maximum cow contact voltages  $< 1$  V rms. The correlation between electrical parameters were as expected from electrical theory. However, specific measurement of each parameter is required because predictive ability is low. Indicators such as ground per mile, primary neutral or secondary neutral-to-earth voltages are not good predictors of cow contact voltage. This is probably due to the prevalence of on farm sources, which can either add or subtract from primary sources. It is imperative to properly identify the voltage sources and their interaction before implementing mitigative action. There was no meaningful correlation between primary neutral-to-earth voltage, secondary neutral-to-earth voltage, cow contact voltage, or ground rod current and either RHA or SCC ( $r < 0.02$ ). The correlation between the monthly average SCC reported by stray voltage investigators and by the USDA for all farms in the Midwest ( $r = 0.58$ ) was an order of magnitude higher than for any electrical parameter. Inappropriate conclusions about changes in SCC and milk production can be drawn if these seasonal trends are not taken into account.
24. Reines, R. S., M. A. Cook, and D. M. Dasho. 1998. Wisconsin's Stray Voltage Experience - An Update. *PSCW Staff Report, Public Service Commission of Wisconsin*.  
Abstract: The Wisconsin Stray Voltage Analysis Team (SVAT) is jointly administered by the State's Public Service Commission and Department of Agriculture, Trade and Consumer Protection. It has been collecting data from on-farm stray voltage investigations since 1989. In addition, the major investor-owned utilities have also recorded information since 1988. This data is submitted every six months and has been documented in an earlier publication. This paper is intended to update the picture from data collected since that publication.

25. Polk, C. 2001. Cows, Ground Surface Potentials and Earth Resistivity. *Bioelectromagnetics* 22(1)7-18.  
Abstract: The “stray voltage” problem on dairy farms is discussed briefly. By reference to the published literature it is shown that a “step voltage” (SV), i.e., a potential difference between front and hind hooves of a dairy cow, much less than the often quoted threshold value of 0.5V, when applied for long periods of time, could possibly affect cow health and milk production. Values as low as approximately 10 mV could conceivably be significant. A measurement program carried on 19 representative Minnesota dairy farms during the summer of 1997 is described. Nine farms had above average (HP) and 10 below average (LP) milk production. Results show that SV was 4.2 times higher on the LP than HP. However, only three farms had SV greater than 9 mV and low milk production on these farms could possibly be due to absence of recommended vaccinations rather than high SV. Soil resistivity ( $\rho$ ) measured in the farm fields was 3.4 times larger on the LP than on HP. The possible origin of SV in relation to electric distribution systems within and to farms is discussed. Relations between SV and  $\rho$  are analyzed. Conditions are specific under which SV in the barn must be related to  $\rho$  measured in the field, rather than the  $\rho$  of the concrete floor of the barn. It is suggested that laboratory research is necessary to establish the significance for cow health and milk production of long term exposure to low SV levels.
26. Reines, R. S. 2001. PSC Stray Voltage Data Update: The Latest Statistics From the PSCW Database. *PSCW Staff Report, Public Service Commission of Wisconsin*.  
Abstract: The charts and statistics provided in this update were derived from the Public Service Commission of Wisconsin's utility stray voltage database containing more than 5,000 entries. The data is submitted by the five largest investor-owned utilities in Wisconsin from their first-time investigations and contains data from both the farm and the utility system. The data contains only AC, rms steady-state voltage and current parameters.
27. Graves, R. E., and T. H. Wilson. 2002. Stray Voltage Issues in Pennsylvania. *ASAE Annual International Meeting Technical Paper* no. 02-3118.  
Abstract: Twenty three Pennsylvania dairy farms were evaluated for stray voltage in a project sponsored by the Pennsylvania Department of Agriculture in 2001. An action level of 1 volt, with a 500 ohm resistor, at cow contact points was selected. All the farms had typical symptoms attributable to stray voltage but most of them were not caused by stray voltage. Because stray voltage was believed to be the cause of their problems, the farms were not investigating other management, equipment or cow health issues. It was also determined that there was no consistent procedure for evaluation or mitigation of stray voltage. Seven recommendations are included in the report. Two important actions suggested are: 1) Establish a standard method for testing for stray voltage and a standard action level where mitigation is indicated to reduce confusion on Pennsylvania farms. 2) Form a statewide task force or committee, representing all interested parties, to adopt standards and address continuing stray voltage issues.
28. Cook, M. A., and R. S. Reines. 2003. Stray Voltage Database Synopsis: Wisconsin's Experience with Stray Voltage and its Mitigation. *NRAES: Stray Voltage and Dairy Farms Conference Proceedings*.  
Abstract: The subject of stray voltage is still a confusing issue to many people in the state of Wisconsin. This is probably true because far too many differing opinions exist as to what actually constitutes 'stray voltage'. The public Service Commission of Wisconsin (PSCW) has a formal definition (endnote 1, page 334) that should help to separate what is not stray voltage from what is stray voltage. However, the true physical and electrical nature of this phenomenon should also be well known. To be acquainted with the limits of what can possibly constitute the whole issue of stray voltage, the PSCW has produced several papers drawing from data maintained in an extensive database (ref. 1 & 2). The database, created in 1989 from data submitted by the major investor owned utilities in the state, is generated from their first time on-farm investigations. The requirements for the data have been modified and expanded several times since that date. The current

database has 106 columns of parametric information and over 6,000 row entries. Not all data entries contain information. Only non-zero entries are recorded. It is very useful to examine the statistics of each of the parameters found in the database and to also contrast and compare them looking for significant correlations. This will provide the reader with both range and character of each parameter. This can aid in the comparison of newly acquired data as a check on the soundness of the data.

29. Roberts, J. R., M. A. Cook, and R. Kasper. 2003. Stray Voltage and Water for Dairy Cattle. *PSCW Staff Report, Public Service Commission of Wisconsin* .

Abstract: In this article consideration will be given to the understanding of water consumption, the relationship of stray voltage to water intake, the interpretation of atypical behaviors associated with water sources, and water quality as these issues relate to dairy cattle.

30. Wilson, T. H. 2003. Pennsylvania's Stray Voltage Perspective. *NRAES: Stray Voltage and Dairy Farms Conference Proceedings* .

Abstract: In February 2001 the Pennsylvania State University began a research project for the Pennsylvania Department of Agriculture (PDA) to examine stray voltage issues on PA dairy farms (Graves et al., 2001). Based on the initial project findings a second project proposal was funded in 2002 to develop an interdisciplinary approach to respond to farmers' stray voltage concerns.

## **Cow Trainers and Fencers**

1. Wakefield, H. R. 1984. Developments in electric fencing. *Agricultural Electronics 1983 and Beyond: Proceedings of the ASAE National Conference on Agricultural Electronics Applications*.
2. Kohli, E. 1987. Effects of the Cow Trainer on Behaviour of the Dairy Cow. *Schweizer Archiv Fur Tierheilkunde* 129(1).  
Abstract: The behaviour of 8-9 cows in each of three herds was observed before and after the use of cow trainers. The trainers were set at both the high and low positions. During the 6-week period when the apparatus was live, the frequency of contacts with it decreased. During the subsequent 3-week period when it was switched off, the frequency of contacts increased. The cowhouses remained cleaner when the device was on. Preparatory behaviour before lying down took longer, indicating a negative effect on welfare. The device also had inhibitory effects on licking of the back while standing erect, stretching after standing up, and other comfort behaviour.
3. Hultgren, J. 1988. The Function of Electric Cow-Trainers and Effects of Them on Behaviour and Physiology: A Review and Methodological Study. *Institutionene for Husdjurshygiens Sveriges Lantburksuniversitet Rapport 24*.  
Abstract: Four cows were selected from a Swedish commercial dairy herd. Two were held in conventionally installed electric cow-trainers, the other 2 acting as controls. Touching of the cow-trainer, eliminative behaviour, (change in) body position, feeding behaviour, comfort behaviour, abnormal behaviour, urine cortisol levels, and state of cleanliness of stall and animals were recorded. The effect of the cow-trainer was most marked on behaviour and urine cortisol levels. Lying down behaviour was particularly seriously affected, although comfort behaviour was also influenced. The disturbed behaviour of the cow-trainer-held animals had a transient effect on urine cortisol levels; however, this was considered a minor stress response from an animal health point of view.
4. Sheldon, L. E. 1988. Experiences of an Independent Consultant Concerning Electric Fencing. *ASAE Annual International Meeting Technical Paper* no. 88-6506.  
Abstract: Electric fence controllers place repetitive pulses of electric power onto fence wires for shock containment of animals. A number of fence controllers of different manufacture were bench and field tested. The most indicative test was a measure of peak voltage under controlled loads. Voltages of 2000-4000 V are necessary for full control. Resistive loads of 100, 500 and 5000 ohms correlate with heavy, medium and light fence loads, resp. Twelve miles of wire on a 4 wire high tensile fence represents a medium load.
5. Simensen, E., O. Sjaastad, and K. Boe. 1988. Effect of the Cow-Trainer on Cleanliness, Behaviour and Plasma Cortisol Levels in Dairy Cows. *Environment and Animal Health: Proceedings of the VIth International Congress on Animal Hygiene*.
6. Turner, L. W., R. S. Moore, E. S. Holmes, W. R. Burris, and S. G. McNeill. 1988. Design considerations for electric fencing of cattle. *ASAE Annual International Meeting Technical Paper* no. 88-3511.  
Abstract: This paper presents an overview of basic design principles for permanent and temporary electric fencing for cattle. Producer experience are described for electric fencing of cattle in controlled grazing systems.
7. Weinreich, W. 1988. Joule rating of fence controllers. *ASAE Annual International Meeting Technical Paper* no. 88-3508.  
Abstract: Different electric parameters are used to define the output performance, voltage, Joules or coulombs for electric fences, leading to confusion if several control fences are to be compared. A proposal is made for a rating system on the basis of the pulse energy (Joule) where the peak voltage is also included.

8. Eyrich, H., and K. Zeeb. 1989. Influence of the Cow Trainer on Oestrus in Dairy Cows. *Kuratorium Fuer Technik Und Bauwesen in Der Landwirtschaft, KTBL Schrift* 336.  
Abstract: The effects of cow trainers on oestrus behaviour were examined on 146 cows in 20 dairy herds and progesterone profiles were established for 126 cows in the post-partum phase (68 on short standings with a trainer and 58 without). The profiles revealed a significantly higher percentage of silent heat in cows with a trainer, a prolonged phase of post-partum acycilia, more frequent disruptions of ovarian function after parturition and more false heat observations, indicating that the cow trainer restricts oestrus behaviour and is not consistent with animal welfare requirements.
9. Manda, M., M. Satou, and I. Kurohiji. 1989. Behavioral response of cattle to electric-fence tapes in different colors. *Japanese Journal of Zootechnical Science* 60(3).
10. Schopper, D., and et al. 1989. Influence of the Cow Trainer on Oestrous Symptoms in Dairy Cows: 2) OVarian Function and Frequency of Silent Heat (Evaluation of Progesterone Profiles). *Tierarzliche Umschau* 44(2).  
Abstract: In 68 dairy cows kept on short standings with a cow trainer, duration of acycilia post partum was significantly longer ( $34.3 \pm 17.8$  vs.  $27.8 \pm 14.1$  days), ovarian dysfunctions (mainly ovarian cysts) occurred more frequently (20.5 vs 12.1%), the frequency of silent heat was higher (69.3 vs. 56.5%), and there was a higher percentage of false observations of oestrus (28.6 vs. 14%) than in 58 cows on standings without a trainer. These results also confirm silent heat as the main reason for suboptimum fertility in cows. 63% of all ovulations were not accompanied by symptoms of oestrus, and this problem was exacerbated by the use of the cow trainer.
11. Gustafson, R. J, and D. F. Winter. 1990. Use of electric current for training and control of animals. *ASAE Annual International Meeting Technical Paper* no. 90-3539.  
Abstract: This paper reviews literature on the use of electric fences for control of animals with emphasis on the electrical characteristics and sensitivity of animals. It summarizes information helpful in determining criteria for acceptable electric shock for control within safety limits and without excessive currents.
12. Hultgren, J. 1991. A Preliminary Study of Behavioural Methods for Assessing the Influence of Electric Cow-Trainers on Animal Health. *Veterinary Research Communications* 15(4).  
Abstract: Various behavioural patterns were assessed for their usefulness in analysing any possible effects of electric cow-trainers on the health of dairy cows. Four cows in a commercial herd were used, which had not previously been exposed to cow-trainers. Two of these were exposed to conventionally installed and managed cow-trainers and 2 were controls. It was concluded that preparation to lie down, lying-down movements and comfort behaviour are suitable for the study of relationships between the use of electric cow-trainers and impaired health in cows.
13. Bergsten, C., and B. Pettersson. 1992. The Cleanliness of Cows Tied in Stalls and the Health of Their Hooves as Influenced by the Use of Electric Trainers. *Preventive Veterinary Medicine* 13(4).  
Abstract: The influence of the cleanliness of cows' stalls on the cows' own cleanliness and on the health of their hooves was investigated in 52 dairy cows tied in stalls with long stanchions from 2 October 1989 to 7 May 1990 in one Swedish dairy herd. 26 of the cows were provided with electric cow trainers throughout this period, 14 did not have trainers and 12 had trainers only for the period between 7 February and 7 May. The hooves of the hind feet were evaluated for interdigital dermatitis and heel-horn erosion (erosio ungulae) on 2 October, 7 February and 7 May, and on this last occasion the dry matter content of the sole horn was measured. The average number of cow-pats deposited on the floors of the stalls with electric trainers was less than one-third of the number in the stalls without them, and the cows in stalls with trainers were approximately 30% cleaner. Between October and February, heel-horn erosion increased significantly only in the cows without electric trainers, and between February and May, heel-horn erosion decreased only in the cows which were

provided with trainers on 7 February. The prevalence of interdigital dermatitis decreased in all the cows throughout the period of housing and there was no significant difference in prevalence between the different groups. The dry matter content of the sole horn was significantly greater in the cows which had electric trainers than in the cows without trainers, and the difference was significant even in the cows which had the trainers only from February to May. There was a significant negative correlation between the dry matter content of the sole horn and the level of heel-horn erosion.

14. Pehrson, B. 1992. The ban on the Use of Cow Trainers Must be Lifted for the Benefit of the Animals. *Svensk Veterinartidning* 44(15).  
Abstract: The author concludes that the ban on cow trainers in Sweden must be lifted for the benefit of animals.
15. Anon. 1993. An Assessment of Cow Trainers. *Technique Agricole* 55(3).  
Abstract: The cow trainer is an electric device comprising a suspended arch which ensures that cows assume the desired position when defecating, with the aim of facilitating waste disposal. The behaviour of 8 cows was observed with and without the use of a cow trainer in convention housing over a 4 week period. It was concluded that the cow trainer restricted the animals' freedom of movement and in particular cows had difficulty in grooming themselves. Therefore, a cow trainer should only be in operation 1 or 2 d per week and should not be used with cows > 18 months old.
16. Cavani C., Fiego D.P.I., and Bianconi L. 1994. Effects of electric fences on pasture utilization and productive performances in dairy ewes. *Progressi Scientifici e Tecnologici in Tema Di Patologia e Di Allevamento Degli Ovini e Dei Caprin. Societa Italiana Di Patologia e Di Allevamento Degli Ovini e Dei Caprini*.  
Abstract: A 15-week crossover trial was carried out between April and August 1992 to evaluate the effects of movable electric fences on pasture management and performance of dairy ewes grazed on hill pasture in the Northern Apennine Mountains, Italy. 36 Langhe ewes were allocated between 2 grazing plots confined by conventional fencing (CF) or movable electrified fencing (EF). Stocking density with the EF was 2X that with CF, and the flocks were changed over approximately half-way through the trial. No significant differences were noted in yield, composition or somatic cell counts of milk between ewes confined by CF or EF. Higher grassland productivity, a more regular consumption of pasture species and a sharp reduction in weed infestation, were observed when EF was used. Contact of the lower electrified wire with the poorly-woolled and highly-sensitive noses of grazing ewes induced a severe shock to the animals and deterred them from crossing the fence.
17. Kennedy M.J., Marchant J.N., Broom D.M., Rutter S.M., Rushen J., Randle H.D., and Eddison J.C. 1995. A behavioural and physiological study of the responses of inexperienced gilts to electric fencing. *Proceedings of the 29th International Congress of the International Society for Applied Ethology*.  
Abstract: Gilts released into a field surrounded by an electric fence for the first time were observed and their heart rate monitored. Most strikes occurred in the first 10 minutes of the first day after which the pigs avoided the fence. Heart rate response did not diminish with subsequent shocks. The magnitude of the heart rate response increased with increasing gestation. It is suggested that contact with an electric fence for the first time during pregnancy could contribute to reproductive upset.
18. Kolz, L. 1995. Electroshock repulsion of waterfowl, aquatic animals, and small mammals. *United States Department of Agriculture Patent no. 5,460,123*.  
Abstract: The present invention comprises apparatus designed to repel, but not injure, warm-blooded aquatic life from a specific aquatic region in an energy-efficient manner. A potential gradient is turned on and maintained between sets of immersed electrodes in response to the detection of the presence of warm-blooded animals in the "watched" volume at the surface and above and below the surface of an aquatic region. The electroshock is applied to the animal through the water by use of an

electrical field generated from an array of electrodes placed in the water. The size, shape, and intensity of the electrical field are independently controlled by use of design criteria which allow the operator to determine the degree of electrical shock to be administered to a specific animal species by controlling the parameters of electrical energy induced into the animal through the water.

## **Current Exposure - Other Species**

1. Bossut, D. F. B., E. H. Page, and M. W. Stromberg. 1984. Production of cutaneous analgesia by electroacupuncture in **horses**: variations dependent on sex of subject and locus of stimulation. *American Journal of Veterinary Research* 45(4).  
Abstract: Cutaneous pain thresholds to pinprick, pinch, and heat stimuli were quantified during control and electroacupuncture trials in 23 horses. Pain thresholds for 8 areas of the body during control trials (no needles) were statistically compared with pain thresholds measured in the same areas of the same horse when given electroacupuncture treatment. Statistically significant increases of pain threshold were interpreted as induced analgesia and occurred mainly in 5 areas of the trunk, but not in the head or extremities. Analgesic efficacy varied between sexes, and among 3 groups of points chosen from Chinese traditional veterinary literature. Analgesia was induced equally well in both castrated males and intact females by the electrostimulation of 5 needles inserted on the gluteal (rump) and lumbar (loins) regions. However, stimulation of 2 needles located only in the gluteal region caused a significant analgesia in females only. In contrast, stimulation of 2 needles located in the thoracic limb was analgesic in males, but infrequently so in females. Therefore, we observed differential analgesia due to an interaction between needle location and sex of subject.
2. Malven, P. V., D. F. B. Bossut, and M. A. Diekman. 1984. Effects of naloxone and electroacupuncture treatment on plasma concentrates of LH [luteinizing hormone] in **sheep**. *Journal of Endocrinology* 101(1)75-80.
3. Przekop, F., and et al. 1984. The Effect of Prolonged Stress on the Oestrous Cycles and Prolactin Secretion in **Sheep**. *Animal Reproduction Science* 7(4).  
Abstract: The effect of repeated and prolonged stimuli on the release of LH and the course of oestrous cycles was studied in Polish Merino sheep. Weak electric shocks were administered to the feet in different phases of the cycle for 9 h daily for 3-4 days. The enduring and repetitive character of the stimuli was expected to induce an emotional state which was similar to management stress. Five out of 26 ewes stimulated in different phases of the oestrous cycle showed inhibition in the pre-ovulatory release of LH and disturbances in the function of the ovaries (cystic or inactive ovaries). The disturbances of the oestrous cycles appeared not only in the course of the cycle in which stimulation was applied, but also in the subsequent ones. Increased plasma prolactin levels after stimulation did not have an inhibitory action on the pre-ovulatory LH release. The impairment of neuro-hormonal regulation is discussed.
4. Appleman, R. D., and et al. 1985. Response of **Pigs** to Stray Voltage. *Minnesota Swine Research, University of Minnesota*.  
Abstract: Summary: Stray voltages, resulting in small electrical currents flowing through pigs' bodies, can adversely affect performance and profits on swine operations. Water consumption was lowered 25 percent when growing pigs were exposed to a 4.0 milliamp current accessing an electrically charged watering nipple. A voltage reading of 3.7 volts elicited this response.
5. Gustafson, R. J., R. D. Appleman, and T. M. Brennan. 1985. Electrical current sensitivity of **swine** for drinking. *ASAE Annual International Meeting Technical Paper* no. 85-3504.  
Abstract: Eight pigs were used for experiments with 60 Hz electrical currents, mouth-to-all hooves. Pigs, given an alternative, showed a preference for a water source with no current, compared to those at 0.25 mA and above. However, when no alternative source existed, greater than 3.0 ma was needed to effect drinking time and 4.0 mA to effect consumption. *Water consumption was lowered 25 percent when growing pigs were exposed to a 4.0 milliamp current accessing an electrically charged watering nipple. A voltage reading of 3.7 volts elicited this response.*
6. Zhuo, H., and H. Ye. 1985. Studies on the role of the cerebral cortex in acupuncture analgesia. II. Effect of electro-acupuncture on cortical single cell discharge evoked by iliohypogastric nerve

stimulation in **goats**. *Journal of South China Agricultural University* 6(2) .

7. Bossut, D. F. B., M. W. Stromberg, and P. V. Malven. 1986. Electroacupuncture-induced analgesia in sheep: measurement of cutaneous pain thresholds and plasma concentrations of prolactin and beta-endorphin immunoreactivity. *American Journal of Veterinary Research* 47(3).  
Abstract: Electroacupuncture at each locus increased ( $P < 0.01$ ) pt (ie, caused cutaneous analgesia) in 6 of 7 body areas, and increased ( $P < 0.05$ ) plasma concentrations of immunoreactive beta E and prolactin. In EA experiments in which good analgesia was induced, plasma betaE was increased more ( $P < 0.05$ ) than in EA experiments in which poor analgesia was induced. This difference was more evident for the Yao Pang locus. Generally, plasma prolactin concentrations were increased more with good analgesia than with poor analgesia for the Yao Pang locus. Electroacupuncture stimulation of the San Yang San Yang Lu locus was associated with higher plasma betaE concentrations than that associated with the Yao Pang locus. Increases in plasma prolactin concentrations were comparable between loci. Intravenous injection of naloxone (1.1mg/kg of body weight) generally decreased the increased PT that had resulted from EA of the Yao Pang locus, whereas naloxone did not have a consistent effect on the increased PT resulting from EA of San Yang Lu locus. In control experiments, naloxone briefly increased plasma betaE concentrations. In EA experiments in which good analgesia was induced, naloxone decreased plasma prolactin concentrations. Because EA-induced increases in plasma betaE and prolactin concentration correlated with the amount of EA-induced analgesia, betaE and prolactin in plasma can be considered indices of analgesia, but their putative function in the mechanisms of endogenous pain inhibition remains equivocal.
8. Domanski, E., and et al. 1986. Differential Behavioural and Hormonal Responses to Two Different Stressors (Footshocking and Immobilization) in **Sheep**. *Experimental and Clinical Endocrinology* 88(2) .  
Abstract: Two different stressors footshocking and immobilization applied for 3 days induced in sheep differential behavioural and hormonal responses in cortisol and prolactin secretion. Immobilization drastically disturbed rumen motoric activity (significantly attenuated its contractions), caused loss of appetite and severe general depression. Footshocking did not induce any of these stressing as compared to footshocking. On the postsressing days after footshocking as well as after immobilization plasma cortisol mesors fell to 50% of the prestimulatory values. The rise of plasma prolactin mesors in footshocked and in immobilized animals on the days of stressing was nearly of the same magnitude. However, a significant difference in the response of prolactin secretion between footshocked and immobilized animals occurred in the circadian rhythmicity of the hormone secretion. Footshocking induced circadian rhythmicity with characteristic acrophases, while immobilization did not induce the circadian pattern of prolactin secretion. An attempt of interpretation of the described phenomena has been undertaken.
9. Gustafson, R. J., R. D. Appleman, and T. M. Brennan. 1986. Electrical Current Sensitivity of Growing/Finishing **Swine** for Drinking. *Transactions of the ASAE* 29(2) 592-596.  
Abstract: Eight growing/finishing pigs were used for experiments with 60Hz electrical currents, administered through a mouth-to-all-hooves. Pigs, given an alternative, showed a preference for a water source with no current compared to those at 0.25 mA and above. However, when no alternative source existed, greater than 3.0 mA was needed to affect drinking time and 4.0 mA to affect consumption.
10. Li, Y. R., R. B. Li, Z. Yu, Q. Q. Zhou, and H. Ye. 1986. Influences of electro-acupuncture on the central venous pressure (CVP) in **cattle**. *Journal of South China Agricultural University* 7(3) .
11. Rushen, J. 1986. Aversion of **Sheep** to Electro-Immobilization and Physical Restraint. *Applied Animal Behaviour Science* 15(4).

Abstract: Thirty-six Merino wethers were forced along a sheep race and were either electro-immobilized using a commercially-available instrument, restrained with the electro-immobilizer electrodes attached, physically restrained in a sheep-handling machine or allowed to run freely through the race. The degree of aversion shown to the place where the treatment occurred was measured by the time taken by the sheep to run through the race on a subsequent occasion ("transient time") and the push-up time required. All forms of restraint increased the push-up and transit times. Sheep that had been electro-immobilized had a greater average transit time after four treatments and a greater average push-up time after two treatments than sheep that were physically restrained, with or without the electrodes attached. These results suggest that sheep find electro-immobilization more aversive than physical restraint. Push-time was increased if a high current was used, but was unrelated to the duration of electro-immobilization (up to 3 min.). Increasing the current increased the time required by the sheep to recover breathing, which was strongly and positively related to subsequent push-up time. The degree of aversion shown decreases with experience of electro-immobilization.

12. Rushen, J., and P. Congdon. 1986. Relative aversion of **sheep** to simulated shearing with and without electro-immobilisation. *Australian Journal of Experimental Agriculture* 26(5).  
Abstract: A Feenix Stockstill immobiliser did not reduce aversion in Merinos. Incorporation of this device in automated shearing systems might reduce sheep handling efficiency.
13. Wilcox, G. C., and H. C. Jordon. 1986. Stray Voltage Affects Performance of **Cage layers**: A field Observation. *Poultry Science (Abstract)* 65 Suppl. 1.  
Abstract: Feed and disease checks failed to indicate why a 43 week old flock of 10,280 S.C.W.L. layers reduced egg production from 83 to 63% in one week and reduced feed consumption 1/3 below normal. Mortality increased from 0.18 to 0.43% per week during the problem period. Water consumption appeared to be depressed because warm water was found in cups far from the inlet of fresh water. Volt meter readings found 0.8 to 0.9 volts between the metal cage and water in the plastic cups and a 1.3 to 1.5 volt potential between the cage and a driven ground rod. Volt readings taken at the entrance panel indicated that the voltage potential was present on the power company's neutral. Corrective action reduced the cage to waterer electrical potentials to 0.2 and 0.3 volts. Water and feed consumption returned to normal. Egg production returned from a low of 45 to 76%. The layers remained abnormally nervous and flighty for several weeks. This electrical disturbance of animals is well documented in dairy cows and appears to be a source of production loss in cage layers.
14. Kenny, F. J., and P. V. Tarrant. 1987. The behaviour of young **Friesian bulls** during social re-grouping at an abattoir. Influence of an overhead electrified wire grid. *Applied Animal Behaviour Science* 18(3).
15. McFarlane, J. M., and S. E. Curtis. 1988. Research Notes: System for Exposing **Chicks** to Experimental Intermittent Electric Shock. *Poultry Science* 67(12).  
Abstract: A system for imposing mild electric shock on chicks was developed to study effects on health, behavior, and performance. Chicks seemed to habituate to the shock over time. Therefore, in one experiment, the current from one point on a foot to another was increased daily from an estimated 2.9 mA on Day 1 to 8.7 mA on Day 7. When exposed to this electric shock regimen between 10- and 17 days of age, chicks weight gain was reduced by 12%, feed intake by 5% and gain:feed by 8%.
16. Tan W., Zuo H., and Ye H. 1988. The influence of electro-acupuncture on the evoked potentials of the cerebral cortex (cep) and the spinal cord surface (ssp) in the **goats**. *Journal of South China Agricultural University* 9(2).

17. Halvorson D.A., Noll S.L., Bergeland M.E., Cloud H.A., and Pursley R. 1989. The effects of stray voltage on **turkey** poults. *Avian Diseases* 33(3) .  
Abstract: Three successive flocks of turkey poults experienced cumulative mortality of 10% to 26% up to the fifth week of brooding. Stray electrical voltage was suspected after no definitive laboratory diagnosis could be made and no evidence of management deficiency was found. Alternating current voltage of 0.2 to 2.5 volts were detected between waterers and the floor and between the water line and gas line. When the water line was equipment-earthed to the electrical service entrance, the subsequent flock had no mortality problem. A series of experiments was conducted to determine the sensitivity of turkey poults to alternating current. Based on these experiments, the voltage levels measured at the farm probably did not cause the mortality experienced in the three flocks. The reason for the farm problem could have been (1) the poults experienced higher voltage than was present when measurements were taken, (2) the voltage may have been intermittent, or (3) there was a difference between the farm environment and the cage battery environment in the experiments.
18. Martin, M. J. D., D. A. Pritchard, and R. G. A. Stephenson. 1989. Electric Shock Conditioning of **Sheep** to Avoid Feed Supplement Troughs in Field Investigations of Diet Supplementation. *Australian Rangeland Journal* 11(1).  
Abstract: The possibility of conditioning grazing sheep not to eat freely available supplements was examined. The technique used a standard electric fence energizer connected to a trough filled with molasses. A flock of 60 wethers and another flock of 120 ewe and wether hoggets were each divided into 3 treatment groups. All groups were initially allowed access to the molasses trough with the energizer switched off. After 2 d, the control group was moved while the energizer was switched on for the other 2 groups; the voltage was measured at 6500 volts. Sheep in 1 group were removed from the yard after 1 d exposure while the other sheep were left with the energizer on for a further 2 d. One and 4 wk later all sheep were exposed to the molasses trough without the energizer turned on. The wethers and hoggets were then placed in 120 and 250 ha paddocks. Numbers of sheep visiting the troughs were checked 6, 18, 22 and 26 wk after introduction. Total success was achieved in creating avoiders and acceptors in their respective groups in the yard. None of the control group rejected supplements throughout the experiment in the paddocks. However, for the other wether groups, between 70 and 73% rejected the supplement. For the hogget groups the rejection rates were 74 and 70%. The behaviour and conditioning of the animals to avoid the troughs suggested that the use of energized troughs as described is not particularly stressful to individual sheep. The technique was only partly successful but it provides a means of comparing supplemented and non-supplemented sheep within a paddock.
19. McFarlane, J. M., and et al. 1989. Multiple Concurrent Stressors in **Chicks**: 1. Effect on Weight Gain, Feed Intake and Behavior. *Poultry Science* 68(4).  
Abstract: Effects of multiple concurrent stressors on Hubbard times Hubbard chicks (Days 10 to 17 posthatch) were studied in a 2-6-factorial experiment that employed as treatments aerial ammonia (A, 0 or 125 ppm), beak trimming (B, sham handled or beak trimmed/cauterized), coccidiosis (X, gavage with 0 or 6 times 10-5 sporulated *Eimeria acervulina* oocysts), intermittent electric shock (E, 0 between 2.9 and 8.7 mA), heat stress (H, 30.4 or 34.8 C), and continuous noise (N, 80 or 95 dB). All stressors, except noise, decreased weight gain (G), increased coefficient of interindividual variation in gain (CV-G), and decreased feed intake (F) and feed conversion efficiency (G/F). Of a possible 57 interactions, only four were significant for G, two for CV-G, and of a possible 26 interactions, only two were significant for F, none for G/F. As number of simultaneous stressors (order) increased, G, F, and G/F decreased and CV-G increased, all linearly. Time chicks spent standing was increased by X; time spent eating increased by X; and time spent drinking decreased by H. No effect of order and few stressor interactions were detected for the behaviors. Although behavior results were inconclusive with respect to synergism, antagonism, or additivity of stressors' effects, performance results indicated that chicks responded to each stressor in the same fashion regardless of whether a stressor occurred singly or concurrently with up to five others. The results

suggest that in practical production situations, where ordinarily poultry experience more than one stressor at the same time, effects of multiple concurrent unrelated stressors on performance may be estimable to a first approximation by summing effects of respective stressors when acting alone.

20. Ratner, A., D. B. Yelvington, and M. Rosenthal. 1989. Prolactin and Corticosterone Response to Repeated Footshock Stress in Male **Rats**. *Psychoneuroendocrinology* 14(5).  
Abstract: The prolactin (PRL) and corticosterone (CORT) responses to footshock stress were measured in male rats after the 1st, 5th and 57th exposure to stress procedure. No reduction in the PRL or CORT responses was seen after repeated application of the footshock stress, and the Ss showed similar behavioral responses throughout. Results indicate that the hormonal and behavioral responses to footshock stress are not attenuated after an animal has been repeatedly exposed to the stress.
21. Steiss, J. E., N. A. White, and J. M. Bowen. 1989. Electroacupuncture in the treatment of chronic lameness in **horses** and ponies: a controlled clinical trial. *Canadian Journal of Veterinary Research* 53(2) .
22. Hotary, K. N., and K. R. Robinson. 1990. Endogenous Electrical Currents and the Resultant Voltage Gradients in the **Chick Embryo**. *Developmental Biology* 140(1).  
Abstract: We have studied some of the electrophysiological properties of 21/2 to 4-day-old (stage 14-22) chick embryos. Using a recently developed two-dimensional vibrating probe, large currents were found to exit the posterior intestinal portal p.i.p.) during the period of tail gut reduction. During this period, epithelial cells lining cloacal regions of the hindgut are dying, thus creating a low-resistance pathway for current flow out of the embryo. Currents entered the intact epithelium over other regions of the embryo. The outward currents at the p.i.p. were first detected at stage 15 and reached their average maximum current density of 112 +/- 10 microamps per square centimeter A/cm<sup>2</sup> at stage 17. After stage 17, the magnitude of the currents decreased, dropping to 16 +/- 0.3 microamps per square centimeter A/cm<sup>2</sup> by stage 22. The currents were reversibly reduced by about 50% when Na was replaced by choline in the bathing solution. The magnitude of the currents leaving the p.i.p. suggested the existence of measurable intraembryonic voltage gradient. The transepithelial potential (TEP) of stage 14-21 embryos was measured lateral to the neural tube through the dorsal ectoderm. For all stages, the combined average TEP was 16 +/- 0.5mV. Differences in the TEP between various regions of the embryo were used to calculate an intraembryonic voltage gradient. At stage 14, before outward current was found at the p.i.p. no significant intraembryonic voltage gradient was detected. At stage 17, when the outward current at the p.i.p. was maximum, a voltage gradient of 21 +/- 5mV/mm (mean=SEM; N = 6) was measured in the caudal end of the embryo. This gradient in some cases was as steep as 33mV/mm. This is well above the minimum level needed to affect the direction of embryonic cell migration in vitro. We hypothesize that this endogenous electrical field acts as a directional cue for neural crest cell movements in the developing chick embryo.
23. Kuchel, T. R., and et al. 1990. Physiological and Biochemical Consequences of Electro-immobilisation in Conscious **Sheep**. *Australian Veterinary Journal* 67(2) .  
Abstract: Electroimmobilisation caused statistically significant increases in mean arterial pressure, heart rate, cardiac output, renal and hepatic and hindquarter glucose and lactate flux, organ and whole body oxygen flux, hindquarter blood flow and core temperature and decreases in arterial and posterior vena cava blood pH, renal and hepatic blood flow and PaCO<sub>2</sub>. Notably, no change occurred in PaO<sub>2</sub>. The metabolic changes demonstrated the capacity of sheep to respond to the increased muscular and cardiovascular work induced by electroimmobilisation. Pulmonary function was not compromised during electroimmobilisation as judged from blood gas changes, and the acid-base changes were rapidly reversed after electroimmobilisation. The recovery to control conditions for all perturbations generally took no longer than 30 min, consistent with a rapid and

physiologically adequate reversal by the animal's homeostatic mechanisms.

24. Quigley, T. M., H. R. Sanderson, A. R. Tiedemann, and M. L. McInnis. 1990. **Livestock** control with electrical and audio stimulation. *Rangelands* 12(3).  
Abstract: A system of training cattle to avoid an area (aversion area) by training them to respond to electrical stimuli was developed. Animals to be controlled wear a collar containing a radio receiver and an electrical stimulator with contacts touching the skin. When a collared animal moves into an aversion area a transmitter signal activates the receiver in the collar and an electrical stimulus is applied and repeated at intervals until the animal leaves the area. Trials were conducted in unfenced grasslands and demonstrated that cattle could be trained in less than 2d to respond to signals in the desired way. *No negative effects were noted.*
25. Tan, K. S., and D. L. Johnson. 1990. Threshold of Sensation for 60Hz Leakage Current: Results of a Survey. *Biomedical Instrumentation & Technology* 24.  
Abstract: Canadian regulations have set a limit of 0.1 mA on leakage currents permitted to flow from patient-applied parts of an electromedical device under single-fault conditions, while international standards, such as International Electrotechnical Commission (IEC) 601-1, have set the limit of 0.5 mA under the same conditions. Canadian agencies have suggested that national standards for electromedical devices should harmonize with widely used international standards by increasing the leakage current limit to 0.5 mA. The authors investigated the question of whether 0.5 mA would compromise safety, or would be unpleasant or painful for the patient. A survey was conducted on the reactions of 95 adult volunteers to 60-Hz alternating currents ranging from 0.01 to 0.5 mA applied through typical ECG electrodes to determine the level at which these volunteers felt a distinctly uncomfortable or painful sensation. Results of this survey confirm that 0.5 mA currents are more than sufficient to induce pain in healthy adult volunteers, and that currents greater than 0.1 mA can evoke a definite sensation. Based on these findings, the authors recommend that the maximum allowable leakage current for patient-applied parts under single-fault conditions should not exceed 0.1 mA.
26. Villeneuve, P. 1990. Does Stray Voltage Affect Egg Production?  
Abstract: The effects of continuous (Exp. 1, 2 and 3) and random (Exp 4 & 5) stray voltage were evaluated on laying hens between 23 and 40 weeks of age. Each experiment lasted from 2-4 weeks. Hens were caged individually in six blocks and four treatments (30 hens/trt) were applied. Continuous voltage as a difference of electrical potential between the nipple drinker and the metallic cage was applied at 0 (control), 1, 2, or 3 volts in Exp 1 at 0, 4, 5 and 6 volts in Exp. 2 and at 0, 7, 8 and 9 volts in Exp. 3. In Exp. 4 and 5 the hens were re-randomized in the same blocks and random voltages were applied at 0, 0 to 3, 0 to 6 and 0 to 9 volts at 1(Exp. 4) or 2 pulses (Exp. 5) every 10 sec. In Exp 1, there was no effect of continuous voltage on laying rate (6.5 eggs/hen/week), daily feed intake (110 g/hen) or daily water intake (210 ml/hen). In Exp 2 and 3, laying rate was not affected by treatment. At times in Exp. 2 and 3, daily feed intake and water intake were different between treatment but these differences were inconsistent and overall there was no effect of treatment. In Exp. 4 and 5, random stray voltage had no influence on laying rate, daily feed intake or daily water intake. Results of the present experiments indicate that continuous or random stray voltage at levels of 0 to 9 volts do not impair egg production. These results were consistent with the electrical resistance of hens which was measured and found to be much higher than that of dairy cattle and pigs.
27. Monteleone, P., and et al. 1991. Failure of Single Electroconvulsive Shock to Affect Daytime Melatonin Production in **Rats**. *Journal of Pineal Research* 10(3).  
Abstract: It has been reported that, in the rat, different types of stressful procedures increase daytime melatonin production. Electroconvulsive shock (ECS) has been shown not to affect daytime pineal melatonin in rats killed 9 hr after its administration. It is possible that the long-lasting interval

between the ECS administration and the sacrifice of the animals obscured an effect of the stressful procedure. In the present study, the effects of acute ECS on daytime melatonin production were evaluated in both ECS- and sham-treated rats killed 30, 60, 120, and 240 min after treatment. As compared with the sham-treated animals, rats receiving acute ECS (80 mA, 0.5 sec) did not show any significant difference in either pineal or serum melatonin levels at any time point after treatment. These data indicate that single ECS does not affect daytime melatonin production in the rat and suggest that the pineal gland may respond differently to the various stressful procedures.

28. Porter, M. 1991. Therapeutic electricity. *Journal of Equine Veterinary Science* 11(1).
29. Robert, S., J. J. Matte, J. Bertin Mahieux, and G. P. Martineau. 1991. Effects of continuous stray voltage on health, growth, and welfare of fattening pigs. *Canadian Journal of Veterinary Research* 55(4).  
Abstract: The effects of simulated continuous stray voltage were evaluated on growing-finishing pigs between the ages of 8 and 21 weeks. Seventy-two pigs were assigned to six blocks of 12 animals each. The following treatments were randomly distributed in each block according to a 2 X 3 factorial design: feeding level (restricted or ad libitum), and voltage level (a potential difference of 0, 2 or 5 V between the feeder or drinker and the metallic floor). During daytime, the applied potential difference of 5 V decreased the eating frequency in both feeding groups and the drinking frequency in restricted-fed pigs. The mean duration of drinking bouts and the total time spent at the drinker were also lower in this last group during the hour following meal distribution. Daily feed intake and average daily gain were lower in the 5 V group than in the 2 V and the control groups from 17 to 21 weeks of age. Finally, gastric lesions, haematological and biochemical variables were not affected by either voltage level.
30. Ghi, P., and et al. 1992. Stress and brain Histaminergic System: Effects of Weak Electric Foot Shock. *Pharmacology Biochemistry and Behaviour* 41(2).  
Abstract: A weak electric foot-shock stressful stimulus (0.5 mA times 1 s times 5 times) significantly increases plasma corticosterone (CS) levels and modifies (3H)-histamine ((3H)-HA) binding site constants related to H-2 receptors in rat cortical membranes. Progressive and total recovery of basal binding characteristics occurs 90 min later. A double-foot-shock stress procedure delays (3H)-HA binding characteristic recovery instead of strengthening stress effects. This finding is further evidence of involvement of the brain's histamine receptors in the response to mild stress.
31. Matte J.J., Robert S., Godcharles L., Bertin Mahieux J., and Martineau G.P. 1992. Factors affecting the electrical impedance of growing-finishing pigs. *Canadian Agricultural Engineering* 34(2).  
Abstract: In a first trial, 12 pigs between the ages of 9 and 22 weeks were used in a 2 x 2 factorial design to measure the effect of 2 levels of 60 Hz ac voltage (2 and 5 V) and 2 flooring conditions (woven wire covered with water (WW) or dry (WD)) on total body impedance (TBI). Whatever the age of the animal or the flooring conditions, the overall TBI was higher (P less-than-or-equal-to 0.003) at 2 V than at 5 V (1300 vs 1091-OMEGA). The effect of age on TBI was dependent upon the wetness of the floor (P less-than-or-equal-to 0.01). At 10 weeks of age, TBI was higher on WD than on WW (3041 vs 1031-OMEGA) while the corresponding difference, at 18 weeks of age, was less pronounced (1036 vs 778-OMEGA). From 18 to 22 weeks, the decrease of TBI persisted on both flooring conditions but was more marked on WW (17%) than on WD (7%). This reduction in TBI with age could be explained by the increase of the contact area and of the pressure exerted by hooves on the floor, which are major factors influencing the quality of floor-hooves contact. In a second trial, two 15 week-old pigs were used in a factorial arrangement of treatments (2 x 3 x 4) to measure the effects of voltage (1 and 2 V), current frequency (60, 1000, 3000 and 10,000 Hz) and flooring surfaces (WW, WD and a copper plate covered with water, (CW)) on TBI. No difference (P greater-than-or-equal-to 0.38) could be measured between the 1 V and the 2 V treatments. Whatever the voltage, the overall value of TBI at 60 Hz on CW was lower (P less-than-or-equal-to 0.01) than on

WD but similar to that measured on WW. However, as current frequency increased, the differences among surfaces disappeared (P less-than-or-equal-to 0.05). These results indicate that a greater amount of current could pass through the body of growing-finishing pigs as they get older and/or heavier. Among the studied factors affecting TBI, wetness of the floor and current frequency appeared to be the most important.

32. Matte, J. J., Robert S., Godcharles L., Bertin Mahieux J., and Martineau G.P. 1992. Stray Voltage: Factors Affecting the Current Perceived by Growing Finishing **Pigs**. *Journal of Animal Science* 70 Suppl. 2.  
Abstract: Stray voltage can be defined as a small difference of voltage potential between two contact points of an animal's body. In pigs, it occurs most commonly between mouth and hooves during eating and drinking episodes. The amount of current circulating between the contact points and perceived by the animal is dependent upon the total body impedance (TBI) which is composed of contacts resistances and the internal body resistance. Twelve pigs were used in a 2 X 2 factorial design.
33. Robert S., Matte J.J., Bertin Mahieux .J, and Martineau G.P. 1992. Stray voltage: its influence on **swine** production during the fattening period. *Canadian Journal of Animal Science* 72(3).  
Abstract: The effects of continuous stray voltage were evaluated on growing-finishing pigs between the ages of 10 and 12 wk. 72 pigs were assigned to 6 blocks of 12 animals each. The following treatments were randomly distributed in each block according to a 2 X 3 factorial design: feeding level (A) (restricted or ad libitum) and voltage level (0, 5 or 8 volts) as a continuous difference of potential between feeder or drinker and the metallic floor. The total drinking time and the number of drinking bouts were lower in the 8-V group than in the 0-V group for restricted-fed pigs during the hour and feed distribution. The percentage of observation time spent drinking during light hours was reduced in the 5-V and 8-V groups at 18 and 20 wk. However, it was only between 14 and 16 weeks of age that water intake was lower in the voltage groups. There was no effect of voltage on mean daily feed intake and average daily gain over the whole fattening period. Nonetheless, the mean eating frequency during light hours from 10 to 20 wk of age was higher in the 8-V than in the 0-V and 5-V groups of restricted-fed pigs, while it was similar in the three groups fed ad libitum (A X V lin.) Stray voltage at 8 increased sitting time and decreased resting time in restricted-fed groups during light hours (A X V lin) but the occurrence of aggressive encounters was very low in the three treatment groups throughout the study. Finally, the metabolic profile, the frequency and the severity of gastric ulcerative lesions and the meat colour were similar among the treatments.
34. Godcharles, L., S. Robert, J. J. Matte, J. Bertin-Mahieux, and G. P. Martineau. 1993. Transient stray voltage: is it detrimental to growth performance, health status and welfare of market **pigs**? *Veterinary Research Communications* 17(1).  
Abstract: Seventy two pigs were studied from 9 to 22 weeks of age in the following treatment groups: constant voltage differential between feeder or drinker and metal floor at 0 volts plus 2-volts pulses (0-2V), 2 volts plus 3-volt pulses (2-5V), 5 volts plus 3 volt pulses (5-8V) and a control with no voltage differential. Pulses were of 3 sec duration as an increase in amplitude of the constant 60 Hz signal, one pulse every 20, 40 and 100 sec during the hour following feed distribution and every 60, 120 and 300 sec at other times. Transient stray voltage had no significant effects on feeding, drinking, sitting or lying activities. At 9-10 weeks of age, a slight increase in rooting bouts was observed in 5-8V pigs, and of head butting of penmates in 2-5V pigs. Water and feed intakes did not differ between groups, but average weight gain was lower at 9-10 weeks in control pigs and higher at 17 and 18 weeks in 2-5V pigs. Gastric ulceration and metabolic profiles showed no differences except that controls had higher total protein and 5-8V pigs had higher CO<sub>2</sub> concentrations, but this was not consistent among ages. No major impact of transient stray voltage on health, growth or welfare of fattening pigs was observed.

35. Kambic, H. E., and et al. 1993. Influence of AC and DC Electrical Stimulation on Wound Healing in **Pigs**: A Biomechanical Analysis. *Journal of Investigative Surgery* 6(6).  
 Abstract: To evaluate the effects of electrical stimulation on the mechanical properties of healing skin, 20 Hanford mini-pigs weighing 10-15 kg with trochanteric pressure ulcers were subjected to electrical stimulation. Examination of the biomechanical properties of the skin and changes in wound area and volume was done on previously wounded and healing pigskin subject to AC or DC electrical stimulation. The behavior of normal pigskin was compared to (1) denervated controls, (2) denervated AC-stimulated skin, and (3) denervated DC-stimulated skin. A denervated limb trochanteric pressure sore model developed in house permitted the use of a 6.5-mm percutaneous cancellous screw for wound formation and a 3-cm-diameter spring compression indenter to create reproducible and uniformly controlled grade 3 or higher tissue ulcers in the monoplegic hind limbs. Denervation was accomplished by right unilateral extradural rhizotomies from L2 to S1 nerve roots. Electrodes were placed 1 cm distal and proximal to the wound periphery, and wounds were stimulated 2 h/day, 5 days/week for 30 days. Dumbbell-shaped skin specimens with a length to width ratio of 3:1 were uniaxially loaded in tension until failure at an extension rate of 150 mm/min. The stiffness values for skin samples oriented parallel to the current flow were reduced by nearly half the values obtained for normal controls. Statistical differences ( $P < .05$ ) were found for stress, Young modulus, and stiffness when compared to normal skin. Samples oriented in the perpendicular direction were comparable to normal skin ( $P = NS$ ). (ABSTRACT TRUNCATED AT 250 WORDS).
36. Robert, S., L. Godcharles, J. J. Matte, J. Bertin-Mahieux, and G. P. Martineau. 1993. Stray voltage in fattening **pigs**. *Journees De La Recherche Porcine En France* 25.  
 Abstract: Pigs were exposed to 0, 2, or 5 V (60 Hz rms) between feeder and drinker and metallic floor. The 2 V exposures produced no change in behaviors. The 5V exposures resulted in some changes in feeding and dinking behaviors and reduced feed intake for 4 weeks of the 13 week exposure period. Gastric lesions, hematological and biochemical variables were not affected at either level.
37. Gregory, N. G., and S. B. Wotton. 1994. Effect of Electrical Stunning Current on the Duration of Insensibility in **Hens**. *British Poultry Science* 35.  
 Abstract: 1. Hens were subjected to electrical stunning at 85, 105 or 125 mA per bird. The time to recovery of physical behaviour was measured in those birds which did not experience a cardiac arrest at stunning. 2. On average the duration of apparent insensibility lasted between 53 and 59 s, and at 105 mA per bird it was as short as 22 s in the bird which showed the quickest recovery. 3. Increasing the stunning current had no effect on the duration of insensibility.
38. Sein, O. B. 1994. Induction of Pubescence in **Swine** with the Using of Transcranial Electrostimulation [Transkranial' Naya Ehlektrostimulyatsiya Polovoj Zrelosti u Svinok]. *Veterinariya*.  
 Abstract: In the article are presented the results of examinations for application of the transcranial electrostimulation of pubescence in swine. It is stated that 30-minutes electrostimulation during 3 days with the using of "Transair-2" device permits to shorten the pubescence period and to considerably increase the quantity of ovulated follicles in replacement swine.
39. Biharo, A., A. Kumar, and S. K. Garg. 1995. Enhancement of antibody production by electro-acupuncture in **goats** immunized with Salmonella typhimurium. *Indian Journal of Animal Sciences* 65.
40. Heyde, H. van der, J. P. de. Mets, H. Hendericks, and M. Debruyckere. 1995. Electrical tensions on **farrowing** house equipment. *Transactions of the ASAE* 38.  
 Abstract: Electrical tensions up to 600 mVDC between the floor and the farrowing crate were noticed. Voltages of the different floor panels not only differed significantly, but even the voltage of

adjacent panels differed up to 400 mVDC. Although the differences remained almost constant during periods up to a few weeks, they changed sometimes suddenly and significantly. Also, on water bowls, feed troughs and concrete floors, galvanic voltages were recorded. No link between voltage, behavior, and production has yet been determined.

41. Marks TA, Ratke CC, and English WO. 1995. Stray voltage and developmental, reproductive and other toxicology problems in **dogs**, cats and cows: a discussion. *Veterinary and Human Toxicology* 37(2)163-172.

Abstract: Ten years ago, after 3 y of investigations, attempts to determine the cause(s) of reproductive and developmental problems at a dog kennel in Allegan County, MI were suspended. This kennel had lost more than 120 litters of Shetland Sheepdogs (Shelties) over the preceding 12 y; many of the puppies that died were deformed as were several that survived. Similar effects occurred in Persian cats, although on a smaller scale, and later in German Shepherds and Golden Retrievers. Such problems began after drilling a deeper water well and the building of a new kennel of concrete and metal fencing in 1969. Prior to that time the kennel owner had successfully bred and raised at least 15 litters/y of mostly Shelties in an old wooden chicken coop. Health problems in the kennel owner prevented her from breeding dogs in the late 1980's. She gradually resumed a more regular breeding schedule in 1989, initially with some success. However, in 1992 reproductive problems returned. Female dogs ceased cycling or had abnormal "unbreedable" seasons. Sperm checks revealed a lack of sperm in four males. Concurrently, neither the Persian nor mongrel female cats in; the kennel showed signs of cycling. Two dairy farmers in Allegan County, who reportedly had similar health, reproductive and management concerns in cows, were contacted. Tests performed at these dairy farms had revealed the presence of what has commonly been called stray voltage. Equipment brought by the farmers to the kennel revealed the presence of AC and DC currents on the premises, which was later confirmed by a Staff Engineer of the Michigan Public Service Commission (RSC). Such current was detected even when the electrical power to the premises was shut off. For example, 2.45 volts AC and -0.150 volts DC were detected at the well head, with variable amounts detected at various locations in the kennel. The current was not constant, with transients (spikes) frequently detected. Similar problems were evident in Van Buren County at a recently constructed kennel about 15 miles south of the kennel in Allegan County. Shortly after moving to the property, health problems not previously experienced by the breeder began cropping up in the dogs. Experts from the power company, the PSC, and 2 independent consultants have taken a variety of measurements on the property. The tests confirmed the presence of stray voltage (AC and DC) with periodic voltage spikes, as well as electromagnetic fields and electric fields. None of the extensive tests have proven the property owner to be at fault. To date no litters have been produced in any of the dogs kept on the property. Bone and muscle problems continue to arise, particularly in young dogs. Occasional interdigital cysts appear and heal spontaneously. Deaths appearing due to electrocution still occur. The dearth of references on stray voltage in the toxicology literature led to this review. The relationship of such currents to the problems found on dairy farms, as well as the 2 dog kennels, is discussed.

42. Robert S., Gagne Giguere S., Girard C.L., and Matte J.J. 1995. The effects of stray voltage on the welfare, productivity and health of piglets, fattening pigs and sows. *1er Colloque Recherche Sur Le Porc a Lennoxville*.

Abstract: Stray voltage (especially  $\leq 5$  V) modified the feeding behaviour of growing-finishing pigs, particularly when feed was restricted. Resting behaviour was disturbed by 8 V or more. However the performance or health of the pigs was not affected by the stray voltage. The amount of stray voltage varied with floor types and was higher on wet floors.

43. Vidali, G., F. G. Silversides, R. Boily, and P. Villeneuve. 1995. Effects of normal sinusoidal electrical voltage and impulses on the behavior and performance of laying **hens**. *Canadian Journal of Animal Science* 75(3).

Abstract: The effects of normal sinusoidal electrical voltages and impulses on laying hens between 23 and 48 wk of age were evaluated. One hundred and twenty hens were caged individually in six blocks of 20 animals each. Within each block, the treatments were distributed in a randomized complete blocks design. Electrical voltages of constant amplitude of 0-3 V, 4-6 V and 7-9 V were applied in exp. 1, 2 and 3, respectively. Voltage differences with random amplitudes of 0-9 V were applied at a frequency of one pulse every 10 s in exp. 4 and a frequency of two pulses every 10 s in exp. 5. In exp. 6, the hens were subjected to voltages of 12-18 V at a frequency of one pulse every 10 s. In exp. 7, hens were placed three per cage and received either 0 or 12 V with one pulse every 10 s. All voltages were applied between the metallic nipple drinker and the metallic cage. Daily water and feed intake, laying rate and behavior of the hens were measured. These voltages did not affect feed or water consumption, laying rate or egg quality. Frequency of eating and drinking behavior, time spent eating and drinking and time spent standing or sitting were not affected by the treatment. Although poor performance of farm animals is occasionally attributed to stray electrical voltages, in this experiment, voltage differences as high as 18 V had no effect on the hens' production and behavior.

44. Robert S., Matte J.J., and Martineau G.P. 1996. Sensitivity of reproducing sows and suckling pigs to stray voltage. *American Journal of Veterinary Research* 57(8).  
Abstract: 120 gilts were randomly assigned to 1 of 3 voltage treatments (40 gilts/treatment): 2-V baseline plus 3-V pulses (2-5 V); 5-V baseline plus 3-V pulses (5-8 V); and control treatment (0-0 V). The constant voltage was applied 24 h/day while pulses of 3 sec duration were applied at irregular intervals. Behaviour was recorded during gestation and lactation. Water and feed intakes were measured daily, milk composition was evaluated once during lactation, and haematocrit, haemoglobin, glucose, total protein, aspartate transaminase, alanine transaminase, albumin, globulins and fatty acids values were measured at mating, weeks 8 and 15 of gestation, parturition and weaning. Prolific ability of sows, mortality and disease of suckling pigs, and growth rate until 56 days of age were recorded. Gilts under voltage were lying down more often and performing less abnormal behaviours than were control gilts. Behaviour of sows and suckling pigs was not affected by treatments. Water and feed intakes were similar among treatments, except during week 1 of lactation where feed intake was lower in the control group. Fecundity and prolific ability of sows, percentage of still-birth, growth rate of suckling pigs, and milk composition were similar among treatments. More suckling pigs died in the 2-5 V group than in other groups, but diarrhoea was more frequent in the control group. Blood metabolites were similar among treatment groups. It is concluded that transient stray voltage at values up to 8 V does not impair the welfare, reproductive performance, or health of sows and suckling pigs.
45. ———. 1996. Stray voltage: sensitivity of fattening **pigs** and factors affecting their resistance. *Pig News and Information* 15(2).  
Abstract: A discussion of published experiments by the authors. It was concluded that continuous or intermittent exposure to up to 8 V does not affect the feeding behaviour and fattening performance of pigs. The authors suggest that stress factors such as feed restriction, flooring materials and management may account for some of the claims of adverse effects from stray voltages.
46. Vidali G., Silversides F.G., Boily R., Villeneuve P., and Joncas R. 1996. Effects of chopped sinusoidal voltages on the behavior and performance of laying **hens**. *Canadian Agricultural Engineering* 38(2).  
Abstract: 120 Babcock hens were studied from 23 weeks of age in 5 consecutive experiments each of 3 weeks and with a 1-week interval between the experiments. The fowls were caged individually (experiments 1 and 2) and then in groups of 3 (experiments 3-5). The treatments were distributed in a randomized complete block design. In the 1st experiment, voltage differences of 0, 3, 6 and 9 V were applied between the metal nipple waterer and the metal cage; in experiment 2, voltages of 0, 12, 15, and 18 V were compared. In experiments 3-5, the effects of 6, 12 and 18 V were studied in

successive experiments. Daily water and feed intake, egg production and behaviour were studied. No effects which could be consistently attributed to voltage were found. The electrical resistance of 23- and 40-week-old hens was measured and found to vary between 350 and 544 k Ohms. Although poor performance of farm livestock is occasionally attributed to stray electrical voltages, in this experiment, voltage differences as high as 18 V had no effect on hen's production and behavior.

47. Morris JP, Ong RM, O' Dwyer JK, Barnett JL, Hemsworth PH, Clarke IJ, and Jongman EC. 1997. Pain-related cerebral potentials in response to acute painful electrical stimulation in **sheep**. *Australian Veterinary Journal* 75(12).  
Abstract: The relationship between late event-related cerebral potential amplitudes and behavioural responses to noxious electrical stimulation, as an indicator of acute pain, was examined in sheep. 96 brief, constant current electrical pulse trains were administered to the front left leg of 8 sheep at 4 intensities (2.5 to 10 mA). An event-related cerebral potential and a graded flinch response were recorded for each stimulus. The flinch response and some event-related cerebral potential components, (such as peak amplitudes 114 {N1}, 187 {P1}, 318 {P2} and 230 {Pm} ms after stimulus onset) were significantly affected as stimulus intensity increased. It is concluded that these corresponding behavioural and event-related cerebral potential changes indicate the usefulness of using changes in the event-related cerebral potential to measure acute pain in sheep.
48. Nam T.C., Seo K.M., and Chang K.H. 1998. Electroacupuncture regional analgesia in **cattle**. *Korean Journal of Veterinary Research* 38(2).
49. Worley J.W., and Wilson J.L. 1998. Effects of stray voltage on laying habits of **broiler breeders**. *ASAE Annual International Meeting Technical Paper* no. 98-3005.  
Abstract: Stray voltage has been suggested as one factor that might contribute to broiler breeders laying eggs in locations other than the nests, causing significant expense to producers. Broiler breeders were subjected to voltage at varying levels (0-9 V a.c.) between slats and laying nests to determine the effect of stray voltage on the choice of laying location. All of the groups of birds (including the control groups) had a high incidence of laying eggs in locations other than the nest indicating that factor(s) other than the applied voltage were causing a problem.
50. ———. 2000. Effects of stray voltage on laying habits of **broiler breeders**. *Applied Engineering in Agriculture* 16(6).  
Abstract: Stray voltage has been suggested as one factor that might contribute to broiler breeder hens laying eggs in locations other than the nests, causing significant expense to producers. Mature and young groups of broiler breeder hens were subjected to voltages at varying levels (0 to 9 VAC) between slats and laying nests to determine the effect of stray voltage on the choice of laying location. These data indicated no difference in laying habits between any of the treatments and control pens, however all of the groups of hens (including the control groups) had a high incidence of laying eggs in locations other than the nest, indicating that factors other than the applied voltage may have been causing a floor egg problem.
51. ———. 2000. Influence of stray voltage on **breeder hens**: a field study. *ASAE Annual International Meeting Technical Paper* no. 00-4129.  
Abstract: With the increased use of mechanical nesting in broiler breeder facilities, the percentage of floor and slat eggs has increased. Many factors are known to influence floor and slat laying, but stray voltage has recently been identified as one possible contributing factor. A growing number of producers with floor egg problems have reported voltage levels ranging from 1 to 18 volts between the nests and the ground. Electric utilities have worked with Cooperative Extension Service engineers to solve the stray voltage problem on a number of these farms, and the next flocks placed in the houses have generally had greatly reduced floor-egg numbers, however the tendency of stray voltage levels to vary over time has complicated efforts to gauge the extent of stray voltage problems.

In this field study, voltages were monitored over a three to five-day period. Fifteen farms that had been identified as having problems with floor-eggs were monitored during this study. Voltages on farm grounding systems ranged from less than 1 volt to 21 volts, and levels over 2 volts were found on eleven of the farms. It was shown that voltages vary both diurnally, with highs occurring in the afternoon and lows at night, and over a period of days, with voltages increasing as the earth dries out. Some of the voltage appears to be coming from off-farm sources, and some from wiring problems on the farms. Floor egg numbers ranged widely as well, with percent slat/floor eggs varying from 1 to 30%. There was no correlation between percent floor eggs and the amount of voltage found. Additional data is needed to determine if any correlation exists between breed of hen or brand of nests and floor egg numbers. Although limited in scope, this study provides evidence that stray voltage exists in many breeder houses and may be a contributing factor to floor and slat egg problems.

52. Worley, J. W., and J. L. Wilson. 2001. Analysis of stray voltage on **broiler breeder** farms. *Journal of Applied Poultry Research* 10(4).  
Abstract: Poultry producers are concerned about the number of eggs that end up on floors and between slats rather than in nests. Stray voltage in mechanized nesting facilities is considered a possible reason for egg losses. Experiments were conducted on 15 farms, all with varying degrees of reported voltage levels between the nests and the ground. Because the voltage levels fluctuated it was difficult to gauge the extent of the exposure problems, but the author concludes that stray voltage is present in many breeder houses and it may be a contributing factor to floor and slat egg problems.

## **Electric and Magnetic Field Exposures**

1. Amustutz, H. E., and D. B. Miller. 1980. A study of Farm Animals Near 765 KV Transmission Lines. *Bovine Practitioner* 15:51-62.  
Abstract: This two-year study of eleven (11) livestock farms was initiated to determine the effects, if any, of electric and magnetic fields from 765 KV transmission lines on farm animals. Nine (9) farms were studied for the full two-year period. One beef farm discontinued operations after ten months and another beef farm after fourteen months. The farm operators made continual observations of their animals' health and submitted bi-monthly reports. A veterinary bi-monthly inspection of the animals was made and a report of each inspection prepared. Eighty-six percent (86%) of the farm operator reports were returned and 100% of the veterinary reports were available and provide the basis for this final report. As would be expected, there were a few health problems and some deaths in beef cattle, dairy cattle, swine, and sheep, but these were not considered uncommon. Animals were maintained under widely variably breeding, feeding, management and housing conditions. All of these factors influenced health, but housing was especially significant in the case of young or debilitated animals during the extremely severe winter weather. Performance of the animals was commensurate with breeding, feeding, management, and housing practices. Some animals performed poorly and others performed extremely well. Thirty-six crossbred pigs gained an average of 1.76 pounds a day for a 116-day feeding period, and required only 3.33 pounds of feed per pound of gain. A seventy-cow Holstein dairy herd reached a rolling herd average of 17,276 pounds of milk per cow per year, which compares to an Indiana average of 10,729 pounds. Nineteen Polled Hereford steer calves were estimated to weigh 575-600 pounds by the owner when they were sold at six months of age. Average weight of six-month old steer calves in Indiana is estimated to be 385 pounds. Fourteen Montadale lambs averaged 95 pounds at 41/2 months of age. Average weight of all such lambs in Indiana is estimated at 92 pounds. Sheep from the same flock won prizes at county and state fairs. The above evidence indicates that animals can and do perform well under 765KV lines, but does not mean to imply that all animal performance in this study was excellent. For a group of animals-as-large as was involved in this study, some problems can be expected. None of the eleven farm operators indicated in any of the bi-monthly reports submitted throughout the two-year study or during investigator's visits to the farms that they observed any health problems with their animals that they thought were caused by the 765KV line. One report stated that horses appeared to avoid the high ground under the line, but another farmer state that his cattle seemed to prefer to be under the line. Neither health, behavior, nor performance were affected by the electric or magnetic fields created by the 765KV line.
2. Kaune, W. T., and R. D. Phillips. 1980. Comparison of the Coupling of Grounded Humans, Swine and Rats to Vertical, 60 Hz Electric Fields. *Bioelectromagnetics* 1(2):117-129.  
Abstract: Published and new data for grounded **humans, swine, and rats** exposed to vertical, 60-Hz electric fields are used to determine field strengths at the surfaces of the bodies and average components of induced-current density along the axes of the bodies. At the tops of the bodies, surface electric fields are increased (enhanced) over the unperturbed field strength present before the subjects entered the field by factors of 17, 7, and 4 for humans, swine, and rats, respectively. For an unperturbed field strength of 10 kV/m, average induced axial current densities in the neck, chest, abdomen, and feet are: 550, 190 250, and 200 nA/cm<sup>2</sup>, respectively, for humans; 40, 13, 20, and 1100 nA/cm<sup>2</sup>, respectively, for swine; and 28, 16, 2, and 1400 nA/cm<sup>2</sup>, respectively, for rats. These data are used to show that the actual electric fields experienced by animals depend strongly on the shape of the body and its orientation relative to the electric field and ground plane. This fact must be taken into account if biological data obtained with laboratory animals are to be used for the assessment of possible hazards to humans exposed to 60-Hz electric fields.
3. Kaune, W. T. 1981. Power Frequency Electric Fields Averaged Over the Body Surfaces of Grounded Humans and Animals. *Bioelectromagnetics* 2.

Abstract: Calculated electric-field strengths averaged over the body surfaces of grounded **humans, swine, rats, horses, and cattle** exposed to vertical, uniform, power-frequency electric fields are presented. To produce the same average fields over the body surfaces of grounded animals, as that experienced by a grounded man exposed to an unperturbed vertical field of 10 kV/m, the following unperturbed fields are required; swine, 19 kV/m; rat, 37 kV/m; horse, 18 kV/m; cow, 18 kV/m.

4. Kaune, W. T., and M. F. Gillis. 1981. General Properties of the Interaction Between Animals and ELF Electric Fields. *Bioelectromagnetics* 2(1)1-11.  
Abstract: An analysis is given of the interaction between extremely low-frequency (ELF) electric fields and **animals** of arbitrary body shape. This analysis is based on three approximations which are valid in the ELF range: In living tissues, capacitive (displacement) currents are negligible compared to conduction currents; effects resulting from the finite velocity of propagation of electromagnetic fields are negligible; skin effect in living tissues is negligible. Major conclusions of the analysis are: (a) The electric field outside the body, the induced charge on the surface of the body, and the total current crossing any section through the body (eg, through the neck or limbs) are completely determined by the characteristics of the applied ELF electric field, the shape of the body, its location relative to ground and other conductors, and any conduction currents from the body to ground or other conductors. (b) All of the quantities in (a) can be measured using conducting animal models. (c) The magnitudes of the electric field outside the body and the induced charge density on the surface of the body are independent of frequency, in the ELF range, when the body is either insulated from or shorted to ground (and any other conductors in the system). (d) The only quantities affected by the electrical properties of the tissues comprising the body are the current density and electric field inside the body. (e) The electric field outside and inside a body will be unchanged by a scaled change in its size.
5. Lee, J. M., and G. L. Reiner. 1981. Transmission Line Electric Fields in the Agricultural Animal Environment. *ASAE Annual International Meeting Technical Paper* no. 81-3502.  
Abstract: Transmission line electric fields and interactions with agricultural animals are described. Utility operating experience and research indicates electric fields do not affect livestock behavior or health. Research is continuing on possible long-term effects. Honeybees can be affected by induced currents and resulting shocks within hives.
6. Hjerlesen, D. L., and et al. 1982. A Behavioral Response of **Swine** to a 60 Hz Electric Field. *Bioelectromagnetics* 3(4)443-451.  
Abstract: It has been shown that rats, given the choice, will spend more time out of a 60-Hz electric field than in it at field strengths greater than or equal to 75 kV/m. This paper describes research to examine the relevance of these data to a different species, the pig. Miniature pigs that had been exposed to a 60-Hz electric field at 30 kV/m for 20 h/day, 7 days/week for as long as 6 months, were tested for their preference for the presence or absence of the field during a 23.5-h period. Similar to earlier results with rats, miniature pigs spent more time out of the electric field than in it during the sleeping period.
7. Margonato V, Viola D, and Cantone A. 1982. Changes in weight and food intake in **rats** exposed to a high intensity electrical field at 50 Hz. *Bollettino Della Societa Italiana Di Biologia Sperimentale* 58(5) 259-265.  
Abstract: To study the possible effect of electrical fields of industrial frequency on gastrointestinal function 3 groups of rats were exposed at different stages of development to an electrical field at 50 Hz and intensity 10, 25 or 100 kV/m for 8 h daily for 48, 35 or 35 days, respectively. There was a significant decrease in gain of rats exposed at 100 kV/m from the 15th day and at 25 kV/m from the 23rd to 26th day compared with that in controls. There was no difference in feed intake. Weight gain in rats exposed to 10 kV/m was not significantly different from that in controls or sham-exposed rats. Food intake was slightly greater in exposed rats from 2 weeks and significantly greater during

recovery.

8. Archer, C. W., and N. A. Ratcliffe. 1983. The Effects of Pulsed Magnetic Fields on **Chick Embryo** Cartilaginous Skeletal Rudiments in Vitro. *Journal of Experimental Zoology* 225(2) 243-256. Abstract: The biological response of cultured 7-day embryonic chick tibiae to small alternating currents induced by pulsed magnetic fields (PMFs) was investigated. It was found that continuous exposure to PMFs over 7 days did not alter the overall DNA content of rudiments nor the incorporation of 3H-thymidine when compared with control tibiae. The overall collagen content of explants was slightly reduced by PMF exposure whilst the incorporation of 3H-proline was significantly suppressed. The synthesis of sulphated glycosaminoglycans was also measured in terms of 35SO4--incorporation, but PMF treatment failed to alter the levels of isotope incorporation. These results suggest that, whereas noncollagenous, and possibly collagenous, protein synthesis is affected by PMF exposure, glycosaminoglycan synthesis is not. Histological and electron microscopical observations substantiated this interpretation and revealed selective inhibition of matrix secretion in the periphery of the proliferative epiphyseal zones in experimental explants. High-power electron microscope examination of these zones showed that PMF-exposed matrix was sparsely invested with fibrous protein while elements of the stellate reticulum had formed large aggregates which were often clumped about the cell membrane. The results are discussed in terms of the possible role of naturally occurring potentials in the development and maintenance of connective tissue systems such as cartilage and bone.
9. Algers, B., and K. Hennichs. 1984. Effects of Electromagnetic Fields on fertility in **Cattle** [Effekter Av Elektromagnetiska Fält På Fertiliteten Hos Notkreatur]. *Svensk Veterinartidning* 36(6)289-292. Abstract: Exposure of cows in 2 herds in Sweden to the magnetic fields generated by 400 kV transmission lines for 25-55 days per year resulted in a significant decrease in fertility. However, exposure of cows in 36 herds to such lines for 6.6-13.5 days per year had no significant effect on the number of inseminations per conception or service period compared with cows in 49 non-exposed control herds. In a 3rd study, replies to questionnaires from 972 farms, of which 250 had cows which were exposed to 400 kV lines for more than 15 days per year, did not reveal any significant differences between exposed and non-exposed cows in the number of inseminations per conception, the interval from calving to 1st insemination, service period, milk yield, congenital defects or the number of cows culled due to infertility.
10. Cockshutt, J. R., A. G. Binnington, and B. P. Wilcock. 1984. Effect of a Low Frequency Pulsating Magnetic Field on the Healing of **Rat** Skin Wounds. *Veterinary Surgery* 13(3)149-153. Abstract: The effect of a pulsing magnetic field on wound healing was tested on experimental full-thickness skin wounds in rats. A magnetoelectric coil applicator was used to deliver two 15 minute episodes of pulsing magnetic treatment daily at 80 Gauss and 60 Hz. Healing was evaluated grossly and by light microscopy 7, 14, 22, 29, 42, and 56 days after incision. No change in rate of wound contracture or epithelialization was seen nor was there any microscopic evidence of enhanced collagen formation or cellular organization as compared with untreated wounds.
11. Mahmoud, A. A., and D. R. Zmimerman. 1984. Reproductive Performance of **Pigs** Exposed to High Voltage Electric Field: Second Generation. *ASAE Annual International Meeting Technical Paper* no. 84-3034. Abstract: This paper summarizes the reproductive performance of cross-bred pigs born and raised under the influence of the electric field due to 345 kV transmission lines. Twelve control and twelve exposed gilts were randomly selected for the breeding experiment. Results show no effects due to the exposure to 345 kV transmission lines.
12. Roy, W. R., and J. M. Lee. 1984. Transmission Line Impacts on Agriculture: Issues and Research. *ASAE Annual International Meeting Technical Paper*.

Abstract: Studies over the last 10 years involving existing lines and ultra-high voltage test lines are reviewed. Overall results indicate no significant effects of electric or magnetic fields on crops or livestock.

13. Algers, B., and K. Hennichs. 1985. The Effect of Exposure to 400 KV transmission Lines on the Fertility of **Cows**: A Restrospective Cohort Study. *Preventive Veterinary Medicine* 3(4) 351-361. Abstract: In a nation-wide retrospective cohort study, farms that had cows grazing under 400-kV transmission lines in Sweden were investigated. All farms with cattle and grazing areas beneath 400-kV lines in Sweden, except for the northwest part of the country where very few farms are located, were sent an inquiry. Information from these farms regarding the period during the summers of 1978-1980 was collected. The proportion of grazing areas and the exposure time for each age group and 3-month period were calculated for each farm. Information was obtained on 106 farms that were exposed to 400-kV lines for 15 days or more per year and that used artificial insemination. This was the exposed group. Thus, 2050 inseminations could be analyzed. In a comparison of the insemination results for each farm, using as non-exposed group all other farms belonging to the same livestock cooperative as the exposed, no statistically significant relationship between exposure of cows to 400-kV lines and inferior A.I. data could be found. Culling frequency as a result of reduced fertility was no significantly different between exposed and non-exposed groups.
14. Mercer, H. D. 1985. Biological Effects of Electric Fields on Agricultural Animals. *Veterinary and Human Toxicology* 27(5)422-426. Abstract: The biological effects of electric fields has been intensively studied in laboratory animals. Most of the effects relating to exposure to electric fields have been observed under artificial conditions and at exceptionally intense fields (40-100 kV/meter). Few studies have been completed in agricultural animals, yet this class of animal probably receives the greatest exposure under actual field conditions. The objective of this paper was to summarize the available scientific data for agricultural animals. Based upon limited experimental data, and a number of years of experience with animals under high-voltage lines, it appears that electric fields of 10 kV/m or less do not represent a biological hazard to agricultural animals.
15. Ottova, A., and et al. 1985. The Effect of Various Inductions of Homogeneous Stationary Magnetic Field on the Hatchability of **Fowl** and Game Birds. *Scientia Agriculturae Bohemoslovaca* 17(1) 63-66. Abstract: Japanese quail eggs (100-200 per batch) were exposed to magnetic fields of 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 Tesla for 5-120 min. Hatchability of fertile eggs after exposure ranged from 65.0% for eggs given a total exposure of 30 Tesla to 78.6% at 1.5 Tesla vs. 56.5-60.7% for unexposed controls. Most differences between the treated eggs and controls were significant. For similar groups of fowl eggs, hatchability of fertile eggs ranged from 81.0% at a total exposure of 3.0 Tesla to 100% at 1.5 Tesla vs. 51.2-92.5 for the controls, the differences between the treated eggs and controls being mostly significant.
16. Algers, B., and J. Hultgren. 1986. Cows Under 400 KV Power Lines Effects on Ovulation and Fertility [Kor Under 400 KV Kraftledning-ffekter Pa Brunst Och Frukstamhet]. *Svensk Veterinartidning* 38(4)229-235 . Abstract: Compared with a similar group of unexposed **cows**, pasturing for an average of 4 months beneath overhead transmission lines (400 kV, 50 Hz) had no effect on ovarian activity, oestrous signs, pregnancy or fetal viability in 58 Swedish Red and White heifers. Observations on diurnal activity in the two herds did not reveal any pattern attributable to electrical forces. In the exposed group the electric field averaged 4 kV/m and the magnetic field 2  $\mu$ T.
17. ———. 1987. Effects of Long Term Exposure to a 400 KV, 50 Hz Transmission Line on Estrus and Fertility in **Cows**. *Preventive Veterinary Medicine* 5(1)21-36.

Abstract: In Swedish Red-and-White heifers exposed to an electric field of about 4 kilovolts/m and a magnetic field of 2 microtesla (by proximity to a 400-kilovolt, 50-hertz electricity transmission line) for 120 days, the length and regularity of the oestrous cycle, intensity of oestrus, plasma progesterone concentration in mid-cycle, number of inseminations per conception and CR were similar to values for 58 heifers enclosed at a distance from the transmission line. None of the parameters studied were found to be influenced by the exposure of the heifers to the 400 kV, 50 Hz transmission line.

18. Sikov, M. R., and et al. 1987. Developmental Studies of Hanford Miniature **Swine** Exposed to 60 Hz Electric Fields. *Bioelectromagnetics* 8(3)229-242.

Abstract: Evaluations of reproductive and developmental toxicology, including teratology, were included as part of a broad screening study in Hanford Miniature swine (HMS) to detect effects of exposure to electric fields. One group (E) was exposed to a uniform, vertical, 60-Hz, 30-kV/m electric field for 20 h/day, 7 days/week; sham-exposed (SE) swine were housed in a separate, environmentally equivalent building. The first generation (F0) gilts were bred after 4 months of study; some were killed for teratologic assays at 100 days of gestation (dg), and the others produced an F1 generation of offspring. The pooled incidence of terata in these litters (teratologic assays and live births) was similar in the E and SE groups. The F0 females, which produced the F1 generation, were bred again after 18 months of exposure and were killed at 100 dg. Malformation incidence in E litters (75%) was significantly greater than in SE litters (29%). No consistent differences in litter size, fetal mass, or mass of fetal organs were detected. The F1 gilts were bred at 18 months of age; defective offspring were found in significantly more of the E litters (71%) than in SE litters (33%). These F1 females were bred again 10 months later and teratologic assays were performed on their second litters at 100 dg. The percentage of litters with malformed fetuses was essentially identical in the E and SE groups (70% and 73%, respectively). There appears to be an association between chronic exposure to a strong electric field and developmental effects in swine, although the change in incidence of malformations between generations and between the first and second breedings makes it impossible to conclude unequivocally that there is a cause-and-effect relation.

19. Kaune, W. T., and W. C. Forsythe. 1988. Current Densities Induced in **Swine and Rat** Models by Power Frequency Electric Fields. *Bioelectromagnetics* 9(1)1-24.

Abstract: Measurements have been made of vector current densities induced by vertical, uniform, 60-Hz electric fields in the torsos of homogeneous models of swine and rats. The observed data were a strong function of the five grounding configurations investigated: all four feet grounded, only front feet grounded, only rear feet grounded, left front and right rear feet grounded, and right front and left rear feet grounded. In the first configuration and with an exposure field strength of 10 kV/m, average total current densities induced in the torsos of pigs and rats were 34 nA/cm<sup>2</sup> and 20 nA/cm<sup>2</sup>, respectively. The corresponding value for human exposure is about 250 nA/cm<sup>2</sup>, 7.3 and 12.5 times larger than for swine and rats, respectively. Current densities measured at 60 Hz can be linearly extrapolated to frequencies in a range extending from at least 1 Hz to 1 MHz. Human and animal current-density data can provide an improved rationale for extrapolating biological data across species. In addition, these data can be used to validate the predictions of numerical models.

20. Raleigh, R. J. 1988. Joint HVDC Agricultural Study: Final Project Report. *Bonneville Power Administration Report*.

Abstract: This 3-year long experimental study provided no evidence that a +/-500-kV DC transmission line caused any effects on **cattle or crops** that would impact commercial farming or ranching operations. Because of cattle were confined year-long to pens directly crossed by the DC line, their exposure to air ions and electric fields was far greater than would typically occur. This further decreases the likelihood that any effects would be observed in a normal livestock operation. Although the objectives of this study were achieved, it should be acknowledged that no single study can answer all the questions that have been raised about the possible biological effects of HVDC

transmission lines. An overall assessment of such effects must also consider the results of previous environmental and laboratory studies. Together, this body of research now indicates that it is unlikely that HVDC transmission lines cause adverse effects on plants, animals or people. (Bonneville Power Administration project conclusion).

21. Angell, R. F., and et al. 1990. Effects of a High-Voltage Direct-Current Transmission Line on **Beef Cattle** Production. *Bioelectromagnetics* 11:273-282.  
Abstract: Two herds of beef cattle were maintained beneath a +/- 500 kV direct-current transmission line during a 30-month period, and were compared with two similar herds maintained away from the transmission line. Exposure of animals under the line were five to 30 times greater than those of control animals, depending on the parameter of interest, with average exposure magnitudes of 5.6 kV/m, 4.1 nA/m<sup>2</sup>, and 13 k ions/cm<sup>3</sup>, respectively, for electric field, ion current, and density of ions. Productivity and health status of cows and calves were similar between lines and control treatments. Mean body mass of cows increased with maturity, from 438 kg in 1985 to 496 kg in 1987. Calf gain averaged 0.93 kg per head per day. No unusual sources of mortality were observed. Based on this confinement study, beef cattle permitted to graze in the vicinity of a high-voltage, direct-current transmission lines are not expected to experience any decrease in frequency of conception, calving, growth rate, or survival.
22. Shaposhnikova, M. G., and T. I. Volokhova. 1990. The Effect of Magnetic Fields on Conception Rate of **Cows**. *Tex.Dokl. i Konf. Mol. Uchenykh i Stud. LKShI, Mart. Leningrad, USSR*.  
Abstract: Cows inseminated with semen that had been exposed to a magnetic field for 1-2 min before insemination had a CR higher by 12.5% than cows inseminated with unexposed semen.
23. Ganskopp, D., R. J. Raleigh, M. Schott, and T. D. Bracken. 1991. Behavior of **cattle** in pens exposed to +/-500 kV DC transmission lines. *Applied Animal Behaviour Science* 30(1/2)1-16.
24. Koch, W. E., and B. A. Kock. 1991. Exposure of **Chicken Embryos** to Selected Magnetic Fields. *Journal of Bioelectricity* 10(1-2)65-80.  
Abstract: Tests were made to determine whether the development of chicken embryos was altered by exposure to time-varying magnetic fields. Unipolar square waves with periods of 100- $\mu$ s, 1, 10, 20, and 30ms, and 20ms bipolar square and sinusoidal waves were tested. The nominal peak strength for each experiment was 1- $\mu$ T. Neither the morphogenesis of the embryo nor the temporal aspects of development was altered by any tested field. Fertile eggs of several different strains of chickens were also tested to determine whether strain sensitivity to certain magnetic fields can account for the reports of positive effects of magnetic fields upon development. No significant alterations were noted in the embryos of any of the tested strains. Published reports of alterations in development following exposure to similar low level magnetic fields have not been confirmed in this laboratory.
25. Zhou, P., and et al. 1991. The Improvement of Reproductive Performance in **Domestic Animals** by the Use of Magnetism. *Journal of Shanghai Agricultural College* 9(2) 141-145.  
Abstract: Implantation of magnetic plates in the testes of **rabbits** significantly improved semen quality and increased ejaculate volume 120 days after treatment, and magnetic treatment of rabbit semen on collection resulted in an increase of 12-24 h in the storage life of the semen. Magnetization of drinking water for **hens** resulted in an increase in the duration of 50% egg production, but there was no significant increase in egg hatchability.
26. Martin, A. H. 1992. Development of **Chicken Embryos** Following Exposure to 60 Hz Magnetic Fields with Differing Wave Forms. *Bioelectromagnetics* 13(3)223-230.  
Abstract: Previous studies in my laboratory have revealed a reproducible and statistically significant increase in the number of malformations in live chicken embryos that had been exposed during the first 48 h of incubation to a pulsed magnetic field (unipolar pulses, 100-pps, 1- $\mu$ -T peak density).

In marked contrast, no adverse effect was seen following similar exposure to 60-Hz, bipolar, unipolar, or split-sine waves at 3- $\mu$ -T peak-to-peak. In the four experiments comprising the present study, differences in the numbers of malformations between control and experimental groups were not statistically significant. Field-free incubation for an additional 72 h after exposure to a bipolar sine wave for 48 h resulted in an increase in normal live embryos in both control and treated groups.

27. Piera, V., and et al. 1992. Influence of Continuous Electromagnetic Fields on the Stage, Weight and Stature of the **Chick Embryo**. *Acta Anatomica* 145(4)302-306.  
Abstract: The influence of continuous electromagnetic fields (0, 181 or 361 Gs/cm<sup>2</sup>) on the development of chick embryo (n = 144) was studied. Several parameters were determined at days 5, 10 and 15 of incubation: stage (following Hamburger and Hamilton), vertex-coccyx length (size) and weight. At 5 days of incubation, all embryos showed a similar stage. However, at days 10 and 15, the embryos exposed to 181 Gs/cm<sup>2</sup> showed a stage significantly superior to that of the others. There were no differences between the exposed embryos and the control ones with regard to weight and stature, except at 15 days when the embryos exposed to 361 GS/cm<sup>2</sup> showed greater weight and stature than those of the controls.
28. Aaron, R. K., and D. M. Ciombor. 1993. Therapeutic effects of Electromagnetic Fields in the Stimulation of **Connective Tissue Repair**. *Journal of Cellular Biochemistry* 52(1)42-46.  
Abstract: The therapeutic effects of electric and magnetic fields have been studied largely for their promotion of connective tissue repair. The most widely studied application concerns bone repair and deals with acceleration of the healing of fresh fractures, delayed and non-unions, incorporation of bone grafts, osteoporosis, and osteonecrosis. More recently the effects of these fields upon the repair of cartilage and soft fibrous tissues have been described. In all these experimental systems and clinical applications an acceleration of extracellular matrix synthesis and tissue healing has been observed. A degree of specificity, in terms of the parameters of applied energy and biological response, is hypothesized.
29. Buch, F., and et al. 1993. The quantification of **Bone Tissue** Regeneration After Electromagnetic Stimulation. *Archives of Orthopaedic and Trauma Surgery* 112(2)75-78.  
Abstract: In this study a titanium implant, the bone harvest chamber (BHC), was used to evaluate the effect of electromagnetic stimulation on osteogenesis. The BHC was inserted with a minimum of surgical trauma in the proximal tibial metaphysis in six adult lop-eared rabbits. Bone anchorage occurred after 4 weeks. After implant incorporation bone tissue was harvested at 3-week intervals with the implant in situ without killing the animal. The regenerated bone tissue was analyzed by means of microradiography and densitometry. A test group and a control group each comprised six rabbits. The test group was stimulated with a 72-Hz electromagnetic field. Bone tissue was harvested from each tibia six times during the stimulation time and twice after the stimulation had been turned off. The control group had the same harvest procedure performed from one leg. Results showed that electromagnetic stimulation can maintain constant high osteogenetic activity. After the electromagnetic stimulation was turned off the osteogenetic activity diminished rapidly and osteogenesis was significantly lower than during stimulation.
30. Cox, C. F., and et al. 1993. A Test for Teratological Effects of Power Frequency Magnetic Fields on **Chick Embryos**. *IEEE Transactions on Biomedical Engineering* 40(7)605-610.  
Abstract: An analysis of 13 studies of the teratological effects of pulsed magnetic fields on chick embryos from ten independent laboratories permits no clear conclusions. Comparatively little has been done to follow up on the reports by Juutilainen and coworkers on the effects of extremely low-frequency, sinusoidal magnetic fields on the malformation rate in chick embryos. Our attempt to follow up on their results using similar but not identical exposures of 10 microT, 50 Hz magnetic fields produced negative results.

31. Debouck, C., M. Rooze, and M. Hisenkamp. 1993. Effect of Electromagnetic Field Amplitudes on **Quail Embryos**: Preliminary Results. *Bioelectrochemistry and Bioenergetics* 30(1-3)189-193. Abstract: To compare the effects of different amplitudes of magnetic and electric fields we have developed a device using solenoids with well-defined characteristics. Quail eggs were incubated and stimulated inside the solenoids for 100 h. No abnormalities and no weight differences between the eggs in the different solenoids were observed. Preliminary results show that only the tibia lengths of embryos stimulated by the highest electric and magnetic field values are significantly increased.
32. Lee, J. M., F. Stormshak, J. M. Thompson, P. Thinesen, L. J. Painter, E. G. Olenchek, D. L. Hess, R. Forbes, and D. L. Foster. 1993. Melatonin secretion and puberty in female **lambs** exposed to environmental electric and magnetic fields. *Biology of Reproduction* 49(4) 857-864. Abstract: This study determined whether chronic exposure of female lambs to the electric and magnetic fields (EMF) of a high voltage transmission line can alter pineal secretion of melatonin and the normal occurrence of puberty. Twenty female Suffolk lambs were assigned randomly in equal numbers to a control and a treatment group. Treatment from 2 to 10 mo of age consisted of continuous exposure within the electrical environment of a 500-kV transmission line (mean electric field 6 kV/m, mean magnetic field 40 mG). Treated lambs were penned directly beneath the transmission line; control lambs were maintained in a pen of similar construction 229 m from the line where EMF were at ambient levels (mean electric field < 10 V/m, mean magnetic field < 0.3 mG). Melatonin was analyzed by RIA in serum of blood samples collected at 0.5-3-h intervals over eight 48-h periods. To assess attainment of puberty, serum concentrations of progesterone were determined by RIA from blood samples collected twice weekly beginning at 19 wk of age. Concentrations of circulating melatonin in control and treated lambs were low during daylight hours and increased during nighttime hours. The characteristic pattern of melatonin secretion during nighttime amplitude, phase, and duration) did not differ between control and treatment groups. Age at puberty and number of subsequent estrous cycles also did not differ between groups. These data suggest that chronic exposure of developing female sheep to 60- Hz environmental EMF does not affect the mechanisms underlying the generation of the circadian pattern of melatonin secretion or the mechanisms involved in the onset of reproductive activity.
33. Zhang, Q., F. L. Tabrah, and G. C. Whittow. 1993. Effect of 60Hz Sinusoidal Electromagnetic Field on **Avian Embryonic** Growth and Oxygen Consumption. *Electro and Magnetobiology* 12(1)27-37. Abstract: Domestic fowl embryonic oxygen consumption, organ growth and maturity, and growth abnormalities were studied after exposure to 2-, 1-, and 0.5-gauss (G) 60-Hz sinusoidal electromagnetic fields (EMF), throughout incubation. Embryonic growth and oxygen consumption increased after exposure to a 2-G EMF but they were inhibited by 1-G EMF. There were no significant biological effects of 0.5-G EMF on embryonic growth and oxygen consumption. Deformities were found in the 2-G and 1-G EMF groups but only in the 2-G group did they reach a statistically significant level. There were no deformities in the 0.5-G EMF group or any of the control groups. Pectoral muscles were most affected by an EMF of 2 G, while the intestine was largely spared the enhanced growth. The intestine was also spared the repression of growth at an EMF of 1 G; the lungs were most affected. Enhanced organ growth was associated with increased tissue maturity, particularly in pectoral muscles. The effects of a 1-G EMF on organ maturity were small but, paradoxically, lung maturity increased.
34. Ziecik, A. J., and et al. 1993. Effect of Electrical Stress Stimuli on Lutenizing Hormone, Prolactin and Cortisol Secretion in **Pigs**. *Investigacion Agraria Produccion y Sanidad Animales* 8(3)269-280. Abstract: The objective of this paper was to study effect of electrical stimulation on tonic and estrogen induced LH secretion in post puberal ovariectomized gilts and on blood plasma concentrations of cortisol and prolactin. In the Experiment I five gilts were electrically stimulated (ES) in the form of footshocks during eight hours and another five were used as control. Blood samples were collected in various time intervals for LH, prolactin and cortisol determination. In

Experiment 2 twenty gilts were i.m. challenged with estradiol benzoate (EB, 10 mg/kg) and then assigned to the following groups: I) Electrically stimulated (ES) during 18-24 and 30-36 h (ES 24 h; n = 4); II) ES 42-48 and 52-60 h (Es 48 h; n = 6); III) ES around 24 plus 48 (ES 24 + 48 h; n = 4) after injection of EB; and IV) which was not stimulated and served as a control. Blood samples for LH, prolactin and cortisol measurement were taken every 6 h from 0 h, immediately before EB, to 96 h. Footshocks significantly increased cortisol concentration in blood during the first hours of stimulation but at the end of treatment cortisol was even lower in ES than in control animals. The electrical stress did not affect the tonic secretion of LH and slightly modified prolactin release in gilts. ES of gilts given EB did not change the prolif of LH secretion during the negative phase (0-48 h) of feedback in all treated groups. Footshocks given during the negative feedback (Group I and III) caused a decrease of the amplitude of LH surge during the positive feedback phase. ES around 48 h after EB (Group II) increased LH concentration in the blood during LH surge (1.4 +- 0.4 vs 0.9 +- 0.2 ng/ml; p lt 0.01). Prolactin levels were higher in all treated groups than in control in the period 0-48 h (p lt 0.05) as well as in group III during 54-96 h after EB (p lt 0.01). Prolactin concentrations were elevated during the period 0-48 h in treated groups and during 54-96 after EB in ES 24 + 48 h group when compared to the control.

35. Shealy, C. N., and C. C. Mauldin Jr. 1994. Modern Medical Electricity in the Management of Pain. *Clinics in Podiatric Medicine and Surgery* 11(1) 161-175.  
Abstract: With the economics of medical care and the history of electrotherapeutics firmly in mind, one should seek treatments that are efficient and effective. There is no question that relief of the symptom of pain must be a primary focus of treatment, whether or not a specific pathology is known. Electric devices may be justifiably used for their placebo effects, if the cost is reasonable, because side effects are minor and infrequent. Research shows specific neurochemical effects of several electrotherapeutic devices, supporting the notion that specific therapeutic effects exist in addition to placebo effects. Passage of time and further research will determine which of the current techniques and devices will find their way into future similar articles or monographs.
36. Lee, J. M., and G. L. Reiner. 1995. Melatonin and Puberty in Female **Lambs** exposed to EMF: A Replicate Study. *Bioelectromagnetics* 16: 119-123.  
Abstract: In an earlier study, we found no effects of 60 Hz electric and magnetic fields (EMF) from a 500 kV transmission line on serum melatonin patterns or on puberty in ten female Suffolk lambs (*Ovis aries*). We conducted a larger replicate study of 15 lambs exposed to a mean electric field of 6.3 kV/m and a mean magnetic field of 3.77 microT and 15 controls exposed to EMF two orders of magnitude weaker than in the line area. The replicate produced essentially the same results as our previous study.
37. Reif, J. S., K. S. Lower, and G. K. Ogilvie. 1995. Residential Exposure to Magnetic Fields and Risk of **Canine** Lymphoma. *American Journal of Epidemiology* 141(4)352, 354-359.  
Abstract: A hospital based case-control study was conducted to determine whether residential exposure to magnetic fields increased risk for canine lymphoma in pet dogs. Cases were patients at a veterinary teaching hospital with histologically confirmed lymphoma diagnosed between 1987 and 1990. Hospital controls with other forms of cancer were obtained by frequency matching on zip code and year of diagnosis. Information regarding the dog's activity patterns, residence history, and exposure to potential confounders was obtained by telephone interview. Wire codes and magnetic fields were measured at the homes at diagnosis of 93 cases and 137 controls. When exposure was categorized into two levels (high or very high wire codes compared with low, very low, or buried lines), the risk was elevated (odds ratio (OR) = 1.6, 95% confidence interval (CI) 0.9-2.9) and increased (OR = 1.8, 95% CI 0.9-3.4) after adjustment for potential confounders. Dogs that lived in homes with very high current codes had the highest risk (OR = 6.8, 95% CI 1.6-28.5). Moderate, imprecise increases in risk (odds ratios of 1.5-1.9) were found for residence in a home with a sidewalk (plumbing), backyard, or front yard magnetic field of 2.0 mG or greater, but not for indoor

measurements at this level. Risk increased among dogs that spent more than 25% of the day outdoors. Laboratory and observational studies of dogs as an animal model for the effects of magnetic fields are recommended.

38. Reilly J.P. 1995. Nerve stimulation of **cows** and other **farm animals** by time-varying magnetic fields. *Transactions of the ASAE* 38(5) 1487-1494.  
Abstract: This article reviews principles of nerve stimulation by time-varying magnetic fields. Physical principles of magnetic induction are combined with biophysical principles of nerve stimulation to define requirements for magnetic stimulation of nerves. Thresholds of magnetic stimulation are derived for dairy cows and compared with commonly encountered environmental fields. Methods for extrapolating cow thresholds to other farm animals are given. It is concluded that environmental fields encountered on the farmstead are far too small to be responsible for nerve stimulation of farm animals.
39. Thompson, J. M., and et al. 1995. Cortisol Secretion and Growth in **Ewe Lambs** Chronically Exposed to Electric and Magnetic Fields of a 60-Hertz 500 Kilovolt AC Transmission Line. *Journal of Animal Science* 73: 3274-3280.  
Abstract: A study was conducted to determine whether chronic exposure of ewe lambs to the electric and magnetic fields (EMF) of a high-voltage AC transmission line affected the cortisol secretion and growth. Twenty Suffolk ewe lambs were assigned randomly in equal numbers to a control and treatment group. Treatment from 2 to 10 months of age consisted of continuous exposure within the electrical environment of a 60-Hz, 500-kV transmission line (mean electric field of 6 kV, mean magnetic field 40 mG). Treated lambs were confined directly beneath the transmission line; control lambs were maintained in a pen of similar construction 229 m from the line where the EMF were at ambient levels (mean electric field < 10 V/m, mean magnetic field < 0.3 mG). Cortisol was analyzed by RIA in serum of blood samples collected at 0.5 to 3 hour intervals over eight 48 hour periods. All ewe lambs were weighed weekly and side-patch wool growth was measured biweekly. Cortisol secretion occurred in a circadian rhythm; daytime serum concentrations were greater ( $P < 0.05$ ) than nighttime concentrations for both groups. Concentrations of cortisol did not differ between the control and exposed ewe lambs. Weight gain and wool fiber length and diameter also were not affected by treatment. These data suggest that chronic exposure of developing ewe lambs to 60-Hz environmental EMF does not affect concentrations of cortisol secretion, body weight gain, and wool growth.
40. Brouard, D., and C. Harvey. 1996. Evaluation of Potential Effects of Stray Voltage Generated by Alternating Current on Hatchery-Raised Rainbow **Trout**. *The Progressive Fish Culturist* 58(1)47-51.  
Abstract: In the province of Quebec, fish farmers have claimed that growth and production of fish are reduced in the presence of very low voltage levels. Stray low voltage at levels of 60 Hz (0-42 mv/m) was confirmed during a survey of nine fish hatcheries in 1990. Because there is a general lack of information of the effects of exposure to stray voltage on hatchery-raised fish, a study was done to evaluate possible effects on the embryonic development, growth rate and survival of rainbow trout *Oncorhynchus mykiss*. The results indicate no effect of electrical fields (5, 50, 500 and 5,000 mV/m) on the appearance and duration of embryonic development or on survival to hatching. Other bioassays conducted on rainbow trout weighing 7 and 116 g that were exposed for 10 and 7.5 weeks, respectively to electrical fields of 5, 50, and 500 mV/m demonstrate that growth rate and survival are probably not affected by electrical fields.
41. Burchard J.F., Nguyen D.H., Richard L., and Block E. 1996. Biological effects of electric and magnetic fields on productivity of **dairy cows**. *Journal of Dairy Science* 79(9)1549-1554.  
Abstract: Sixteen multiparous Holstein cows (weighing  $600 \pm 50$  kg, at  $184.8 \pm 52$  days of lactation and

at 101.9±43 days of gestation) were confined to wooden metabolic cages and exposed to a vertical electric field of 10 kV/m and to a uniform horizontal magnetic field of 30 µtesla. Cows were divided into 2 replicates of 8 cows each. One replicate was exposed for 3 periods of 28 days each. During the 1st period the electric and magnetic fields were off; during the 2nd period they were on; and during the 3rd period they were off. The 2nd replicate was exposed for 3 periods also but the activity of the fields was reversed (1st period on; 2nd period off; and 3rd period on). Venous blood samples were obtained twice weekly to examine hydrocortisone and progesterone concentrations and once weekly to examine pH and blood gases (O<sub>2</sub> and CO<sub>2</sub>). Milk samples were collected once weekly to examine milk components (fat, protein, SNF and somatic cell counts). Milk yield and feed consumption were examined daily. There was no variation in bicarbonate, pH or partial pressure of O<sub>2</sub> and CO<sub>2</sub> in the blood which could be attributed to exposure to electric and magnetic fields. Moreover, plasma hydrocortisone concentrations, uncorrected milk yield and milk components other than milk fat were not correlated with exposure to electric and magnetic fields. However, there were correlations between exposure to the electric and magnetic fields and increased DM intake, 4%-FCM yield, milk fat content and plasma progesterone concentrations.

42. Detlavs I, Dombrovska L, Turauska A, Shkirmante B, and Slutskii L. 1996. Experimental study of the effects of radiofrequency electromagnetic fields on animals with **soft tissue** wounds. *Science of the Total Environment; Paper Presented at the International Conference on the Effect of Radio Frequency Electromagnetic Radiation on Organisms, Skrunda, Latvia, June 17-21, 1994* 180(1) 35-42.

Abstract: The effect of radio frequency electromagnetic fields (RF EMF) was studied on Wistar rats with excised full-thickness dermal wounds in the interscapular region. The wounded regions of experimental animals were subjected to EMF for 30 min daily during the first 5 days after wound infliction. Control animals received no treatment. RF EMF with (1) frequency 53.53 GHz without modulation; (2) frequency 42.19 GHz without modulation; (3) frequency 42.19 GHz, but with a frequency modulation band 200-MHz wide were used. On the 7th day the animals were terminated and the granulation-fibrous tissue (GFT) developed in the wounds was subjected to complex quantitative biochemical analysis. RF EMF without frequency modulation decreased the amounts of glycoprotein macromolecules, diminishing the inflammatory exudation. In striking contrast, under the influence of RF EMF with frequency modulation, hexoses and especially sialic acid concentrations were significantly elevated. This indicated intensification of exudative phenomena. As a consequence of inflammation inhibition in the treatment without frequency modulation, the total collagen accumulation was lowered. However, when frequency was modulated, the inflammatory phenomena were intensified, and pronounced accumulation of collagenous proteins was noted. The experiments confirm the effects of non-thermal EMF on the healing processes of animals with soft tissue wounds.

43. Burchard, J F, D H Nguyen, and E Block. 1998. Effects of electric and magnetic fields on nocturnal melatonin concentrations in **dairy cows**. *Journal of Dairy Science* 81(3)722-727.

Abstract: Sixteen multiparous, pregnant, lactating Holstein cows (weighing 600 ± 50 kg, at 184.8 ± 52 d of lactation, and at 101.9 ± 43 d of gestation) were confined to wooden metabolism cages and exposed to a vertical electric field of 10 kV/m and a uniform horizontal magnetic field of 30 µT. The trial was conducted using a switchback statistical design. Cows were divided into two sequence groups of 8 cows each. One sequence group was exposed for three periods of 28 d each. The electric and magnetic fields were off during the first period, on during the second period, and off during the final period. The second sequence group was exposed for three periods also, but the activity of the fields was reversed (on during the first period, off during the second period, and on during the third period). On d 25 of each exposure period, blood samples were obtained every 0.5 h for 14 h starting at 1700 h to determine melatonin concentration. Nocturnal melatonin concentrations did not show any variation that could be attributed to exposure to electric and magnetic fields.

44. Burchard, J F, D H Nguyen, L Richard, S N Young, M P Heyes, and E Block. 1998. Effects of electromagnetic fields, on the levels of biogenic amine metabolites, quinolinic acid, and BETA-endorphin in the cerebrospinal fluid of **dairy cows**. *Neurochemical Research* 23 (12) 1527-1531. Abstract: Eight multiparous non-lactating pregnant Holstein cows at 198 +/- 35 d of gestation, weighing 608 +/- 24 kg, were confined to wooden metabolic cages in an electric and magnetic field chamber with a 12:12 h light:dark cycle. Subarachnoidal catheters were installed 5 d before the activation of the electric and magnetic fields. The cows were exposed to electric and magnetic fields (60 Hz, 10 kV/m and 30 muT) continuously except for the feeding and cleaning time for an average of 21.44 +/- 1.4 h per day for a period of 30 d. Cerebrospinal fluid samples were collected on three consecutive days before an exposure period of 30 d, on the last 3 d of the exposure period, and for 3 d starting 5 d after the exposure period. The concentrations of beta-endorphin, tryptophan, 5hydroxyindoleacetic acid, homovanillic acid, 3-methoxy-4-hydroxyphenylethyleneglycol and quinolinic acid in cerebrospinal fluid were determined. There was a significant increase in quinolinic acid, and a trend towards an increase in tryptophan, findings consistent with a weakening of the blood-brain barrier due to exposure to the electric and magnetic fields.
45. Burchard, J F, D H Nguyen, and E Block. 1999. Macro- and trace element concentrations in blood plasma and cerebrospinal fluid of **dairy cows** exposed to electric and magnetic fields. *Bioelectromagnetics* 20(6)358-364. Abstract: Eight multiparous, nonlactating pregnant Holstein cows (at 198 +/- 35 days of gestation and weighing 608 + 24 kg) and seven nonlactating nonpregnant ovariectomized heifers (weighing 370 + 29 kg) were confined to wooden metabolism crates in an electric and magnetic field chamber. Subarachnoidal catheters were inserted before the activation of the electric and magnetic fields. For 30 days, cows and heifers were continuously exposed in separate trials to electric and magnetic fields (60 Hz, 10 kV/m, and 30 muT). Blood plasma and cerebrospinal fluid samples were collected for 3 consecutive days before the exposure period, the last 3 days of the exposure period, and for 3 days starting 5 days after the exposure period. Concentrations of Ca, Mg, Cu, Zn, Fe, Mn, Na, P, and K in blood plasma and cerebrospinal fluid were determined. Exposure to electric and magnetic fields resulted in decreased concentrations of Mg in blood plasma and in increased concentrations of Ca and P and decreased concentrations of Fe and Mn in cerebrospinal fluid.
46. Rodriguez, M., D. Petitclerc, D. H. Nguyen, E. Block, and J. F. Burchard. 2002. Effect of Electric and Magnetic Fields (60 Hz) on Production, and Levels of Growth Hormone and Insulin-Like Growth Factor 1, in Lactating, Pregnant **Cows** Subjected to Short Days. *Journal of Dairy Science* 85:2843-2849. Abstract: Cows exposed to a vertical electric field of 10 kV/m and a horizontal magnetic field of 30 muT in a crossover design showed no change in mean growth hormone GH concentration, but a treatment x hour interaction was detected. Overall, the yield of milk or its components was not affected by EMF exposure, but milk yield was significantly higher for the exposed animals during wk 4 of treatment. Previous studies showed increased dry matter intake (DMI) and fat corrected milk in dairy cows exposed to EMF. Because EMF exposure has been shown to suppress pineal release of melatonin in some species, it was hypothesized that EMF effects resemble those of exposure to long days. Previous studies have shown that DMI and milk production increase in dairy cattle in response to long day photoperiods, and this has been observed in association with increased circulating insulin-like growth factor 1 (IGF-1), but not growth hormone (GH). The hypothesis that EMF acts by modifying the response to photoperiod was tested by subjecting dairy cows to controlled EMF exposure while keeping them under short-day conditions. Sixteen lactating, pregnant Holstein cows were exposed to a vertical electric field of 10 kV/m and a horizontal magnetic field of 30 muT in a crossover design with treatment switchback. Two groups of eight cows each were exposed to EMF for 16 h/d in either of two sequences. Each sequence consisted of three consecutive 28-d periods. All animals were maintained under short day conditions (8 h light, 16 h dark) during the trial. DMI and plasma IGF-1 were increased (P < 0.01) during EMF exposure (17.03 vs.16.04

kg/d, SE = 0.4;  $137 \pm 6$  ng/ml vs  $126 \pm 6$ , respectively). The mean GH concentration was not affected, but a treatment  $\times$  hour interaction was detected, with GH lower for the EMF exposed animals during the first 16 h of the sampling period, and higher for the last 8 h. Overall, the yield of milk or its components was not affected by EMF exposure, but milk yield was significantly higher for the exposed animals during wk 4 of treatment.

47. Rodriguez, M, D Petitclerc, D H Nguyen, E Block, and J F Burchard. 2002. Effect of electric and magnetic fields (60 Hz) on production, and levels of growth hormone and insulin-like growth factor 1, in lactating, pregnant cows subjected to short days. *Journal of Dairy Science* 85(11)2843-2849. Abstract: Electric and magnetic fields (EMF) are generated by the transmission of electricity through high tension lines traversing rural areas. Previous studies showed increased dry matter intake (DMI) and fat corrected milk in dairy cows exposed to EMF. Because EMF exposure has been shown to suppress pineal release of melatonin in some species, it was hypothesized that EMF effects resemble those of exposure to long days. Previous studies have shown that DMI and milk production increase in dairy cattle in response to long day photoperiods, and this has been observed in association with increased circulating insulin-like growth factor 1 (IGF-1), but not growth hormone (GH). The hypothesis that EMF act by modifying the response to photoperiod was tested by subjecting dairy cows to controlled EMF exposure while keeping them under short-day conditions. Sixteen lactating, pregnant Holstein cows were exposed to a vertical electric field of 10 kV/m and a horizontal magnetic field of 30  $\mu$ T in a crossover design with treatment switchback. Two groups of eight cows each were exposed to EMF for 16 h/d in either of two sequences. Each sequence consisted of three consecutive 28-d periods. All animals were maintained under short day conditions (8 h light, 16 h dark) during the trial. DMI and plasma IGF-1 were increased ( $P < 0.01$ ) during EMF exposure ( $17.03$  vs.  $16.04$  kg/d, SE=0.4;  $137 \pm 6$  ng/ml vs  $126 \pm 6$ , respectively). The mean GH concentration was not affected, but a treatment  $\times$  hour interaction was detected, with GH lower for the EMF exposed animals during the first 16 h of the sampling period, and higher for the last 8 h. Overall, the yield of milk or its components was not affected by EMF exposure, but milk yield was significantly higher for the exposed animals during wk 4 of treatment.
48. Burchard, J. F. 2003. Electric and Magnetic Field Research at McGill University. *NRAES: Stray Voltage and Dairy Farms Conference Proceedings* . Abstract: The results of six experiments on the effects of EMF exposure on dairy cows conducted at McGill University are summarized. Milk production and composition, feed consumption, blood hormonal profiles and cerebrospinal fluid (CSF) components were assessed during different periods of exposure. Most of the variables assessed did not show any variation caused by EMF. However, there was a positive association between EMF and feed consumption, milk fat content, blood plasma progesterone during pregnancy, and estrous cycle length. Also, there were changes in the mineral and neurotransmitter metabolite concentrations in the SCF that showed a relationship to the EMF. In conclusion, it could be stated that EMF cause a biological response in dairy cattle, affecting the productivity variables, which remained within the normal distribution of the population of dairy cattle in Quebec. These responses were also observed in some physiological variables. We speculate that the changes do not represent a health hazard for exposed cattle; however, they warrant the necessity of further research.
49. COMAR: IEEE Committee on Man and Radiation . 2003. Electromagnetic Hypersensitivity. COMAR Technical Information Statement Approved 6/27/02 . Abstract: Certain individuals experience a variety of health symptoms, which they attribute to exposure to electric or magnetic fields from sources such as power lines, household appliances, visual display units (VDUs), light sources, mobile telephones and mobile phone base stations. This perceived sensitivity to electromagnetic fields has the general name "electromagnetic hypersensitivity" or EHS. The fields that electromagnetically hypersensitive individuals consider to be the cause of their symptoms vary considerably, but they are invariably far below recommended

exposure limits, and very far below field levels that are known to produce adverse effects in unaffected humans. This Technical Information Statement describes what is known about EHS and summarizes recommendations from medical groups for helping people with EHS. So far, at least 9 provocation studies have been reported on electromagnetically hypersensitive individuals (for a review of work through the mid-1990s see Bergqvist 1997). The studies have been overwhelmingly unsuccessful in being able to link EHS symptoms in these subjects to exposures to electric or magnetic fields. The symptoms reported by electromagnetically hypersensitive individuals, such as headache, fatigue, and stress, are common and nonspecific, i.e. they may have many causes. There is also clear evidence that psychological factors are important in some cases. The Bergqvist committee recommended that the starting point for all treatment should be the health symptoms of the individual, and not his or her perceived need for electrical “sanitation” of the workplace or home. Electromagnetic field surveys in normal workplace and residential environments are extremely unlikely to uncover the presence of fields that can be related to the symptoms of the EHS individual. In helping electromagnetically hypersensitive individuals, it is important to try to identify and treat any relevant health, environmental, or occupational hygiene problems that might be present, without assuming that they are caused by exposure to electric or magnetic fields. The committee also stressed that the information should include a clear statement that no scientific basis currently exists for a connection between EHS and exposure to electromagnetic fields.

50. Rodriguez, M., D. Petitclerc, J. F. Burchard, D. H. Nguyen, E. Block, and B. R. Downey. 2003. Responses of the estrous cycle in dairy cows exposed to electric and magnetic fields (60 Hz) during 8-h photoperiods. *Animal-Reproduction-Science*. 77(1-2)11-20.  
Abstract: To study the effects of exposure to extremely low frequency (ELF) electric and magnetic fields (EMF) on the estrous cycle of dairy cows under short-day photoperiod, 16 non-lactating, non-pregnant Holstein cows were exposed to a vertical electric field of 10 kV/m and a horizontal magnetic field of 30  $\mu$ T for 16 h per day in a cross-over design consisting of two sequences. Each sequence included three periods, and each period corresponded to the duration of one estrous cycle. All animals were maintained under short photoperiod (8 h light/16 h dark) during the trial. Exposure to EMF had an impact on the duration of a complete estrous cycle ( $P < 0.01$ ) and on the duration of the luteal phase ( $P < 0.01$ ). The mean duration of one cycle was  $19.5 \pm 0.4$  for the control and  $21.3 \pm 0.4$  days for the exposed animals, respectively. The mean duration of the luteal phase was  $15.4 \pm 0.4$  days for the control and  $17.2 \pm 0.4$  days for the exposed group. The total area under the progesterone (P4) curve, the amplitude of the curve or the slope of the P4 rise at the onset of the luteal phase were not affected by EMF exposure. Results indicate that exposure to EMF may increase the duration of the estrous cycle.