

Review of Research on DC Electrical Exposure

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Advanced Stray Voltage Analysis course 27 October 2005

Review Publications

Applied Bioelectricity, J.P. Reilly, 1998

The responses to DC voltage and current exposure are explained well by neuro-electric models.

Cardiac Stimulation and Fibrillation: Both AC and Dc currents can disrupt the rhythm of the heart. The greater fibrillation efficacy of 60 Hz relative to DC arises because the AC stimulus is a more efficient promoter of multiple ventricular responses. For 1 second exposure DC required 4 times more current (500 mA) than 20 Hz AC current (100 mA rms) to produce cardiac stimulation in dogs (page 215).

Sensory and muscular Responses: In practice DC sensory and muscular thresholds are about equal to peak AC currents or about 1.4 times higher than AC rms values.

Electrical and Biological Effect of Transmission Lines: A Review. J. M. Lee, 1996. Bonneville Power Administration.

Chapter 6: DC Transmission

The small currents intercepted by people or animals near a DC transmission line appear to be insignificant. Compared to AC lines, it is less likely that the electric field will be perceived or that nuisance shock will occur. Personnel who have worked near the BPA 600 kV DC test line have reported no harmful effects from the line. A Science Advisory Committee formed by the state of Minnesota concluded that there was no indication that the 400 kV DC line presented a risk to human health from short term exposure

The Minnesota Environmental Quality Board subsequently sponsored a statistical study to determine whether dairy cattle were affected by the 400 kV Line. No differences were found in milk production, calving interval, rate of culling, reproductive problems or incidence of abortions. The Science Advisors reconvened to consider results of electrical monitoring and to review recent research. They concluded that new information still indicated that there was little likelihood of either acute or chronic health effects of air ions or DC electric fields.

Overall there appears to be no evidence that the electric fields and ions of DC lines pose and hazards to public health. It has been suggested that self reported health effects from some people in Minnesota may be related to stress, apparently associated with controversy over the line, or perceived hazards.

Environmental studies of DC lines are useful because they deal with exposures that actually exist from operating lines. BPA sponsored a study in Oregon in which cattle were frequently observed feeding or resting near the lines. The principal researcher conducting the study spent hundreds of hours on the right of way and never perceived the electric field and never experienced any shocks.

An extensive long term study of beef cattle under a 500 kV DC line was designed to simulate ranching and conditions. There were no statically significant differences in growth or reproduction between cattle raised under the line and control animals. Behavioral studies indicated that from 5 to 11 percent fewer cattle occupied areas directly under DC conductors (not correlated with DC field or audible noise). Such a small effect would not be noticeable in a normal ranching operation

Related papers on DC Field Exposures

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

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.

Angell, R. F., and et al. 1990. Effects of a High-Voltage Direct-Current Transmission Line on Beef Cattle Production. Bioelectromagnetics 11:273-282.

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/m², and 13 k ions/cm³, 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.

Research on Current Exposure: Dairy Cows

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.

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?

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).

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.

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.

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.

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.

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, 3rd harmonic content and DC offset were documented and shown to agree with other studies.

Aneshansley, D. J. 2003. Stray Voltage Research at Cornell University. NRAES: Stray Voltage and Dairy Farms Conference Proceedings.

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).

Current Exposure - Other Species

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).

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 ($P = NS$).

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.

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**