Literature Review and Synthesis of Research Findings on the Impact of Stray Voltage on Farm Operations

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1. Scope of this Report

- Literature review
- Pathways whereby stray voltage can affect animals
- Symptoms indicative of stray voltage
- Minimum voltage (or current) level at which impacts can be expected.
- Measures for mitigating stray voltage
- Review of regulatory measures

Ways That Stray, or Tingle, Voltage Can Impact Farm Operations

- Direct effects
  - Mild behavioral reactions = sensation
  - Involuntary muscle contraction = twitching
  - Intense behavioral responses = pain
- Severity depends on
  - amount of electrical current (milliAmps) flowing through the animal's body
  - Body pathway
  - Individual animal Sensitivity

Indirect effects

- Animals avoiding certain exposure locations
  - Reduced water intake if exposure is required for animals to access watering devices,
  - Reduced feed intake if exposure is required for animals to accesses feeding devices or locations.
- Difficulty of moving or handling animals in areas of voltage/current exposure
- Release of stress hormones produced by contact with painful stimuli

Basic concepts of voltage, current, and resistance

- Ohm's law = relationship between
  Voltage, Current and Resistance
  - If voltage (across animal contact points) is increased, the current flowing through the animal will increase
  - If resistance (of contact points) is increased, the current flowing through the animal will decrease
    - 1 milliAmp = 1/1000th of an amp

$$\textbf{Current (Amps)} = \frac{\textbf{Voltage (Volts)}}{\textbf{Resistance (Ohms)}}$$

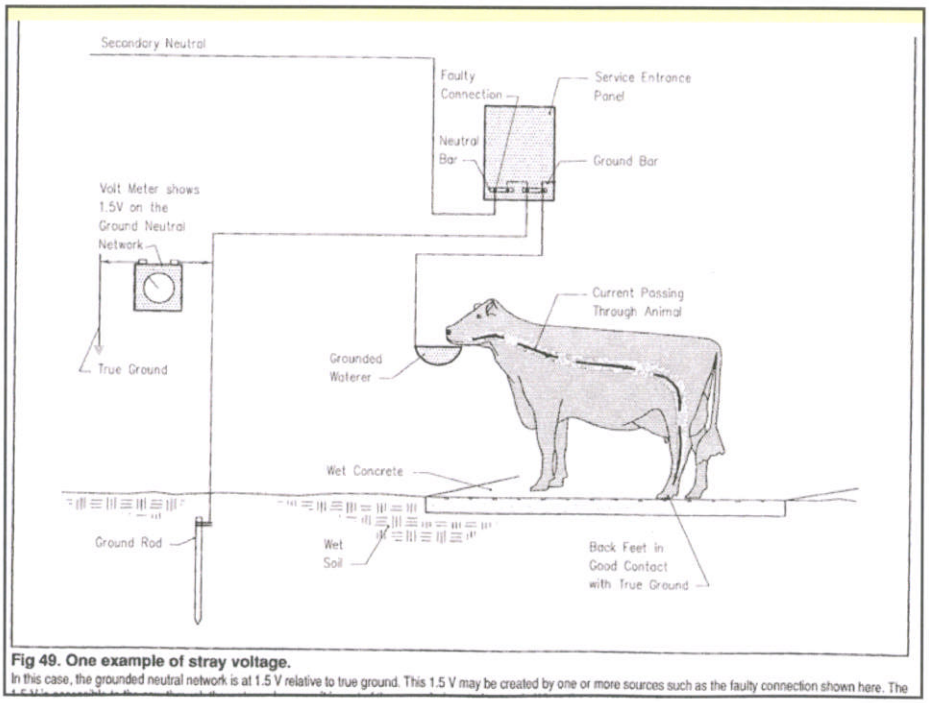
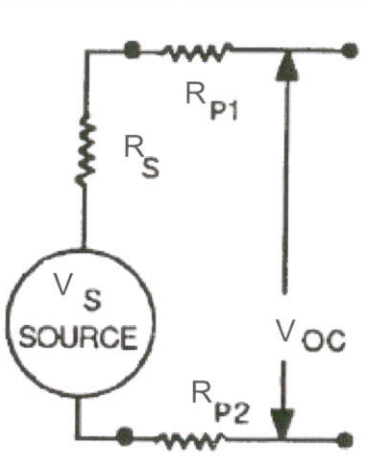


Fig 49. One example of stray voltage.
In this case, the grounded neutral network is at 1.5 V relative to true ground. This 1.5 V may be created by one or more sources such as the faulty connection shown here. The

Elements of the Source Circuit

- Vs = Voltage Source (I*R on neutral wire)
- Rs = Source Resistance
- Rp1 = Path Resistance 1
- Rp2 = Path Resistance 2
- Voc = Open Circuit or Source Voltage



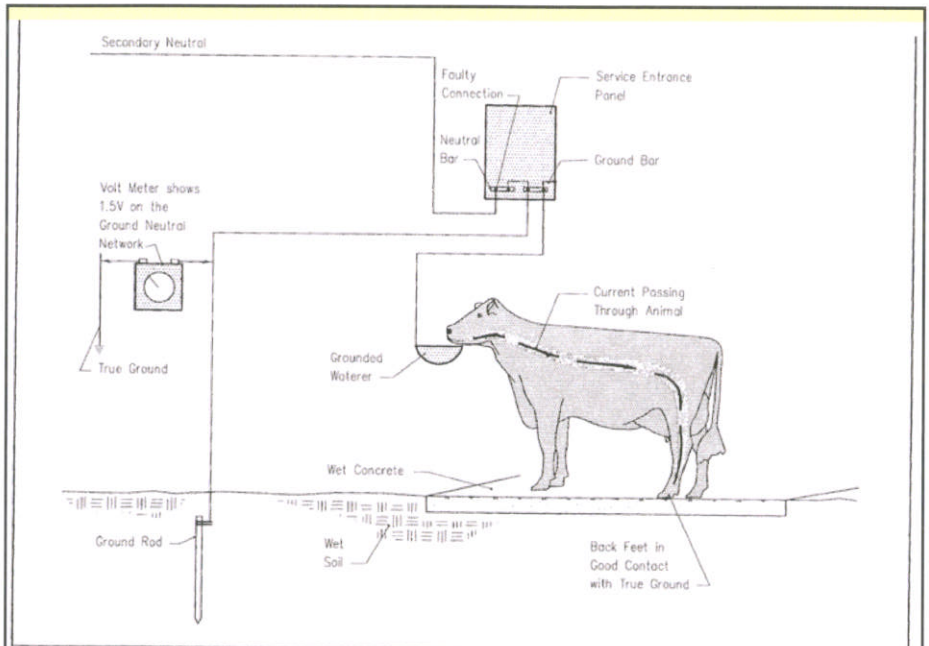
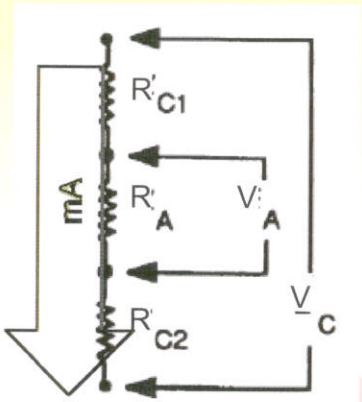


Fig 49. One example of stray voltage.
In this case, the grounded neutral network is at 1.5 V relative to true ground. This 1.5 V may be created by one or more sources such as the faulty connection shown here. The

Elements of the Animal Circuit

- mA = current through animal
- Rc1 = contact Resistance (Muzzle or front hooves)
- Ra = body Resistance
- Rc2 = contact resistance (all hooves or rear hooves)

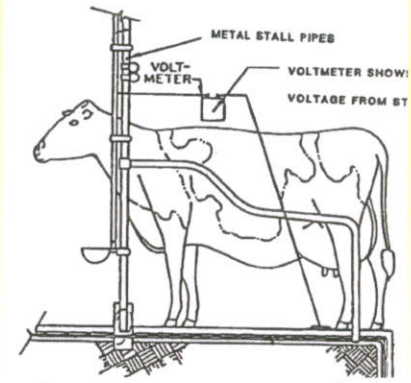


Importance of Proper Circuit Identification

V(source)	R(Source)	R(animal + contact)	Animal Contact voltage	Animal contact current
1 volt	100 Ohms	500 Ohms	0.8 Volts	1.7 milliAmps
1 volt	100 Ohms	1000 Ohms	0.9 Volts	0.9 milliamps
1 volt	1000 Ohms	1000 Ohms	0.5 Volts	0.5 milliamps

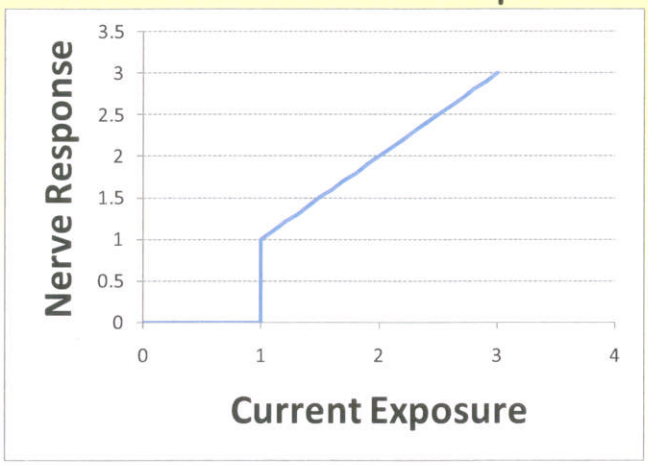
The Problem of Contact Resistance

- The most variable part of the electrical circuit
- Contact resistances will increase with:
  - smaller contact surface area
  - reduced contact surface pressure
  - drier contact surfaces
  - the amount of debris on contact point
  - resistance value of the debris at the contact margin
- The accepted practice by researchers and regulators has been to assume worst-case (lowest practical values) for contact resistances.



contact. For evaluation purposes, it is often sufficient to consider the worst case resistance, i.e., the lowest resistance likely to be encountered. We consider 500 Ω for the sum of contact and body resistances to be a very conservative estimate of the worst case, or minimum, resistance that is likely to be encountered.

Sensory and Motor Nerve Stimulation and Response



Threshold of Response
(so that they do not fire all the time)

The Bio-mechanics of Nerve Stimulation

- As current levels increase
  - No response below threshold
  - Sensory responses just above threshold
    - Tingling, warmth, startle
  - Motor response
    - Involuntary muscle contraction, twitch
  - Pain

Behavioral Responses

- Each animal will have a behavioral response threshold to current exposure for a particular contact pathway
- Studies have used a variety of behavioral response thresholds
- most sensitive behavioral indicators of perception
  - high variability, rapid acclimation to unfamiliar
- annoyance and/or aversion
  - Change eating / drinking behaviors
- Current applied in a periodic manner
  - repeated series of 'startle' behaviors
- Involuntary muscle contraction
  - Most repeatable, Higher current threshold than sensation

Literature Review 1962-2008

- 61 Studies of voltage/current application to cows
- 26 Studies of voltage/current application to other farm species
- 8 Studies of Cow Trainers and Fencers
- Studies Reviewed for
  - Data Collection
  - Data analysis
  - Repeatability

Research Groups Farm Animals and Electrical Exposures

US
U Minnesota - Gustafson/ Cloud/ Brennan/ Appleman/Henke-Drenkard
Cornell - Aneshansley/Gorewit/Price/Wilson/ Ludington/Southwick
Michigan - Surbrook/Kirk/Althouse/Fick
U Missouri - Currence/ Winter/ Stevens/ Dick
Johns Hopkins - Reilly
Purdue - Albright
UWEX - Hendrickson / Kammel
USDA Beltsville - Lefcourt
Washington - Lee et al.
USDA ARS - Stetson
U of Wisconsin - Reinemann/ Scheffield/ Wiltbank/ LeMire/ Armentano/ McGuirk/ Laughlin/
PSCW - Dasho/ Cook/ Reines
DATCP - Kasper/ Roberts/Hansen/Ryder
Minnesota PUC - Hendrickson/ Patoch
Quigley
Halvorson
Godcharles

Canada
Ontario- Rushen
Alberta - Thorne
McGill - Burchard/ Rodriquez/
New Liskeard - Gumprich
Australia
Damask
New Zealand
Phillips, Whittlestone, Woolford, Salisbury
Germany
Bergsten
Oswald
Sweden
Algers
Hultgren
Pehrson
France
AroParisTech - Roussel, Ragalma

29 groups more than 70 people

New Zealand: Phillips,1962

- First published Cow study
- Voltages on milking plants in New Zealand 0 to 20 V - most between 3 and 10 V.
- Sources of voltage: unbalanced loads and High resistance neutrals
- Voltage applied teat-to-rear hooves
- After these experiments **3 volts** was chosen as a likely minimum level for response.

New Zealand: Woolford, 1972

- Use Current Exposure in an attempt to reduce variability of responses
  - front to rear hooves
  - wetted flank to 4-hooves
- changes in cow behavioral when currents reached 3 to 8 milliAmpere
- judged to be uncomfortable for currents of 4.5 to 12 milliAmpere

New Zealand: Whttlestone, 1975

- Operant conditioning system as a more objective method of measuring behavioral responses
  - cows turned on an electric current by pressing a second manipulanda in order to receive crushed barley
- behaviors changed with currents of
  - 6 mA for the udder, 7 mA for one teat
  - 6 mA for rump, 4 mA chest area.

USDA 1991 Summary

- Consensus opinion of 15 credible researchers
- *distressed that our research results were being misinterpreted*
- *Recommend action levels from <u>2 to 4 Volts</u>*
  - *As conservative as possible to account for indirect losses due to problems resulting from inappropriate response of farmers to changes in animal behavior*

USDA 1992 Summary

- *To relate voltage measurements to current, the worst case (500 Ohms) and more realistic (1000 Ohms) Resistancs were used.*
- *Attempts to reduce cow contact voltages to below 0.5 to 1.0 V are unwarranted, and totally unnecessary*
- No contradiction to these findings in 2003 NRAES review.

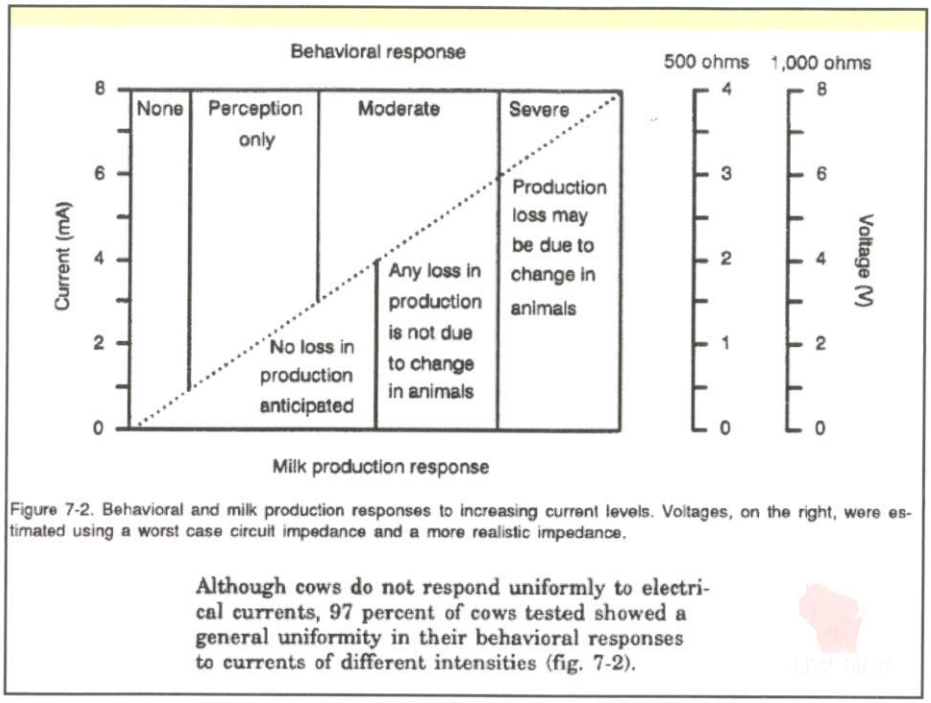
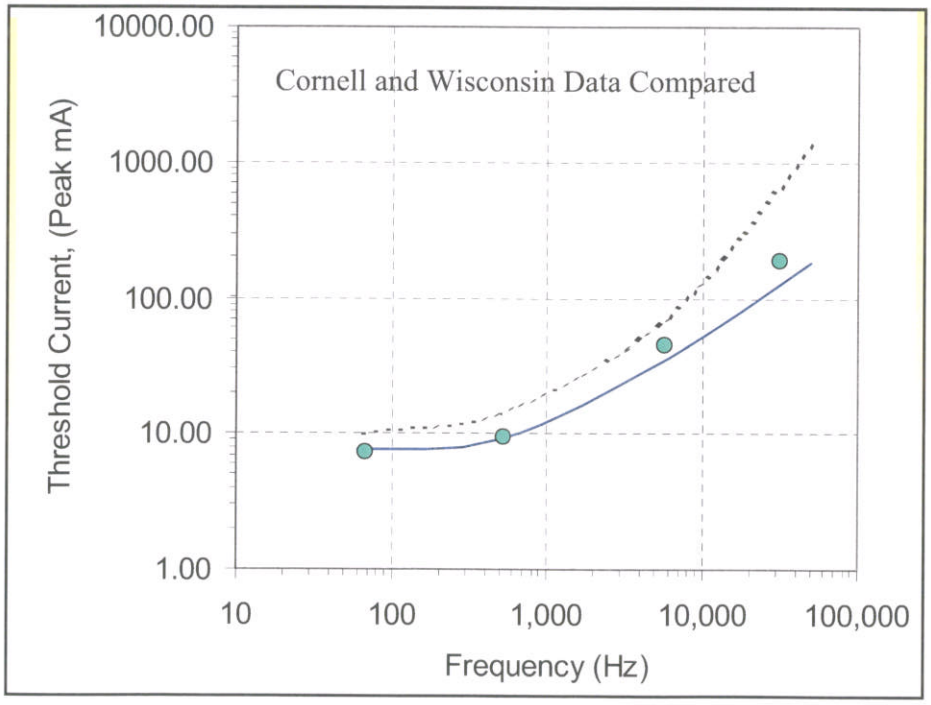
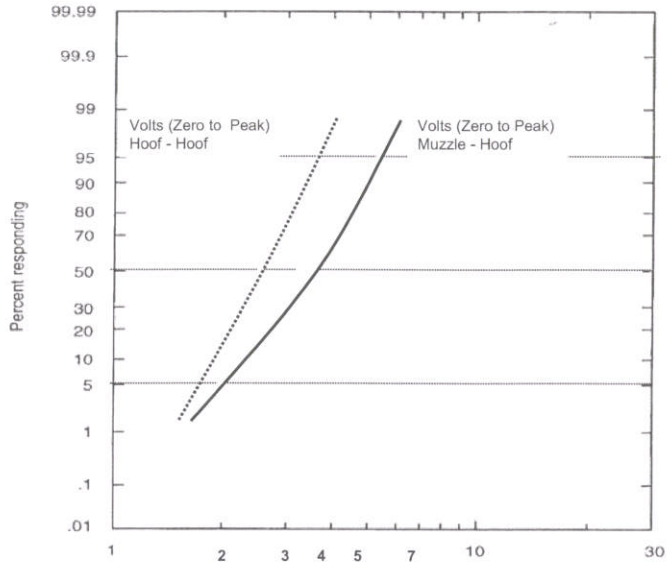


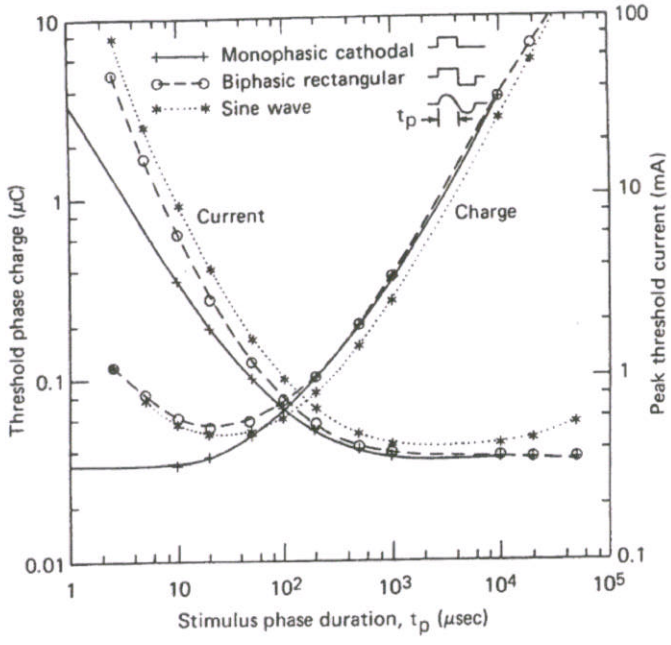
Figure 7-2. Behavioral and milk production responses to increasing current levels. Voltages, on the right, were estimated using a worst case circuit impedance and a more realistic impedance.

Although cows do not respond uniformly to electrical currents, 97 percent of cows tested showed a general uniformity in their behavioral responses to currents of different intensities (fig. 7-2).

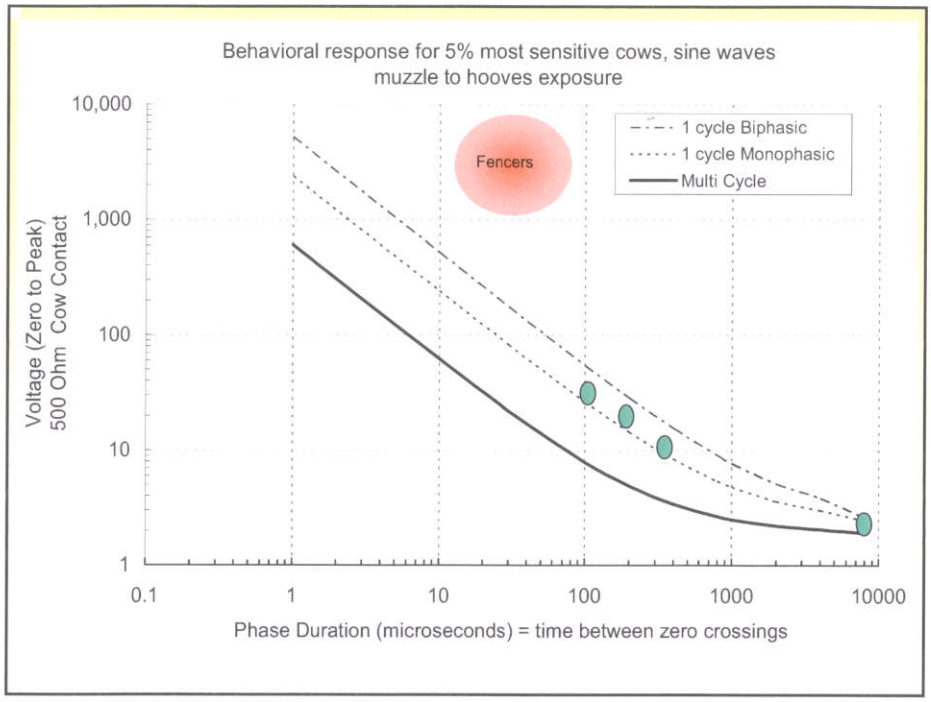


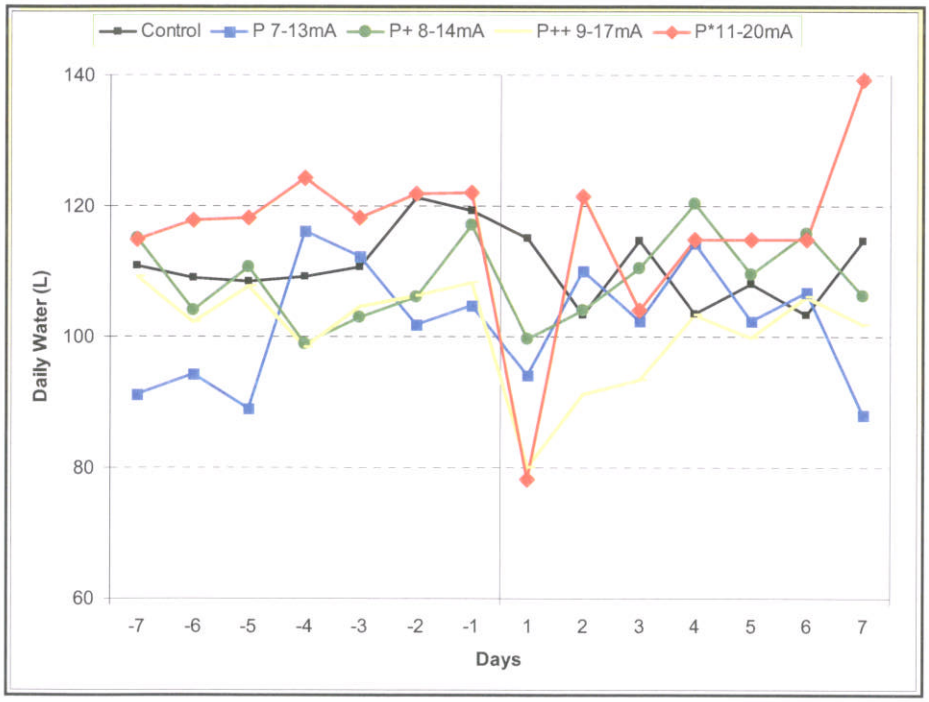
Approximate 60 Hz Steady State Behavioral Response Distribution

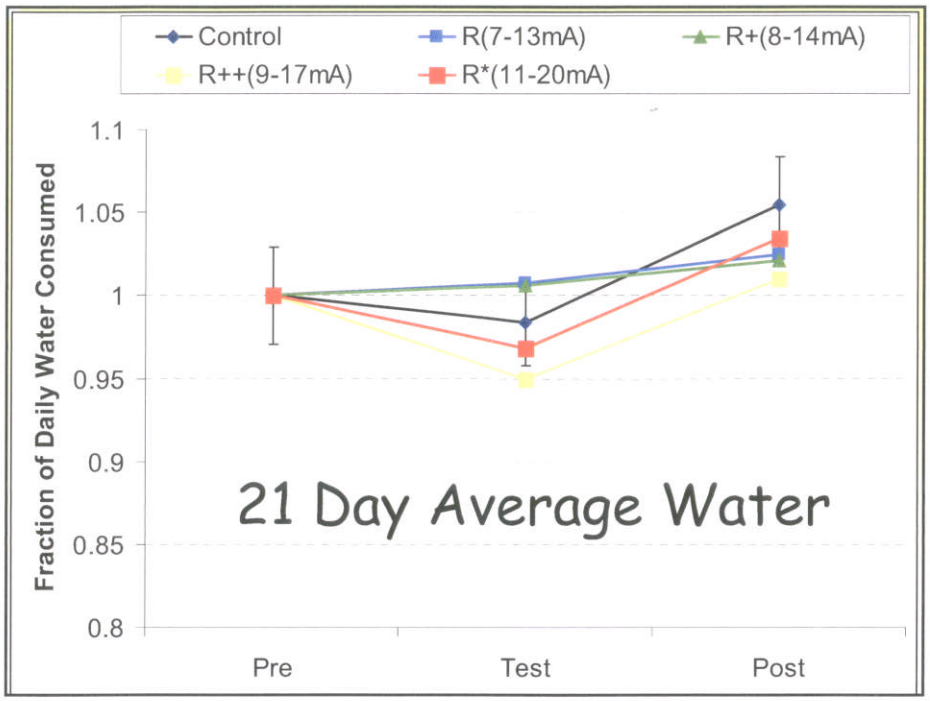


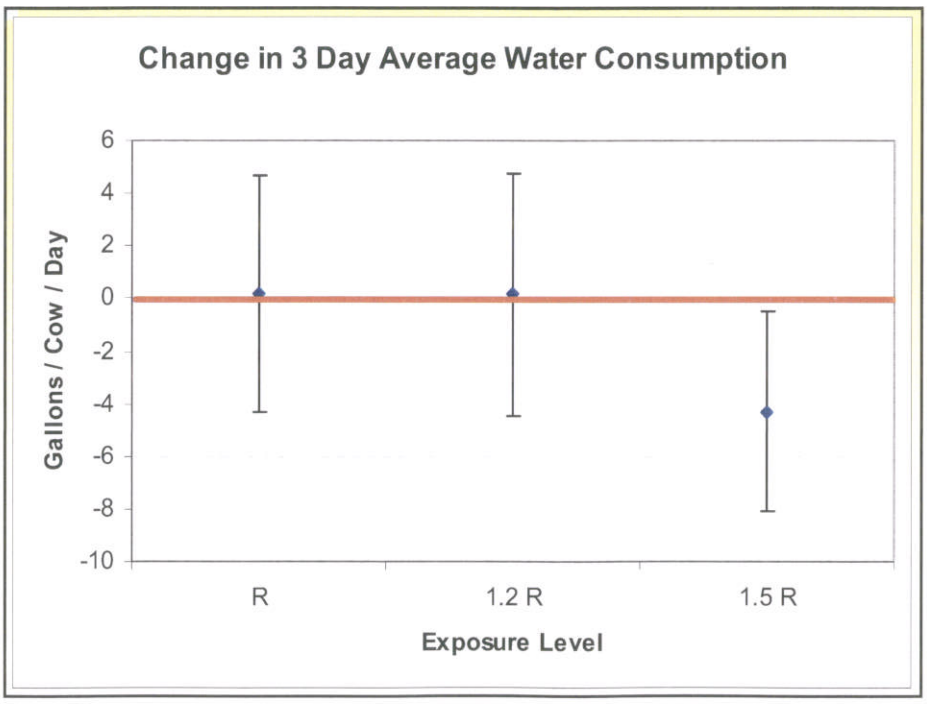


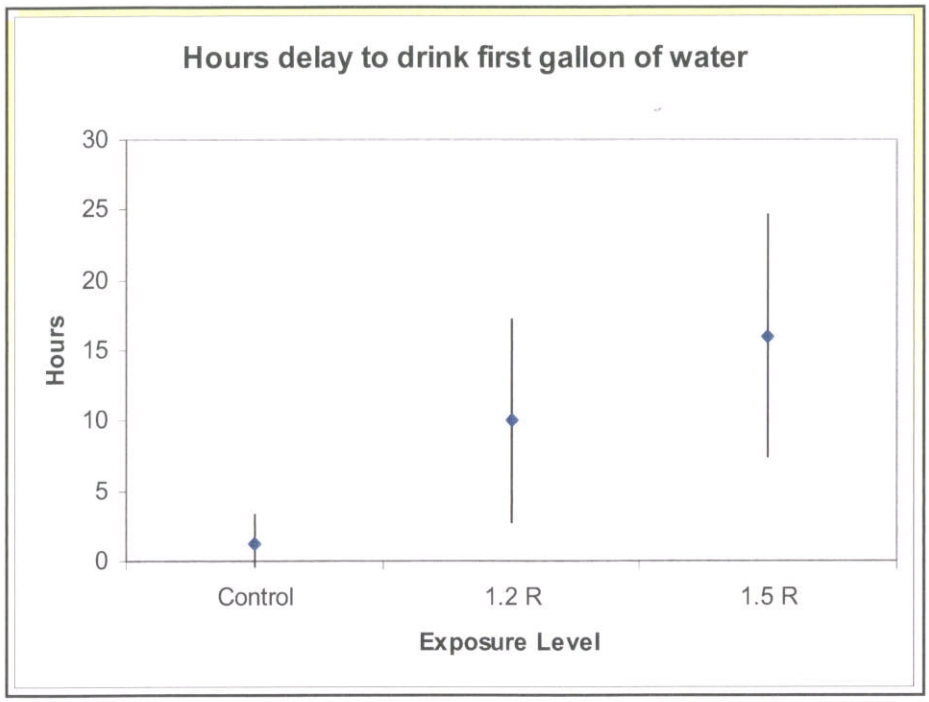
J.P. REILLY
BIO-
ELECTRICITY
1998


Behavioral response for 5% most sensitive cows, sine waves
muzzle to hooves exposure
10,000
1,000
100
10
1
Voltage (Zero to Peak)
500 Ohm Cow Contact
Fencers
1 cycle Biphasic
1 cycle Monophasic
Multi Cycle
0.1
1
10
100
1000
10000
Phase Duration (microseconds) = time between zero crossings


Control
P 7-13mA
P+ 8-14mA
P++ 9-17mA
P*11-20mA
140
120
100
80
60
Daily Water (L)
-7
-6
-5
-4
-3
-2
-1
1
2
3
4
5
6
7
Days


Control
R(7-13mA)
R+(8-14mA)
R++(9-17mA)
R*(11-20mA)
Fraction of Daily Water Consumed
1.1
1.05
1
0.95
0.9
0.85
0.8
21 Day Average Water
Pre
Test
Post

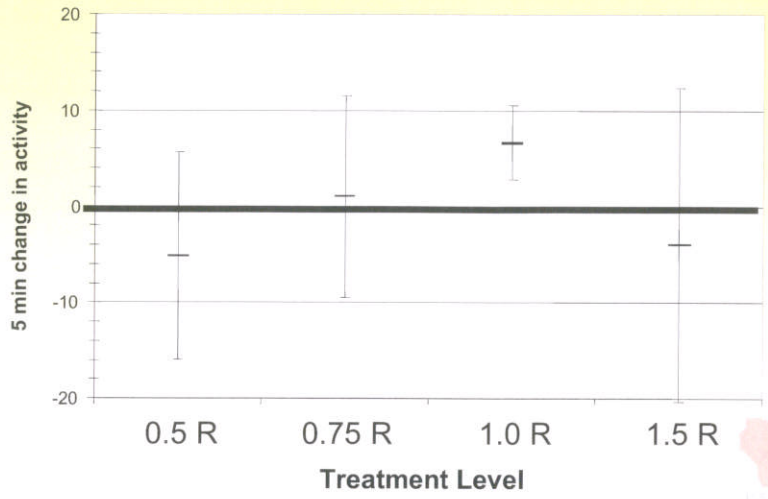

Change in 3 Day Average Water Consumption
Gallons / Cow / Day
6
4
2
0
-2
-4
-6
-8
-10
R
1.2 R
1.5 R
Exposure Level



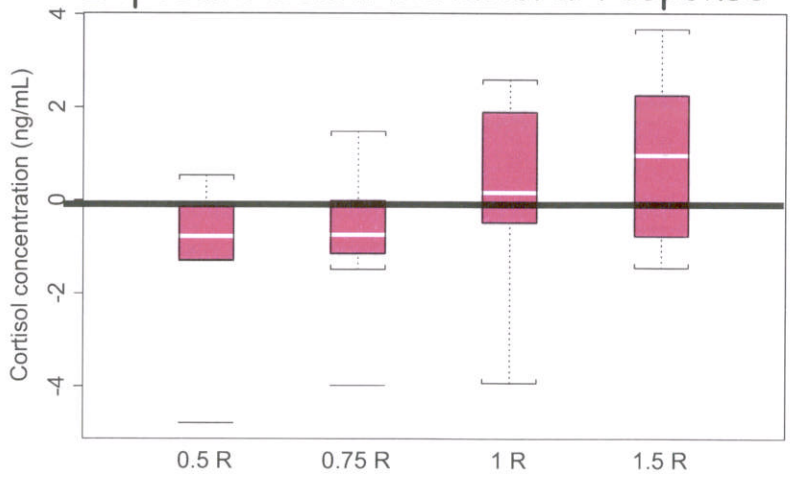
Continuous Vs. Intermittent Exposure

Hrs Delay	Ave Diff.	P-value	Significant
Control vs. One shock	-0.4	.14	No
Control vs. Intermittent	-0.4	.21	No
Control vs. Continuous	+5.6	<.01	Yes

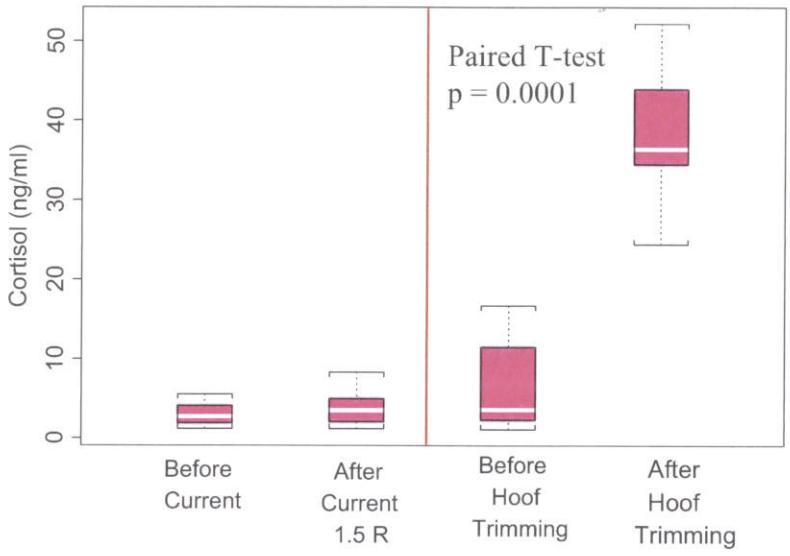
Change in cow activity in response to current exposure



No increase in Cortisol for Current Exposure below behavioral response



No Cortisol response for current exposure
Big Cortisol response for hoof trimming



Immune function conclusions

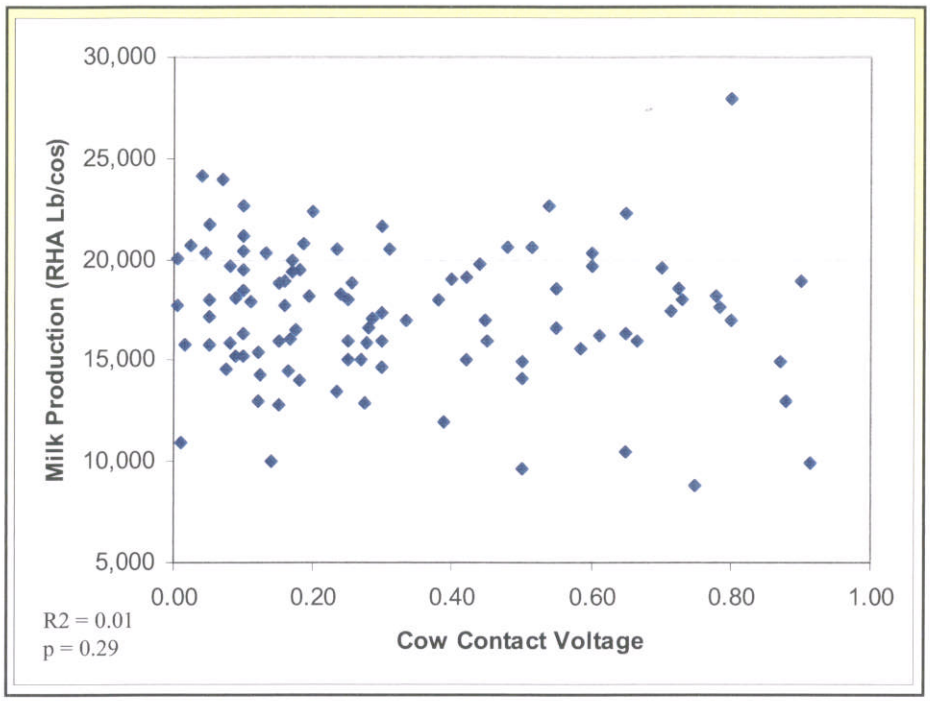
- Small subset of immune system regulators showed possible changes
  - most disease processes affect a wider spectrum of regulators
  - Type I errors, large number tested (?)
- Any possible impacts of electrical exposure on immune function health and disease are of relatively small and difficult to detect
- 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

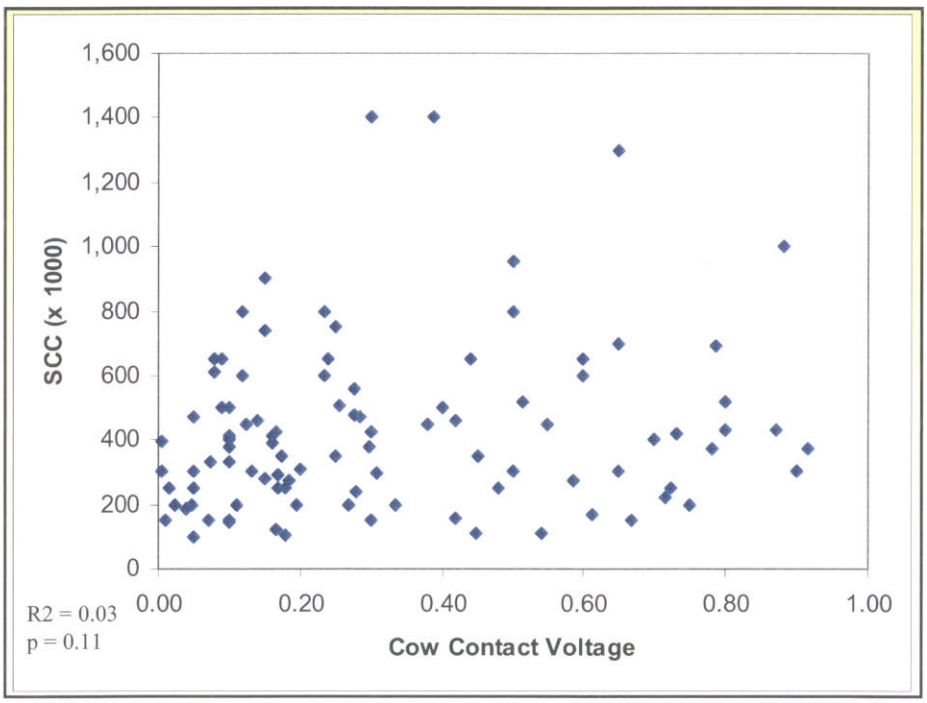
Wisconsin Field Study

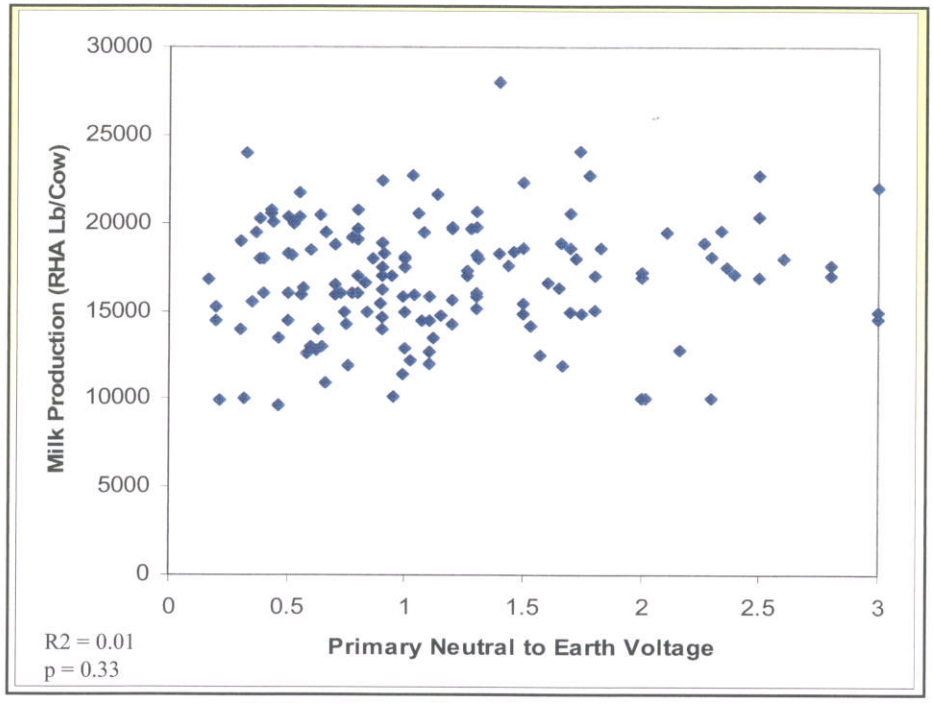
- Stray Voltage Analysis Team (SVAT)
  - Public Service Commission of Wisconsin (PSCW)
  - Wisconsin Department of Agriculture Trade and Consumer Protection (WDATCP)
  - > 360 Investigations 88-98
- Electric Utilities
  - 8000 First-Time Farm Investigations 93-2007

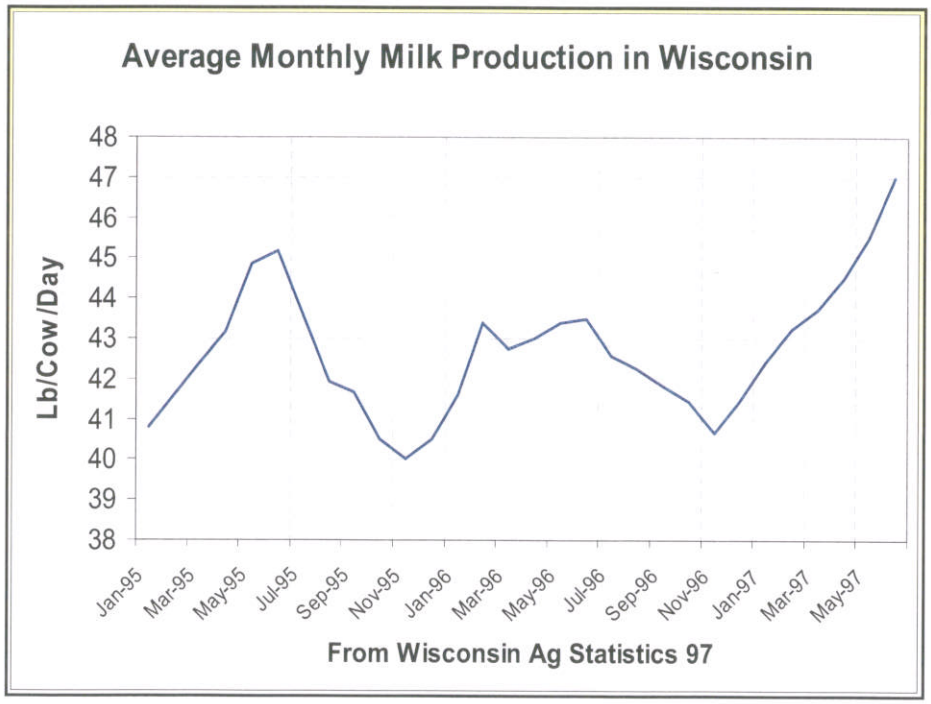
PSCW Field Study
8000+ Farms
No Correlation Between

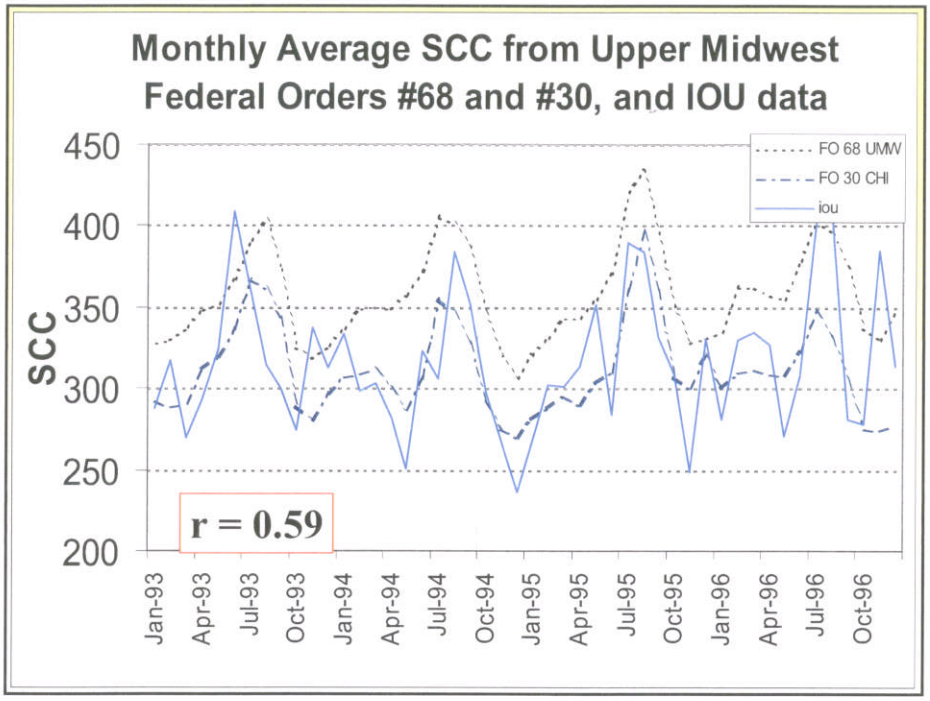
- Milk production or Somatic Cell Count and
  - Primary NEV
  - Secondary NEV
  - Cow Contact Voltage
  - Ground Rod Current


30,000
25,000
20,000
15,000
10,000
5,000
Milk Production (RHA Lb/cos)
0.00
0.20
0.40
0.60
0.80
1.00
Cow Contact Voltage
R2 = 0.01
p = 0.29


1,600
1,400
1,200
1,000
800
600
400
200
0
SCC (x 1000)
0.00
0.20
0.40
0.60
0.80
1.00
Cow Contact Voltage
R2 = 0.03
p = 0.11


30000
25000
20000
15000
10000
5000
0
Milk Production (RHA Lb/Cow)
0
0.5
1
1.5
2
2.5
3
Primary Neutral to Earth Voltage
R2 = 0.01
p = 0.33


Average Monthly Milk Production in Wisconsin
48
47
46
45
44
43
42
41
40
39
38
Lb/Cow/Day
Jan-95
Mar-95
May-95
Jul-95
Sep-95
Nov-95
Jan-96
Mar-96
May-96
Jul-96
Sep-96
Nov-96
Jan-97
Mar-97
May-97
From Wisconsin Ag Statistics 97



Review of Sensitivities of Other Species

- Swine
  - greater than 3.0 mA was needed to affect drinking time and 4.0 mA to affect consumption.
  - feed intake, daily gain were lower in the 5 V group than 2V and control
  - up to 8 V does not impair the welfare, reproductive performance, or health of sows and suckling pigs
  - Up to 8 V no significant effects on feeding, drinking, sitting or lying activities. slight increase in rooting bouts 5-8V head butting 2-5V

Review of Sensitivities of Other Species

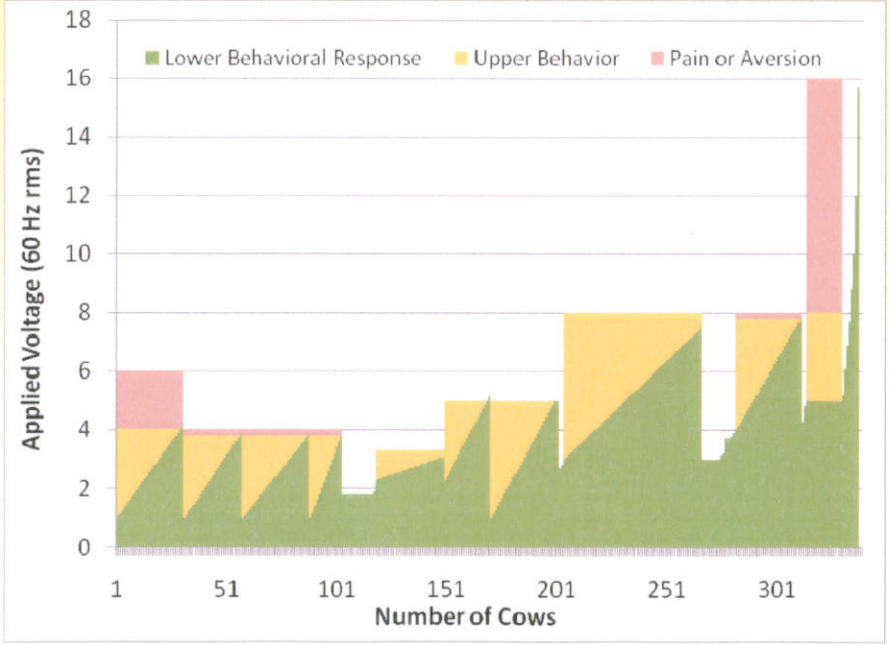
- Sheep
- Above 5.5 V ewes tended to spend more time eating and to eat more from the non-electrified feeder
- At 5V and upwards, lambs spent less time eating in the electrified feeder

Review of Sensitivities of Other Species

- Poultry
  - 0 to 9 volts did not impair egg production
  - electrical resistance of hens much higher than cattle and pigs
  - as high as 18 V had no effect on hens' production and behavior (2)
  - stray voltage present in many breeder houses may contribute to floor eggs
  - factors other than up to 9 V may have been causing a floor egg problem.

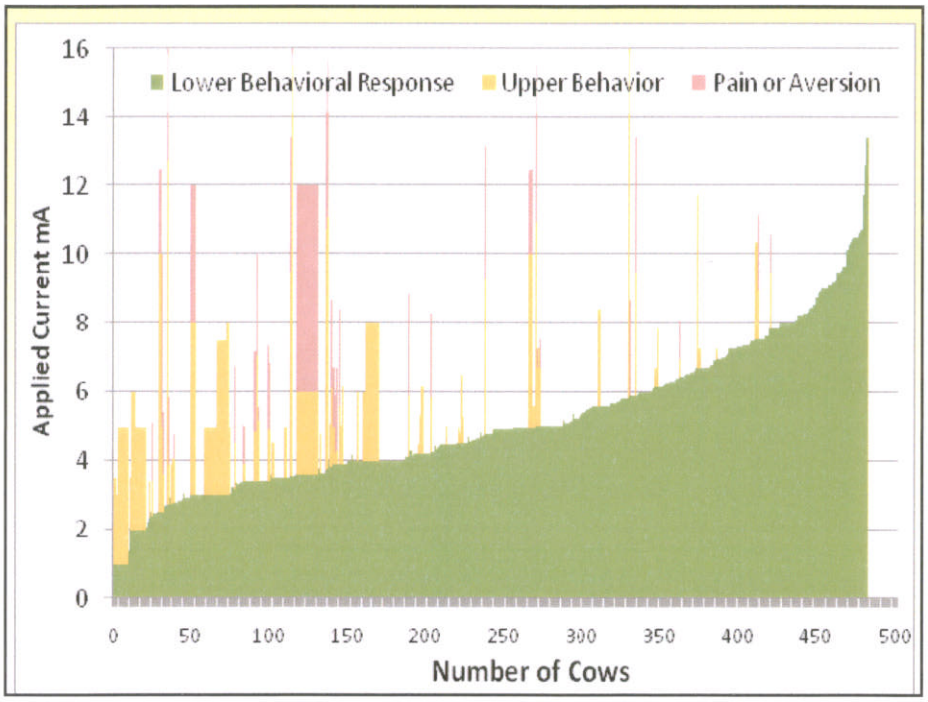
5. Synthesis of Research Findings

- Compilation of all known experiments in which responses to voltage or current exposure were documented
- Spanning 1962 to 2007 (45 Years)
- From Research Groups Around the World
- Over 100 Scientists Represented



Over 300 cows with constant VOLTAGE exposure

- Most studies report on group average rather than single animal responses
- Many studies report moderate behavioral between the range from 2 and 8 volts (60 hz rms)
  - Studies using metallic waterer - metallic floor plate found some delays to drink at 1 Volt
  - Studies using concrete floor did not report behavioral changes at 1 Volts
- Some studies report severe aversion of a few animals between 4 and 8 volts
  - Refusal to drink for up to 36 hours
  - Kicking at milking unit



Over 450 cows with constant CURRENT exposure

- Many studies report on single animal responses
- Behavior response thresholds vary
  - Moderate: Blink of an eye, nose twitch
  - Pronounced: Involuntary muscle contraction
  - Aversive: Stop Drinking
- Most behavioral response thresholds between from 2 and 8 milliAmps (60 Hz rms)
  - One study reported moderate responses at 1 mA with a nose press to metal plate (current concentration)
- Aversion occurs at higher levels than behavioral response

- Over 300 cows with constant voltage exposure
  - Most responses 2 to 8 Volts
- Over 450 cows with constant current exposure
  - Most responses 2 to 8 Milliamps
- Over 750 Cows Tested
  - 1000 Ohms reasonable estimate of cow + contact resistance in real-world situations
  - May be some unusual cases as low as 500 Ohms

Animal Response to Stray Voltage

Avoidance behavior	Well documented
Milk production	Documented only for extreme exposure
Somatic cells	Not documented
Reproduction	Not documented
Milkout problems	Only at very high levels
Stress Hormones	Only at very high levels

Exposure Conditions Required to Produce an Effect

- Adverse effect requires BOTH annoying current AND forced exposure
- Contact resistance
  - 500 ohms is worst case
  - 1000 Ohms is typical
  - Dry contacts or bedding will increase contact resistance
- Location
  - Areas vital to normal daily activities
- Times / day
  - Annoying stimulus must occur frequently

Levels That Affect Farm performance

- Current exposure < 3 mA may produce mild behavioral changes in a small percentage of cows
  - Corresponding to < 2 to 3 Volts
  - Aversive behaviors likely short-lived
  - No physiological changes
  - Changes likley undetectable on most farms

Levels That Affect Farm performance

- Current exposure from 3 to 6 mA may produce observable behavioral changes in some cows
  - Corresponding to 3 to 6 Volts
  - May produce short term changes in eating/drinking for some cows depending on location and time of exposure
    - Likely difficult to detect
  - Aversive behaviors likely short-lived
  - May produce mild increase in 'stress' hormones in some cows

Levels That Affect Farm performance

- Current exposure above 6 mA likely to produce some behavioral changes in most cows and pronounced behaviors in some cows
  - Corresponding to > 6 Volts
  - Likely to produce changes in eating / drinking for some cows depending on location and time of exposure
    - May be detectable on some farms
  - May produce increase in 'stress' hormones in some cows

Diagnosis

- Animal behavior or other symptoms CANNOT be used to diagnose stray voltage problems
  - All known responses to stray voltage exposure can be produced by other causes
- The ONLY WAY to determine if stray voltage is a potential cause is to perform electrical testing