Established and Non-Established Levels of Concern for Contact Voltages

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1.1 Introduction

Levels of concern for contact voltages have been established for animal contact, for skilled trade industries, and by various safety and standards organizations. It is important to understand how these levels have been derived in order to ensure that appropriate methods are employed—if and when new levels of concern are established. With this in mind, the objectives here are to:

- Summarize the effects of current flow through the body for situations where a proposed new level of concern may be of interest
- Summarize "established" levels for human and "non-farm animal" contact scenarios
- Discuss historical aspects of the established levels of concern
- Discuss the procedure(s) necessary for establishing new levels for contact scenarios where a level does not presently exist

1.2 Effects of Current Flow Through the Body

There are a number of defined effects due to current flow through the body, ranging from involuntary muscle reaction to heart fibrillation. Thus, dependent upon the objective, established limits for contact voltage (and subsequent current flow) situations are notably different. For example, when there is an aversion concern for farm animals, the "equivalent voltage" level of concern at 1 to 2 Vac is very low compared to the levels established by OSHA (>50 Vac) for worker safety. Because of the different objectives, there will be differing levels of concern. These objectives, based on the effects of current flow through the body, can be categorized into three areas for short-term 50/60-Hz ac contact scenarios:

1. Aversion – Examples include animals avoiding a metal grate, animals not wanting to drink water, and humans not wanting to enter a pool or hot tub.
2. Injury – The actual level of concern here is referred to as "startle reaction," where the result is a possible injury (such as falling from a ladder or spilling a pan of boiling water).
3. Fatalities – The level of concern here is "heart fibrillation" or "respiratory paralysis."

The most challenging aspect of defining thresholds for these three areas is that:

- There are differences in the body-part impedances for animals versus humans.
- There are differences for the various current paths and the respective amount of "heart current" flow.
- There are differences in the actual point-to-point contact mechanisms (hand-to-foot, chest-to-foot, and so on) for both wet and dry conditions.

These differences present the challenge of having to either deal with multiple limits for the same scenario or going with the most conservative value for all combinations. To illustrate the point, an energized street-level service box may cause a serious injury to an animal while that same voltage level may cause no impact to a human that is wearing rubber-soled shoes.

1.3 Published Levels of Concern for Human and Animal Contact Scenarios

A number of levels of concern exist for various contact scenarios. For the purposes of comparison, Table 1 provides a representative selection of these established values for human contact situations. This table proves useful for comparison and discussion regarding the development of new proposals for limits.

Table 1: Summary of Published Contact Voltage Levels of Concern for Humans

Reference Document	Published Level	Concern Category	Other comments
UL-101 [5]	0.75 milliamps (hardwired with ground conductor) 2,000-ohm human body impedance model.	Reaction Current	This standard supplies some interesting insights that might be applied to power system contact voltages in that a current flow across a conducting medium or grounding grid and into the earth may need to be measured and a limit applied to define acceptable or unacceptable performance. It defines "reaction current" as a threshold current above which a substantial portion of the population may be caused to act involuntarily to the sensation of current
UL-60950-1 [20]	42.4 Vac and 60 Vdc is the stated limit under dry conditions and human hand path.	Shock Hazard	The standard states that body impedance depends on the area of contact, moisture in the area of contact, and the applied voltage and frequency. It also states that steady-state voltages up to 42.4 V peak, or 60 Vdc, are not generally regarded as hazardous under dry conditions for an area of contact equivalent to a human hand.
IEC 479-1 [7]	25 Vac clearly safe, 50 Vac marginally safe (depending on duration). 1000 ohm test value cited	Shock Hazard	Annex B of IEC 479-1 states that 100 living humans were tested up to 25 Vac under dry conditions without serious injury occurring. Table 1 in the document shows body impedance values for various percentiles of the population and supports a 1,000-ohm test value (hand to foot) to cover approximately 99% of the population.
OSHA "Electrical Standard; Proposed Rule" (29 CFR Part 1910) 2004 [23]	Circuits operating above 50 Vac or 50 Vdc.	Shock Hazard	This standard states that "except as elsewhere required or permitted by this standard, live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by use of approved cabinets or other forms of approved enclosures."
NFPA 70E [22]	30 Vrms or 60 Vdc. 500-ohm wet human body resistance.	Shock Hazard	This standard states that a voltage of 30 Vrms, or 60 Vdc, is considered safe except when the skin is broken; in such a case, the internal body resistance can be as low as 500 ohms, so fatalities can occur. (1) At 5 mA, shock is perceptible. (2) At 10 mA, a person may not be able to voluntarily let go of the hazard. (3) At about 40 mA, the shock, if lasting for 1 second or longer, may be fatal due to ventricular fibrillation.

Reference Document	Published Level	Concern Category	Other comments
IEEE Yellow Book – Std. 902-1998 [18]	Currents as low as a few (10) milliamps and voltages above 50 V can cause fibrillation. 500-ohm minimum body resistance for wet conditions or cuts and abrasions. 100-500 ohms for immersion situations (Table 7-2)	Heart Fibrillation	Voltage levels as low as 50 V with low skin resistance and current flowing through the chest area can cause fibrillation, which can result in death. The standard also states that any 60 Hz current of 10 mA or more may be fatal for a 150-lb human. Those between 75 mA and 4 A can be fatal from heart disruption. Those above 5 A may be fatal from severe internal or external burns. The standard states that data have been compiled showing the voltage(s) required to force certain current values through a person of circuit resistance of 500 ohms. Although this appears to be low for human body resistance, it can be approached by someone who has sweat-soaked cloth gloves on both hands and a full hand grasp of a large energized conductor and a grounded pipe or conduit. The standard suggests that a circuit value as low as 37.5 V could be dangerous for persons with hand cuts, abrasions, or blisters.
NACE [34]	15 volts.	Shock Hazard	NACE RP-0177 "Mitigation of Alternating Current and Lighting Effects on Metallic Structures and Corrosion control Systems" considers 15 volts ac open circuit to constitute an anticipated shock hazard.
NESC [25]	51 volts.	Shock Hazard	Table 441-1 states: "When working with live lines, contact with voltage at or above 51 Vac line to ground or line to line should be avoided."
NEC [26]	Circuits operating above 50 Vac or 50 Vdc or 15 V for wet areas.	Shock Hazard	Article 110 states that circuits operating at greater than 50 V must be guarded against accidental contact. Article 680 states that near pools and spas, a GFCI must be installed for circuits operating above 15 V so that there is no shock hazard during relamping.
IEEE Std 80 [8]	60 Vac for 4 sec. 1000 ohm human body impedance	Shock Hazard	This standard suggests that 60 Vac or less for up to 4 seconds is in the safe area. Also states: "It should be remembered that the choice of a 1000 Ω resistance value relates to paths such as those between the hand and one foot or both feet, where a major part of the current passes through parts of the body containing vital organs, including the heart. It is generally agreed that current flowing from one foot to the other is far less dangerous.

1.4 Historical Aspects of Established Levels of Concern

It is important to understand from a historical standpoint how existing limits and levels of concern were established in order to ensure that appropriate methods are employed for developing future limits. Having built-in "factors of safety" can ensure that the researchers do not make erroneous assumptions relative to establishment of any new limits. The comments supplied for Table 9-1 above provide summary insights into some of the rationale behind these established levels. The text indicates that at least a few of the established levels of concern have "factors of safety" already built in.

For example, Reilly [1, p. 291] explains that if we look at the testing and sampling methodology utilized by Underwriters Laboratories (UL) to help define the ANSI leakage current limits, we find that the UL conducted experiments with human volunteers holding cups of rice and applied a series of random currents. First, tests were performed for a contact from one (hand or wrist) to the other arm (where the other arm was immersed in saltwater). This provides a "wet-versus-dry" impedance factor of safety that is "built in" relative to the ultimate limit.

Next, the test team established that women were more sensitive than men, and so all of the follow-on tests were conducted with a sample of 20 women (in essence this cuts out 50% of the population) and provides a second "built in" factor of the safety.

Finally, the average reaction considered borderline hazardous was 2.2 mA, and a limit of 0.5 mA was ultimately adopted. This provides a third factor of safety in the form of a 0.25 multiplier. Ultimately by recombining the male and female population, the limit of 0.5 mA minimizes the chance of a startle reaction to less than 1% of the total human population.

1.5 Parameters to Consider for Development of Levels of Concern

The relevant parameters that should be considered in the establishment of limits include:

1. **Current threshold –** A current threshold must be established based on the intended avoidance objective. (aversion? injury? fatality?)
2. **Body Path Resistance –** For conversion of a current threshold to a voltage level (or vice versa), the defined body-path resistance is necessary. The type of contact should define the path as hand-to-foot, foot-to-foot, hand-to-hand, front-paw-to-rear-paw, and so on.
3. **Body Weight –** The literature suggests that body weight may be useful in approximation of current sensitivity, but Reilly [1] points out that the researchers are not in consensus agreement on whether body weight is useful for safety criteria. In order to be conservative, the most sensitive species (dogs) has been selected to define most heart fibrillation safety criteria.
4. **Factor of Safety –** Unlike the factor of safety considerations for voltage insulation or for bridge construction, human and animal current thresholds present a wide range of values. Therefore, there is no simple way to select a single number that can be used as a limit. Successful past methods for developing a "built in" factor of safety include:

    a. **Percentage of Population –** Similar to what is used for the ANSI leakage current limits and the Wisconsin dairy cow perception thresholds, researchers may opt to use a percentage of the population likely to not be effected by a given current threshold.
    b. **Wet versus Dry Threshold –** For most contact voltage scenarios, wet conditions represent a worst case because the skin, the paw, or the hoof contact resistance is at a minimum when wet. Therefore, if thresholds or limits consider the wet case, an inherent factor of safety is built in. According to IEC 479-1 [7], for levels up to 50 Vac and under wet conditions, the impedance decrease can be as much as 25%.
    c. **Injury Threshold –** Injuries to body tissue caused by electric current flow is different from injuries due to a startle reaction, and as such a conservative threshold of perhaps "half the injurious value" should be considered. For example, the selection of a current or voltage could be justified based on an impedance value equivalent to one half of the 5th percentile impedance for the respective species. There are standards to consider here as well. For example, in Annex B of IEC 479-1 [7], 100

living humans were tested up to 25 Vac under dry conditions without serious injury occurring.

1.6 Proposed Process for Development of New Levels of Concern

Regarding the rationale and testing behind the ANSI limits, one should see that 0.5 mA should not be used out of context for establishing limits for earth currents, pipeline workers, manhole covers, and so on. However, if the limit and its historical rationale are carefully and systematically applied in conjunction with a specific body resistance value and a clearly defined measurement procedure, this particular value could be useful for residential wet-area (pool and spa) complaints.

What we can derive from the historical limits and the rationale behind those limits is that *a scientific methodology* does apply to the establishment of the established limits, and we can benefit from past research to articulate that process. The literature provides a large and diverse selection of both voltage and current limits already. Therefore, taking advantage of the rationale behind those established limits yields the following approach or procedure for development of new limits:

1. State the condition where the limit will be proposed (street-level metallic objects, pools, and spas, and so on).
2. Refer to existing standards (such as Table 9-1) to find any "similar reference scenario" to ensure that an appropriate limit cannot be pulled directly from existing material.
3. If nothing in the existing standards is applicable, define the objective (aversion, injury, fatality).
4. Define the species where the limit will apply (humans, dogs, or other species).
5. Define the contact mode(s) such as hand-to-hand, foot-to-hand, and so on.
6. Based on the condition (from 1) where the limit will be proposed, define a worst case voltage expectation
7. Estimate a minimum body impedance value based on the contact mode(s) and the worst case voltage expectation
8. Consider how wet or dry conditions might warrant either raising or lowering the impedance value.
9. Estimate the complete circuit current path impedance value
10. Define the current threshold(s) based on the objective and taking into consideration the contact scenario(s) as well as the full current path impedance value.
11. Where practical, reduce the current threshold(s) to a single worst case and articulate/document the factors of safety that have been considered in that limit.
12. Calculate the voltage limit(s) that apply to the contact scenario and the species based on the current threshold(s) and the impedance value(s).
13. Define the appropriate measurement protocol for the limit(s).

An Application Example –The following scenario provides an example utilizing the preceding 12 step procedure to identify a potential level of concern

Wet Contact Locations (Swimming Pools, Hot Tubs, and So on)

1. ***State the condition where the limit will be proposed*** – The condition where the limit applies is the area immediately surrounding the **pool or spa water, within touch or step distance**.
2. ***Refer to existing standards to find any "similar reference scenario"*** – Reviewing Table 9-1, there are no similar pool or spa limits, but there is some information related to NEC article 680 and a 15-V shock hazard reference that should be researched further. Also, there are references to application of "minimal" resistance values for immersion conditions of 100 to 500 ohms in IEEE 902 that should be researched further to understand the context related to the *applicable voltage levels*.
3. ***If nothing in existing standards apply, then define the objective*** – The objective in this case is **aversion** (nuisance shock due to tingling perception where persons may be afraid to get back into the pool).
4. ***Define the species where the limit applies*** – The species where the limit applies is **humans**.
5. ***Define the contact mode(s) such as hand-to-hand, foot-to-hand, and so on.*** – The contact mode(s) can be **"upper arm to hand," "torso to lower leg,"** or other combinations where the affected person is in the water and is sitting at the waters edge or is in the process of exiting the water via a ladder, handrail, or other.
6. ***Based on the condition (from 1) where the limit will be proposed, define a worst case voltage expectation*** – The contact scenario is the swimming pool where the voltage source is nearly always elevated NEV and **worst case would not exceed 10 Vac**. This voltage value will be important when considering the body path impedance because body impedance changes with the applied voltage (see Table 3-1).
7. ***Estimate a minimum body impedance value based on the contact mode(s) (from 5) and the worst case voltage expectation (from 6)*** – Under this scenario, Table 3-1 would suggest at least a 2,000 ohm hand to foot body resistance value for 5% of the population. Because the most likely contact mode(s) would be torso to lower leg or chest to hand, the 2,000 ohm value might be realistically reduced to **500 ohms** or perhaps less!
8. ***Consider how wet or dry conditions might warrant either raising or lowering the impedance value*** – The impedance values need to be factored for **wet conditions** and very minimal body resistance and current paths such as hand to chest (when exiting the pool via a ladder or torso to foot (when sitting poolside with feet in the water. Fortunately, these are aversion and not fatality objectives! For this scenario, it is not unreasonable to expect as low as perhaps **200 ohms for the body impedance path**
9. ***Estimate the complete circuit current path impedance value*** – This determination is not simple, but the full circuit source in this case is the energized pool water through the body path back through the cement deck and the earth and back through the grounding electrodes. The largest impedance would be the wet body part in contact with the pool deck so the 200 ohm body impedance would be in series with and estimated 1,800 to 2300 ohms of contact impedance. for a **total path impedance of 2000 to 2500 ohms**.
10. ***Define the current threshold(s) based on the objective (from 3) and taking into consideration the contact scenario(s) (from 5) as well as the full current path impedance value (from 9)*** – Based on the aversion objective and considering the contact scenario(s), the currents that cause **perceptible complaints are most likely 0.5 mA or greater**

11. ***Where practical, reduce the current threshold(s) to a single worst case and articulate/document the factors of safety that have been considered in that limit*** – Reducing the current threshold(s) to a **single worst-case 0.5 mA** value would suggest that only a small percent of the population is able to perceive this value. Because the level of concern is pool use aversion, the **factor of safety is not applicable** for this case, however only a few percent of the population can perceive 0.5 mA.
12. ***Calculate the voltage limit(s) that apply to the contact scenario and the species based on the current threshold(s) and the impedance value(s)*** – The applicable voltage level that applies to the contact scenario and the to the human species would yield a minimum voltage level of perception at **1.0 to 1.25 volts**. Note that this may explain why some children and female adults have been known to perceive and complain about voltage levels in this exact range, but it is a small percentage of the complaints that result from voltages this low.
13. ***Define the appropriate measurement protocol for the limit(s)*** – We should consider using a **load resistor of 200 ohms** to evaluate the currents that may be flowing through the body path.

Note: the preceding is simply an application example and should not be construed as a recommended level of concern. To develop a level of concern or a limit, the process requires industry expert consensus and field validation.

Because this methodology incorporates the basic process used to establish some of the limits found in existing standards, it can be readily applied to the other areas of interest where no existing limit is available. The possible areas where future levels or limits may be useful include:

- Wet contact locations (swimming pools, hot tubs, and so on)
- Non-wet area residential contact locations
- Above-ground pedestrian-level contact locations (light poles, bus shelters, and so on – with applicable mainly to humans)
- Street-level contact locations (manhole covers, grates, service boxes, and so on – with applicability to pets and to humans)