Determining Voltage Levels of Concern for Human and Animal Response to AC Current

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Presentation Summary

- Parameters controlling body current and impacts
- Summary of human and animal testing
- Terminology for perceptible levels
- Existing publications with voltage or current levels
- Important criteria for developing levels of concern (LOC)
- Comparing criteria among the standards and publications
- Boiling the criteria down to a systematic process
- Application example
- Final comments and recommendations

All source references are included on the final slide

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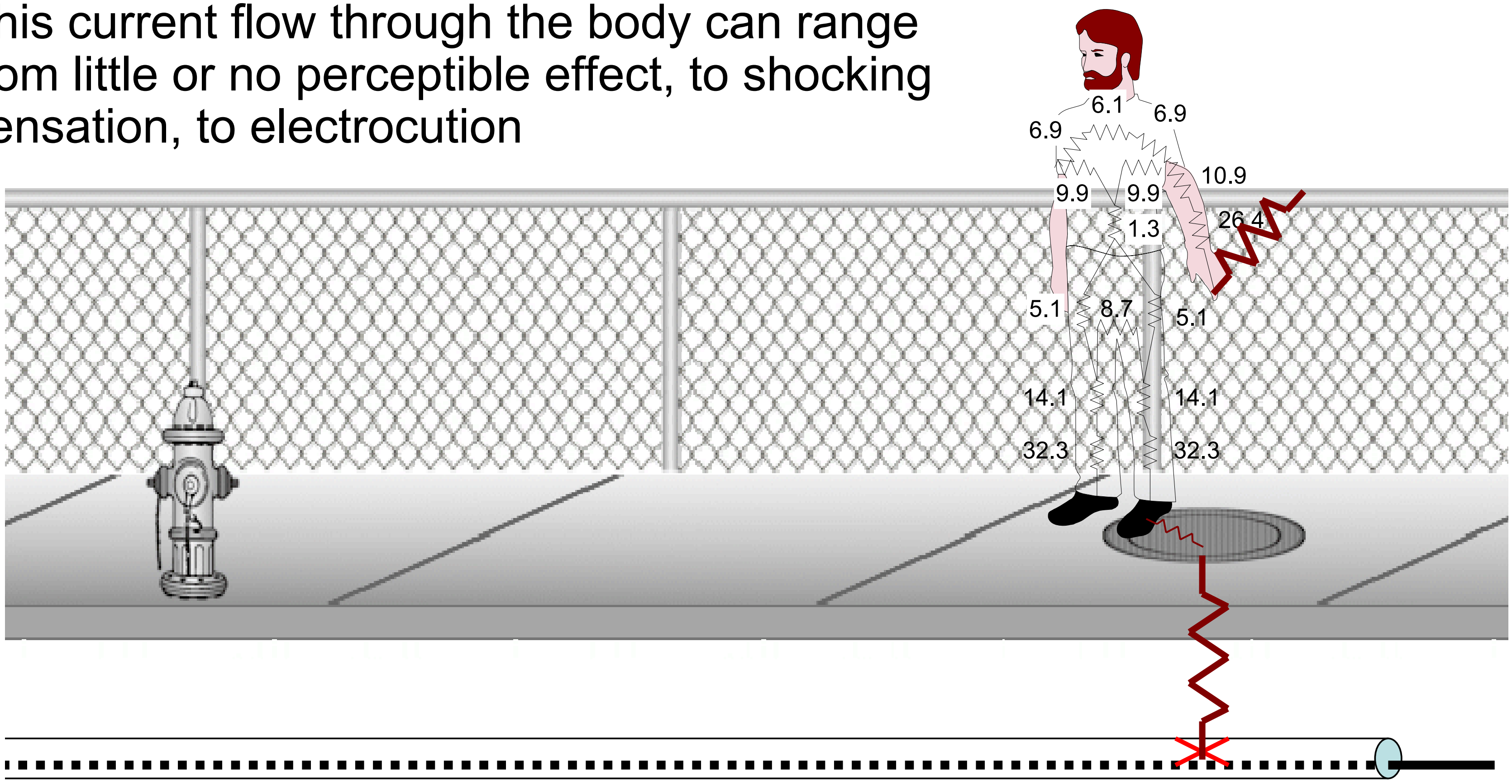
Parameters Controlling Body Current and Impacts on Humans and Animal

- Whenever a sufficient voltage potential is present between two points – In close enough proximity – for a human or an animal to bridge the gap between them, there is the possibility for a current path through the body
- This current flow through the body can range from little or no perceptible effect, to shocking sensation, to electrocution



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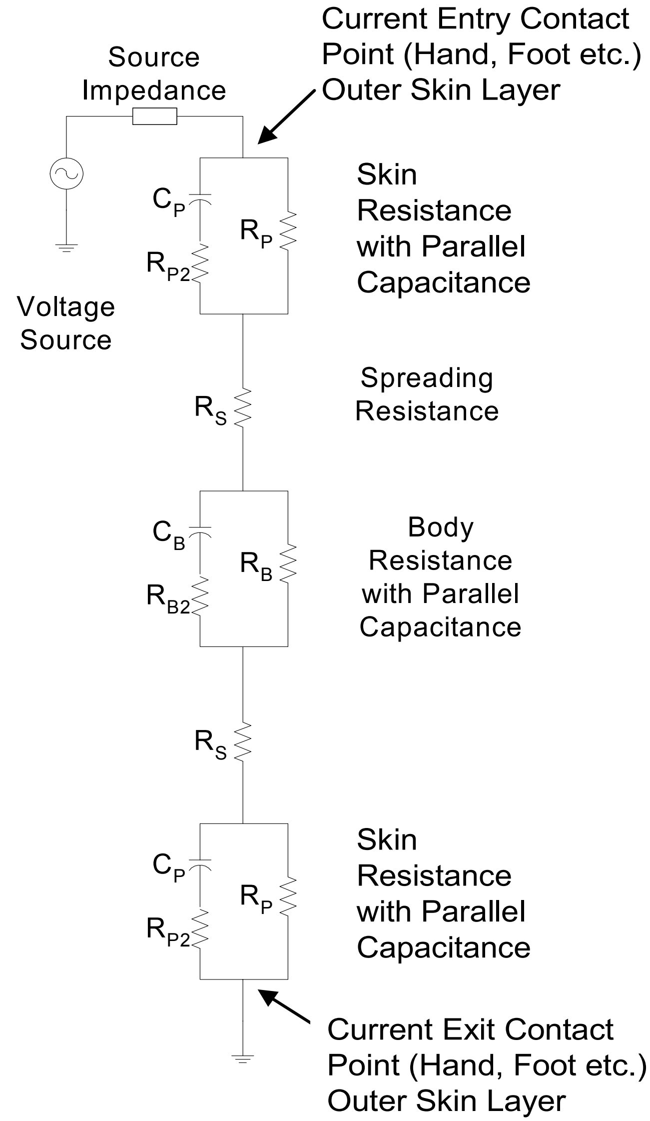
Body Effect Dependencies

- The effect on a given body is dependent upon [6]:
  - the path impedance
  - the applied frequency
  - the current magnitude
  - the duration of the current flow



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Questions that Must Be Answered in Order to Establish a Level of Concern

- What are the important variables that define human and animal body impedance?
- What impedance ranges are useful for characterization of humans?
- What impedance ranges are useful for characterization of different animals?
- Based on the impedance ranges, what 50/60-Hz contact voltage levels may be considered acceptable or unacceptable?
- What are the voltage and/or current levels that an investigator may be most interested in?

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Questions that Must Be Answered in Order to Establish a Level of Concern

- Contact Impedance of the skin for humans, and hoofs or paws for animals tends to be at least 30 times greater than the internal tissue impedance, therefore the contact impedance and the environment (wet, salty sweat, or dry) becomes the dominant variable
- Human Body Impedance - For dry conditions, 1000 ohms is frequently cited as a conservative number for a bare foot to hand contact and values below 200 ohms might apply for a swimming pool or a hot tub
- Animal Impedance – The literature is not specific on impedance values other than for dairy cows (500 ohms is a value frequently used there), but the values cited for humans (200 to 1000 ohms) are conservative values for dogs and other animals as well
- Acceptable and Unacceptable 50/60 Hz contact voltage levels– Based on the 200 ohm wet value and the 1000 ohm dry value, the voltages can be calculated dependent upon the threshold of interest (perception, reaction, startle, fibrillation etc.)

Reference sources for these values: 2,3,4,5,6,7,9,15

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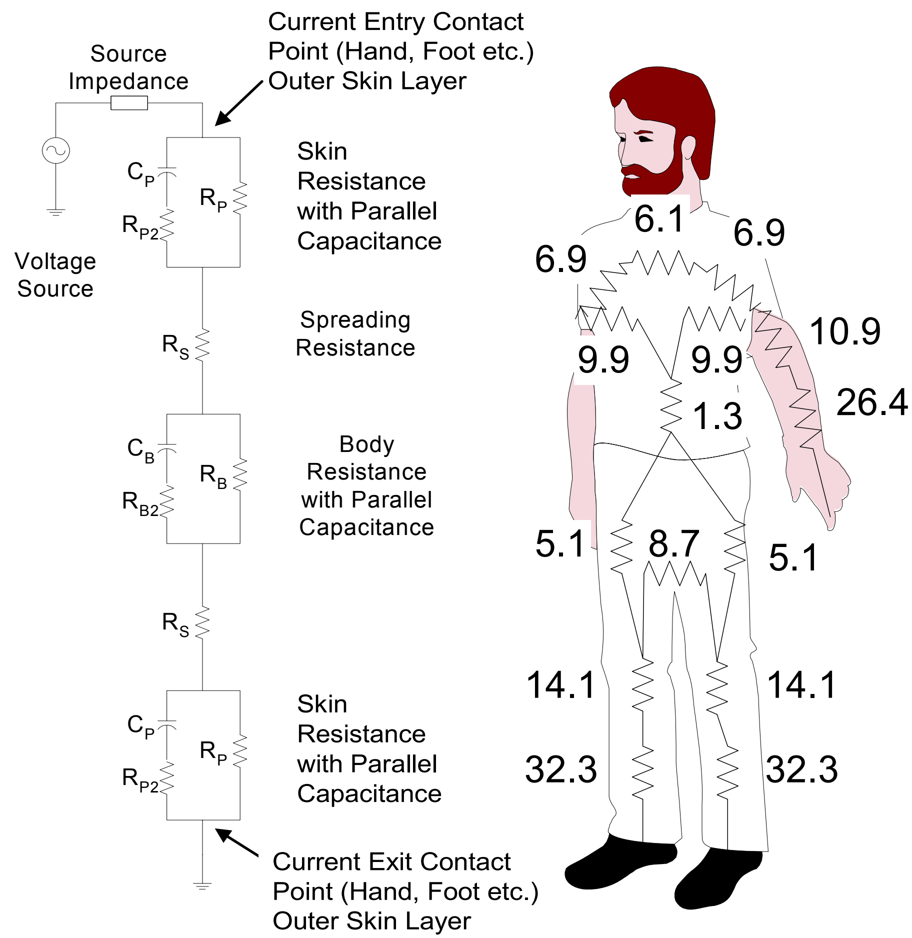
Impedance Parameters Impacting Body Currents

Figures from Sutherland et. al. [15] Table from IEC 60950-1

Touch Voltage	5th percentile		50th percentile		95th percentile	
	Hand-hand	*Hand-foot*	*Hand-hand*	*Hand-foot*	*Hand-hand*	*Hand-foot*
25	1750	1225	3250	2275	6100	4270
50	1450	1015	2625	1838	4375	3063
75	1250	875	2200	1540	3500	2450
100	1200	840	1875	1313	3200	2240
125	1125	788	1625	1138	2875	2013
220	1000	700	1350	945	2125	1488
700	750	525	1100	770	1550	1085
1000	700	490	1050	735	1500	1050
Asymptotic	650	455	750	525	850	595

The 'other' current path impedances such as the external contact medium, (earth, cement, metal, liquids, etc.) and the source impedance are wide ranging variables, they are either omitted or considered as a series addition



Human Body Impedance Components and Path Percentages [15] derived from [6]

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Terminology for Perceptible Currents Humans

Summary of Published Current Thresholds (in mA) For 60 Hz Exposure Source: Sutherland et al. [15]

	Women		Men	
Threshold	0.5% more sensitive than stated value	50% more sensitive and 50% less sensitive	0.5% more sensitive than stated value	50% more sensitive and 50% less sensitive
Perception for Touch	0.07 mA	0.24 mA	0.10 mA	0.36 mA
Perception for Grip	0.28 mA	0.73 mA	0.40 mA	1.10 mA
Startle		2.2 to 3.2 mA		
Let-Go Current	6.0 mA	10.5 mA	9.0 mA	10 mA (adult 68 kg)
Breathing Difficulty (Respiratory Tetanus)		15 mA		23 mA
Respiratory Paralysis				30 mA (adult 68 kg)
Fibrillation - Most conservative -			75 mA (5-second, adult 68 kg)	250 mA (99.5%, 5-second, adult 68 kg)
Heart Paralysis				4,000 mA (adult 68 kg)
Tissue Burning				≥5,000 mA (adult 68 kg)

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Three Reactions to Body Current that are Useful for Level of Concern or Limit Setting

- ***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
- ***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)
- ***Fatalities –*** The level of concern here is "heart fibrillation" or "respiratory paralysis"

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Challenges to Obtaining a Single Value for a Level of Concern or a Limit

- There are differences in the body part impedances for animals as compared to humans
  - Humans may or may not be wearing shoes
  - Cuts and abrasions are significant changes to path Z
- There are differences for the various current paths and the respective amount of “heart current” flow
  - Foot to Foot path yields very little heart current for a human but could be significant for a dog
- There are differences in the actual point to point contact mechanisms (hand to foot, chest to foot etc.) for both wet and dry conditions
- Humans and animal can create more innovative contact scenarios than levels of concern are designed to address

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Existing Publications with Voltage or Current Levels 15 Vac 'Wet' to 60 Vac Dry

Reference Document	Published Level	Concern Category
UL-101 [4]	0.75 milliamps reaction current - 2,000-ohm human body Z.	Reaction Current
UL-60950-1 [8]	42.4 Vac and 60 Vdc is the stated limit under dry conditions and human hand path.	Shock Hazard
IEC 479-1 [9]	25 Vac clearly safe, 50 Vac marginally safe (duration dependent). 1000 ohm body impedance cited	Shock Hazard
OSHA Rule" (29 CFR Part 1910) [10]	Circuits operating above 50 Vac or 50 Vdc.	Shock Hazard
NFPA 70E [11]	30 Vrms or 60 Vdc. 500-ohm wet human body resistance.	Shock Hazard
IEEE Yellow Book – Std. 902-1998 [5]	Currents as low as (10) milliamps and voltages above 50 V can cause fibrillation. 500-ohm minimum body resistance for wet conditions or cuts. 100-500 ohms for immersion (Table 7-2)	Heart Fibrillation
NACE [12]	15 volts.	Shock Hazard
NESC [13]	51 volts.	Shock Hazard
NEC® [14]	Circuits operating above 50 Vac or dc or 15 V for wet areas.	Shock Hazard
IEEE Std 80 [2]	60 Vac for 4 sec. 1000 ohm human body impedance	Shock Hazard

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Comparing Criteria Among the Standards and Publications

- Factors of Safety – *Not the Same*
- Wet vs Dry Objectives – *Not the Same*
- Safety Objectives – *Not the Same*
- Conclusions:
  1. Unless the scenario is identical - Rely on the biophysical data and the condition of interest - and not other published values from existing standards!
  2. Insure that limit objectives are clearly articulated to avoid future misapplication of potential IEEE 1695 information
  3. Documentation in the standards appendices is invaluable in understanding true levels of concern as opposed to levels of concern with built in factors of safety

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Boiling the Criteria Down to a Systematic Process to Develop Levels Of Concern

- The literature provides a large and diverse selection of both voltage and current limits already
- 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
- 13 steps define the methodology as follows:
  - 1. State the application scenario where the limit will be proposed (street-level metallic objects, pools, and spas, and so on)
  - 2. Refer to existing standards (such as Table 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 level of concern objective (aversion, injury, fatality)
  - 4. Define the species where the limit will apply (humans, dogs, or other species)

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Boiling the Criteria Down to a Systematic Process to Develop Levels Of Concern

– 5. Define the contact mode(s) - hand-to-hand, foot-to-hand etc…
– 6. Based on the application scenario (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 body impedance value
– 9. Estimate a 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 to a single worst case and articulate/document any factors of safety that have been considered
– 12. Calculate the voltage limit(s) that apply to the contact scenario and the species based on the current threshold and the impedance value(s).
– 13. Define the appropriate measurement protocol for the limit(s)

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Application Example for a Swimming Pool

- **<u>Step 1</u>** - State the condition where the limit will be proposed
- For this case, the condition where the limit applies is the immediate area surrounding the pool or spa water, within touch or step distance.

- To minimize step and touch distance, If a conductive pole is used for the skimming net, it should be replaced with fiberglass or plastic

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Step 2 – Refer to Existing Standards to Find Any "Similar Reference Scenario"

- Reviewing the standards summary table, 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
- 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
- NACE has a 15 Vac limit for gas pipelines most likely assuming the workers may be exposed to voltage conditions in a wet muddy trench
- It is not clear if the 15Vac values do or don't have a 2x factor of safety

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Step 3 – If Existing Standards Do Not Apply, Then Define the Level of Concern Objective

- Our 'objective' options are: Aversion, Injury, and Fatality
- In the swimming pool example NEC® 680 and IEEE 902 and the NACE document are useful for understanding the contact scenario under wet conditions
- They don't necessarily address the particular objective for this scenario which is **'aversion'** due to 'perception'
- The perception is 'nuisance shocking' or a so called 'tingling sensation' causing persons to be afraid to get back into the water

	Women		**Men**	
Threshold	0.5% more sensitive than stated value	50% more sensitive and 50% less sensitive	0.5% more sensitive than stated value	50% more sensitive and 50% less sensitive
Perception for Touch	0.07 mA	0.24 mA	0.10 mA	0.36 mA
Perception for Grip	0.28 mA	0.73 mA	0.40 mA	1.10 mA
Startle		2.2 to 3.2 mA		

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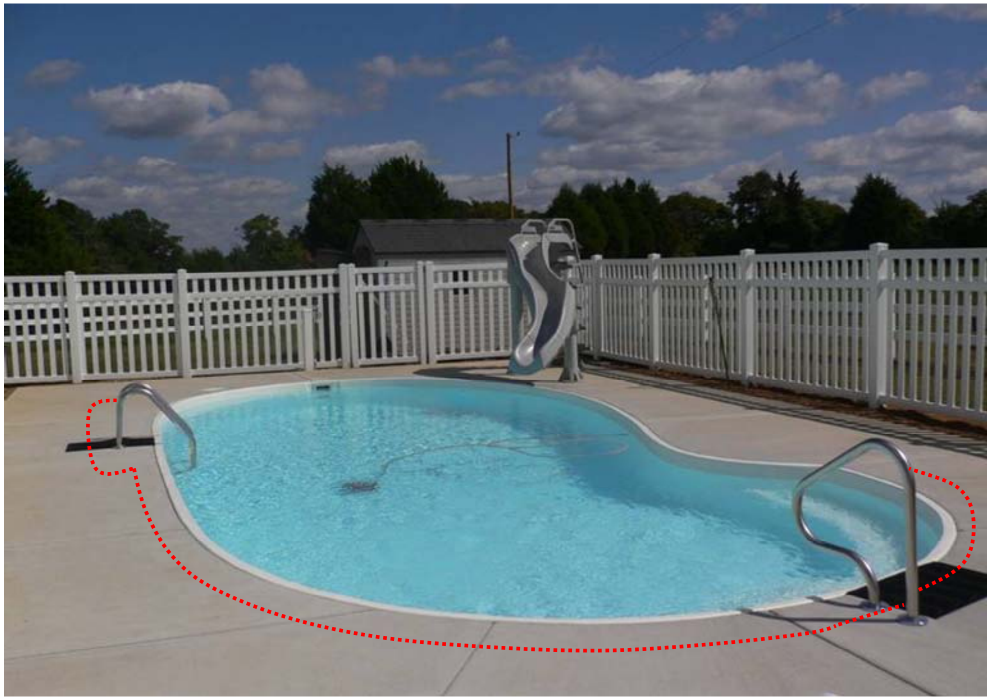
Step 5 – Define the Contact Mode(s) Such as Hand-to-Hand, Foot-to-Hand, and So On

- For swimming pool aversion scenario, the contact mode(s) can be:
  - Upper arm to hand" – for a person reaching out of water
  - Torso to lower leg or calf – for a person sitting on deck with feet in the water
  - Chest to hand(s) – for a person in the process of exiting the water via a non-immersed metallic handrail
  - Hand to foot – for a person standing in a puddle of water 'poolside' and touching an immersed hand rail



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Step 6 – Based on the Application (Pools and Spas) 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 *generally* does not exceed 10 Vac
- This voltage value will be important when considering the body path impedance because the outer layer skin resistance (and subsequent total body impedance) changes with the applied voltage

Touch Voltage	5th percentile		50th percentile		95th percentile	
	Hand-hand	*Hand-foot*	*Hand-hand*	*Hand-foot*	*Hand-hand*	*Hand-foot*
25	1750	1225	3250	2275	6100	4270
50	1450	1015	2625	1838	4375	3063
75	1250	875	2200	1540	3500	2450
100	1200	840	1875	1313	3200	2240
125	1125	788	1625	1138	2875	2013
220	1000	700	1350	945	2125	1488
700	750	525	1100	770	1550	1085
1000	700	490	1050	735	1500	1050
Asymptotic	650	455	750	525	850	595

Adult total body impedance including skin resistance - Source IEC 60950-1

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Step 7 – Estimate a Minimum Body impedance based on Contact Mode(s) and Worst Case Voltage

- Under this scenario, The IEC table would suggest rougly 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 would be realistically reduced to 500 ohms or perhaps less!

Touch Voltage	5th percentile		50th percentile		95th percentile	
	Hand-hand	*Hand-foot*	*Hand-hand*	*Hand-foot*	*Hand-hand*	*Hand-foot*
25	1750	1225	3250	2275	6100	4270
50	1450	1015	2625	1838	4375	3063
75	1250	875	2200	1540	3500	2450
100	1200	840	1875	1313	3200	2240

Adult total body impedance including skin resistance - Source IEC 60950-1

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Step 8 – Consider How Wet/Dry Conditions Might Warrant Raising or Lowering the Impedance Value

- The impedance values need to be factored for wet conditions and:
  - Very minimal body resistance
  - Current paths such as hand to chest (when exiting the pool via a non-immersed handrail)
  - torso to foot or calf (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 a body current path impedance as low as 200 ohms

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Step 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 (very small resistance)
  - Through the body path (a few hundred ohms)
  - Back through the cement deck and the earth (a few thousand ohms skin to cement) and
  - Back through the grounding electrodes (20 to several hundred ohms)
- The minimum full circuit path impedance would be the sum of all of these and is most likely in the 2000 to 2500 ohm range.

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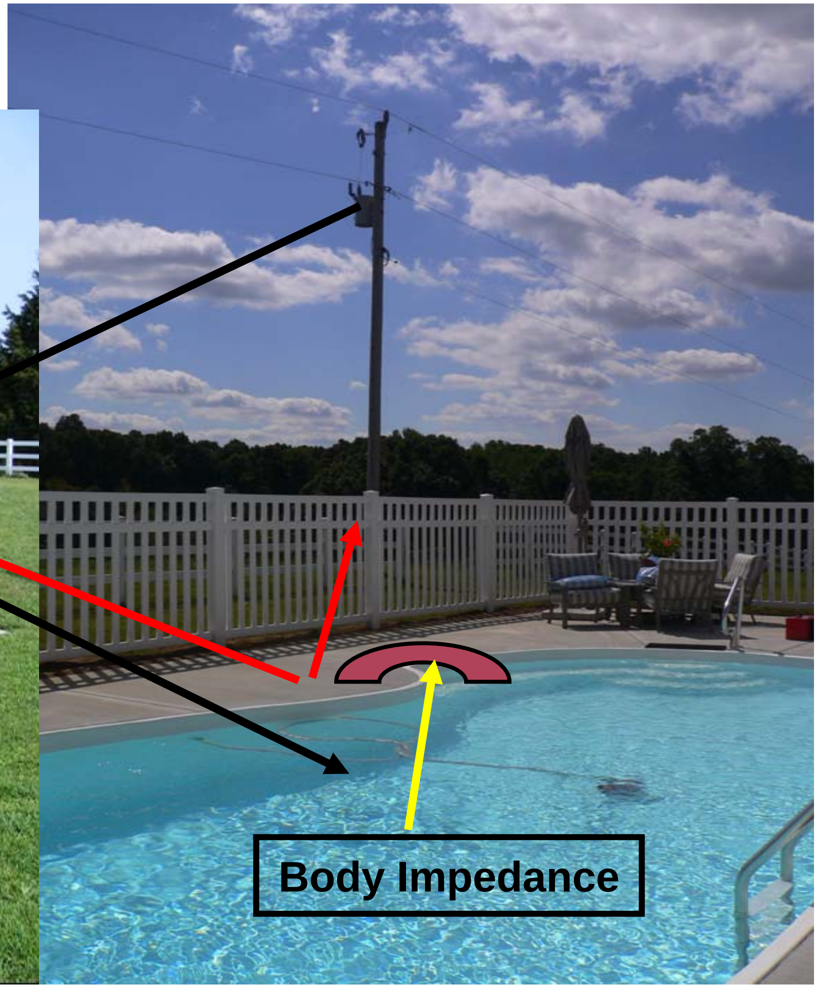
Step 9 – Estimate the Complete Circuit Current Path Impedance Value

Primary neutral to pool water light should be just a few ohms

In 'unbonded' situations
Cement decking to the ground rods <u>may</u> be a few hundred ohms

Surface area of skin contact to cement is the 'big Z factor'



Step 10 – Define Current Threshold Based on the Objective (3) Contact Scenario (5) and Impedance (9)

- Based on the **'aversion'** objective (3) and
- Considering the contact scenario(s), (5) where worst case is just a few hundred ohms and full path is impedance (9) is a few thousand ohms
- The currents that 'arbitrarily' cause perceptible complaints are can be between 0.5 mA and 5.0 mA depending upon whether it is a sensitive adult or child
- Because actual perception thresholds vary so greatly amongst the population and are different for adult males, adult females and children, low end of the current range may imply perception for only a small percentage of humans

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Step 11 – Select a Single Worst Case Current Threshold

- 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
- For the pool and spa application, 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, adding a factor of safety is not applicable for this application and this fact should be noted in the supporting literature

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Step 12 – Calculate the Voltage Limit(s) That Apply to the Contact Scenario and the Species

- This calculation is based on the current threshold(s) and the impedance value(s) using ohm's law (V = I x R)
- The applicable voltage level that applies to the contact scenario and to the human species would yield a minimum voltage level of perception at 1.0 to 1.25 volts were R is 2,000 to 2,500 ohms and I is 0.0005 amps.
- This may explain why some children and female adults have been known to perceive (and complain) about voltage levels in this very range
- Note that it is a fairly small percentage of the complaints that result from voltages this low

Disclaimer – 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 would require industry expert consensus and field validation!

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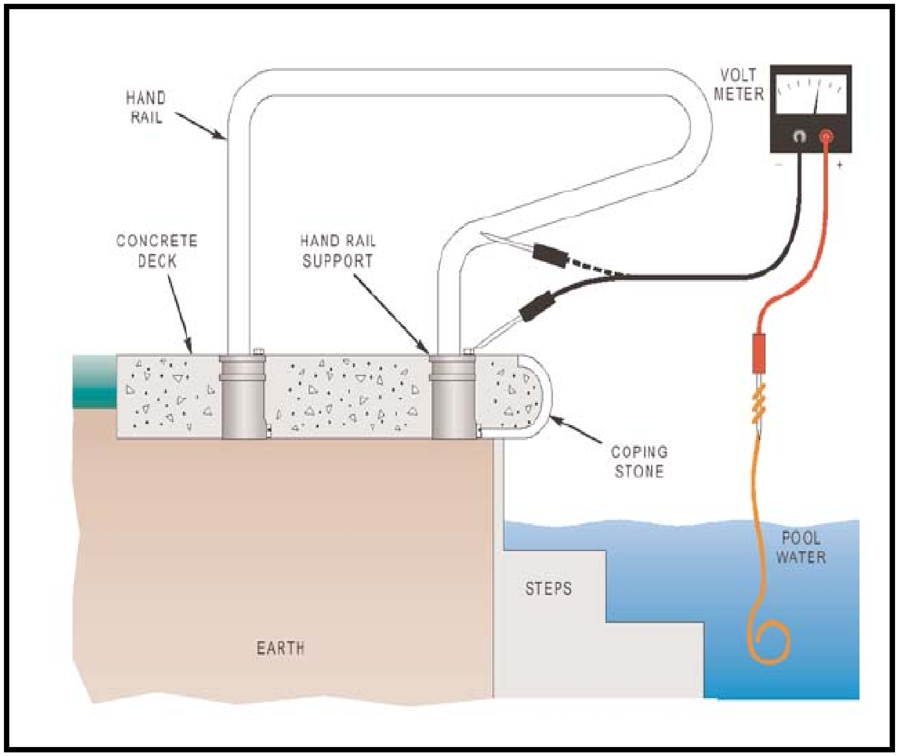
Step 13 – Define the Appropriate Measurement Protocol for the LOC

- The appropriate measurement protocol for the applicable voltage level is a typical residential shocking complaint investigation procedure
- In this case,a high impedance true rms meter is used to measure the ac voltage between the pool water and various contact points within step and reach distance of the water
- The investigator may also consider using a load resistor of 2000 ohms to evaluate the currents that may be flowing through the body path



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Final Comments and Recommendations

- This process is an adaptation of the basic process used to establish the limits found in existing standards
- 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)

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