Swimming Pool Stray and Contact Voltage Research Outcomes

Electric Power Research Institute

Note: This document is a draft for review and EPRI is soliciting subject matter expert input. EPRI intends to finalize it before year end 2018 – once the SMEs have provided input.

2018 testing by EPRI has determined that nuisance tingling sensations for swimming pool users are precursors to a swimming pool that could become an unsafe shock hazard during 120Vac household line faults. To understand this phenomenon from a scientific basis, EPRI has tested the different types of in-ground pool shell designs to include both the conductive types and the non-conductive types.

The primary objectives of the testing were to understand:

1. How and why voltage gets to the pool water and to the conductive metal parts around the pool
2. Why equipotential bonding between the pool deck and any of the other bonded parts and the water is so challenging
3. Which pool types are at the greatest risk of becoming electrically unsafe

The testing results provide for an industry that is better informed and able to develop recommendations to promote effective electrical safety in pool environments. This knowledge is beneficial for pool installers and pool owners. The recommendations will promote a safer electrical environment for new pools and for existing pools that exhibit signs of being electrically unsafe.

1.0 Overall Findings:

The remainder of this document will provide the fact-based science necessary to support these conclusions, but for the purposes of summary, the key findings applicable to all in-ground pool types were:

- Uncleared electrical faults from 120/240 Vac residential service, 208Y/120 Vac or 240/120 Vac or 480Y/277 Vac commercial services as well as any higher voltage AC distribution services *can all create unsafe voltage levels* on metal parts and conductive surfaces in the pool area.
- Missing bonding or inadequate bonding around the pool perimeter decking surface allows unsafe levels of current to flow through humans and animals during uncleared electrical faults and equipotential applications are necessary to bring the deck, the water, and all other conductive parts to the same voltage simultaneously.
- The NEC 680.26 – 2005 compliant installation using an equipotential grid creates a safe zone on the deck surface. During electrical fault events, the equipotential grid enables all of the energized parts to float together safely at the same voltage potential. Note that the (safe zone) only applies to the surfaces immediately above the gridded mesh and therefore surfaces outside the gridded mesh perimeter are not made safe.
- The NEC 680.26 – 2017 alternate means using a single bare copper wire does not adequately bond the (deck or the earth) to the other conductive parts and therefore no equipotential surface and no (safe zone) is achievable on top of the single bare copper wire.
- With a properly installed equipotential grid, pool users and installers can be confident that the deck and the water and all conductive parts will (elevate together during faults and will drop together during normal conditions), leaving no opportunities for an unsafe voltage differential.

2.0 How and why do faults and corresponding voltages get coupled to the pool area?

This particular topic can be best understood with a visual as shown in the following Figure:

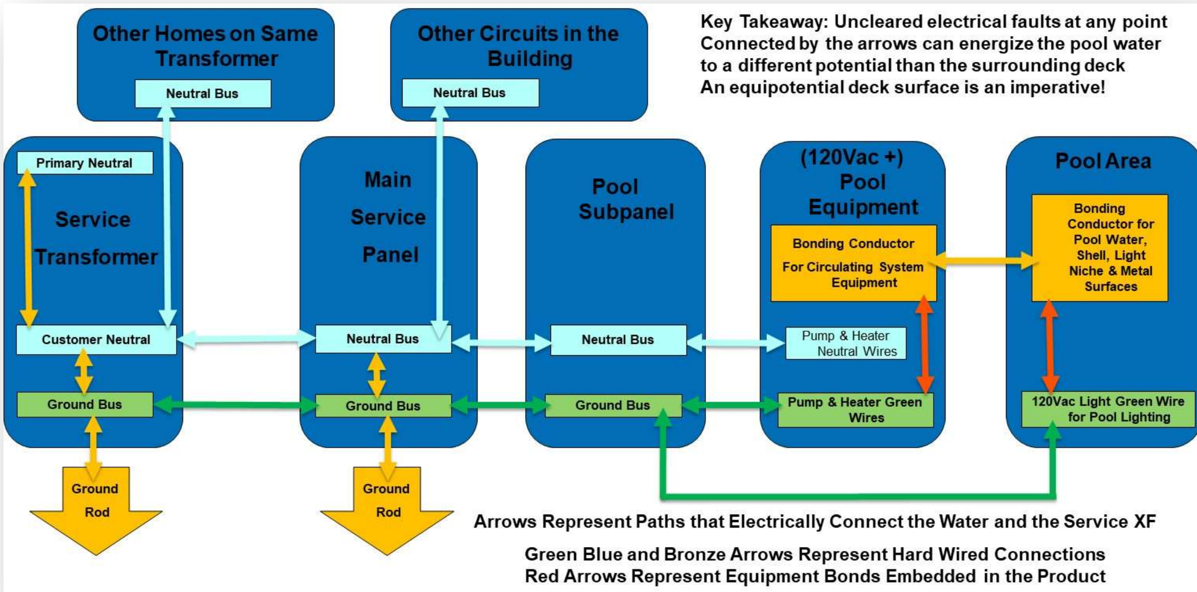


Figure 1. Simplified Connectivity Path between Water and Service Transformer

Referring to the Figure 1, it is visually apparent that every block connected by the colored arrows has been either (intentionally or unintentionally) electrically bonded or interconnected. This includes the neutral system, the safety grounding system and all of the equipment and parts in the pool area and supporting the water circulating system. If this seems hard to believe, confirm it by taking an electric resistance or ohm meter reading between a neutral receptacle in a household bedroom or bathroom and connect the other lead to one of the bonded metal parts at the home's swimming pool. The meter should measure less than one ohm of impedance (resistance) – which is an indication of a continuous connection between them. This effectively means a fault condition anywhere in the home, at a neighbor's home or on the utility side can all generate elevated voltage levels on the neutral system and subsequently on bonded pool water.

There are three fundamental principles of electricity that allow the fault voltage to couple to the pool water – but not couple to the surrounding dirt (earth) as follows:

1. **Interconnection –** A voltage impressed on any metal (conductive) part will also be impressed on every other element that is bonded to that part. Figure one depicts this idea where every arrow interconnects to the rest of the arrows and allows a fault voltage at any node in the system to appear at all of the other nodes.
2. **Bonded Parts –** Relative to the water in a swimming pool, the NEC requires connecting (or bonding) of all conductive parts around the pool including the rebar if applicable, the handrails and so on. Since in-ground pools need a water circulation system, the *bonded parts* at the pool area are then bonded to the pump and any other applicable 120V equipment such as lights and heaters. The bonding then extends or interconnects with the safety green wires for these 120V appliances and those green wires extend back to the electric subpanel – which has bonds and green wires that extend to the main service and these extend out to the service transformer. This is represented more fully in Figure 1.

3. **Voltage Differences –** To broadly summarize the issue, we bond all the conductive parts together to eliminate static charge - to eliminate touch potentials between the metal parts and the pool water – and to earth or ground them all. By doing so, we inadvertently invite fault voltages and (neutral voltage drop from load currents i.e. voltage drop = load current - times – wire impedance) over to the pool water through the interconnection to the green wires and bonding conductors that we are using for the protection (again refer to Figure 1). Since we cannot (effectively) bond the conductive parts to the dirt or earth around the pool, we end up with a *voltage difference* and shock hazard (during uncleared electrical faults) unless we are standing on some type of equipotential surface.

With a better understanding of Figure 1, and of how interconnection and bonding actually couple voltages to the pool area, we can envision many scenarios where the pool water gets energized. One of the more common scenarios is when the underwater light retaining ring energizes the water because that underwater light ring is electrically connected and electrically bonded to the safety green wire that ultimately goes all the way back to the service panel. For older conductive shell pools, we see complaints where swimmers feel tingling in their bodies while fully immersed in the water near the underwater light and for non-conductive shells, the complaint is for swimmers simultaneously in contact with the deck and the water. Since these nuisance tingling sensations are the precursor to more significant shock hazards, this is precisely why one of the recommended practices is to use two conductor LED lighting instead of the more dangerous (120 Vac lighting and wiring) and where possible to remove it from older pools.

3.0 Why is it so Difficult to Bond the Pool Deck?

Simply put, dirt and soil are not bondable because they are not solid materials. Further concrete and pavers are not bondable in the way metal conductive parts are. In fact, about the best we can practically achieve is a connection that is between 1/100th and 1/1000th as good as the bonding we get between metal parts. This is why the rods and grids we use for earthing the power system are called grounding rods and grounding mats as opposed to being called bonding rods or bonding mats. Typical rod and grid resistances between the metal and the earth range from an average value of about 100 ohms to a best case for a really well grounded substation copper grid at about five ohms. To be clear, (we can earth or ground) our electrical systems and get good static charge dissipation, but we can't effectively bond the system to the earth.

What's the solution: The simple solution is to replicate what is done at power substations. Whereby a (zone of protection) is created on the earth surface where personnel will be walking around and touching equipment. This is done with a conductive metal grid in the earth beneath all areas where humans require safe step and touch potentials. The implementation requires bonding of the metal grid to the other conductive elements and create a (zone of protection) on the surfaces above the metal grid. It should be noted that the deeper the grid is buried beneath the surface, the less effective it becomes, so embedding the grid in the decking materials is desirable for both performance and for corrosion longevity.

4.0 Which pool types are at the greatest risk of becoming electrically unsafe

To be very clear, any in-ground swimming pool – when properly constructed with an equipotential deck and properly bonded parts will be an electrically safe pool for many-many years. The specific pool installations where a concern exists include every pool that has required a shock or perception investigation in the past and in general any pool that has been constructed without an equipotential grid in the deck area.

To be unbiased in representing this concern, this shock issue with electrical safety at these unsafe pools is generally limited to a dozen or fewer incidents per year and only when fault events occur. The greatest practical risk is with uncleared faults. These are faults which can persist for hours or longer that could pose a safety hazard at an at risk pool. EPRI's best estimate of the number of these uncleared faults is about 100 per year on average throughout North America. We don't have good data on the number of times per year a fault persists on the customer side or how many time per year a customer has a miswiring or a lost neutral problem, but those averages would be additive to the 100 per year on the power system side to better gauge the risk.

Finally with regard to conductive vs non-conductive in ground pools, early research done by EPRI was focused on vinyl and fiberglass lined pools because those were the predominant pools where shock complaints were being investigated, but recent testing has found that it doesn't matter which pool type – and that all in-ground pool types can become electrically unsafe. Given the same conditions, non-conductive pools will typically be more prone to shocks between the water and the surrounding deck while conductive pools will be prone to both those incidences as well as scenarios where a current can flow through the water and incapacitate a swimmer fully immersed in the water. The full results can be found in the Appendix of this document.

5.0 Detailed Results

Between September 2010 and July 2018 EPRI has conducted a plethora of tests at in ground swimming pool to understand shock and perception concerns with greater technical basis.

The tests conducted provide results for three scenarios as follows:

- Baseline Results – Before any equipotential bonding means have been installed
- Single #8 Solid Bare Copper Ring Results – Where the ring is installed per NEC Article 680.26 specifications.
- Equipotential Grid (#8 Solid Bare Copper) – Where grid is constructed and installed per NEC Article 680.26 specifications.

Key Findings:

1. The overall results of these comprehensive EPRI tests show that electrical <u>*faults from customer side service voltages (120/240) produced unsafe levels of current through humans.*</u> *The two unsafe conditions include scenarios when they are* standing on a wet pool area deck and/or when they are simultaneously contacting the decking and water.
2. Installing the NEC compliant Solid Bare Copper ring did not reduce the voltage gradient or the currents through the human body to safe levels. The single ring is unsafe during customer faults and within the three-foot perimeter around the pool shell, we measured between 35 and 50 milliamps (mA) of current through the load resistors.
3. Installing a Copper Equipotential Grid per the Article 680.26 specifications does reduce the voltage gradient and reduces the corresponding body currents to safe levels. The copper equipotential grid provides a safe equipotential surface during customer faults as we measured less than 5mA of current through the load resistors everywhere within the 3 foot perimeter of interest.
4. To put these current levels into perspective, the consensus from IEEE yellow book, UL, EPRI and IEEE 1695 publications consider 5mA as a safe let go threshold, 10mA as muscle contraction lock up threshold where injury or drowning could occur, 35mA as a fibrillation threshold of concern for children and 70mA as a fibrillation threshold of concern for adults.

Test Detail: The following figure color codes the test results for the conductive and non-conductive pool shell types and the different equipotential bonding means. The interpretation of the results is based on current levels measure through a load resistor. This enables better definition of safe vs unsafe vs lethal conditions. The results are as follows.

- Areas colored green indicated a safe equipotential condition under all test conditions and at all voltage levels tested. This means the current levels measured through the load resistors never exceeded 5mA

- Areas colored red indicate shock levels that are unsafe. Meaning they would could cause muscle lock-up or heart fibrillation for swimmers (when they are in the water and simultaneously contacting the red deck areas). As a point of reference, with 120Vac faults, the measured currents between the water and the deck were ranging from 35 to 50mA in the red areas (with the bonding ring and were as high as 160mA without the bonding ring
- Areas colored orange or dark orange indicate shock levels that are unsafe but more likely to cause injury as opposed to complete heart fibrillation. These measurements during 120 Vac faults ranged from 10-35 mA.
- The greenish yellow dashed lines indicate the pool deck perimeter zone area at 3 ft from the inner pool shell. This is the zone of interest where it is desirable to always keep the current levels within the green color or less than 5mA.
- The simple conclusion is the equipotential grid is the only safe option under residential 120Vac fault conditions

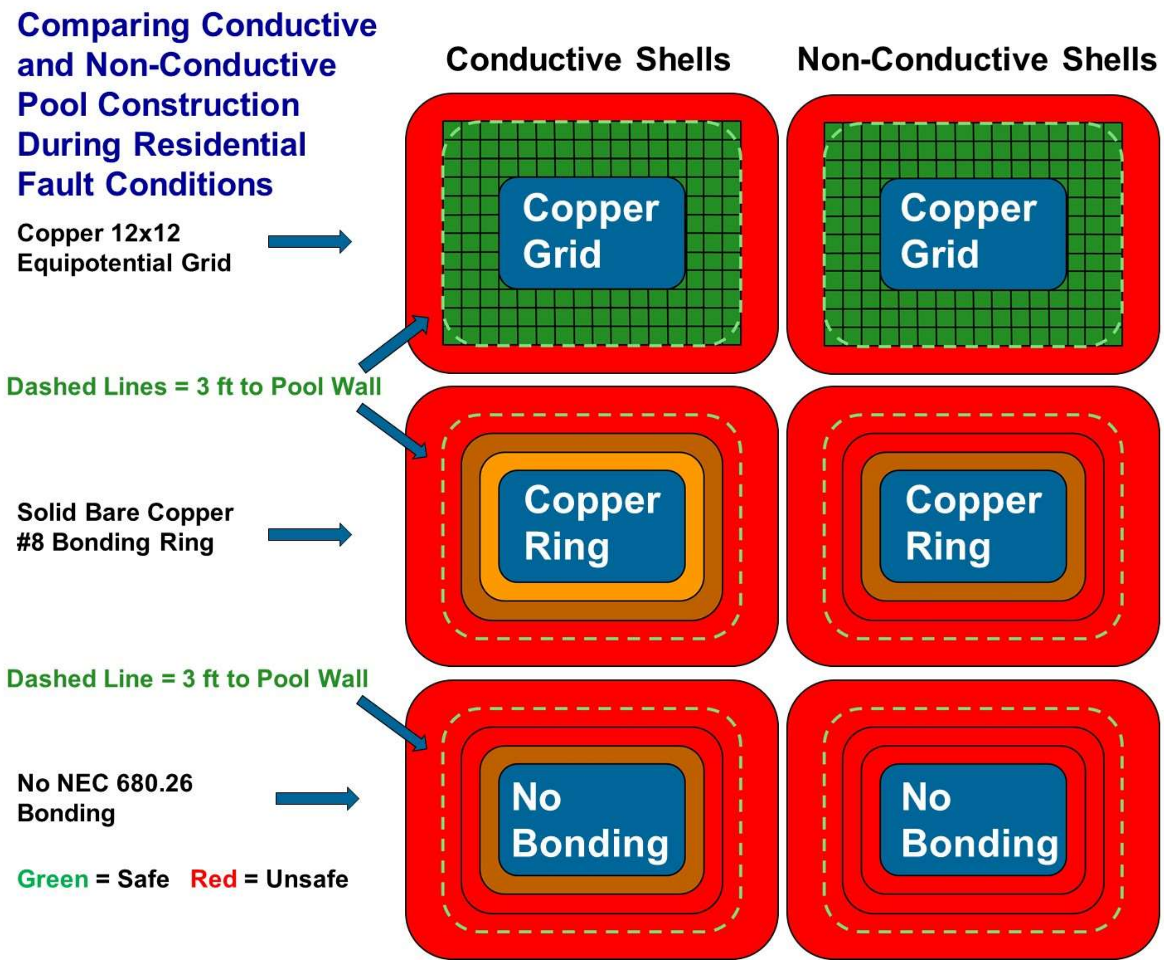


Figure 2. Summary of EPRI Test Data from 2010 to 2018 Comparing Deck Equipotential Options.

As previously stated, public comment is being solicited on these test results through October 15th 2018. At that point a final document will be finalized and posted on the http://strayvoltage.epri.com website. Comments should be directed to ddorr@epri.com

Appendix A:

This appendix describes the test setups and summarizes the measurement results from the compendium of In-Ground Pool testing conducted by EPRI. The test procedure was vetted with a team of subject matter experts that regularly conduct test and measurement assessments at in-ground swimming pools. Nationally recognized test labs and others skilled in the art of testing will appreciate that this testing is defensible to best practices for test and measurement and will recognize that many of the tests one would normally do in a stray/contact voltage investigation (such as determining a source and verifying the voltage is real and not a static reading) were not necessary here - as we are dealing with known sources and know electrical configurations at test structures. Thus the following assumptions will be verified and then used for the data collected for the test record:

Wet vs Dry Conditions - It is always assumed that wet conditions create greater current flows through a human or an animal than dry conditions. Therefore, for the test record, we first verified the assumption by doing the testing with both wet and dry conditions. The key takeaway: as expected the wet conditions were the worst case.

Load Resistors and Human Body Current Equivalents – For comprehensive testing we evaluated the effects of different values of load resistors in the circuit to understand how they impact measured voltages. The load resistors are useful to determine currents through the body and convert the voltage readings to the more important criteria of body currents through the heart and chest path as well as through the muscle areas. The key takeaway: a 200 ohm load resistor is appropriate for representing a human submerged in a salt water pool with just the arms reaching out onto the decking and a 500 ohm load resistor is appropriate for other conditions such as a human lying on the wet deck with their calves and feet in the water.

Voltage Levels – to verify the assumption that voltages will be linear and consistent, all tests were done with a minimum of three voltage levels. The results were indeed linear - meaning the data can confidently be converted or extrapolated to any other higher or lower fault voltage levels of interest.

Measurement Plates – We did find variations in the voltage levels depending on the size of the deck measurement plate and whether or not salt water was used to wet the plate. The key takeaway is that a minimum plate size of 48 square inches should be used as that is similar to the surface area of a human's hands and forearms. IEEE 1695 -2016 recommends wetting the plate with salt water as the results become more consistent and repeatable that way.

Water Chemistry – The testing clearly shows that salt water pools are more conductive than other chemical compositions. When replicating the tests, it is not necessary to use salt water in the pool, but it is useful to wet the plates with a salt water solution.

Overview

The objective of the testing was to compare the different equipotential bonding options described in NEC article 680.26 and to evaluate how each one performs, relative to one another as well as compared to the case where no equipotential surface is present. These three conditions evaluated include:

- Configuration with just subgrade material and no equipotential ring or grid to get the baseline values.
- Configuration where an NEC 680.26 - 2017 code compliant equipotential bonding ring is used
- Configuration where an NEC 680.26 -2015 code compliant equipotential bonding grid is used

For each configuration a voltage is applied to the equipotential bonding system. This applied voltage is representative of an uncleared power system fault (meaning the breaker at the facility service or subpanel did not open or the GFCI did not operate). Once the bonding infrastructure is energized a measurement is recorded to document the difference in voltage between the perimeter bonding infrastructure and the pool decking area. If the equipotential bonding beneath the pool deck is adequate, then the voltage measured between the subgrade, the deck surface, any of the other bonded elements should be less than one tenth of a volt ac, regardless of the applied voltage level. Depending on the meter being used the noise floor may be two or three tenths of a volt ac, so it is important to touch the measurement leads together and use the meter's noise floor as the baseline and not blindly apply the one tenth volt as the pass fail criteria.

To confirm that equipotential performance is adequate regardless of applied voltage, the tests also consider three different voltage levels applied to the bonding infrastructure. Finally, to verify that the equipotential is maintained throughout the deck areas, the measurements taken are inclusive of (the deck area at different distances) from the pool perimeter (inner wall).

The basic measurement circuit is shown in Figure 3. However, one may want to assess and understand any impacts the water chemistry or the decking materials have on the optimal performance of the bonding network. To understand these variables and their potential to impact the measurements, the tests can be done before the pool is filled with water and repeated again, after the pool is filled with water. Further it is useful to repeat the tests before the surface decking material is laid and test again after the decking is laid. This should provide the optimal equipotential performance results for all test conditions of interest and will promote repeatability if others desire to replicate these results.

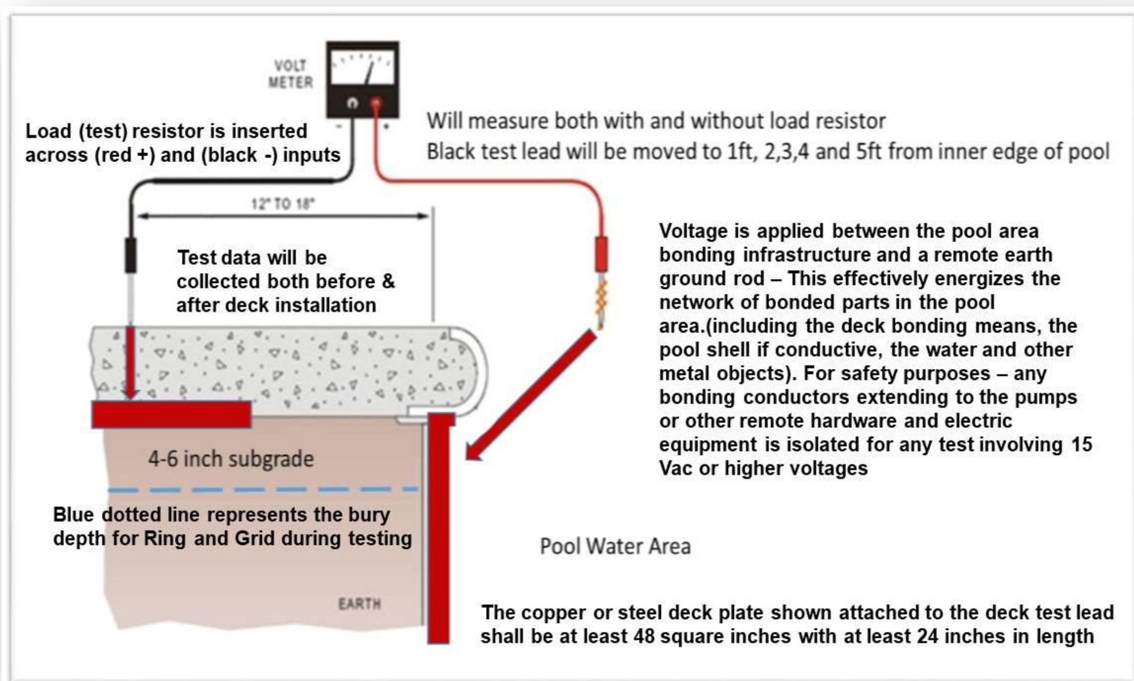


Figure 3. Basic Test and Measurement Configuration for the Conductive Pool Construction.

Supporting Background:

To reduce voltage gradients in and around swimming pools, the National Electric Code Article 680.26 requires equipotential bonding for all conductive parts as well as for the deck areas immediately surrounding the pool perimeter. The intent of the equipotential bonding is not to eliminate the voltage gradients – but rather to cause everything within the pool and the surrounding perimeter and decking to elevate together (at or near) the same voltage levels.

A Distinction Between the Terms Grounded and Bonded – Since the pool is in contact with the earth and the all of the bonding conductors and surfaces are all in contact with the earth, the system is naturally earthed or grounded – however, it is important to recognize that grounding only helps to keep static voltages from building up between conductive parts but the grounding does not provide any type of equipotential bonding. In fact, ships and airplanes provide excellent examples of why the equipotential bonding performance does not rely at all on any grounding means or connections to earth.

Expected Results – Since we are aspiring to evaluate equipotential in these tests, the way to consider successful outcomes is as follows:

- Lower voltage numbers equate to better equipotential performance
- By using a load resistor to represent a human body path we can determine the level of current expected and distinguish between safe and unsafe outcomes for each test configuration.
- By using multiple test voltages and proving the results are linear – anyone skilled in the area will be able to convert the results to any other voltage level and expected body currents may be derived.

In other words, the lower the measured voltage difference between the bonded pool infrastructure and the deck area, the better the equipotential performance. If the equipotential bonding below the pool deck is adequate, then the voltage measured between the subgrade any of the other bonded elements should be less than one tenth of a volt ac, regardless of the applied voltage level.

About the Tests – The testing will be designed for consistency and repeatability such that anyone desiring to replicate the results at other pool structures can do so and should expect extremely similar if not identical outcomes and conclusions – while keeping in mind soil composition, water chemistry, decking type, wetness of the test area, size of the deck measurement plate and bury depth of the bonding elements will all shift the baseline levels up or down slightly – but the shift shouldn't impact the overall linearity or applicability of the results.

To eliminate the possibility of the (deck surface material) skewing the results one way or the other, one of the test leads shall measure *the surface of the subgrade* (upon which the final deck materials would be poured or laid. To make this measurement connection, a conductive, metal plate of copper, stainless steel or other steel material (at least 48 square inches in surface area) and at least 24 inches long shall be placed on top of the subgrade. This steel plate shall be referred to as the deck measurement point. The steel plate shall be centered at the test distances meaning at the 24 inch distance the plate will be placed 23 inches away and extend to 25 inches away from the pool wall, with the long distance of the plate parallel to the pool wall. The test will be repeated with three voltage levels. The tests will again be replicated once the final deck surface is installed.

To eliminate the possibility of (water chemistry) skewing the results one way or the other, the second test lead shall connect directly or indirectly through a bonding conductor extension, to one of the #8 solid copper pigtails that are bonded to the rebar and encased in the Gunite shell. To further eliminate any skewing, all testing is to be conducted before (and then again after) the pool is filled with water. This second test lead shall be referred to as the (bonded parts measurement point).

Measurement Protocol – Referring back to figure one as a reference, the following test procedure shall be used:

1.) Connect the voltage source hot lead to the bonding infrastructure of the pool and connect the voltage source neutral lead to a remote earth ground rod (driven at least 40 feet away from the pool perimeter).
2.) Energize the voltage source and apply 120Vac to the bonding infrastructure in the pool.
3.) Verify with a voltmeter that the applied voltage is present between the remote earth ground rod and various bonded elements in the pool area (rebar or pigtails, bonding ring and any other exposed metal parts).
4.) Connect the leads to the measurement points as shown in Figure One.

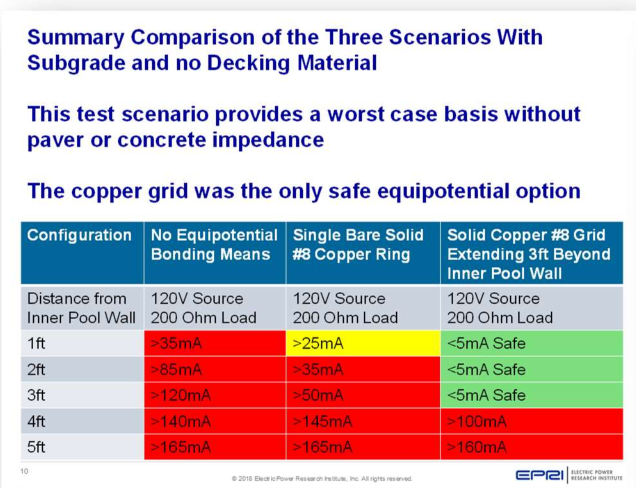
5.) Record the measured voltages with the deck measurement point lead placed approximately (one foot away) from the pool perimeter and repeat the process at 2,3,4 and 5 feet distance away from the pool perimeter. Record the (open circuit voltage or V_{OC}) measurements with the designation V_{OC} -1ft, V_{OC} -2ft, etc.
6.) Repeat step five with a 500ohm resistor placed across the meter leads. Record the measurements with the designation V_{500}-1ft, V_{500}-2ft, etc.
7.) Repeat step five with a 200ohm resistor placed across the meter leads. Record the measurements with the designation V_{200}-1ft, V_{200}-2ft, etc.
8.) Repeat step five with a 1000 ohm resistor placed across the meter leads. Record the measurements with the designation V_{1000}-1ft, V_{1000}-2ft, etc.
9.) Repeat steps one to eight with a second voltage – such as half or twice the original test voltage
10.) Repeat steps one to eight with a third voltage – such as 25% of the original test voltage

This same test procedure is repeated for the following three configurations:

a.) Baseline: With plain subgrade around the pool and no equipotential bonding ring or grid
b.) With the NEC Article 680.26 compliant equipotential ring
c.) With the NEC Article 680.26 compliant supplemental copper equipotential grid

Results:

Test Condition A – Sample of the Baseline Data – Voltage Differences between pool shell to wet soil at various distances from shell - No equipotential bonding means installed								
Applied Voltage	Measured Surface Gradient	Distance from Pool Inner Perimeter (water edge)						
		1ft	2ft	3ft	4ft	5ft	10ft	100ft
111Vac – (11.3 amps)	V_{OC}	11Vac	24Vac	36Vac	47Vac	52Vac	78Vac	111Vac
	V_R	9Vac	21Vac	33Vac	44Vac	47Vac		105Vac


Summary Comparison of the Three Scenarios With Subgrade and no Decking Material

This test scenario provides a worst case basis without paver or concrete impedance

The copper grid was the only safe equipotential option

Configuration	No Equipotential Bonding Means	Single Bare Solid #8 Copper Ring	Solid Copper #8 Grid Extending 3ft Beyond Inner Pool Wall
Distance from Inner Pool Wall	120V Source 200 Ohm Load	120V Source 200 Ohm Load	120V Source 200 Ohm Load
1ft	>35mA	>25mA	<5mA Safe
2ft	>85mA	>35mA	<5mA Safe
3ft	>120mA	>50mA	<5mA Safe
4ft	>140mA	>145mA	>100mA
5ft	>165mA	>165mA	>160mA

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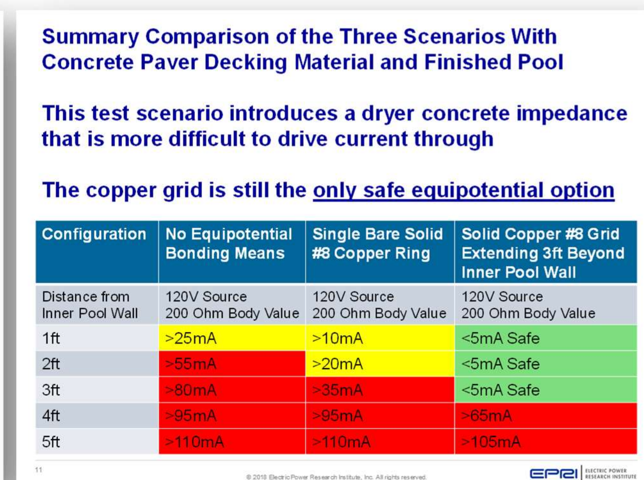
Summary Comparison of the Three Scenarios With Concrete Paver Decking Material and Finished Pool

This test scenario introduces a dryer concrete impedance that is more difficult to drive current through

The copper grid is still the only safe equipotential option

Configuration	No Equipotential Bonding Means	Single Bare Solid #8 Copper Ring	Solid Copper #8 Grid Extending 3ft Beyond Inner Pool Wall
Distance from Inner Pool Wall	120V Source 200 Ohm Body Value	120V Source 200 Ohm Body Value	120V Source 200 Ohm Body Value
1ft	>25mA	>10mA	<5mA Safe
2ft	>55mA	>20mA	<5mA Safe
3ft	>80mA	>35mA	<5mA Safe
4ft	>95mA	>95mA	>65mA
5ft	>110mA	>110mA	>105mA

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Figure 4. Summary Tables with Configuration Results and Current Measurements

Recommendation and Next Steps:

EPRI will facilitate a public testing and education session on this topic at their Lenox MA test facility on October 16th and 17th 2018. This is a public event that requires pre-registration on EPRI events site at: http://www.cvent.com/d/AmhDi1hbKEaiT2Mifz2AFA/snh9/P1/1Q?