

Session One:

Electrical Workplace Safety - Seven Electrical Safety Habits

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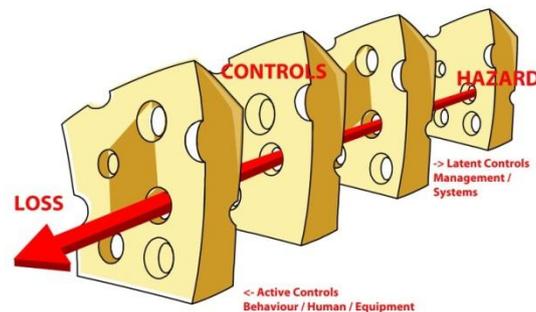
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Introduction

Accidents are generally not a simple one person, one error and one harm event. In the book titled Human Error [1], the author references a Swiss Cheese Model as shown in Picture 1. The literature claims that several controls have the ability to eliminate or substantially reduce loss or harm. Achieving these controls with the level of comprehensiveness to totally prevent an incident is the challenge.



Picture 1: The Swiss Cheese Model for Loss¹

After having investigated more than 150 electrical safety incidents, the root causes have offered a representative database to the team at e-Hazard. Hugh Hoagland, senior partner at the company was able to combine data from standards, best practices and investigations in order to formulate the key *loss of control* elements which require a core focus. This paper discusses these seven electrical safety habits.

The Seven Electrical Habits

The Swiss Cheese Model refers to latent and active controls. The seven electrical habits achieve a balance between the latent and active controls. Latent controls such as engineering and safety management systems operate in the background whilst active controls such as human behaviour and equipment operability occur in

¹ Source <http://www.dfwhcfoundation.org/what-is-the-swiss-cheese-model-of-harm>

the foreground since these can be seen happening. It is difficult to claim that a particular habit takes precedence, so the habits are not introduced in order of importance. Each habit can be considered a lifesaving intervention.

Habit 1: Always verify absence of voltage and use insulating gloves and tools.

Summary

Never attempt to make contact with a circuit unless the circuit has been verified as potential free, any stored energy released and the system is maintained in this state. Testing is considered touching. During the period of making safe or working live, utilize insulating gloves and tools.

Gloves

Any person who has received a shock whilst working inside a panel can vouch on the ease at which such an incident could occur. An action which has the potential to result in shock has the potential to cause an arc flash. As such, safety standards require protection against electrical shock and electrical arc flash.

Dielectric gloves tested to the ASTM D120 *Standard Specification for Rubber Insulating Gloves* [2] should be used for shock protection. The ASTM Working Committee F18.65.08 chaired by Hugh Hoagland is developing a test method to determine the arc rating of gloves.

Table 1: ASTM D120 Dielectric Classification of Gloves

Glove Class	Maximum Use Voltage AC/DC	Glove Label Colour
00	500V / 750V	Beige
0	1000V / 1500V	Red
1	7500V / 11250V	White
2	17000V / 25500V	Yellow
3	26500V / 39750V	Green
4	36000V / 54000V	Orange

It is important to note that the dielectric glove is present in various colours; however the colour of the label cannot change as it is standardised as per Table 1.

The natural rubber glove does not aim to provide mechanical protection. In fact a single instrument wire can puncture the dielectric glove. It is for this reason and also for added arc flash protection that leather over protectors are used.

Gloves should be inspected each time before use. The gloves should be inspected for pin holes, cracks, ozone damage and embedded objects. A dielectric test is required on dielectric gloves once every six months in order to

comply with the NFPA 70E – 2012 *Standard for Electrical Safety in the Workplace* [3].

Insulating Tools

When a circuit is verified as dead and maintained in that state and no other exposed live conductors are present, normal un-insulated tools are perfectly acceptable. For all other cases insulated tools are required. Such tools must comply with either the ASTM F1505 - 10 Standard Specification for Insulated and Insulating Hand Tools [4] or IEC 60900 Live working - Hand tools for use up to 1 000 V a.c. and 1 500 V d.c [5] standards. A dual substrate tool is recommended. Typically these are orange over yellow as shown in Picture 2. When the yellow is visible the tool should be removed from service.



Picture 2: Insulated hand tool to IEC 60900 with an orange over yellow substrate

Verification

Always test before touch using the live-dead-live rule. Utilise a voltage tester to a known live circuit and verify that the tester is functional. Test the circuit on which work is going to be performed. Then test a live circuit part to ensure that the meter is operational. Low voltage multimeters or test sticks could be utilised.

When working with low voltage multimeters, know the limitations of the unit and ensure that the probes are connected for either voltage or current measurements. For circuits below 1000V, CAT III probes with non-slip covers and tips less than 4mm shown in Picture 3 are recommended. In instances where the probes are fused, a self-test function is critical to ensure that a false zero potential is not observed.



Picture 3: Low voltage meter with CAT III 1000V Fused Probes with tips less than 4mm

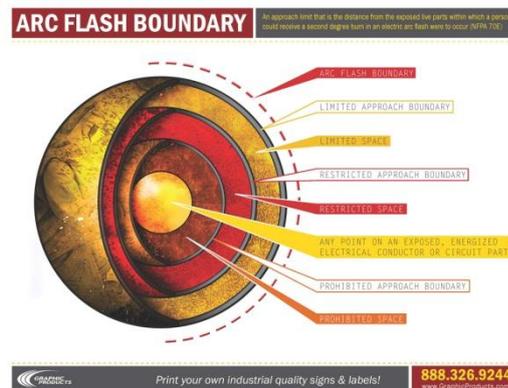
Habit 2: Establish boundaries for worker safety from shock and arc flash hazards.

Summary

In the presence of exposed energised conductors, establish shock boundaries for workers. When exposed energised conductors are present or when interacting with equipment in such a manner that an arc flash could occur, establish arc flash protection boundaries for workers.

Shock Boundaries

NFPA 70E – 2012 defines both AC and DC shock boundaries. These boundaries are termed the limited approach boundary, restricted approach boundary and the prohibited approach boundary. The boundaries only exist when exposed energised conductors are present i.e. a shock hazard exists. Each boundary is the function of the root mean square AC voltage or DC voltage and are shown in Picture 4.



Picture 4: NFPA 70E defines shock protection Boundaries²

Arc Flash Boundaries

In the presence of exposed energized conductors or when interacting with equipment in such a manner that an arc flash could occur, the NFPA 70E – 2012 requires that arc flash protection boundaries be stipulated.

The arc flash protection boundary is that distance from the arc at which the onset of second degree burns will not occur. Various methods such as the NFPA 70E – 2012 tables and those discussed in the NFPA 70E – 2012 Annexure D could be used to determine the arc flash protection boundary. Usually power systems or electrical protection parameters will be required and the arc flash boundary is independent of the shock boundaries.

² Source from website <http://www.duralabel.com/images/af-infographic-big.jpg>

Habit 3: Always use arc-rated daily work wear and a face shield.

Summary

Use an arc rated one piece coverall or an arc rated two piece shirt and trouser when in the workplace. The best form of protection is one which is always on, irrespective of the presence of a hazard.

Arc Rated Daily Work Wear

Around 80% of all arc flash related fatalities are due to the ignition of clothing. Getting workers behind arc rated clothing will go a long way in preventing fatalities. Workers should utilise daily work wear typically ranging from 8 cal/cm² to 15 cal/cm² before entering the workplace. Such clothing should comply with either ASTM F1506 *Standard Performance Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards* [6] or IEC 61482-2 *Protective Clothing Against the Thermal Hazards of an Electric Arc - Part 2: Requirements* [7].

Many terms have been utilised to explain fabric historically such as flame retardant, flame resistant, fire retardant, fire resistant, inherently fire resistant, treated material amongst others. All arc rated clothing has these traits, however, not all of the aforementioned fabric types are arc rated. End users should always look for a cal/cm² rating permanently affixed to the garment and a valid test report from an accredited laboratory. Samples of valid reports can be found at <http://www.arcwear.com/arctest/arctest.php>.

Fabric which could melt such as polyester, poly-cotton, nylon, spandex amongst others are expressly prohibited for use as outerwear, innerwear or underwear by the NFPA 70E – 2012.

Arc Rated Face Shields

Arc rated face shields should comply with ASTM F2178 *Standard Test Method for Determining the Arc Rating of Face Protective Products* [8] and ANSI Z87.1 *Occupational and Educational Personal Eye and Face Protection Devices* [9]. A face shield should typically clip on to an existing safety cap, however, the test methods require that the system be tested as it would be used in the field. This requirement means that the ratchets, clips, visor / face shield, chin cup and brow cup are all exposed to the requirements of the ASTM F2178 test method.

It is not uncommon to find clear face shields in the workplace. Such face shields, when exposed to an electric arc, will burn, melt and drip onto clothing increasing the severity of the burn.

Habit 4: Always use an earth leakage or ground fault circuit interrupter device with cord and plug connected tools and extension cords.

Summary

If human contact is possible on any domestic or light industrial circuit, earth leakage protective devices must be used.

Arc Rated Daily Work Wear

A mere 110V is enough to result in a fatality. Sweat, general humidity and water substantially reduce the body's resistance which increases current flow through the body. In the United States a ground fault circuit interrupter (GFCI) as shown in Picture 5 is utilised and in South Africa and Europe an earth leakage device is located in the local distribution board.



Picture 5: Ground Fault Circuit Interrupter

Having these protective devices installed is not merely enough. The operability of the devices should be verified periodically. In addition the necessary personal protective equipment, such as a leather glove, should be used when operating domestic and light industrial tools.

Habit 5: When Feasible Create an Electrically Safe Work Condition.

Summary

An electrically safe work condition is a set of operations which confirms and maintains a system in such a state that no electrical harm is possible.

Electrically Safe Work Condition

The NFPA 70E – 2012 has defined the requirements to create an electrically safe work condition. In order to promote retention, e-Hazard.com has developed the antonym ISOLATE:

I - Identify all energy sources and check drawings for ring or back feeds

S - Shutdown all sources feeding the equipment

- O** - **Open** disconnect switch or circuit breaker
- L** - **LO/TO**: Apply lockout and tagout devices
- A** - **Assure** that contacts are open, visually when possible
- T** – **Test** and verify all phases and neutral is dead and test the tester
- E** - **Employ** safety grounds (**earths**) for HV and where necessary

The **ISOLATE** steps are clear and necessary to establish an electrically safe work condition, however, the following must be considered:

1. The process of creating an electrically safe work condition is dangerous. Approaching circuit parts or conductors that may be energized is inherently unsafe. Electrical hazards are not visible to the naked eye.
2. Wearing the proper personal protective equipment (PPE) does not create an electrically safe work condition. In fact, PPE is not mentioned in **ISOLATE**. The process assumes that the person establishing an electrically safe work condition is wearing the appropriate PPE until the process is complete.
3. e-Hazard.com has found, in several accident investigations, that one of more of the **ISOLATE** steps was not completed. Electrical incidents are preventable and establishing an electrically safe condition eliminates shock and arc flash hazards.

Habit 6: Identify Greater Hazard Levels and Adopt Proper PPE or Engineering Controls to Mitigate those Hazards.

Summary

Arc flash hazards which are not addressed by daily work wear should be identified and a process used to establish, implement, control and thereby mitigate such hazards.

Greater Arc Flash Hazard

Habit 3 calls for the provision of arc rated daily work wear, however, greater hazards exists in certain environments or under certain operating conditions. In this case a standard Hazard Risk Category (HRC) 2 will not suffice and additional HRC(s) should be considered as described in Table 2.

Table 2: Table 130.7(C)(16) derived from the NFPA 70E – 2012 describing Hazard Risk Categories

Hazard Risk Category (HRC)	Protective Clothing and PPE
0	Protective Clothing, Non-melting or Untreated Natural Fibre (i.e., untreated cotton, wool, rayon, or silk, or blends of these materials) with a Fabric Weight of at Least 4.5 oz/yd ² or 150g/m ²
1	Arc-Rated Clothing, Minimum Arc Rating of 4 cal/cm ²

2	Arc-Rated Clothing, Minimum Arc Rating of 8 cal/cm ²
3	Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 25 cal/cm ²
4	Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 40 cal/cm ²

Arc Flash Hazard Analysis

NFPA 70E - 2012 Article 130.3 require that shock and arc flash hazard analysis be performed. The most common techniques are the use of the NFPA 70E – 2012 tables or the IEEE 1584a – 2002 *Guideline for Performing Arc Flash Calculations* [10].

It is imperative to note that the network analysis or table references must be revisited if the electrical network was changed or after a five year period from the last study. Associated equipment labelling and clothing should also be verified.

Equipment Labelling

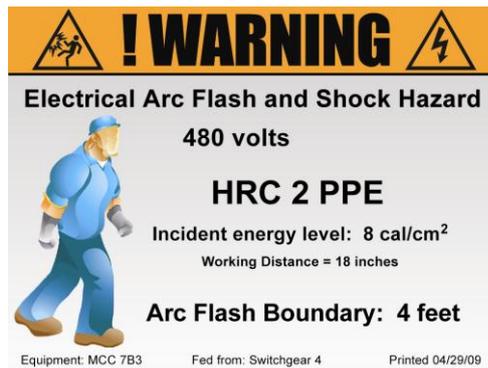
Labelling of equipment should follow after completion of an arc flash hazard analysis. The label should contain as a minimum the following information:

- At least one of the following:
 - a. Available incident energy and the corresponding working distance
 - b. Minimum arc rating of clothing
 - c. Required level of PPE
 - d. Highest Hazard/Risk Category (HRC) for the equipment
- Nominal system voltage
- Arc flash boundary listed below

In addition it is recommended that the following information be included:

- Date when the label was printed
- Fed from supply (Upstream device)
- Equipment Identity

Many variations are possible and customisation to the organisations corporate identity may further promote awareness of the safety sign. Picture 6 shows a label which complies with the NFPA 70E – 2012 Article 130.5 Arc Flash Hazard Analysis.



Picture 6: Label as per NFPA 70E – 2012

Additional Controls

The following general commentary is also applicable to the greater risks.

- Eliminate the hazard by de-energizing, locking out and tagging the circuit parts or conductor. Visually verify that the circuit parts and conductors are de-energized.
- Use engineering controls to design and thus eliminate the exposure to the hazard.
- Use administrative controls and perform labelling, training, safe work practices, work plans and establish a live electrical work permit program.
- Provide and ensure the correct use, storage and care of arc rated protective clothing and personal protective equipment.

Habit 7: Measure, audit and continuously improve electrical safety processes.

Summary

NFPA 70E – 2012 requires annual auditing of electrical safety practices in the workplace. Since the NFPA 70E standard has a three year review cycle, it is important that an organisations safety program is updated to comply with the standard.

Measurement and Auditing

The NFPA 70E – 2012 has defined the requirements to create an electrical safety program. The electrical safety program consists of principles and procedures.

In the context of the Swiss Cheese Model, the principles form the latent controls such as maintenance strategies, maintenance plans, plant/task specific hazard identification and risk assessments, qualifications and training matrices, determination and provision of the appropriate PPE amongst others. The procedures form the active controls such as the use of PPE and the correct tools, operating the correct equipment, interpreting the data correctly amongst others.

The latent and active controls within this habit require verification. The NFPA 70E – 2012 requires that the electrical safety program be measured for completeness and subsequently audited. The audit itself should be comprehensive enough to ensure that no gaps exist. It is for this reason that an independent expert or a skilled and experienced member of the engineering or management team controls this task.

Conclusion

Electrical arc flash safety is a holistic program which aims to prevent loss and damage. The mere distribution of arc rated PPE does not achieve safety. An electrical safety program consists of many steps which can be continuous, once-off and time or event based. Some steps achieve a safer environment within a very limited time frame, human resource base or within a defined budget.

The Swiss Cheese Model refers to key *loss of control* elements which need to be defined and prevented from occurring. Having conducted more than 150 accident investigations globally, e-Hazard has defined seven key elements which can prevent harm in most incidents. These elements are referred to as the *Seven Electrical Habits* by e-Hazard. These habits are listed as:

Habit 1: Always verify absence of voltage & use rubber insulating gloves & tools.

Habit 2: Establish boundaries for worker safety from shock and arc flash.

Habit 3: Always wear arc-rated daily wear and a face shield.

Habit 4: Always use an earth leakage or GFCI with cord and plug connected tools and extension cords.

Habit 5: When feasible always create an electrically safe work condition.

Habit 6: Identify higher hazards and adopt proper PPE or engineering controls to mitigate those hazards.

Habit 7: Measure, audit and continuously improve electrical safety processes.

However, in this ever evolving and improving field of electrical safety, technical requirements and systems are constantly changing. As such any person or organisation wishing to effectively implement the Seven Electrical Habits needs to ensure that the habits are not only known but are thoroughly understood. It is strongly recommended that the following steps be used to establish a basis and encourage the effective implementation of the Seven Electrical Habits.

- Attend a NFPA 70E® training class like the e-Hazard 1 Day LV Qualified Class.
- Provide NFPA 70E® training for all employees.

- Update the organisations single line drawings.
- Conduct a detailed hazard analysis study using experts and software tools (list of commonly used software is listed in Annexure A).
- Provide Labels on all electrical equipment.
- Select the appropriate PPE to protect against arc flash and shock.
- Develop a detailed electrical safety program which is reviewed annually.
- Determine a hazard mitigation strategy.
- Audit for compliance

Making the Seven Electrical Safety Habits a habit will make your workplace safer.

Biography of Authors

Al Havens

Al brings more than 40 years of electrical safety experience to the classroom, 26 of which as Senior Electrical Engineer for U.S. Gypsum (USG). He currently provides instruction in the application and use of the NFPA 70E® standard in both low and high voltage environments for e-Hazard Management, LLC. He has taught hundreds of classes and well over 1000 people. He has presented papers at the IEEE Electrical Safety Workshop, the International Electrical Testing Association (NETA) Conference, and the IEEE Pulp and Paper Industry Conference on electrical safety issues. His contact information is al.havens@e-hazard.com, Office: 502-716-7073 Cell: 312-310-3080.

Hugh Hoagland

Hugh Hoagland is among the world's foremost experts on electrical arc testing and safety. His career change began with safety testing at LG&E Energy, later, he worked as R & D Director for NASCO, a manufacturer of protective outerwear solutions. He has helped develop most of the arc-resistant rainwear used in the world today as well as creating the first face shield to protect against electric arcs.

Before moving to full-time training and consulting, Hugh worked for Cintas developing their strategy for meeting the needs of OSHA 1910.269 and NFPA 70E standards before moving to full time training and consulting. He has helped development of legislation and standards in both the US and Europe. He sits on several industry committees and is a featured speaker at safety conferences and events.

Zarheer Jooma

Zarheer Jooma is a professionally registered electrical engineer with the Engineering Council of South Africa and a senior member of the South Institute of Electrical Engineers. He is the director of the South African branch of the US based company **e-Hazard**. The company consults to garment manufacturers, performs arc flash calculations and electrical safety consulting work, NFPA accredited electrical arc flash training, garment testing and SANS 724 compliance. Hugh Hoagland operates and manages the US based companies **e-Hazard** and **Arc Wear**. The company Mission sums up their international commitment. ***'We help people who work around electricity go home safely to their families'***

Bibliography

- [1] J. Reason, Human Error, Cambridge: Cambridge University Press, 1990.
- [2] ASTM D120 Standard Specification for Rubber Insulating Gloves, 2006.
- [3] NFPA 70E – 2012 Standard for Electrical Safety in the Workplace, 2012.
- [4] ASTM F1505 - 10 Standard Specification for Insulated and Insulating Hand Tools, 2010.
- [5] IEC 60900 Live working - Hand tools for use up to 1 000 V a.c. and 1 500 V d.c, 2012.
- [6] ASTM F1506 Standard Performance Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards, 2010.
- [7] IEC 61482-2 Protective Clothing Against the Thermal Hazards of an Electric Arc - Part 2: Requirements, 2009.
- [8] ASTM F2178 Standard Test Method for Determining the Arc Rating of Face Protective Products, 2012.
- [9] ANSI Z87.1 Occupational and Educational Personal Eye and Face Protection Devices, 2003.
- [10] IEEE 1584a – 2002 Guideline for Performing Arc Flash Calculations, 2002.

ANNEXURE A

List of common commercial power system simulation tools sourced from the wiki web OpenElectrical. More details available at:

http://www.openelectrical.org/wiki/index.php?title=Power_Systems_Analysis_Software

- ASPEN
- BCP Switzerland (NEPLAN)
- Commonwealth Associates (Transmission 2000)
- CYME
- DIgSILENT (PowerFactory)
- Energy Computer Systems (SPARD)
- Electrocon (CAPE)
- ESA (EasyPower)
- GDF Suez (Eurostag)
- GE Energy (PSLF)
- IPSA Power
- MILSOFT (Windmil)
- OTI (ETAP)
- Manitoba Hyrdo International (PSCAD)
- MathWorks (SimPowerSystems)
- Nexant (SCOPE)
- Power Analytics (EDSA)
- Powertech Labs (DSATools)
- PowerWorld
- ReticMaster
- Siemens PTI (PSS/E and SINCAL)
- SKM (Power*Tools for Windows)