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Facing the Changing Electrical Hazard

Presented to the
IEEE – PES Luncheon Meeting
Fort Worth, Texas
August 17, 2004

by
Neil Van Geem, PE & Wayne P Blackley, PE

Facing the Changing Electrical Hazard

- Recognition
- Estimation
- Mitigation

Electrical Hazard

- **Element #1**
  - **Shock or Contact**
    - **We've known this one for years**

Charles Dalziel (1904-1986) quantified this in the 1950s

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Current Range & Effect on 68 kG Man

Current (60hz)	Physiological Effects	Feeling or Lethal Incidence
• <1 mA	None	Imperceptible
• 3 - 10 mA	Pain Sensation	
• 10 mA	Paralysis Threshold -	

– Cannot release hand; if no grip, victim may be thrown clear; may progress to higher current & be fatal.

Based on research by Charles Dalziel, circa 1955

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Current Range & Effect on 68 kG Man

- 30 mA Respiratory Paralysis –
  - Stoppage of breathing (Frequently fatal).
- 75 mA Fibrillation threshold 0.5 %
  - (1 person out of 200)
- 250 mA Fibrillation threshold
  - 99.5 % for exposure > 5 seconds

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Current Range & Effect on 68 kG Man

- **4 Amps — Heart Paralysis Threshold**
  - Heart stops for duration of current passage. For short shocks heart may start on interruption of current. (Usually not fatal from heart dysfunction)
- **>5 Amps — Tissue Burning**
  - Not fatal unless vital organs are burned

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Obviously we cannot risk contacting voltages much above 50 volts

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Mitigation

- Work Position
- Work Practices
- Rubber
  - Gloves
  - Blankets
  - Hose
  - Insulated Tools

The first big challenge?

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Electrical Hazard

- **Element #2**
  - **Explosion or Blast**

Installed pressure relief devices on transformers - 1970's
A B Chance develops Blast Blankets - 1980's

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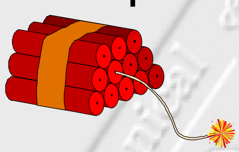
Explosion or Blast



- **Dynamite or Electrical Arc**
- **Both create expanding gases!!**

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Explosion or Blast
Expanding Gases

- **In a 30-06 - 50,000 psi sends a 147 grain bullet at 2700 ft/sec.**
- **Water turned into steam expands @ ratio of 1670/1**
- **WE USE STEAM TO TURN TURBINES!**

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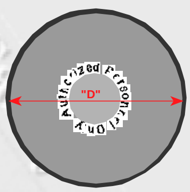
Explosion or Blast
Expanding Gases

- Copper expands @ a ratio of 67,000/1
- What happens when a cubic inch of copper is vaporized in this switch??

Explosion or Blast

- PSI - How big is one PSI?

- If a Manhole Cover
  - Has Diameter of 30”
  - And weighs 100 pounds



- Equilibrium PSI is:
  - 100LBS. ÷ 706.9 Sq.In. = 0.14 PSI

An Actual Event
Cable Termination Failure
Smithsonian Museum of Natural History, Washington DC

- Fed from PEPCO System
- 13.8kV Cables terminated in compound filled chamber

Cable Termination Failure

- Cover dimensions
  - 18” x 25” Square
  - ¼ inch thick flat steel plate
- Explosion blows cover completely off

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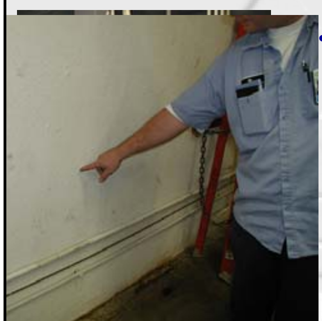
Cable Termination Failure



- Explosive force leaves imprints of nuts and panel in masonry wall 4 - 5 foot away

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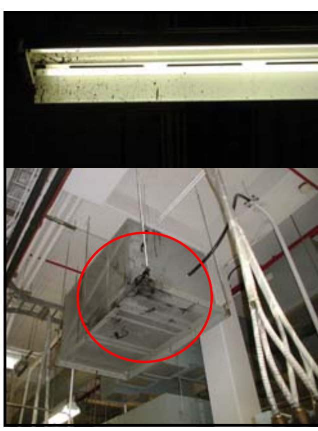
ion Failure



- Blows hot molten compound on to lighting fixtures, wall, ceiling and other equipment

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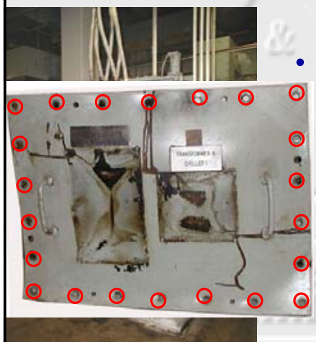
Cable Termination Failure



- Expanding gases cause 22 5/8”nuts to strip off bolts.
- Fault current approx 26kA

Cable Termination Failure

- Plate severely warped & bent

Cable Termination Failure

- What if a worker had been standing here

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Electrical Hazard

- **Element #3**
  - **Arc or Flash**

Mary Stoll
quantified burns in the 1960's

Ralph Lee wrote
"Electrical Arcs - The Other Electrical Hazard" in 1981

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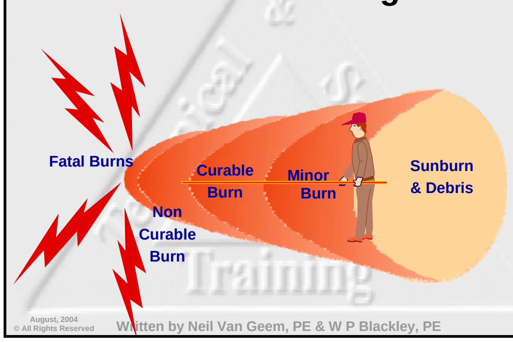
Flash Distances determine when work is energized.



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ARC - FLASH HAZARD

- ***YOU DON'T HAVE TO TOUCH IT!!!***

Persons standing next to this accident would also be burned!!

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HOW HOT IS HOT?

- Humans Normal Temperature 98.6°F
- Water boils at 212°F
- Clothing spontaneously ignites 750° - 1500°F
- Gold melts at 1063°F
- Lightning 60,000 °F

ELECTRIC ARCS REACH 35,000°F

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HOW HOT IS HOT?

- How hot is an electric arc?
- Hiroshima, Japan (8/6/45)
  - When the atomic bomb exploded there were outlines of humans left on concrete walls from the heat.
  - Temperature?
    - 7,000° Fahrenheit

ELECTRIC ARCS REACH 35,000°f

Source: Discovery Channel

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Burn Probability

- Based on Stoll Curve
- Indicates 2nd degree burns start at 1.2 cal/cm^2

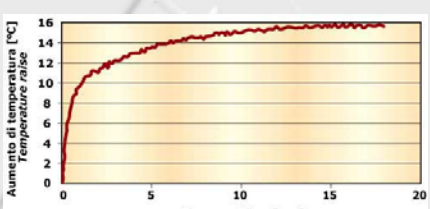

Figure 1. Stoll curve. Typical sensor temperature rise vs time
Curve taken from Measuring the Performance of Fabric Systems to Protect Against the Thermal Effects of Electric Arcs published by NT New Textiles.

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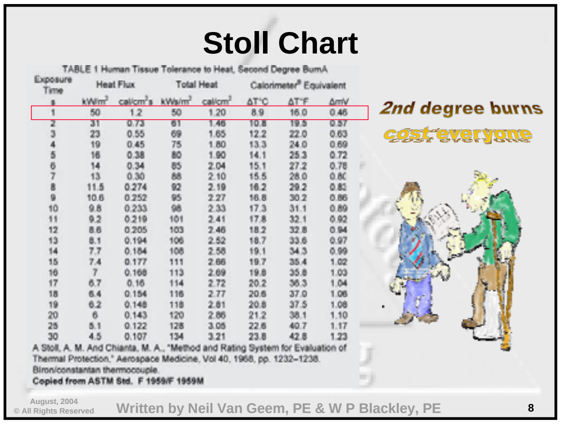
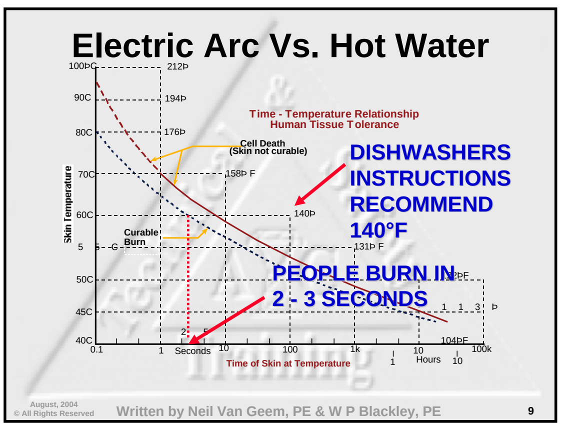
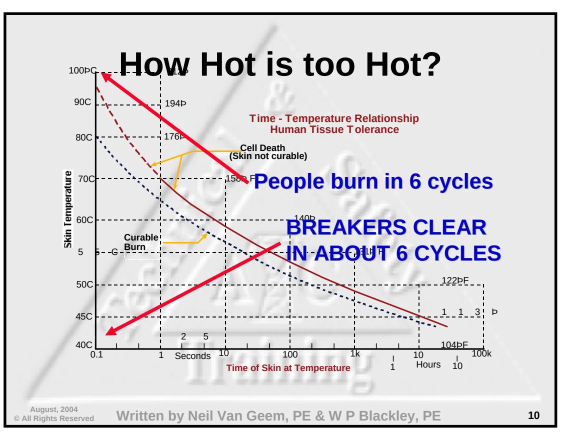


TABLE 1 Human Tissue Tolerance to Heat, Second Degree BurnA

Exposure Time	Heat Flux		Total Heat		Calorimeter[B] Equivalent		
s	kW/m²	cal/cm²s	kWs/m²	cal/cm²	ΔT°C	ΔT°F	ΔmV
1	50	1.2	50	1.20	8.9	16.0	0.46
2	31	0.73	61	1.46	10.8	19.5	0.57
3	23	0.55	69	1.65	12.2	22.0	0.63
4	19	0.45	75	1.80	13.3	24.0	0.69
5	16	0.38	80	1.90	14.1	25.3	0.72
6	14	0.34	85	2.04	15.1	27.2	0.78
7	13	0.30	88	2.10	15.5	28.0	0.80
8	11.5	0.274	92	2.19	16.2	29.2	0.83
9	10.6	0.252	95	2.27	16.8	30.2	0.86
10	9.8	0.233	98	2.33	17.3	31.1	0.89
11	9.2	0.219	101	2.41	17.8	32.1	0.92
12	8.6	0.205	103	2.46	18.2	32.8	0.94
13	8.1	0.194	106	2.52	18.7	33.6	0.97
14	7.7	0.184	108	2.58	19.1	34.3	0.99
15	7.4	0.177	111	2.66	19.7	35.4	1.02
16	7	0.168	113	2.69	19.8	35.8	1.03
17	6.7	0.16	114	2.72	20.2	36.3	1.04
18	6.4	0.154	116	2.77	20.6	37.0	1.06
19	6.2	0.148	118	2.81	20.8	37.5	1.08
20	6	0.143	120	2.86	21.2	38.1	1.10
25	5.1	0.122	128	3.05	22.6	40.7	1.17
30	4.5	0.107	134	3.21	23.8	42.8	1.23

A Stoll, A. M. And Chianta, M. A., "Method and Rating System for Evaluation of Thermal Protection," Aerospace Medicine, Vol 40, 1968, pp. 1232–1238.
Biron/constantan thermocouple.
Copied from ASTM Std. F 1959/F 1959M





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SKIN TEMPERATURE RISE IN 0.1 SECONDS

TEMPERATURE RISE IN SKIN IN 0.1 SECOND							
Arc Diameter		20 in.	24 in.	30 in.	36 in.	60 in.	120 in.
Inches	Cm	50.8 cm.	61 cm.	76 cm.	91 cm.	152 cm.	308 cm.
1	2.54	34°c	24°c	15°c	11°c	4°c	1°c
		63°f	43°f	27°f	19°f	7°f	2°f
2	5.08	138°c	96°c	61°c	43°c	16°c	4°c
		249°f	173°f	111°f	77°f	28°f	7°f
3	7.62	310°c	215°c	138°c	96°c	34°c	9°c
		557°f	387°f	248°f	172°f	62°f	16°f
4	10.2	549°c	381°c	244°c	170°c	61°c	15°c
		988°f	686°f	439°f	305°f	110°f	28°f
6	15.2	1230°c	854°c	547°c	380°c	137°c	34°c
		2214°f	1537°f	983°f	633°f	245°F	62°f
8	20.3	2196°c	1525°c	976°c	678°c	244°c	61°c
		3953°f	2745°f	1756°f	1220°f	439°f	110°f
10	25.4	3425°c	2379°c	1523°c	1058°c	381°c	95°c
		6167°f	4282°f	2739°f	1903°f	695°f	172°f
12	30.5	4941°c	3431°c	2196°c	1526°c	549°c	137°c
		8894°f	6176°f	3951°f	2745°f	987°f	248°f
16	40.6	8740°c	6069°c	3885°c	2699°c	971°c	242°c
		15733°f	10925°f	6989°f	4840°f	1745°f	439°f

BREAKERS CLEAR IN ABOUT 6 CYCLES

- A Person's skin - **20 inches**
- From a - **4 In. Diameter ARC**
- Will reach a Temperature of **988°F**
- <u>in 6 cycles!</u>

Based on Ralph Lee's paper

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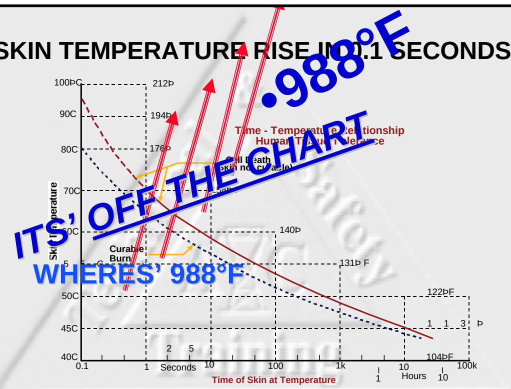
SKIN TEMPERATURE RISE IN 0.1 SECONDS



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Burn Defined

- First degree burns affect the outer layer of the skin, causing pain, redness, and swelling

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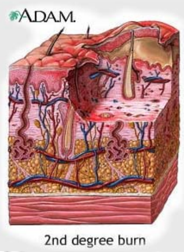
Burn Defined

•Second-degree burns affect both the outer and underlying layer of the skin, causing pain, redness, swelling, and blistering



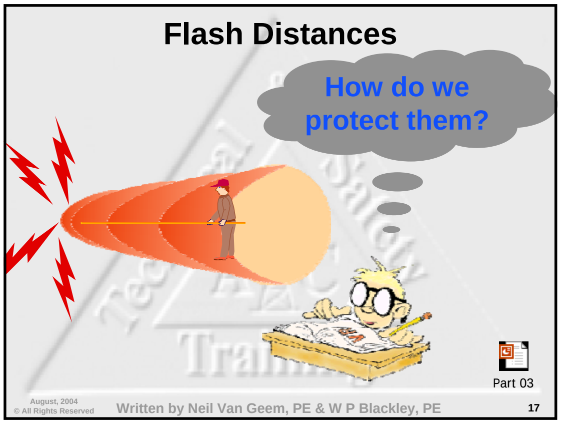
Burn Defined

•Third-degree burns extend into deeper tissues, causing brown or blackened skin that may be numb

The question is:

"What does it take to protect the worker?

"And how do we predict and/or mitigate these events??"


Flash Distances
How do we
protect them?
Part 03
August, 2004
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Mitigation of Arc/Flash

- Work Position
- Hard Hats
- Eye Protection
- Work Practices

And FR Clothing

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Mitigation of Arc/Flash

FR Clothing

What kind?

How Much?

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Mitigation of Arc/Flash

FR Clothing

Remember they have to work in the stuff!!

The objective is to have just enough!!

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Predicting Burn Severity

(At least 5 methods exist)

- •Calculating Burn Energy
  - •Ralph Lee's Method
  - •NFPA 70 E
  - •IEEE Std. 1584
  - •Heat Flux by Alan Privette – Duke
  - •ArcPro- Ontario Hydro Technologies
- •Most based on the Stoll Curve

Each method has limited applicability

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NFPA Calculations

for V < 600v & 16Ka < I_f < 50 kA

D.6.1 Arc in Open Air. The estimated incident energy for an arc in open air is

$E_{MA} = 5271D_A^{-1.9593}t_A\{0.0016F^2 – 0.0076F + 0.8938\}$

where:
E_{MA} = maximum open arc incident energy, cal/cm^2
D_A = distance from arc electrodes, in. (for distances 18 in. and greater)
t_A = arc duration, seconds
F = short-circuit current, kA (for the range of 16 kA to 50 kA)

NFPA 70E–2004 Edition

D.6.2 Arc in a Cubic Box. The estimated incident energy for an arc in a cubic box (20 in. on each side, open on one end) is given in the following equation. This equation is applicable to arc flashes emanating from within switchgear, motor control centers, or other electrical equipment enclosures.

$E_{MB} = 1038.7D_B^{-1.4738}\{0.0093F^2 – 0.3453F + 5.9675\}$

where:
E_{MB} = maximum 20 in. cubic box incident energy, cal/cm$_2$
D_B = distance from arc electrodes, inches (for distances 18 in. and greater)
t_A = arc duration, seconds
F = short circuit current, kA (for the range of 16 kA to 50 kA)

NFPA 70E–2004 Edition

IEEE Calculations using IEEE 1584 for V<600

$E = 4.184\ C_f\ E_n\ (t/0.3)\ (610^x/D^x)$
where
***E* is incident energy (J/cm^2)**
C_f is a calculation factor
1.0 for voltages above 1kV, and
1.5 for voltages at or below 1kV
E_n is incident energy normalized 15
***t* is arcing time (seconds)**
***D* is distance from the possible arc point to the person (mm)**
***x* is the distance exponent from Table 4.**

Prediction Challenges

Requires Complex Empirical Equations

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IEEE 1584 –

- Calculations consider three-phase arcs in enclosures and in air. Published input ranges are:
  - Voltage of 208 to 15,000 volts
  - Bolted fault current of 0.700 to 106 KA
  - Grounding variations
  - Equipment enclosures of commonly available sizes
  - Gaps between conductors of 13 mm to 152 mm (0.5 to 6 inches)
- The equations were developed from curve fitting of results of values measured from extensive testing .

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NFPA 70 E

- NFPA 70E – Calculations consider three-phase arcs in enclosures or in air.
- Tested values were limited to a distance from the arc of greater than 18" only and for bolted fault currents for the range from 16 KA to 50 KA and for system voltages rated 600 volts and below. The equations were developed from curve fitting results of values measured on limited testing (compared to IEEE 1584). Some general conclusions resulting from the testing which developed the equations and as reported in an IEEE paper, "Predicting Incident Energy to Better Manage the Electric Arc Hazard on 600-V Power Distribution Systems" of the IEEE Transactions on Industry Applications Vol. 36, No. 1, January/February 2000 were:
- Effects of arcs in an enclosure are 1.5 to 2.5 that of the same arc in open air up to currents of 30 KA and 2.5 to 2.8 for currents of 30 to 50 KA
- Only three phase arcs were considered
- Tests matched Lee's equation calculations for open air arcs between 16 and 35KA when calculating burn boundary distance
- Poor correlation was found between equations for this testing range and for ARCPRO or the Duke Heat Flux calculation program.

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Lee's Calculation –

- Calculations are theory based and are developed to consider maximum arc power.
- It considers three-phase arcs in open air and calculations use bolted fault current input.
- IEEE 1584 recommends this calculation method for medium voltage arcs (Above 15 KV) in open air at substations and for transmission and distribution systems.

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ARCPRO

- Considers single-phase arcs in air using theoretical equations. The calculations use arc current rather than bolted fault current input.
- Published Input Ranges
  - Arc current of 0.2 KA to 100 KA (verified for 3.5 KA to 21.5 KA)
  - Arc duration of 0.05 to no limit in cycles (verified from 4 to 30)
  - Arc gap of 1 to 20 inches (verified from 1 to 12 inches)
  - Source voltage (open circuit voltage across the gap in volts) of "any that will sustain the arc"
  - Electrode material choice of copper or stainless steel
  - Distance from arc of 0.4 to 400 inches (verified from 8 to 24)
- In an appendix it is recommended that the results of the calculation be multiplied by 1.5 to convert to an arc in a box. It further states that this gives "an extremely preliminary approximation."

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Duke Heat Flux Calculator

- This method is based on empirical values developed from measurements. It is made available to the public at no charge.
  - Developed by Alan Privette of Duke Power
  - Based on single- phase arc in air, and arc current.

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Predicting Burn Probability Methods

- Calculating Burn Energy for voltages over 600 volts use:
  - Ralph Lee's Method
  - Heat Flux by Alan Privette – Duke
  - ArcPro- Ontario Hydro Technologies

Every method has limited applicability & gives different answers!

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Predicting Burn Probability on Distribution Circuits

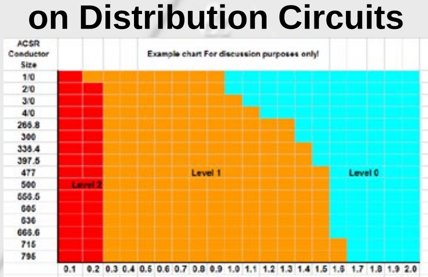

Table limited to ACSR, 12.47 kV circuit, 10 kA and 10 cycles.
If anything changes every thing does!

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Final Analysis

- User should be experienced in fault analysis and safe work procedures.
- Many ways exist to mitigate hazards
- Additional FR Clothing is not the only solution
- Consider
  - Alternate work practices
  - Reduced clearing times
  - Fault limiting fuses

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Mitigation Methods

- Reduced
  - Faster Clearing
  - Fault Current
- Increased Clearances
- Work Position
- Face Shields
  - (No exposed skin)

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The Future

- OSHA - Dave Wallis has stated that future OSHA standards will reflect NFPA 70 E approach
- Increased research to improve predictability of arc effects

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Today’s Action

- It may not be law yet but no one wants to see this happen!

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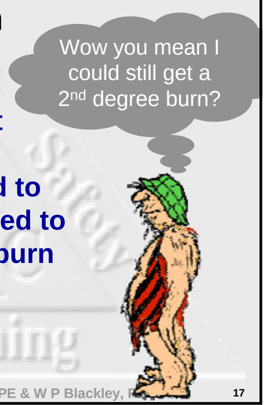
Today’s Action

- And remember that when 5.0 cal/cm^2 clothing is exposed to 5.0 cals it is expected to allow a 2nd degree burn 50% of the time!



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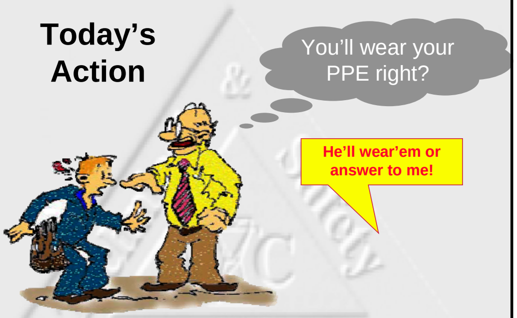
Today’s Action



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Thanks for having us here today!
Questions?
• Ands remember Mother told us not to play with FIRE!
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