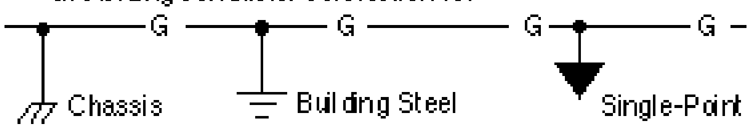
LEGEND

(1) Grounding conductor connection to:



(2) Isolation transformer, rated at 2 x Operating Voltage + 1KV with electrostatic shield. See Chapter 4, paragraph 4.3.6.A.

(3) Transductor with insulation between center conductor and AC winding rated at 2 x Operating Voltage + 1 KV.

(4) Low voltage side (RB) of voltage divider (RA, RB) with parallel resistors such that if one or two resistors open circuit, hazardous voltages are not produced. See Chapter 12.

(5) Reserved For Future Use.

(6) Back-to-back zener diodes that can survive peak energy under fault conditions. See Chapter 4, paragraph 4.3.6.C.

(7) High impedance path to reduce voltages introduced into control area to safe values.

(8) Capacitor in AC control circuit with high enough voltage rating to absorb energy under fault conditions. See Chapter 6.

(9) Vacuum switch having appropriate isolation rated at 2 x Operating Voltage + 1 KV between actuating coil and high-voltage contacts.

(10) Fiber optic, RF, infrared, etc. having a path long enough to make arc-over less than credible. See Chapter 4, paragraph 4.3.6.B.

SYMBOLS

(M) Manual operator, (E) Electrical Operator

[K] Sequential (Kirk-Key) Lock

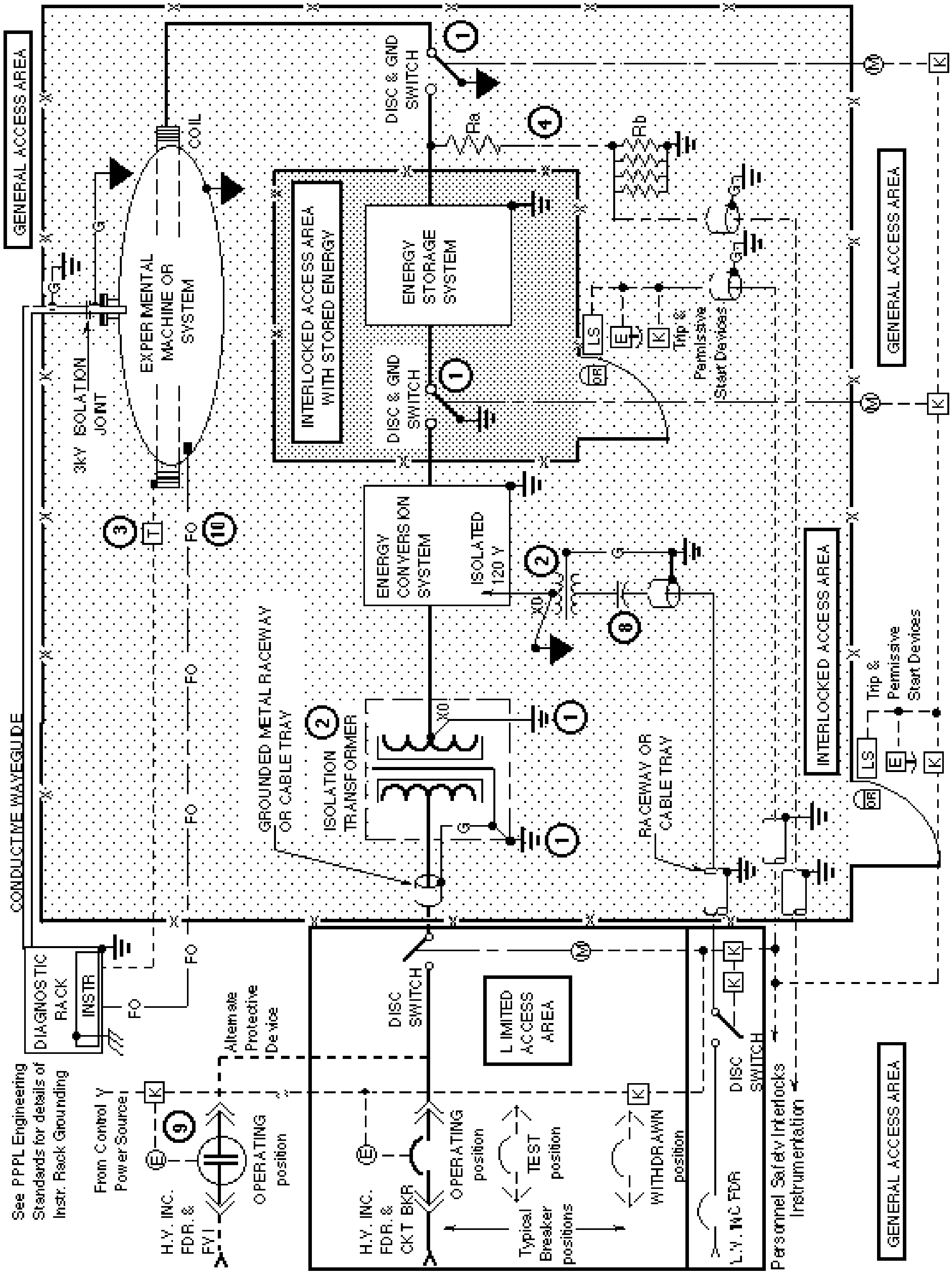
[E] Emergency Stop (E-Stop) Pushbutton Station

"Orange" (High Security) Padlock

[LS] Position sensing door-switch

ATTACHMENT B - Isolation diagram

The Isolation Diagram illustrates some acceptable safety practices and procedures which are not intended to be restrictive. Alternate methods may be used as long as they meet the requirements of Section 2.0.



ATTACHMENT C - Form 5008.2-1 - Permit for climbing or walking on cable trays

PERMIT FOR CLIMBING OR WALKING ON CABLE TRAYS

CABLE INSTALLER TO FILL OUT SPACES BELOW

Requested by ______________________ Ext. _________ Date ______________

Permit start date:_____________________________ Permit end date:________________________

Brief description of work ____

____

Referenced Installation Procedure No (Attach a copy to this form):______________________________

State reasons why it is necessary to climb or walk on cable trays:________________________________

____

Are personnel protection requirements covered in the procedure? _____________ ❑ yes ❑ no

Are high-power cable deenergizing procedures provided or referenced? ________ ❑ yes ❑ no

Are procedures to protect the cables provided or referenced?_________________ ❑ yes ❑ no

ENGINEERING/OPERATIONS TO FILL OUT SPACES BELOW

What structural analysis or review has been done?____

____

Signature of person certifying that structure is safe for intended activity:__________________________

❑ **APPROVED -**

❑ **DISAPPROVED -**

SUPERVISOR Date

ES&H DIVISION TO FILL OUT SPACES BELOW

THE FOLLOWING RECOMMENDATIONS APPLY TO THE INSALLATION PROCEDURE SPECIFIED ABOVE

HAZARDS	PERSONNEL PROTECTIVE EQUIPMENT		SPECIAL REQUIREMENTS
❑ Flammable	❑ hard hat	❑ rubber gloves	❑ Air Monitoring
❑ High toxicity	❑ bump cap	Class__________________	❑ CPR Training
❑ Special hazard	❑ other__________________	Date gloves last tested:	❑ Safety Watch
Specify______________		❑ Other________________	❑ Other

Comments:____

____

❑ **APPROVED -**

❑ **DISAPPROVED -**

ELECTRICAL SAFETY OFFICER Date:

Date:

ATTACHMENT D CAPACITOR BANK INSPECTION FORM (CBI)

ELECTRICAL INSPECTOR SHALL FILL OUT SPACES BELOW

CB NAME:____________________________________CB ID Letters:_____________

Inspected By_________________Ext._______Date________Last Inspection________

1. Are there Access Procedure for this CB? _ yes…._ no **AP No.**_______________

2. Are there Unresolved Safety Concerns? _ yes…._ no If yes…Specify Concern

2a. Who has corrective action?_________________**2b.** Completion date:___________

3. Does area contain any source of ionizing or non-ionizing radiation? _ yes _no

If yes, Identify source____

4. Does area contain oil filled electrical or mechanical equipment? _ yes _no

If yes, Identify equipment____

5. Arc Flash/ Personnel Protective Equipment available and currently tested?_ yes _no

6. Yellow CB information sign is correct and agrees with CB data base? _ yes _no

7. Are accessors have current CA 1: _yes _no CA 2: _yes _no CA 3: _ yes _no
Cap bank training CA 4: _yes _no CA 5: _yes _no CA 6: _ yes _no

8. Accessors demonstrates knowledge of circuits…….._Good… _Adequate… _ LTA

9. Quality and availability of As Built Drawings:…….._Good… _Adequate… _ LTA

10. Interlock system test of access door:………………._Good… _Adequate… _ LTA

11. Maintenance of Isolation and Grounding Switches:.._Good… _Adequate… _ LTA

12. Maintenance of Shorting Resistors:……………….._Good… _Adequate… _ LTA

13.Condition of grounding circuits and equipment:……_Good… _Adequate… _ LTA

14.Accessor demonstrates grounding procedure:……..._Good… _Adequate… _ LTA

15.Verify short-circuit withstand ratings of conductors: _Good… _Adequate… _ LTA

16.Condition of barriers; No non-electrical hazards:…..._Good… _Adequate… _ LTA

17.Access space sufficient for "safing" operations:……_Good… _Adequate… _ LTA

18.Area lighting under normal accessing conditions:…._Good… _Adequate… _ LTA

19. Safety Watch communication available:.._Phone ext._______2 way Radio..._PA sys
_Other:____***LTA = Less Than Adequate**

Operating and/or Maintenance restrictions _ NONE _ AS FOLLOWS

Comments:____

____

_ APPROVED _ APPROVED WITH RESTRICTIONS _ NOT APPROVED

Cog, Safety Person________________________________ **Date**______________

Interlock Coordinator______________________________ **Date**______________

ATTACHMENT E - ELECTRIC ARC BURNS **Edited by Dr. W.T. Thomas**

INTRODUCTION

Protective measures to minimize the risk of current flow through the body are discussed in the previous Chapters of this Section. This Attachment provides information for hazards analysis to evaluate the potential problems of high-temperature electric arcs. Recommendations to reduce associated risk are included.

THE ARC AS A HEAT SOURCE

The electric arc is widely recognized as a very high level source of heat. Common uses are arc welding and electric arc furnaces, even electric cauterizing of wounds to seal against infection while deeper parts are healing. The temperatures of metal terminals are extraordinarily high, being reliably reported to be 20,000°K (about 35,000°F)[1]. One investigator reports temperatures as high as 34,000°K, and special types of arcs can reach 50,000°K. The only higher temperature source known on earth is the laser, which can produce 100,000°K.

The intermediate (plasma) part of the arc, the portion away from the terminals, the "shank" of the dog-bone, figuratively, is reported as having a temperature of 13,000°K. In comparison, the surface temperature of the sun is about 5,000°K, so the terminal and plasma portions are about 2-1/2 times, respectively, as hot as the sun's surface.

Heat transfer is a function of the difference between the fourth power of their absolute temperatures:

$$h = C \times 3.68\,(T_e^4 - T_a^4) \times 10^{-11} \qquad \text{(Eq. 1)}$$

where h = heat transfer, w/in^2; w/6.45 cm^2
C = absorption coefficient of absorbing surface
T_e = absolute temperature of emitting surface, °K
T_a = absolute temperature of absorbing surface, °K

This relationship is useful when the two bodies are large in extent, and relatively close together, so that little heat is lost from edge effects. It is much more useful for the purposes of this study to separate this heat transfer into two elements:

1. The total heat emanating from the source.
2. The proportion of this heat absorbed by unit area of the absorbing object. This is inversely proportional to the square of the distance of separation, similar to light emanating from a central source.

The heat generated by a source per unit of surface area is:

$$h = 3.68 \times T^4 \times 10^{-11}\ \text{w/in}^2 \qquad \text{(Eq. 2)}$$
$$= 0.571 \times T^4 \times 10^{-11}\ \text{w/cm}^2$$

The temperature is known, but not the area of the source; this will be developed subsequently.

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED…

To find the heat received by an object, per unit area, we need to know:

Q_S = heat emitted from the source, per unit area
A_S = total surface area of the source
r = distance from the center of the source to the object
A_O = projected surface area of the object along a plane normal to the source–to–object direction
Q_O = heat absorbed by the projected surface of the object

From these, the following relationship is obtained:

$$Q_0 = [(Q_S\, A_S) / (4\pi r_s^2)][A_o] \qquad \text{(Eq. 3)}$$

Figure 1 is useful in visualizing this relationship. In English, this is saying that the heat received per unit projected area of the object is the heat radiated per unit area of the source times the surface area of the source, divided by 4 times the square of the radius from source to object.

For portions of the receiving object which are not at right angles to the source-object radius, the surface heat density must be multiplied by the cosine of the angle between the surface and direction of the source. For ninety degrees this multiple is 1.

For simplicity, we will consider the receiving object is a sphere, and it will have a diameter which gives the specific surface area. Thus, the diameter of the sphere will be a function of the arc wattage.

DEVELOPMENT OF ARC SIZE

In a bolted fault, there is no arc, so there will be little heat generated there. Should there be appreciable resistance at the fault point, temperature there could rise to the melting and boiling point of the metal, and an arc would be started. The longer the arc becomes, the more of the available system voltage will be consumed in it, so there will be less voltage available to overcome the supply impedance, and the total current will decrease.

This is illustrated in Figure 2. The system has rated voltage E_∞, and total fault impedance to the fault of Z_s. Four arc conditions are shown, one of zero length (bolted fault), one of short length (sub. 1), one of moderate length (sub. 2), and one of greater length (sub. 3). Since the arc impedance is almost purely resistive, and that of the supply system almost purely inductive, the voltage drop across the arc and the supply system are in quadrate for all arc lengths. The locus of the intersection of the vectors of the supply voltage, E_s, and arc voltage drop, E_a, is a semicircle with diameter of E_{so}, the supply system drop for a bolted fault, also equal to E_∞. For this range or arc lengths, the total current is represented by current vectors I_o, I_1, I_2, and I_3, all at right angles to their E_s's. The magnitude of the "I" vectors is proportional to that of the E_s vectors, since they are related by the constant Z_s, ($I = E_s/Z_s$).

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED…

The total energy in the arc, then, is the product of E_s and I. This is zero for the bolted fault, appreciable for condition 1, very substantial for sub. 2, then decreasing for condition sub. 3, where the arc voltage increases only moderately while the current decreases substantially. Also, somewhere in the region between sub. 2 and sub. 3, the length of the arc may become so long that the arc is self-extinguishing, or at least self-stabilizing at a low current level.

It has been found that sub. 2, where the arc voltage drop equals the supply system voltage drop, yields the maximum arc wattage condition. Here, the arc voltage drop is 70.7% of the supply voltage, and the current is 70.7% of the bolted fault level. These are in phase, so the product is pure power, even though the system power factor is 45^0 lagging at the time, due to the supply system impedance of 0 pf. Under these conditions the maximum arc wattage is 0.707^2 of 0.5 times the maximum kVA bolted fault capability of the system at that point.

Thus, it may be seen that the maximum arc energy in watts is 0.5 times the maximum bolted fault VA at a given point. There will be lower arc energies than this, but there is no way to predict them. Just as in shock hazard, one must base arc blast hazard possibility on the maximum possible conditions. So, a judgement on the wattage of a possible arc will be the system voltage times one-half the maximum bolted fault current. Our hazard possibility then, is readily calculable for the complete range of system voltages and available bolted fault currents, determining the arc wattage, the size sphere this represents, and the temperature rise per unit time in a unit surface at the full range of distances from the arc. These calculations have been carried out in preparation of Tables I, II, and III, and Curves 1,2, and 3. These do not take into account the heat which is reflected from the flesh, as dependent on the coefficient of absorption of skin. When white skin is light-colored and clean, this absorption coefficient is about 0.5, but when it is dirty or dark, the coefficient is nearly unity. Also, the calculations do not take into account heat reflected from surfaces near the arc; this additional heat from reflection from other surfaces plus the likelihood that the skin may be dirty or dark is the reason for omitting this factor.

This reflectance factor is useful in choosing personnel protective equipment; if this equipment is colored very white, it will reflect about 90% of the radiant heat from an arc and will absorb a much smaller quantity for conduction to the wearer. Note that this is for radiant heat from sources above 3,500°K only; however, not the normal flame-type heat sources. Even with non-heat-protective clothing, the lighter colors will absorb less heat and will therefore give more protection.

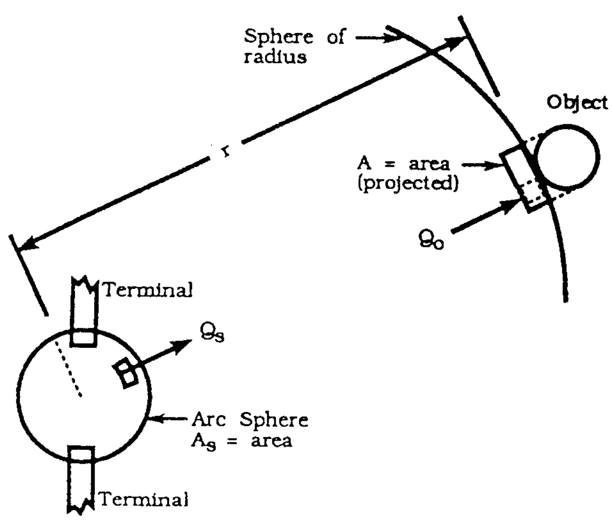


Figure 1
Illustration of Arc Source
and heat-receiving object.

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED...

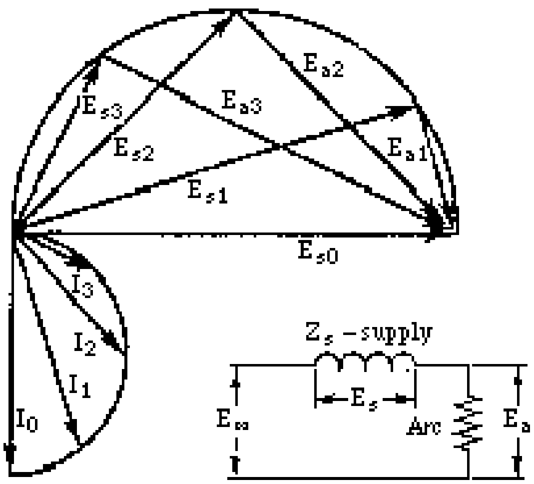


Figure 2
Vector Diagram of
Voltages and Currents, with
division between Source Arc Drops as
Arc Length is varied.

Table I
Maximum power in Three Phase Arc, **MW**

Bolted Fault, **kA**	System Voltage, **kV**					
	0.48	2.4	4.2	7.2	13.2	34.5
1	0.42	2.0	3.6	6.3	11.4	29.8
2	0.83	4.2	7.2	12.5	22.8	59.6
3	1.25	6.2	10.8	18.7	34.8	91.0
5	2.08	10.3	18.0	31.2	57.1	149.2
10	4.15	20.8	36.0	62.3	114.2	295.5
15	6.23	31.1	54.0	93.4	171.3	447.4
20	8.3	41.5	72.0	120.5	228.3	596.7
30	12.5	62.2	108.0	186.8		
40	16.6	83.0	144.0			
50	20.8	103.8	180			

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED…

Table II

Diameter of Arc Sphere vs. Arc Power

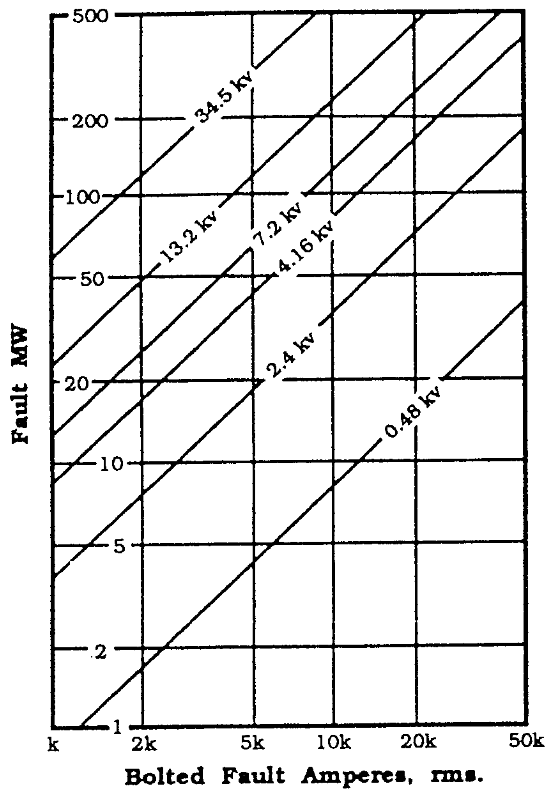
Arc Power, MW	Surface Area in^2	Sphere Dia. in.	Sphere Dia. cm.
0.25	0.415	0.363	0.922
0.5	0.829	0.514	1.308
1.0	1.65	0.725	1.84
2.5	4.15	1.14	2.90
5.0	8.29	1.62	4.11
7.5	12.44	1.99	5.05
12.5	20.73	2.57	6.55
25.0	41.46	3.63	9.22
50.0	82.92	5.14	13.06
75.0	124.38	6.29	15.98
100	165.84	7.27	18.47
150	248.76	8.88	22.56
250	414.60	11.49	29.18
500	829.20	16.1	40.89

Table III

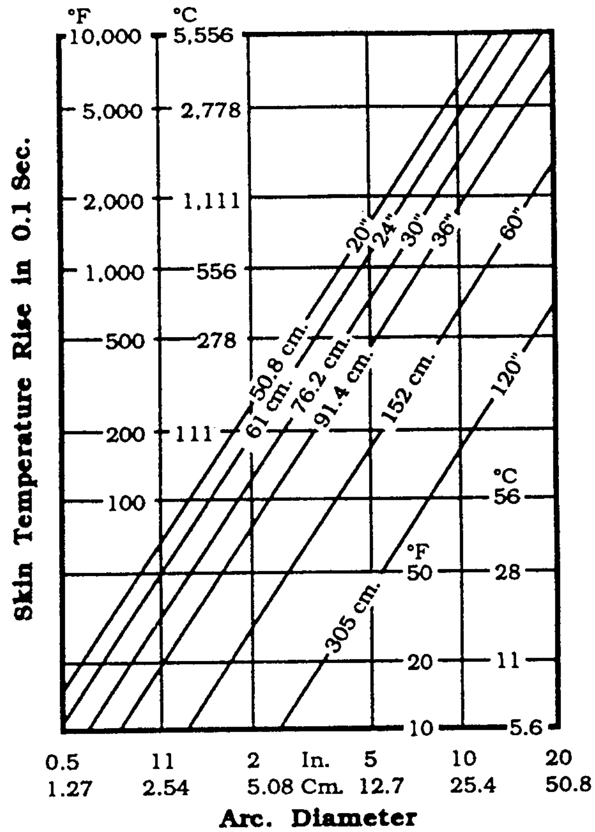
Temperature rise (°F) in skin in 0.1 Sec. (6 cycles)

Arc Sphere Diam. in.	Arc Sphere Diam. cm.	Distance from Center of Arc Sphere in inches: 20	24	30	36	60	120
1	2.54	63	43	27	19	7	2° F
2	5.08	249	173	111	77	28	7° F
3	7.62	557	387	248	172	62	16° F
4	10.2	988	686	439	305	110	28° F
6	15.2	2214	1537	983	633	245	62° F
8	20.3	3953	2745	1756	1220	439	110° F
10	25.4	6167	4282	2739	1903	695	172° F
12	30.5	8894	6176	3951	2745	987	248° F
16	40.6	15733	10925	6989	4840	1745	439° F

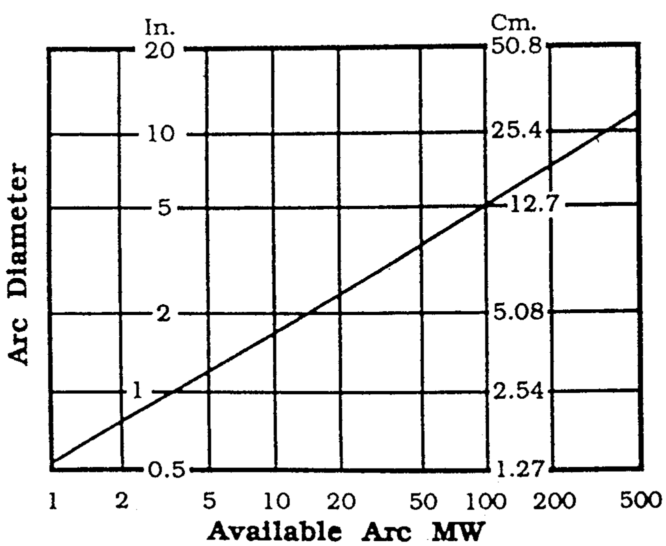
ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED…



Curve 1
Bolted Fault Amperes, Rms

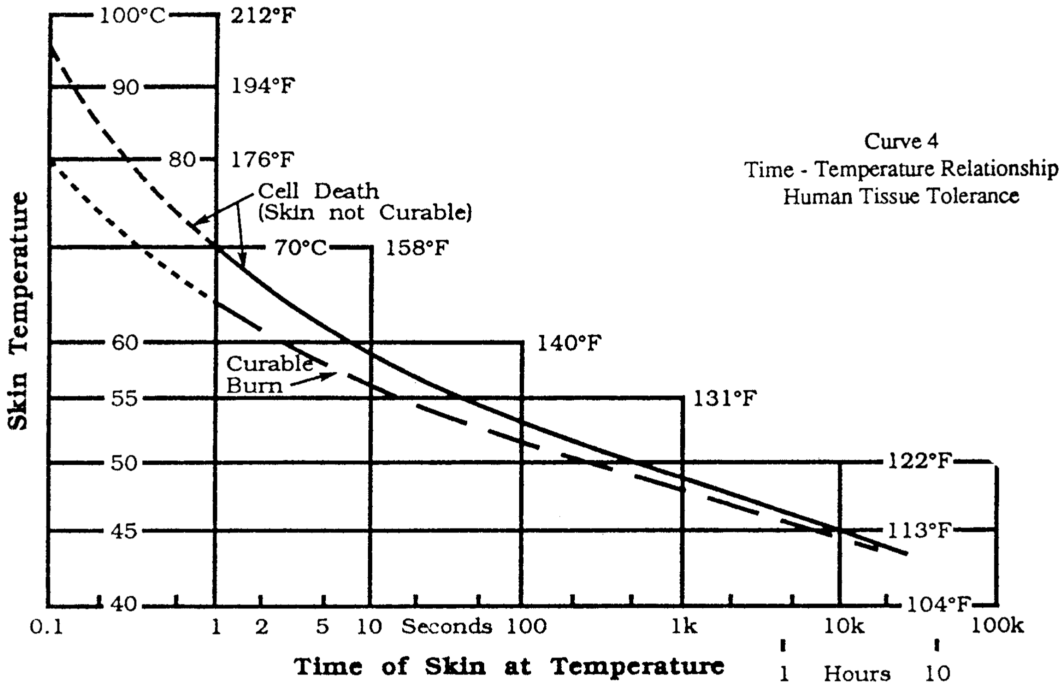


Curve 3
Skin Temp. Rise in 0.1 Sec.
for Various Distances



Curve 2
Arc Diameter Determination

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED...



By considering the total power in the arc to be absorbed by a layer of human epidermis at the respective surface of a sphere at the various radii, the results would be calculable by determining the temperature rise of a hollow sphere having a wall thickness of 1/16th (the average skin thickness) and a radius of the respective distances from the center of the source, for the range of the arc power being considered.

EFFECT OF TEMPERATURE ON HUMAN TISSUE AND CLOTHING

Human beings can exist in only a relatively narrow range close to normal blood temperature, 97.7°F (36.5°C). Ambience much below this level require the body to be insulated with clothing, and ambience slightly above this temperature can be compensated for by perspiration. Artz [4] shows that at as low skin temperature as 44°C, (110°F), the body temperature equilibrium mechanism begins to break down in about six hours, so cell damage can occur beyond six hours at the temperature. Between 44°C and 51°C, the rate of cell destruction doubles for each 1°C temperature rise, and above 51°C the rate is extremely rapid. At 70°C, only one second duration is sufficient to cause total cell destruction

Curve 4 shows the relationship between time to cell death and temperature, according to Artz [4]. A second, lower line in Curve 4 shows the time-temperature curve of a curable burn. The extrapolation of available data to times below 1 second indicates that any tissue temperature of 96°C and above for 0.1 seconds will cause incurable burns.

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED…

So the portion of Curve 3 above 96°C (205°F) represents total destruction of the tissue directly exposed. Recasting the intercepts of the line back into Curve 1, it is seen that the danger points for 36 inches (9) cm spacing (radius) of the various voltages are:

Table IV

Maximum Transformer Ratings for non-fatal Skin Burn, Various Voltages, at 36 in. Radius

Transformer **kV**	Bolted Fault Current Available, **kA**	Maximum Transformer Rating, **MVA**
0.48	40	1.9
2.4	8	1.83
4.2	4.2	1.75
7.2	2.6	1.75
13.2	1.4	1.74
34.5	0.54	1.75

Table V

Distance vs. Capacity of Source for Hazardous Burn at 0.1 Second

Distance **in.**	Distance **cm.**	Maximum Rating of Source, all Voltages **MVA**
20	50.8	0.54
24	61.0	0.78
30	76.2	1.21
36	91.4	1.75
60	152.4	4.86
120	304.8	19.4

Normally, the customary spacing varies directly with the voltage of the equipment. One would approach 480 Volt equipment much more closely than 34.5 kV equipment. However, the burn hazard is proportional to arc KW (source kVA), so we can inter-relate kVA of source with distance at which hazardous burning could occur as in table V.

Assuming standard transformer impedances, the transformer MVA ratings will be 10 percent of the arc MW values for 0.75 MVA transformers and larger, 8 percent for smaller ones, omitting motor contribution since it is of such short duration.

The following equations are developer to permit ready calculation without resorting to the figures within this Chapter.

$$D_c = \sqrt{2.65 \times MVA_{bf} \times t} \qquad \text{(Eq. 4)}$$

$$= \sqrt{5.3 \times MVA \times t} \qquad \text{(Eq. 5)}$$

$$D_f = \sqrt{1.96 \times MVA_{bf} \times t} \qquad \text{(Eq. 6)}$$

$$= \sqrt{39 \times MVA \times t} \qquad \text{(Eq. 7)}$$

where: D_c distance for a just curable burn,

D_f distance for a just fatal burn, ft.,

MVA_{bf} bolted fault MVA at point involved,

MVA transformer rated MVA, 0.75 MVA and over
For smaller ratings, multiply by 1.25

t Time of exposure in seconds.

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED…

Table VI

Distance vs. Energy Relationship

Distance in.	Distance cm.	Arc Energy - MW Curable	Arc Energy - MW Incurable
20	50	5.2	7
24	61	7.5	10
30	76.2	11.8	16
36	81.4	17	23
60	152.4	47	64
120	304.8	189	256

Table VII

Distance for Burn fron 0.1 Sec. Arc to be:

Xfmr MVA	Just curable D_c- ft.	Just curable D_c-in.	Just fatal D_f ft.	Just fatal D_f in.
0.3	1.01	12.12	0.82	9.8
0.5	1.30	15.6	1.06	12.7
0.75	2.00	23	1.63	19.5
1.0	2.30	27.6	1.87	22.5
1.5	2.82	33.8	2.29	27.5
2.0	3.26	39.1	2.65	32
3.0	4.00	48	3.24	39
5.0	5.15	62	4.18	50
10	7.28	87	5.91	71

Note that the burn hazard is related to the power or VA rating of the source, not the voltage of the circuit supplying the arc. It is the kW in the arc, not the supply voltage, which provides the burning energy.

Curve 3 and Table VI are based on exposure of 0.1 seconds, or 6 cycles of 60 Hz current, typical of older oil circuit breakers. For different exposure times, the temperature should be multiplied by the ratio of actual time to 0.1 second. There are numerous modifying conditions, including movement of an are to another location, or burning off of a conductor upstream. Such conditions cannot be relied on, so safety precautions need to be taken for the worst case conditions.

Expanding on Eq. 5 and Eq. 7 – Table VII is the reverse of Table VI which interrelates transformer MVA rating and distances for just curable and just fatal burns.

For times other than 0.1 Second, the distance should be multiplied by the square root of the actual time to 0.1 second.

No specific criteria exist for relating D_c to first and second degree burns, but distance ratios of 6 and 3 may be estimated, respectively, for these two classifications of skin burns.

A further problem evolves from the ignition of clothing from the heat of the arc. Depending on material and thickness, clothing will ignite at the 400°C to 800°C. It requires several seconds to remove clothing or snuff out the fire. Meanwhile, the victim is being subjected to direct contact of the flame temperature of the cloth, or about 800°c for this period of time. Serious deep burns, frequently fatal, result from this exposure.

Synthetics, such as polyester, rayon, acetate, and nylon, are likely to melt and drip in an arc situation. Clothing made from natural fibers, such as cotton and wool, will ignite and burn when impacted by a low-level electric arc (or other flame source).

ATTACHMENT E - ELECTRIC ARC BURNS CONTINUED…

Investigations conducted by Commonwealth Edison Co, in Chicago, IL., determined that the flame-resistant cotton clothing is a good compromise between three sets of characteristics. First, the material is self-extinguishing upon removal of heat source and is an acceptable thermal barrier which prevents heat flux from causing serious burn injuries. Second, the garments are able to "breathe," i.e., they permit normal perspiration to condense and be absorbed. Third, the flame-resistant properties must perform for the life of the garment even after many washings.

Duke Power Co. has tested heavyweight (11 oz. per yard or more) cotton and wool garments as well as flame resistant clothing. The conditions present during the tests involved a 10 cycle (0.167 sec), 3.8kA electric arc, 12 inches in length, and located 12 inches away from the test material. The heavyweight cotton and wool did not ignite and meets the requirements of OSHA 1910.269(1)(6)(iii) as flame resistant. The American Society for Testing and Materials has adopted a new standard, ASTM F1506-1994, for clothing to be worn for the protection of electrical workers who could be exposed to an electric arc. Successful testing to the Duke Power Co. arc test and the vertical flame test specified in ASTM F1506 should qualify such clothing as flame resistant meeting the requirements of OSHA 1910.269(1)(6)(iii).

Additionally, electric arcs expel droplets of molten terminal metal, which showers the immediate vicinity, similar to, but more extensive than arc welding. These droplets, at temperatures of 1000^{o}C or more, will ignite clothing instantly, and cause spot burns on contact. The eyes are especially susceptible to these droplets. Serious cornea damage could result if safety glasses were not worn.

PROTECTION MEANS

Suitable protection for use where arcing sufficient to cause curable burns include the following:

Leather, rather than canvas, gauntlet gloves used over protective rubber gloves;
Safety glasses;
Leather safety shoes;
Non conducting hard hat;
Flame resistant clothing or covering over normal work-clothes

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(2) M.G. Drouet and F. Nadeau: "Pressure Waves due to Arcing Faults in a substation." IEEE TP F79 172-8

(3) W.R. Wilson: "High Current Arc Erosion of Electric Contact Materials." AIEE TP 55-215

(4) R.R. Conrad & D. Dalasta: "A New Ground Fault Protection System for Electrical Distribution Circuits." I&CP Conference, May 22 –25, 1967 and published in 1967 IGA Transactions

(5) 5R.D. Hill: "Channel Heating in Return Stroke Lighting" Journal of Geophysical Research, Jan 20, 1971

ATTACHMENT F - PRESSURES DEVELOPED BY AC ELECTRIC ARCS

INTRODUCTION

As well as flash burns from electric arcs (1), nearby personnel are propelled away from such arcs by pressure developed by the arcs. This can cause falls and other injuries, as well as damage to nearby situations. A relationship is developed between arc current and pressure for an applicable range of distance.

For familiarization with some units used for pressures used in the SI (metric) the following table may be useful:

Standard International
1 Newton (N) = 0.2248 pound force (lbf)
1 Newton/m^2 = 0.0209 lb/ft^2
1 Atmosphere = 2116 lb/ft^2
= 1.0125×10^5 N/m^2

BACKGROUND

Reports of the consequences of electrical power arcs in air include descriptions of the rearward propulsion of personnel who were close to the arc. In many cases, the affected people do not remember being propelled away from the arc, even some not remembering the arc occurrence itself. The relative infrequency of power arcs has tended to minimize interest in determining the nature and magnitude of this pressure. Not only than, but the heat and molten metal droplet emanation from the arc cause serious burns to nearby personnel (1), which also tend to reduce interest in the rearward propulsion and pressures generated.

Another consequence of arcs is structural damage. One power arc in a substation of the Quebec Hydroelectric system caused collapse of a nearby substation wall. To determine the magnitude of pressure generated by the arcing fault, M.G. Drouet and F. Nadeo, of the Institute de Recherche de I'Hydro-Quebec were assigned to develop theoretical and practical bases for this phonomenon. The results of their work are described in a 1979 paper, "Pressure Waves due to Arcing Faults in a Substation" (2) Drouet and Nadeau's work showed a disparity of somewhat greater than one order of magnitude between the theoretical and actual measured pressures, a phenomenon attributed by a discusser, Dr. Nettleton, as due to a very high frequency component of pressure not recorded by measuring apparatus. Regardless of this, they measured amplitudes of pressure from 100kA, 10kV arc that reached about 400 lb/ft^2 (2×10^4 N/M^2) at a distance of 3.3ft. (1m). This pressure is about ten times the value of wind resistance which walls are normally built to withstand. Factory Mutual guidelines indicate that overpressures in the range of 300 to 450 lb/ft^2 (1.4×10^4 N/m^2 to 2.2×10^4 N/m^2) are sufficient to shatter non-reinforced concrete or cinder block walls.

Pressures on projected areas of individuals at 2ft. (0.6m) from 25 kA arc would be about 160 lb/ft^2 (7.7×10^4 N/m^2). This is sufficient to place a total pressure on the front of an individual of 480 lbs or 2100 N. Pressures in the 350 lb/ft^2 (1.6×10^4N/m^2) are damaging to human ears. Where anticipated overpressure exposures exceed 200 lb/ft^2 (1×10^4N/m^2), the use of ear protection is indicated. The protection should preserve audible communications, i.e., through the use of electronic communication head-sets or their equivalent.

ATTACHMENT F - PRESSURES DEVELOPED BY AC ELECTRIC ARCS continued…

The pressures from an arc are developed from two sources, the expansion of the metal in boiling, and the heating of the air by passage of the arc through it. Copper expands by a factor of 67,000 in vaporizing, much as water expands about 1670 times in becoming steam.[3] This accounts for the expulsion of near-vaporized droplets of molten metal from an arc; these are propelled for distance of about 10 ft (3m). Expanding metal also generated plasma (ionized vapor) outward from the arc for distances proportional to the arc power. With copper, 53 J will vaporize 0.05 in^3 (0.328 cm^3) [4], producing 3350 in^3 (54,907 cm^3) of vapor. A single cubic inch (16.39 cm3) of copper vaporizes into a volume of 1.44yd^3 (1.098m^3). The air in the arc stream expands in warming up from its ambient temperature to that of the arc, or about 35,000°F (20,000°K). This heating of the air is related to the generation of thunder by passage of lighting currents through it.

Dr. R.D. Hill [5] developed theoretical pressures at distances of 0.75 to 4 cm. (0.295 to 1.575 in.) from 30 kA peak lighting stroke. These pressures ranged from 40 atmospheres down to 9 atmospheres. Dr. Hill's data were plotted on Figure 1, on log-log scale and the straight line of his points extrapolated to 100 cm (39.37 in.) distance, at which distance the pressure would have been 0.45 atmospheres. Multiply this 0.45 by the ratio of 200/30, to match the peak power of the Drouet-Nadeau (D-N) tests, the Hill data becomes 3 atmospheres, rather close to the D-N theoretical value of 2.7 atmospheres.

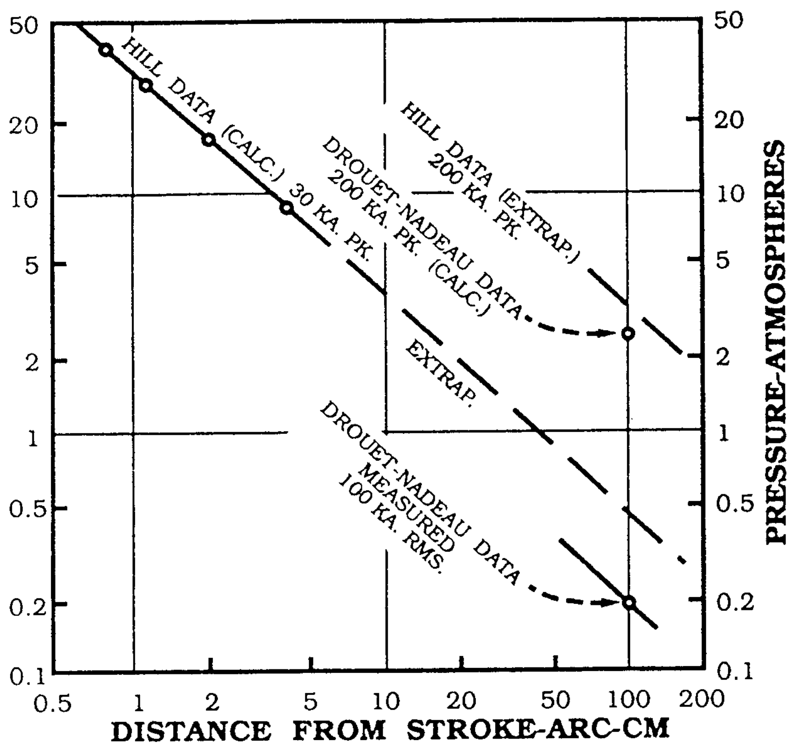


FIGURE 1
PRESSURE VS DISTANCE
FROM STROKE OR ARC

HILL DATA (CALC)
DROUET & NADEAU
DATA (CALC & MEAS)

ATTACHMENT F - PRESSURES DEVELOPED BY AC ELECTRIC ARCS continued…

The actual measured pressure, by D-N from a 200 kA peak, 100 kArms current, was 0.19 atmospheres, or 0.07 times the calculated theoretical pressure. Since this is the only available measured pressure level, it will be used to generate a family of lines, shown herein as Figure 2. In Figure 2 pressures are shown for arc currents ranging from 1 kA to 100 kArms, for a range of distances of 0.5 ft to 100 ft. (15cm to 30M) from the arc center to the point of interest. From this, the pressure may be determined for a 25kA arc at a distance of 2 ft. (60 cm) to be 160 lb/ft2 (7656 N/m2), etc. This pressure has at least one useful aspect, the individuals close to an arc are propelled rapidly away from the heat source, substantially reducing the degree of burn that they are exposed to.

The hot vapor emanating from the arc starts to cool immediately. While hot, however, it combines with the oxygen in the air, forming an oxide of the metal in the arc. These products continue to cool and solidify, and become minute particles in the air, appearing as smoke, black for cooper and iron, and grey for aluminum. The particles are still quite hot and will cling to any surface they touch, actually melting into many insulating surfaces they may contact. This is believed by many to be carbon particles. The oxide particles are most difficult to remove, as surface rubbing is not effective. Abrasive cleaning is necessary for plastic insulations, and a new surfacing compound must be applied, or leakage will be severe and would likely cause termination or splice failure within a few days.

Persons exposed to severe pressure from proximity to the arc are likely to suffer short-time memory loss, and not remember the intense explosion of the arc itself. This is a consequence of a brief concussion which interferes with the transfer from short-time to long-time memory. This phenomenon has been found true even for high-level electric shocks.

So it is evident that persons working in conditions where power arcing is possible should be protected not only against arc burns but against falling (as from ladders and scaffolds) and against ear damage.

A simple equation was developed to define the family of curves shown in Figure 2, and is defined as follows:

$$P = 11.65 \times \frac{(kA)}{R^{0.9}} \qquad \text{(Eq. F1)}$$

Where P = Pressure developed by arc in lbs./ft.^{2}

kA = Short circuit current$_{rms}$ in kiloamps

R = Distance in feet from arc center to area of interest

ATTACHMENT F - PRESSURES DEVELOPED BY AC ELECTRIC ARCS continued…

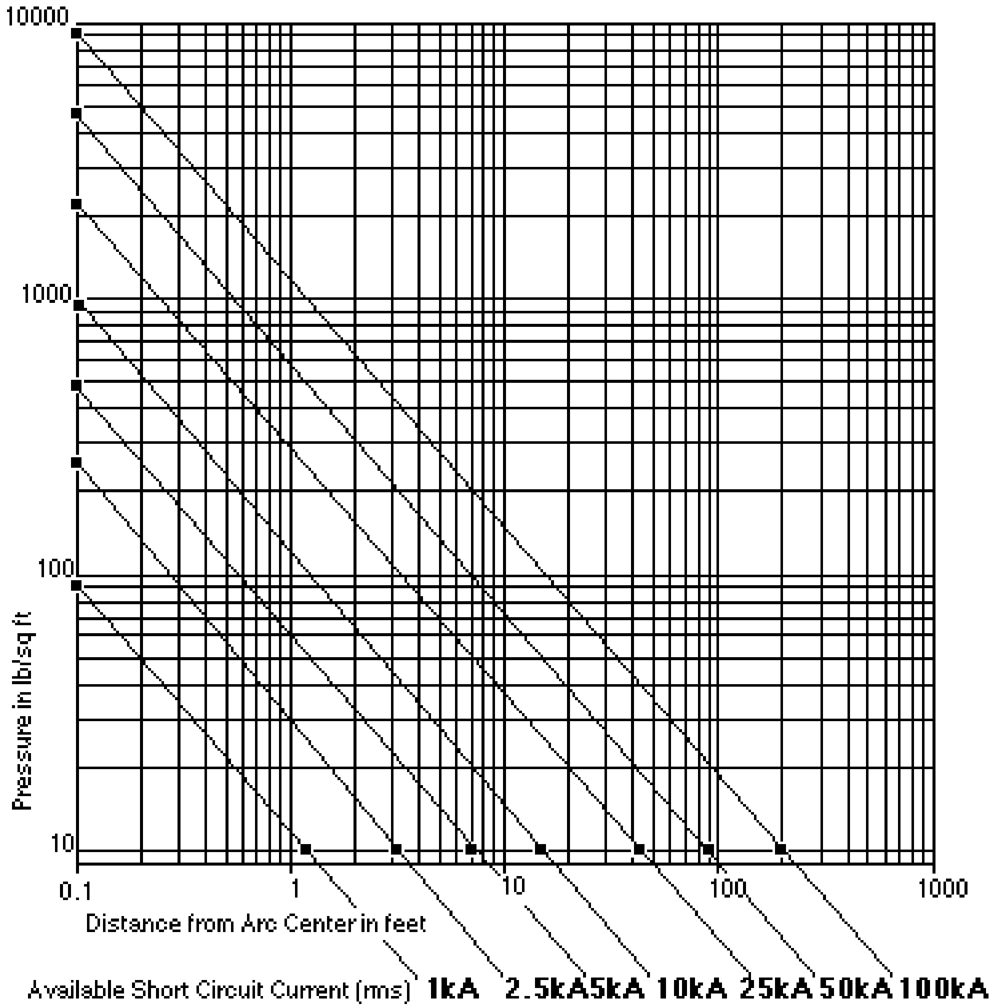


Figure 2
Short Circuit Overpressure
Pressure (lb/sq ft) vs Distance from Arc (ft)
Current in Kiloamperes rms

REFERENCES

(1) R.H. Lee: "The Other Electrical Hazard –Electrical Arc Blast Burns" IEEE TP IPSD 81-55.
(2) M.G. Drouet and F. Nadeau: "Pressure Waves due to Arcing Faults in a Substation" IEEE TP F79 172-8
(3) W.R. Wilson: "High Current Arc Erosion of Electric Contact Materials" AIEE TP 55-215
(4) R.R. Conrad & D. Dalasta: "A New Ground Fault Protection System for Electrical Distribution Circuits." I&CP Conference, May 22-25, 1967 and published in 1967 IGA Transactions
(5) R.D. Hill "Channel Heating in Return Stroke Lightning" Journal of Geophysical Research, Jan 20, 1971

ATTACHMENT G - SAMPLE CALCULATION OF FLASH PROTECTION BOUNDARY

ARC ENERGY AND TEMPERATURE RISE

The following provides an explanation of the development of the arc energy temperature rise on a person's exposed skin due to the various strengths of electric arc blasts at various distances from the involved person. The formulae used in this explanation are from Ralph Lee's paper, "The Other Electrical Hazard, Electrical Arc Blast Burns," IEEE Transactions Industrial Applications, Vol. 1A-1B, No. 3 Page 246, May/June 1982. The calculations are based on worst case arc impedance Attachment e.

BASIC EQUATIONS FOR CALCULATING FLASH PROTECTION BOUNDARY DISTANCES

The short-circuit symmetrical amperes from a bolted 3-phasefault at the transformer terminals is calculated with the following formula:

$$I_{sc} = \left\{ \left[\text{MVA base x } 10^{6}\right] \Big/ \left[\sqrt{3} \text{ x V}\right] \right\} \text{ x } \left\{ 100 \big/ \%Z \right\} \qquad \text{(Eq.1)}$$

Where: I_{SC} is in Amperes; V is in Volts; and % Z is based on the transformer MVA.

A typical value for the maximum power in MW in a three phase arc may be calculated using the following formula:

$$P = \left[\text{Maximum bolted fault in MVA}_{bf}\right] \text{ x } 0.7072 \qquad \text{(Eq.2)}$$

The flash protection boundary distance is calculated in accordance with the following formulae:

$$P = 1.732 \text{ x V x } I_{SC} \text{ x } 10^{-6} \text{ x } 0.707^{2} \qquad \text{(Eq.3)}$$

$$D_{C} = \left[2.65 \text{ x MVA}_{bf} \text{ x t}\right]^{1/2} \text{ ; or} \qquad \text{(Eq.4)}$$

$$D_{C} = \left[53 \text{ x MVA x t}\right]^{1/2} \text{ ; or} \qquad \text{(Eq.5)}$$

Where:

D_c = Distance in feet of person from arc source for a just curable burn, i.e., skin temperature rise over a 30°C ambient remains less than 50°C.

MVA_{bf} = Bolted fault MVA at point involved

MVA = MVA rating of transformer. For transformers with MVA ratings below 0.75 MVA, multiply the transformer MVA rating by 1.25.

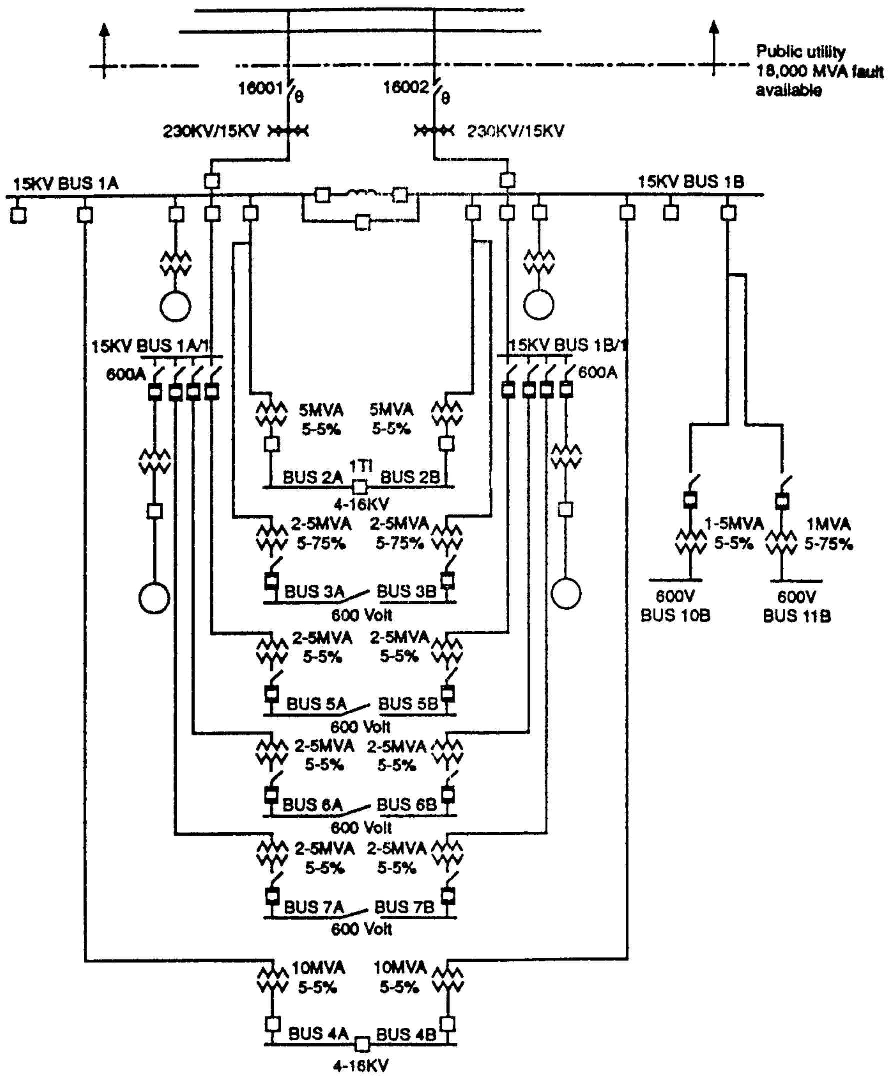
t = Time of arc exposure in seconds.

ATTACHMENT G - SAMPLE CALCULATIONS OF FLASH PROTECTION BOUNDARY CONTINUED…

The clearing time for a current limiting fuse is approximately 1/4 cycle or 0.004 seconds. The clearing time of 5kV and 15kV circuit breakers can be 0.110 seconds or 7.5 cycles in a 60 Hz system. This time consists of 0.016s, for device 50 relay operation 0.014s for device 86 relay operation, and 0.080s for the breaker contacts to clear the arc. The normative values used in these calculations are 0.1 seconds and 6 cycles.

SINGLE LINE DIAGRAM OF A TYPICAL INDUSTRIAL COMPLEX

The single line diagram illustrates the complexity of a power distribution system in a typical large industrial plant. It is the basis used to evaluate the flash burn hazards at various locations in the distribution system and to perform the sample calculations that follow.



ATTACHMENT G - Sample Calculations Of Flash Protection Boundary CONTINUED…

Many of the electrical characteristics of the system and equipment are shown in Table 1. The sample calculation is made on the 4160 volt Bus 4A or 4B. Table 1 tabulates the results of calculating the flash protection boundary each part of the system.

1. Calculation is on a 4160 volt bus
2. Transformer MVA (and base MVA) = 10 MVA
3. Transformer impedance on a 10 MVA base = 5.5%
4. Circuit breaker clearing time = 6 cycles
5. Based on (Eq. 1), calculate the short circuit current:

$$I_{sc} = \left\{ \left[10 \times 10^{6}\right] \Big/ \left[\sqrt{3} \times 4160\right] \right\} \times \left\{ \frac{100}{5.5} \right\}$$

$$I_{sc} = 25,000 \text{ Amperes}$$

6. Based on (Eq. 3), calculate the power in the arc

$$P = 1.732 \times V \times I_{sc} \times 10^{-6} \times 0.707^{2}$$

$$P = 1.732 \times 4160 \times 25,000 \times 10^{-6} \times 0.707^{2}$$

$$P = 91 \text{ MW}$$

7. Based on (Eq. 4), calculate the curable burn distance:

$$D_c = \left[2.65 \times \left(MVA_{bf}\right) \times t\right]^{1/2}$$

$$D_c = \left[2.65 \times \left(1.732 \times 4160 \times 25,000 \times 10^{-6}\right) \times t\right]^{1/2} = 6.9 \text{ feet} \Rightarrow 7.0 \text{ feet}$$

Or, using (Eq. 5), calculate the curable burn distance using an alternate method:

$$D_c = \left[53 \times MVA \times t\right]^{1/2}$$

$$D_c = \left[53 \times 10 \times 0.1\right]^{1/2} = 7.28 \text{ feet}$$

ATTACHMENT G - Sample Calculations of Flash Protection Boundary CONTINUED…

Table 1

Flash Burn Hazards at Various Levels in a Large Industrial Plant

1	2	3	4	5	6	7
Bus Nominal Voltage Levels	System or Transformer MVA	System or Transformer %Z	Short Circuit Symmetrical Amperes	Arc MW	Fault Clearing Time-Cycles	Distance from Arc to Skin**
230,000 V	9000	1.11	23,000	4000	6.0	46.0
13, 800 V	750	9.4	31,300	374	6.0	14.1
Load Side of all 13.8 kV Fuses	750	9.4	31,300	374	1.0	5.8
4,160 V	10	5.5	25,000	91	6.0	7.3
4,160 V	5	5.5	12,600	45	6.0	6.7
Line Side of Incoming 600 V Fuse	2.5	5.5	44,000	23	6.0	3.7
600 V Bus	2.5	5.5	44,000	23	0.25	0.74
600 V Bus	1.5	5.5	26,000	27	6.0	2.8
600 V Bus	1.0	5.57	17,000	17	6.0	2.3

**Distance limits skin temperature to a curable burn, i.e., limits skin temperature rise to 80°C or less

ATTACHMENT H - SAMPLE CALCULATIONS OF ENCLOSED AC ARC OVERPRESSURES

INTRODUCTION

Converting copper conductors into a plasma as a consequence of short circuit energy can be approximated using a few assumptions. Calculations which use these assumptions can give an estimated pressure change for a fixed volume.

CONDITIONS

Initial conditions consist of an electric circuit that has sustained a solid/bolted polyphase fault of 110kA which is presumed to flow for 5 cycles within an enclosed cubicle. Shock wave effects are neglected in favor of a uniform pressure rise. This event is presumed to occur adiabatically.

CHARACTERISTICS OF COPPER

Melting Point	1085°C
Boiling Point	2567°C
Specific Heat, Solid	0.0923 Calories/gram at 20°C (varies with temperature)
Latent heat of fusion	49.0 Calories/gram
Latent Heat of Vaporization	1130.3 Calories/gram
Atomic Weight	63.5 grams/mole
Density	8.92 grams/cc^3

EQUIVALENCIES

238.9 Calories/gram	1.0 kilojoule/gram
61.3 in3	1.0 Liter volume
1 Mole	6.02×10^{23} Atoms$_{Cu}$ (Molecules)
1 Mole Volume	22.4 Liters at standard conditions

CALCULATIONS

1. To vaporize 1 gram of Copper from 20°C (C_P = 0.0923) to 1085°C (C_P = 0.1189); (C_{Pavg} = 0.1056)

   $Q_{total} = Q_1 + Q_2 + Q_3 + Q_4$

   Q_1 = 0.1056 x (1085 - 20) = 112.5 Calories

   At 1085°C, Q_2 = 49.0 Calories

   From 1085°C to 2567°C

   Q_3 = 0.118 x (2567 - 1085) = 174.9 Calories

   Q_4, heat of vaporization = 1130.3 Calories

   Q_{total} = 1466.7 Calories/gram

ATTACHMENT H - SAMPLE CALCULATIONS OF ENCLOSED AC ARC OVERPRESSURES Continued...

2. Converting: Calories / gram to Kilojoules/gram

$$\frac{1466.7 \text{ Calories /gram}}{238.9 \text{ Calories /Kilojoule}} = 6.14 \text{ kJ /gram}$$

3. Presuming 100% offset, then I_{max} = 110 kA and the average fault current I_{avg} = 55 kA.
   The duration of the arc is 5 cycles, such that t = 5/60 sec. = 0.0833 sec.
   The voltage drop across the arc is E_{arc} = 200 volts.

4. Converting I_{sc} to equivalent weight of copper, W_{cu}

   $Q = I_{sc} \times E_{arc} \times t$ (duration of arc in seconds)

   $Q = 55 \times 10^3$ amps x 200 volts x 0.0833 sec. = 916.3 kJ

$$W_{cu} = 916.3 \text{ kJ} \times \left(\frac{1 \text{ gram}_{cu}}{6.14 \text{ kJ}} \right) = 149.3 \text{ gram}_{cu}$$

5. Determine quantity of moles (M)
   M = Weight / Atomic weight = 149.3 gram x (63.5 grams / Mole)$^{-1}$ = 2.35 $Mole_{cu}$

6 Equal volumes of gasses at the same temperature and pressure contain the same number of molecules.
Therefore, to find the volume (V) of the copper plasma at 2567°C:

$$V = 2.35 \text{ Moles} \times \left(\frac{22.4 \text{ liters}}{1 \text{ Mole}} \right) \times \left(\frac{2567° + 273°}{273°} \right) = 548 \text{ liters}$$

$$548 \text{ liters} \times \left(\frac{61.3 \text{in}^3}{1 \text{ liter}} \right) = 33{,}590 \text{ in}^3; \text{ or } 33{,}590 \text{ in}^3 \times \left(\frac{1 \text{ft}^3}{1728 \text{ in}^3} \right) = 19.4 \text{ ft}^3$$

7. The change in pressure (ΔP) within a fixed volume, for example, 5000 liters at 2567°C is:

$$\Delta P = \left(\frac{548 \text{ liters}}{5{,}000 \text{ liters}} \right) \times 14.7 \text{ psi} = 1.61 \text{ psi}$$

REFERENCES

1. Handbook of Physics and Chemistry, 1989 and 1992
2. Metals Reference Handbook, 9th Ed. 1979; American Society of Metals

ATTACHMENT I DEVELOPMENT OF PPPL ELECTRICAL SAFETY CRITERIA

PPPL isolation criteria originated as a design requirement for stored energy systems having high voltage/energy. Later it was represented as a general requirement imposed when high voltage/energy systems were operating. Current isolation criteria requires redundant, independent barriers between the hazard of high voltage equipment or circuits and the worker. Redundant barriers may also be necessary to reduce the hazard of low voltage systems. The probability of operator error should be evaluated.

ENERGY-ISOLATION CRITERIA DEVELOPMENT

1959-1960

PPPL Drawing No. SK5020, dated December 28, 1959 entitled "Isolation Practices on High Energy Storage Systems" shows design features that were considered to be acceptable for both equipment protection and personnel safety. These design features were available in contemporary high voltage and high energy experimental apparatus. It is the earliest document in our files that has the PPPL criterion of separation of energy sources and workers:

> **"The purpose of this isolation (practice on high energy systems) is to prevent damage to building electrical systems, control panels outside the high energy area in the event of faults. Such equipment, as well as personnel will not be damaged or injured in the event of any two possible simultaneous equipment faults." (Underlining as shown on PPPL SK5020)**

It is clear that a third barrier is contemplated in this 1959 failure criterion. The multiple barrier concept is illustrated in FIGURE 1…..

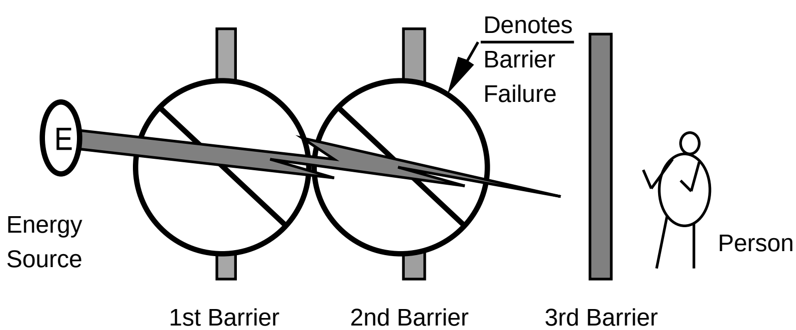


FIGURE 1

The earliest version of the PPPL Safety Manual in our files is a product of C-Stellarator Associated and it is dated April 11, 1960. This manual has a "General Requirements" section for Operating Conditions, which is different than that of the PPPL SK5020. The manual states:

> **"In general, two concurrent failures of components must occur before the equipment and personnel are endangered."**

ATTACHMENT I DEVELOPMENT OF PPPL ELECTRICAL SAFETY CRITERIA CONTINUED…

The condition is satisfied if two barriers or energy isolation devices (EIDs) are provided between the energy source and the worker. When both barriers fail, the worker is endangered. The concept is illustrated diagrammatically in FIGURE 2.

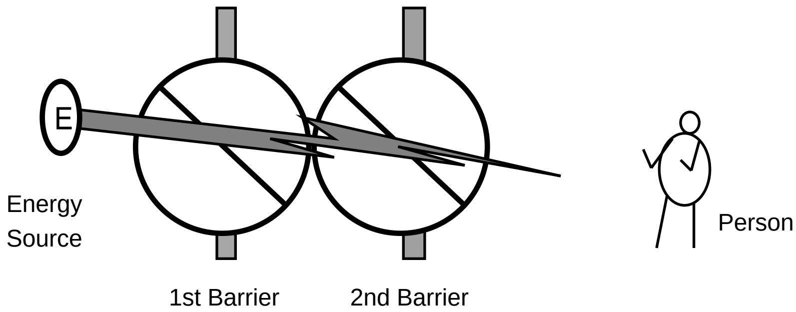


FIGURE 2

1975

The 1975 version of the Safety Manual restated the 1959 criterion. It was still in the form of an operating recommendation:

> **"When equipment is in operation, all parts accessible to personnel should be isolated from high voltage and high energy… such that two simultaneous (and independent) failures will not endanger the personnel involved. Failure of one isolating component should be improbable and independent of failures of other components."**

This condition can be satisfied only if three barriers or EIDs exist between the energy source and the worker which brings us back to FIGURE 1.

1982-83

The authors of the 1982/83 Revision of 1 of Section 2.0, HSD-5008, the PPPL Health and Safety Manual, reaffirmed the three-barrier rule (FIGURE 1) as a requirement when applied to Operating Conditions. It also provided two new ways to accept high voltage isolating devices.

A) Intervening components which have been manufactured as a standard product line and which have been type-tested… and installed… (per) generally accepted good engineering practices and (industry consensus standards).
B) PPPL products that have been individually tested and conform to (industry consensus standards).

1986

In 1986, the Department of Energy provided a quantified definition of the word 'credible," i.e., having a probability equal to or less than $1x10^6$ /year, to describe the likelihood of postulated failures. The term "simultaneous" was recognized to include conditions that lead to failures over time, such as position switcher that have become loose or misaligned from vibration or lack of maintenance.

ATTACHMENT I DEVELOPMENT OF PPPL ELECTRICAL SAFETY CRITERIA CONTINUED…

1988

Isolation criteria were improved in the 1988 Revision 2 of Section 2.0 through the introduction of barriers, barrier failure analysis techniques, including part of the IEEE single-failure criterion, and examples of acceptable barriers. For the first time, barrier philosophy included the DOE's limiting definition of "credible" events. Using this relatively new definition of credible, acceptance criteria for barriers became possible.

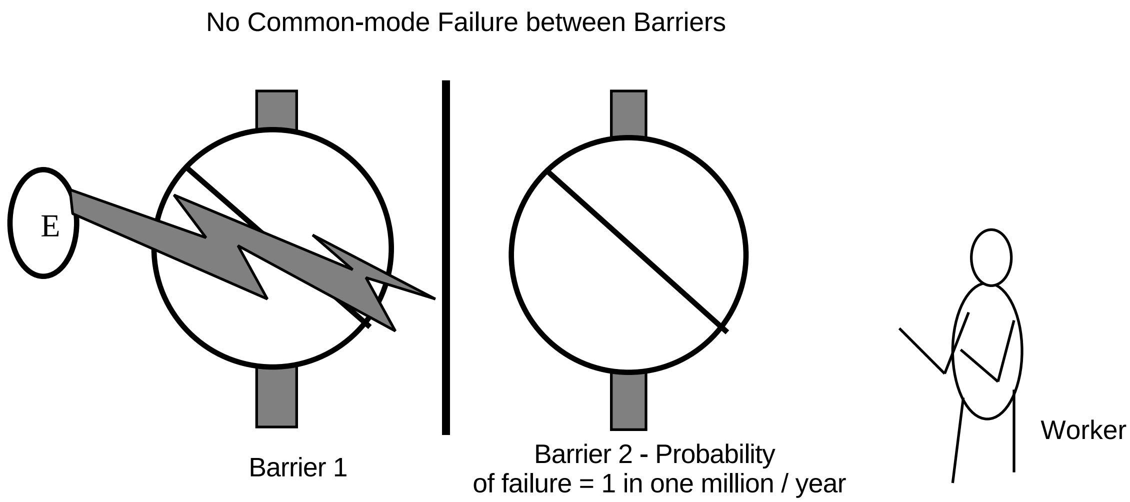
For all practical purposes, the term 'energized", "live", and "operating" represent the same hazards when referring to electric conductors. We presume, at any given time, some parts of the electrical systems at PPPL may be energized. Even if the offsite 138kV and 26kV power systems were shut down and isolated, we must consider the on-site generators, UPS's, and stored energy systems as potential sources of energy. We conclude that any workable isolation criteria must consider those circumstances during the facility or project's life-cycle under which workers approach potentially live electrical components. The high voltage criteria are:

> **"2.5.4.1 Energized parts of high-voltage (above 600V ac or dc) equipment and circuits shall be isolated from surfaces exposed to personnel by two acceptable, independent energy barriers, one of which shall be designed to survive any credible (i.e. having a probability ≥ 1 x 10^6/yr) failure mode. Two acceptable, independent energy barriers are required between all undergrounded conducting parts that extend from high-voltage/energy sources or enclosures to areas or devices that are accessible to personnel. A safety barrier may be used in lieu of one of the above energy barriers."**

The criterion for circuits operated at 600 volts or below is:

> **"2.5.4.3 Energized parts of low-voltage (600 V ac or dc or below) equipment and circuits shall be isolated from surfaces exposed to personnel by at least one acceptable, independent energy barrier."**

Illustrated as follows:



ATTACHMENT I DEVELOPMENT OF PPPL ELECTRICAL SAFETY CRITERIA CONTINUED…

EQUIPMENT FAILURE AND HUMAN ERROR

There are two categories of equipment failures. Time dependent failures are in the first category. They are quantified as failure rates, e.g., one in two hundred per month or 5×10^{3}/month.

Demand failures are the second category of equipment failures. They are stated as unitless probabilities, e.g. one in twenty-five hundred or 4×10^{4}. Demand failures are most often used to quantify the failure of components that are required to change state. Components that are arranged in series form an "and" logic gate. The demand failures are multiplied to determine the demand failure of the set. For example, UL listed, molded-case circuit breakers are used as energy isolation devices when they are placed between an energy source and a worker. Representative samples of circuit breakers most survive 2500 test-operation under UL test procedures without failure. The probability of a demand failure of two such breakers connected in series, presuming no common mode failures is $(4 \times 10^{-4}) \times (4 \times 10^{-4}) = 1.6 \times 10^{-7}$.

A safety-tagged hard ground may be placed on the ungrounded circuit-conductors in lieu of LO/TO on the second circuit breaker. The demand failure for fixed grounding-switches is the same as that of circuit breakers. However, the demand failure for currently-tested portable grounding sticks is considered to be on the order of 2×10^{-4}.

The probability of equipment demand failure should be evaluated in conjunction with the probability of human error. Human error is quantified as the probability that an authorized person fails to correctly perform a task such as restoring a system to the correct configuration after maintenance or testing.

In a probabilistic risk assessment (PRA), the probability of human error while performing a task on electrical equipment typically is conservatively assumed to be about 0.03 per task. This value may be reduced if any of the following recovery factors apply:

a. Errors can be assessed as recoverable by a factor of 0.01 by a compelling signal or activity such as the use of LO/TO or completion of accessing procedure before access to equipment is permitted.
b. Errors are recovered by a factor of 0.1 by post-activity tests if the tests are performed correctly. Examples include testing for "0" volts in a LO/TO procedure or the observation of currently calibrated instruments or meters.
c. If a second qualified person, or safety watch, is required to directly verify component status after completion of the activity by the original performance, then a recovery factor of 0.1 applies. No recovery credit is given for either activity unless a written check-off list is used during the activity.
d. If a shift or daily check of component status is required using a written check-off list, than a recovery factor of 0.1 applies to the probability of human error.

If all these recovery factors are applied to a task, then the risk of human error is reduced to a probability of $(0.03) \times (0.01) \times (0.1) \times (0.1) \times (0.1)$ which is on the order of 3×10^{-7}.

When the probability of human error is considered along with that of demand failure, they form an "or" logic gate which is additive. It is evaluated as $(3 \times 10^{-7}) + (1.6 \times 10^{-7}) = (4.6 \times 10^{-7})$. If an activity requiring protection by these series-connected breakers were to happen twice each year, then the probability of failure would be evaluated as $2/\text{yr} \times 4.6 \times 10^{-7} = 9.2 \times 10^{-7}/\text{yr}$. If the product of the number of annual occurrences of the activity and the sum of equipment demand failure and operator error exceed 1×10^{-6}/yr. Then additional energy isolation devices should be used in the activity to lower the probability of failure.

ATTACHMENT I DEVELOPMENT OF PPPL ELECTRICAL SAFETY CRITERIA CONTINUED…

VISIBLE BREAKS

The National Electrical Safety Code recognizes the circuit breakers in 5 kV or 15 kV metal-clad switchgear constitutes a visible break when placed in the withdrawn position.

It is PPPL practice to consider that the grounded metal shutters of drawout type metal-clad switchgear circuit breakers constitute two breaks or two energy isolation devices (EIDs) for the purpose of a failure analysis. If the shutters are of non-conducting material, then the likelihood of common-mode failures, such as arc-over may also need to be considered.

REFERENCES FOR ATTACHMENT I:

DOE STD 1030-92	“Guide to Good Practices for Lockouts and Tagouts”
PPPL Dwg. SK-5020	“Isolation Practices on High Energy Storage Systems”
ESH-001	“Safety, Accident Prevention, and Equipment Protection Tags”
ESH-016	“Control of Hazardous Energy Sources via Lockout/Tagout of Energy Isolation Devices”