ELECTRICAL
IGNITION DEMYSTIFIED

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Abstract – Electrical ignition is a major cause of accidental fires. The statistics belie conventional wisdom about electricity and related fires. The process of fire development, the energy associated with the electrical ignition, and the energy associated with the fuels which will burn are common areas of misconception.

Even among scientists, there is substantial misunderstanding about energy and how it influences fire and propagation in an electrical system. The paper looks at industry standards, prior publications, science, and laboratory validation to discern the proper process of electrical energy related fires and combustion.

INTRODUCTION

Electrical ignition is a major cause of accidental fires. The statistics belie conventional wisdom about electricity and related fires. [1]

- An estimated 25,900 residential building electrical fires were reported to fire departments within the United States each year. These fires caused an estimated 280 deaths, 1,125 injuries and $1.1 billion in property loss.
- Residential building electrical fires resulted in greater dollar loss per fire than residential building nonelectrical fires.
- In 79 percent of residential building electrical fires, the fire spread beyond the object where the fire started.
- The leading items most often first ignited in residential building electrical fires were electrical wire/cable insulation (30 percent) and structural member or framing (19 percent).

Myths about electrical ignition are often perpetuated by outdated information and lack of science, even by trained engineers, scientists, and investigators. [2] Some of the more common discrepancies have to do with the energy necessary for a fire and the fuel associated with an event.

The components of a fire are well-known including oxidizer, fuel, and ignition. Each contributes an aspect of mystic to the uninitiated in a particular scenario.

The difficulty arises in analyzing any time-related event. Time-related failures generally cannot be replicated. The premise has been argued and accepted in Federal court. [3]

Since time-related failures cannot be replicated, individual evaluations are the only experimental path. When laboratory analysis is conducted consistent with the scientific method of NFPA 921, experiments are performed individually so the conditions can be controlled and the effects can be observed. [4]

The combination of controlled experiments and analysis can then be used to determine composite effects. The procedure will be followed in the analysis of electrical energy ignition.

WHAT IS IGNITED?

NFPA 921 is the Guide for Fire and Explosion Investigation. Article 5.1.2.1.1 explains the process. [4]

> *Combustion of liquid fuels and most solid fuels takes place above the fuel surface in a region of vapors created by heating the fuel surface. The heat can come from the ambient conditions, from the presence of an ignition source, or from exposure to an existing fire. The application of heat causes vapors or pyrolysis products to be released into the atmosphere, where they can burn if in the proper mixture with an oxidizer and if a competent ignition source is present or if the fuel's autoignition temperature is reached.*

The process of a material being heated to release vapors is commonly referred to as "off-gassing". In reality the burning wood or plastics is not the solid material (other than in smoldering), but the off-gassing of products which then combust.

Do not try this at home. Gasoline will not ignite if a lighted match is thrown in the container; however, the fuel is ignited with a wick. The fuel is not volatile enough to reach a combustible mixture from the energy in a match, but the persistent heat of the wick drives off enough vapors to be ignited. A similar observation can be made with many plastics.

PLASTICS

Plastics are hydrocarbon derivatives, with a wide range of properties. The melting temperatures of some hydrocarbon derivatives are shown. [4]

Table 1 - Melting Points of Common Hydrocarbons

Material	***°C***	***°F***
Paraffin	49-75	120-167
Plastics nylon	176-265	349-509
Plastics PVC	75-105	167-221

The polymers are thermoplastics commonly found in electrical applications. Nylon is a higher temperature material while PVC is on the lower end of temperature ratings. PVC is the material most commonly found in standard thermoplastic wire such as THW and MTW, which are used in construction and in appliances.

The melting temperature is the condition where the solid material transitions to a fluid. Prior to that point, the vapors which were trapped or frozen have begun off-gassing. As anyone who has been in a wire storage facility on a warm day knows, vapors are escaping the plastics and detectable by the distinct odor of the material at much a lower temperatures than the melting value.

A reasonable temperature at which plastics are offgassing is identified by the Relative Temperature Index (RTI) [24]. This value is the temperature below which no properties of the plastic are lost. Three different RTIs are typically reported Electrical (Elec), Mechanical (Mech), and Mechanical Impact (Imp). The *lowest* of these typically indicates that offgassing has occurred in the plastic. RTIs for common plastics are typically between 65°C and 125°C.

PLASTIC SELF-EXTINGUISHING

Since they are hydrocarbons, thermoplastics will burn. Various materials are added to the thermoplastic to change the burn response.

Underwriters Laboratory (UL) has developed a flammability rating for materials which are commonly used in manufacture of products. [5] The rating is particularly relevant to the promotion of burning, should ignition occur.

UL 94 Flammability ratings

Rating	***Properties***
5VA Surface Burn	Burning stops within 60 seconds after five applications of five seconds each of a flame (larger than that used in Vertical Burn testing) to a test bar. Test specimens MAY NOT have a burn-through (no hole). **This is the highest (most flame retardant) UL94 rating.**
5VB Surface Burn	Burning stops within 60 seconds after five applications of five seconds each of a flame (larger than that used in Vertical Burn testing) to a test bar. Test specimens MAY HAVE a burn-through (a hole).
V-0 Vertical Burn	Burning stops within 10 seconds after two applications of ten seconds each of a flame to a test bar. NO flaming drips are allowed.
V-1 Vertical Burn	Burning stops within 60 seconds after two applications of ten seconds each of a flame to a test bar. NO flaming drips are allowed.
V-2 Vertical Burn	Burning stops within 60 seconds after two applications of ten seconds each of a flame to a test bar. Flaming drips ARE allowed.
H-B Horizontal Burn	Slow horizontal burning on a 3mm thick specimen with a burning rate is less than 3"/min or stops burning before the 5" mark. H-B rated materials are considered "self-extinguishing". **This is the lowest (least flame retardant) UL94 rating.**

The document, UL 94, identifies the ratings and the amount of burn that may occur.

A common misconception is that the materials are not flammable. Consider the highest level V-0 rating used with some PVC wires. A flame is applied for 10 seconds and the fire goes out within 10 seconds after removal of the flame. Typical V-1 insulation may burn for 60 seconds after two applications of flame for 10 seconds.

Even a flat piece of wood cannot be ignited with this small quantity of energy. The condition is a limited energy application like the diesel and match. When adequate heat is applied, the plastic material obviously will burn. Look at any appliance or house wire which has gone through a fire and the wire insulation has burned.

Babrauskas has shown the ignition temperature for PVC ranges from 308 to 440 °C [7]. The temperature is time dependent with a 1 second contact igniting at a temperature of 480°C and a 10 second contact reduced to

370°C. Similarly, the time to ignition is inversely proportional to the heat density. PVC has the lowest required heat density of the plastics tested. [6] In later research, he showed the ignition temperature range lowered to 250°C (482°F). [7]

Similarly, NFPA 921 states [4]

The initial fuel could be part of a device that malfunctions or fails. Examples include insulation on a wire that is heated to its ignition temperature by excessive current, or the plastic housing on an overheating coffee maker.

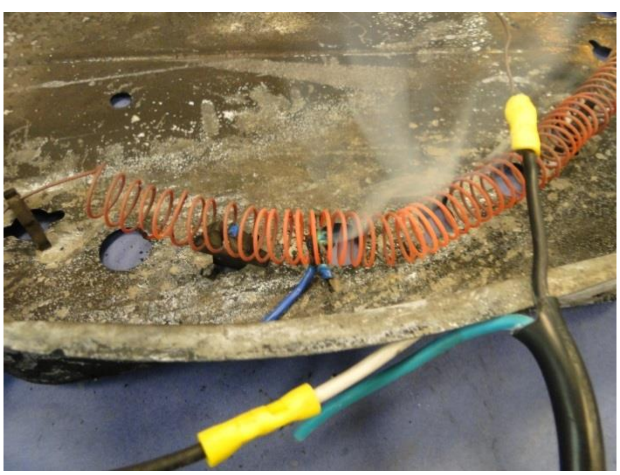
The fire statistics shown at the beginning validate that electrical insulation is the fuel first ignited in 30% of electrical related fires. Obviously, flame retardant PVC can be ignited by electrical failure.

An electrical fault may exist for some time causing the insulation to off-gas sufficient quantities of hydrocarbons which can be ignited. The U/L rating is called self-extinguishing, with a limited time exposure to a flame. Longer duration exposure to on-going electrical energy will ignite PVC insulation.

HOT WIRE IGNITION

Since electrical energy is persistent and a fault is concentrated along the conductor, a hot-wire ignition illustrates the effect better than a flame. A heating element is used to represent the electrical ignition device. The heater was connected to a standard 120 VAC circuit with circuit breaker.

Wire insulation consisting of thermoplastic PVC rated at 105°C with a V-1 flammability was taken from an appliance. The PVC was placed in contact with the hot-wire.



As the wire became hot, the insulation began to smoke, which is evidence of rapid off-gassing. Then the PVC flashed and free-burned. Just prior to ignition, a spark was observed. A spark is consistent with electrical faulting. The hot-wire operated at a temperature of approximately 400°C and a power intensity of approximately 39 W/cm.

HYDROCARBON DERIVATIVES

The amount of energy (heat) in a particular mass is not greatly different for any of the hydrocarbon derivative materials as shown in our book on *Failure Analysis [5]*. Therefore, just looking at heat effects, it would be difficult to tell the difference between propane and plastics that have burned. [4]

Table 2 - Comparison of Chemical Properties of Different Hydrocarbons

Measure	***Methane***	***Propane***	***Gasoline***	***Diesel***	***Poly-ethylene***	***Poly-styrene***	***Poly-ester***	***PVC***	***Toluene***
Energy/vol MJ/l	9 cmpres .038 gas	25.3 liq. .094 gas	34.2	37.3	42.6	43.5	35.6	25.2	42.4
Vaporization Liquid to gas	238	270							
Ener. density MJ/kg	53.6	49.6	46.4	46.2	46.3	41.4	26	18	66.2
Density liq'd g/ml	.415	.505	0.737	0.89	1.2	0.903			0.867
Sp Grav	0.55	1.55			.95	1.04	1.7	1.5	
LEL – UEL Vol %	5.3 - 15	2.1–10.4	1.4 – 7.6	0.6-7.5		1.1-6.1			1.2-7.1

As a relative comparison, TNT has energy density of 4.6 MJ/kg, while PVC used in wire insulation has an energy density 4 times greater at 18 MJ/kg. The difference in the materials is not the amount of energy that is available, but the release rate of that energy.

The energy in a PVC insulated wire was analyzed. An AWG 18 wire, with 600 volt insulation, rated at 105C with a V-1 rating was evaluated. This is the smallest size wire commonly used for a power conductor. A strip of insulation only 1 cm (0.4 in.) long has a volume of 0.085

cc. With a density of 1.4 g/cc, the specimen has a mass about 0.12 g and contains 2.14 kJ of energy.

A joule is explained by an apple which has a gravitational force (weighs) about 1 Newton, being lifted one meter (3.3 ft.). The energy from one centimeter of PVC insulation, if harnessed and efficiently converted, would be equivalent to the energy to raise the apple over 7,000 feet.

Another way to consider the quantity of energy is the temperature rise. A joule raises the temperature of 1 gram of cool, dry air by 1.8°F (1.0°C). The mass of the PVC sample is about 0.12 g. Linearly extrapolating all the energy in the sample to temperature would raise the temperature to about 16,000°C.

HYDROCARBON IGNITION ENERGY

The previous discussion quantified the amount of energy in hydrocarbons. The next question is how much energy is required to ignite petroleum based products. The results are summarized. [4]

Gas/Vapor	***Minimum Ignition Energy (mJ)***
Hydrocarbons	<0.28

Note, one milliJoule is 0.001 Joule. As an example of the extremely small amount of energy, an electrical arc of 0.2A at 10 V for ½ cycle produces 16 mJ, which is magnitudes greater than required for ignition.

Another illustration is the spark discharge from a human is about 10 mJ. Hydrocarbons and derivative vapors are extremely easy to ignite with minimal energy.

COMPOTENT IGNITION SOURCE

In order for ignition to occur, there must be adequate energy available from the source. A competent ignition source is defined [4].

An ignition source that has sufficient energy and is capable of transferring that energy to the fuel long enough to raise the fuel to its ignition temperature.

Clearly, hydrocarbon vapors can be ignited with very little energy as shown above.

A second part of the definition is raising the fuel to temperature. Two very different temperatures are involved. The autoignition temperature is where the material will combust due to ambient conditions. Autoignition is substantially higher that the combustion temperature associated with direct heat transfer.

The ignition of hydrocarbons and organic materials is determined by thermochemical decomposition sometimes called pyrolysis. Pyrolysis is defined [4].

A process in which material is decomposed, or broken down, into simpler molecular compounds by the effects of heat alone; pyrolysis often precedes combustion.

The thermochemical decomposition involves the simultaneous change of chemical composition and physical phase, is irreversible, and is the first step in gasification. The process is most commonly observed in organic materials exposed to high temperature. The process of pyrolysis is used to convert ethylene dichloride into vinyl chloride to make PVC. [8]

Melting of hydrocarbon derivatives is a prime example of thermochemical decomposition. The direct heat temperature correlates to the melting temperature. [9] Persistent energy applied at a temperature above melting over time results in a change of state, which releases hydrocarbon gas which is ignitable.

INSULATION IGNITION

Numerous authors have shown that electrical energy provides a competent ignition source under a variety of conditions.

Babrauskas has shown that a cause of electrical ignition of PVC insulation is current conducting across a carbonized path. PVC wire is susceptible to being charred at very low temperatures only slightly above the melting point. The plastic becomes semi-conducting at 160°C after a short term of only 10 hours. Longer term failures occur in 1 month at the very low temperature of 110°C, which is very significant since the wire has a rating of 105°C. [7]

The propensity to failure leads to an interesting observation that the UL and IEC temperature classifications are “unduly optimistic”. [7]

The paper includes research by Stricker showing PVC insulations off-gas at temperatures much lower than their rating, and none of the 90 or 105°C rated PVC insulation should be operated at greater than 71°C. [7]

The ignition temperature for pure PVC is very high, but wire insulations have different formulations. The auto ignition temperature has been shown to vary from 250 – 454°C. The piloted ignition range is 240-422°C. [7]

A fascinating observation is quoted,

In general, ignition of PVC wires/cables will occur due to electrical mechanisms at much lower temperatures *than those needed to ignite the polymer in the absence of electric current…* [7]

PARALLEL / SERIES FAULTS

Shea addresses arcing faults and their impact on circuit protective devices. Parallel faults exist between a line and grounded conductor. These are commonly called a short. [10,11]

Parallel fault current depends on the circuit impedance including the impedance of the short path between conductors. Sputtering arcs are intermittent and consume low current. In many cases, the current in parallel faults is not sufficient to trip standard circuit breakers or fuses. [10, 11]

Series faults are unintended arcing in series with the line or the neutral. These often result from a poor connection which my glow. The glow can cause PVC insulation to char. The copper oxide formed from the high resistance connection reaches temperatures in excessive of 1235°C, the melting temperature of copper oxide. Flame retardant additives such as antimony also contribute to char.

Shea makes an interesting quote.

Starting at room temperature, when PVC wiring is burned, it generally chars and self-extinguishes the flame. However, if the insulation is at an elevated temperature, particularly near or above its melting point, 180°C, the material does not self extinguish but readily burns. [10,11]

In addition the plasticizers begin to decompose and off-gas at temperatures as low as 105°C.

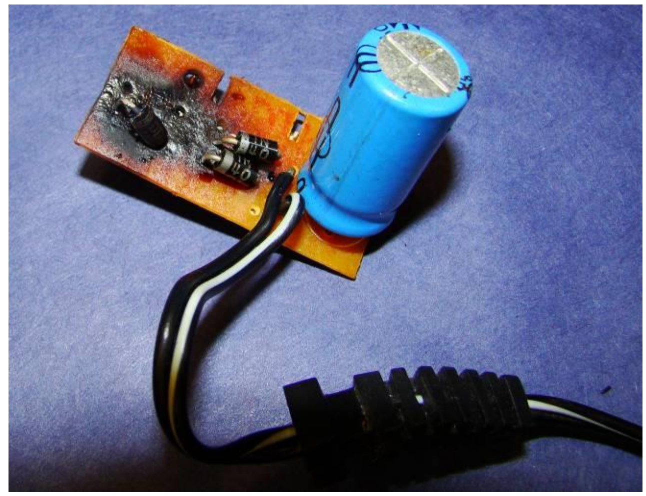
The arcing over char creates more heat which continues to off-gas providing fuel for combustion. Conventional thermal and thermo-magnetic circuit interrupters are not exposed to adequate energy for a trip to occur. Arc-fault breakers are necessary to protect from sustained arcing faults.

LOW ENERGY IGNITION

Durham et al demonstrated ignition can occur at extremely low energy from limited power sources. Small plug in power supplies, defined as Class 2 and commonly called wall-warts, are generally considered not adequate to ignite based on U/L ratings. The limited power sources were tested in a variety of conditions. [13]

A high-impedance connection with a known resistance was applied between the low voltage wires from the power supply. A quick note is appropriate. A connection is considered low-impedance, meaning the value is near zero Ohms. A high-impedance connection is any value greater than zero. A one Ohm connection may be considered high-impedance connection.

Two mechanisms of ignition were observed. AC power supplies ignited materials adjacent to the connection. DC power supplies tended to ignite the diodes and the circuit board adjacent to the transformer as well as the material at the connection.



The low-end amount of power required to create ignition varied from about 12 to 22 watts at voltages in the 9 – 15 volt range.

ELECTROCHEMICAL IGNITION

Vicars et al address electrochemical processes which contribute to low energy ignition. Chemical contaminants create a corrosive residue on circuit boards. The residue provides a path for fault current which creates a thermal event that can cause UL94 V-0 flame rated FR4 laminate to burn. [14].

ROHS (Reduction of Hazardous Substance) process has led to reduction of halides such as bromine which are flame retardant. The contaminants on a circuit board can cause spontaneous operation as well as faults which can overload devices connected to the board and result in fire ignition.

Arc-tracking and sustained ignition are created with voltages of 3.3, 9, and 12 volt batteries. [15]

With research similar to our investigations, Vicars et al illustrated class 2 transformers can deliver current much greater than their 1.67 A rating. [14]

CASCADING FAILURES

Investigators often consider electrical faults to be an almost instantaneous event, and the premise may be accurate for a catastrophic failure.

In time-related failures, in reality, the process is a progressive, cascading event. Consider a poor or high-resistance connection. The poor connection creates increased resistance, which causes increased heating that promotes oxide formation. The oxide is conductive but adds resistance to the connection. This added resistance creates additional heating which promotes even more oxidation. Ultimately, the connection becomes hot enough to promote off-gassing and ignition of surrounding fuels.

The authors have demonstrated that other electrical failure mechanisms in insulation operate in a similar cascading fashion, where the ultimate failure may be a true short-circuit. [15, 16, 17]

Consider a small nick or deterioration of insulation on a 120 Volt circuit. Initially, insulation resistance may be a kiloOhm with a leakage current of 0.12 Amps. The incremental current would hardly be noticed on a 20 Amp circuit, but the heat generated would be 14 Watts, well within the range which can cause failure.

The heat causes further deterioration in the insulation down through 120 Ohms. Now the current is 1 A, still barely noticeable, but with a heat of 120 Watts, which is much greater than the quantity for ignition.

The additional heat continues deterioration of the insulation down to a resistance of 6 Ohms with a leakage current of 20 Amps and a generated heat of 2400 Watts. That much power at a connection for one minute produces 144,000 Joules. In addition, small arcs have likely occurred, providing sufficient energy for ignition of the vapors. Surrounding materials including insulation will have off-gassed and likely been ignited.

A 20 Amp breaker or fuse will not have cleared the circuit. Many investigators will miss the failure because the protective device did not operate. [18]

Even at deterioration down to one Ohm fault, the circuit will continue to supply power for a period of time.

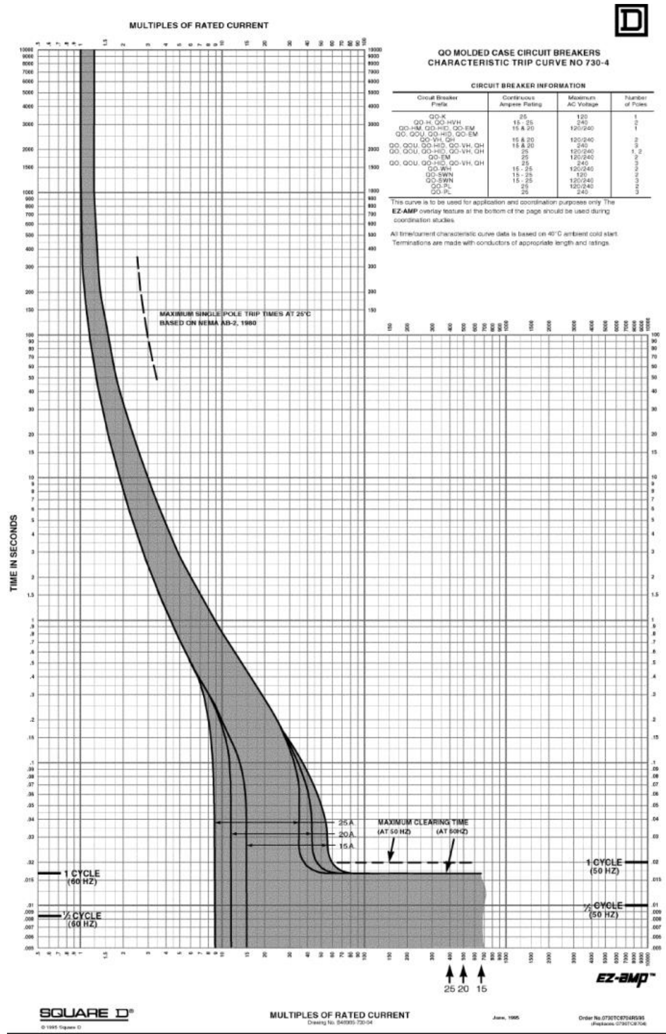
PROTECTIVE DEVICES

Traditional protective devices such as circuit breakers and fuses will not necessarily respond to arcing faults including high resistance connection faults.

The operating characteristic of traditional protective devices is called an inverse I-squared-t (I^2t) curve. The curve is plotted as current versus time. The shape of the curve varies with the current squared. The energy required to trip the device is proportional to the area under the curve.

The short-circuit (fault) device is primarily for protection of the incoming power line. A short-circuit will draw very large amounts of current in a very short time. Typically, current amounts greater than six (6) times full load current (FLC) are considered a short. [18, 19]

The trip curve for a standard 20A circuit breaker is shown [20].



A standard 120 Volt, 20 Amp circuit breaker will run continuously at 20 Amps. The breaker asymptotically approaches its rating above 300 seconds. The available energy through the breaker is calculated at 300 seconds but in reality is infinite, since the breaker will not trip.

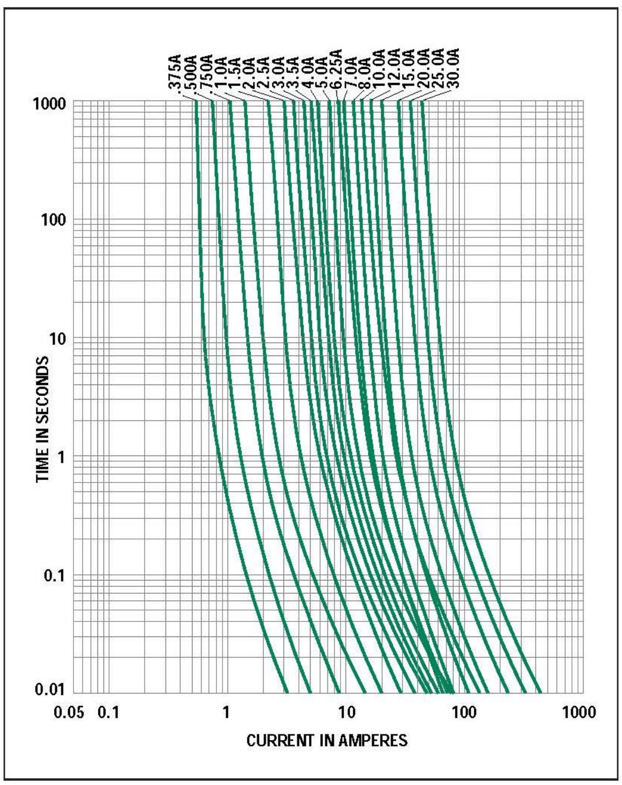
$$E = V I t = 120 * 20 * 300 = 720{,}000 \text{ Joules}$$

720 kJ is the continuous energy available, which well exceeds the quantity necessary to ignite wire insulation and plastics.

A typical fuse used in appliances has the following curve. Consider the 20 Amp fuse which correlates with the circuit breaker. The fuse time current curve is the third curve from the right. [21]

The fuse will operate continuously at 20 Amps. The circuit impedance for the current is 120 V / 20 A = 6 Ohms.

Littelfuse® | 3AB Slo-Blo® Type Fuse 325/326 Series



Since a short circuit is considered to be 6 times the rated current, the circuit impedance is reduced to 1 Ohm. Under that fault condition, the fuse will blow in about 0.07 seconds.

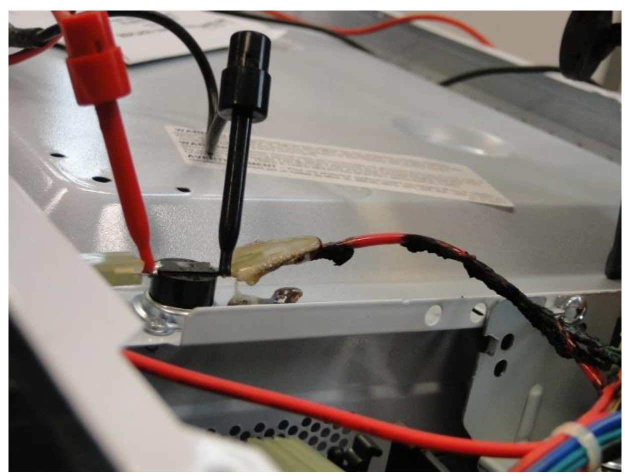
In a cascading fault, a large amount of energy is transferred through the impedance before the protective device will operate. In conditions less than a direct short-circuit, the protection likely will not operate at all.

THERMAL CUT-OFF

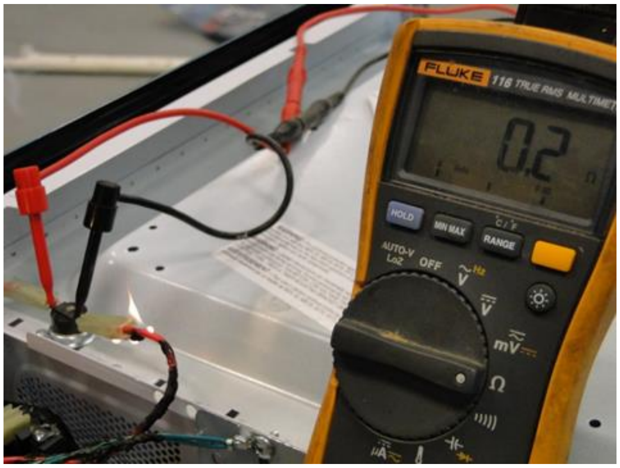
Some circuits use a thermal cut-off to remove electrical energy if the temperature gets too high. These devices typically operate within their prescribed rating when heat is directly applied. A common misconception is adjacent heat will open the device. However, adjacent heat will not trip the device since energy drops off with the separation distance cubed.

An artifact recovered from an appliance shows the TCO undamaged from an adjacent fire. The TCO has a very low rating of a 135 – 15°F, but did not open to prevent the fire.

Another appliance TCO was evaluated. The device has a nominal rating of 100°C. Direct flame was applied to the connector insulation, which melted and burned. The TCO did not open the circuit.



The location and orientation of a TCO is critical to its performance. Otherwise, adjacent burning can occur with no impact on the flow of the electrical circuit as seen in the photo.



METAL CABINET

Another common misconception is fire will be contained within the metal framework of an appliance. FEMA statistics shown above declare that 79% of fires spread beyond the object where the fire started. [1]

A controlled experiment used a metal clad dryer. Fire was initiated in the plastic lint screen while the dryer was operating. No damage was observed for 30 seconds. Then staining was noted. The motor stopped operation in 52 seconds. The fire continued to progress, burning plastic, deforming the metal, and allowing escape out the newly created orifices. Clearly, metal enclosures do not contain an internal fire.

CORRUGATED STAINLESS STEEL TUBING (CSST)

Corrugated stainless steel tubing (CSST) is a flexible pipe for distribution of gas within a residential or commercial structure. CSST is prone to damage by lightning. The CSST is penetrated, allowing gas to escape and be ignited by the arc.

A paper by Durham et al addressed lightning, developed the electrical characteristics of the tubing, and addressed the propensity for failure. [22, 23] The paper listed 10 characteristics which contribute to the failure and ignition. Based on the physical and electrical characteristics approximately 10 times more energy is required to puncture a black steel pipe than the thermal energy required for the CSST.

Additional research has shown the concentration of energy is even greater for the CSST than the cylindrical black pipe.

The 8.6 joules of energy used to create the penetration in corrugated tubing is in the range of penetrations that have been observed before, and for which published material exists.

Comparisons of the mechanical configuration of pipe and tubing were performed related to electric field and energy concentration. The corrugated tubing has high ridges which concentrate the electric field and the energy disbursed during a discharge. Cylindrical pipe disburses the energy over a much larger area distributing the discharge.

The figure shows the electric discharge to the top of the ridge during the laboratory tests.

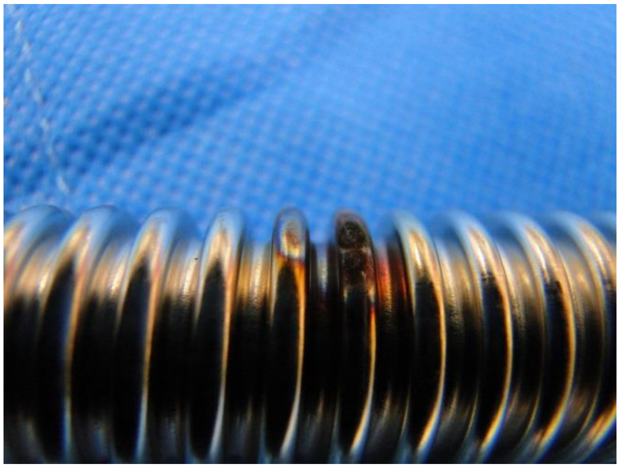
The area is related to the radius of curvature at the ridge versus the radius of curvature of the cylindrical pipe. The nominal external radius of the corrugated ridge is .04“, while the nominal radius of 1/2” steel pipe is 0.42”, which is greater than a factor of 10.

The energy density (J/m^3) concentration is the inverse of the cube of the radius. The inverse square for the tubing is 15625 while the inverse cube of the pipe is 13.5. Assuming complete transfer, the concentration of energy on the tubing ridge is over 1157 times great.

Therefore, cylindrical pipe will have 1157 times less energy density discharge to the surface. Less energy density results in less likelihood of penetration failure.

The combination of less material thickness and more concentrated energy makes the probability of failure of corrugated tubing due to electrical transients over 1000 times greater than conventional pipe of the same nominal diameter.

A close-up shows the faulting occurs at the top of the ridge.



Based on calculations shown, the corrugated tubing is penetrated by electrical energy much more easily than alternative piping systems.

Electrical discharge occurs when corrugated tubing is near components which are electrically energized. The product fails when exposed to adequate electrical-magnetic energy, including the energy from an electrical fault.

Penetration in pipe will allow gas to escape which can be ignited by electrical discharge in the presence of air.

The amount of energy to ignite the escaping gas is minimal. Natural gas has minimum ignition energy of 0.28 milliJoules (mJ), while propane is only 0.25 mJ. [4].

RADIANT HEAT BARRIERS

Energy conservation makes economic sense. In an effort to reduce energy transfer from a structure to the surrounding atmosphere, radiant barriers are employed. A common type is a reflective aluminum film attached to a flexible substrate which often contains hydrocarbons.

The barrier is typically installed in an attic on the underside of the rafters and around any external walls. Like CSST, the aluminized barrier is susceptible to lightning damage resulting in fire.

The very large surface area builds up a substantial charge when lightning is discharged. The charge is discharge through a very concentrated point to a ground path. As with other circuits, the discharge across a resistive path can result in heat build-up and ignition of combustible materials.

The charge buildup from radiant barrier installed on a sloped roof structure with a footprint of 2,000 sq ft was calculated to be near 8 Coulombs. This is a large charge. The current for a 100kV discharge at this charge level was 140A, which releases 140MW of power for the duration of the discharge.

Our laboratory has lightning simulation equipment consisting of a 100,000 volt ac source and a standard C62 waveform generator, in addition to myriad other instruments including a partial discharge system.

A layer of radiant barrier was constructed on a wooden platform not unlike a structure. The 100,000 volt source was connected to the barrier and an air gap of approximately 1 cm was created to a grounded conductor.

As expected the air gap became ionized and began arcing near 30,000 volts. An unanticipated occurrence serendipitously confirmed the risk of electrical discharge. The current began a track on the surface of a 2x4 from the barrier to physical earth.

Materials such as wood, styrofoam type insulation, and polymers of some barriers were ignited during the research.

The energy in a lightning discharge is readily calculated. A typical waveform is 100,000 Volts at 50,000 Amps and discharges in 50 microseconds with average energy of half the value.

$$E = V I t/2 = 100K * 50K * 50e^{-6} /2 = 125000 J$$

The quantity is many orders of magnitude greater than necessary to ignite materials.

SUMMARY

1. Electrically initiated fires are common.
2. The fuel first ignited is often insulation, other plastics and hydrocarbons.
3. Thermoplastic including PVC readily combusts when held at temperatures above its RTI.
4. Electrical faulting is often a condition such as a high-impedance connection rather than a direct short.
5. Normal protective devices such as fuses and breakers will not detect many faults.
6. TCO's will not detect temperature which is away from direct contact.
7. Metal enclosures and plastic covers are easily deformed in fire, permitting combustion to escape.
8. CSST configuration has a high concentration of energy on the ridges when lightning discharges and increases the likelihood of ignition.
9. Radiant heat barriers capture a large charge during a lightning event and ignite combustibles when the surface discharges.

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