Table V(B). Skin Temperature Tolerance Relationship

Skin Temperature	Duration	Damage Caused
110°F	6.0 hours	Cell breakdown begins
158°F	1.0 second	Total cell destruction
176°F	0.1 second	Curable (second-degree) burn
205°F	0.1 second	Incurable (third-degree) burn

For evaluating burns, protective proprieties of personal protection equipment, and the thermal energy resulting from an arc-flash, the industry has progressed to utilizing calories/centimeters^2 (cal/cm^2) as a unit of measure. For instance, the incident energy is a measure of thermal energy at a specific distance from an arc-fault; the unit of measure is typically in cal/cm^2. Another example where cal/cm^2 is used as a measure is for various types of PPE with distinct levels of thermal protection capabilities rated in cal/cm^2.

1.2 cal/cm^2 is considered the threshold for a curable (second-degree) burn.

Note: *medical treatment may still be required if bare skin is exposed to this level of flash — full recovery would be expected.*

In addition to burn injuries, victims of arcing faults can experience damage to their sight, hearing, lungs, skeletal system, respiratory system, muscular system, and nervous system. The speed of an arcing fault event can be so rapid that the human system can not react quickly enough for a worker to take corrective measures. The radiant thermal waves, the high pressure waves, the spewing of hot molten metal, the intense light, the hurling shrapnel, and the hot, conductive plasma cloud can be devastating in a small fraction of a second. The intense thermal energy released can cause severe burns or ignite flammable clothing. Molten metal blown out can burn skin or ignite flammable clothing. Failure to remove or extinguish burning clothing quickly enough can cause serious burns over much of the body. A person can gasp and inhale hot air and vaporized metal sustaining severe injury to their respiratory system. The tremendous pressure blast from the vaporization of conducting materials and superheating of air can fracture ribs, collapse lungs and knock workers off ladders or blow them across a room.

What is difficult for people to comprehend is that the time in which the arcing fault event runs its course may only be a small fraction of a second. In a matter of only a thousandth of a second or so, a single phase arcing fault can escalate to a three phase arcing fault. Tremendous energies can be released in a few hundredths of a second. Humans can not detect, much less comprehend and react to events in these time frames.

There is a greater respect for arcing fault and shock hazards on medium and high voltage systems. However, injury reports show serious accidents are occurring at an alarming rate on systems of 600V or less (notably 480V systems and to a lesser degree 208V systems), in part because of the high fault currents that are possible. But also, designers, management and workers mistakenly tend not to take the necessary precautions that they take when designing or working on medium and high voltage systems.

VI. The Role of Overcurrent Protective Devices In Electrical Safety

If an arcing fault occurs while a worker is in close proximity, the survivability of the worker is mostly dependent upon (1) the characteristics of the overcurrent protective devices, (2) the arc-fault current, and (3) precautions the worker has taken prior to the event, such as wearing personal protective equipment appropriate for the hazard. The selection and performance of overcurrent protective devices play a significant role in electrical safety. Extensive tests and analysis by industry have shown that the energy released during an arcing fault is related to two characteristics of the overcurrent protective device protecting the affected circuit:

1. The time it takes the overcurrent protective device to open. The faster the fault is cleared by the overcurrent protective device, the lower the energy released.
2. The amount of fault current the overcurrent protective device lets through. Current-limiting overcurrent protective devices may reduce the current let-through (when the fault current is within the current-limiting range of the overcurrent protective device) and can reduce the energy released.

Lowering the energy released is better for both worker safety and equipment protection. The photos and recording sensor readings from actual arcing fault tests (next page) illustrate this point very well. An ad hoc electrical safety working group within the IEEE Petroleum and Chemical Industry Committee conducted these tests to investigate arc-fault hazards. These tests and others are detailed in "Staged Tests Increase Awareness of Arc-Fault Hazards in Electrical Equipment," *IEEE Petroleum and Chemical Industry Conference Record*, September 1997, pp. 313-322. This paper can be found at www.bussmann.com under Services/Safety BASICs. One finding of this IEEE paper is that current-limiting overcurrent protective devices reduce damage and arc-fault energy (provided the fault current is within the current-limiting range). To better assess the benefit of limiting the current of an arcing fault, it is important to note some key thresholds of injury for humans. Results of these tests were recorded by sensors on mannequins and can be compared to these parameters:

Thresholds for injury to humans

- Just Curable Burn Threshold: 80°C / 176°F (0.1 sec)
- Incurable Burn Threshold: 96°C / 205°F (0.1 sec)
- Eardrum Rupture Threshold: 720 lbs/ft²
- Lung Damage Threshold: 1728 - 2160 lbs/ft²
- OSHA Required Ear Protection Threshold: 85db (for sustained time period)*

**An increase of 3db is equivalent to doubling the sound level.*

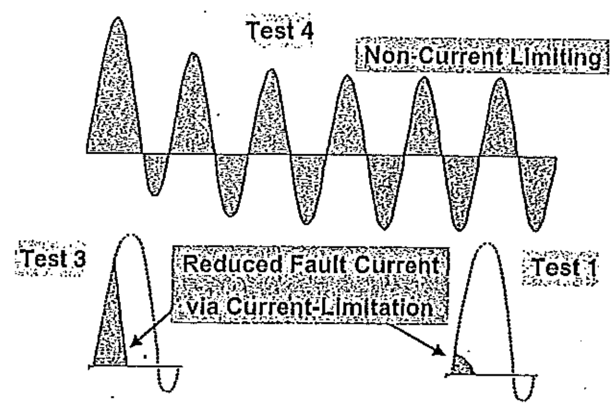
Staged arc-flash tests

Test 4, Test 3 and Test 1: General All three of these tests were conducted on the same electrical circuit set-up with an available bolted three-phase, short-circuit current of 22,600 symmetrical rms amps at 480V. In each case, an arcing fault was initiated in a Size 1 combination motor controller enclosure with the door open, as if an electrician were working on the unit while energized or before it was placed in an electrically safe work condition. Test 4 and Test 3 were identical except for the overcurrent protective device protecting the circuit. In Test 4, a 640A circuit breaker with a short-time delay is protecting the circuit; the circuit was cleared in 6 cycles. In Test 3, KRP-C-601SP, 601A, current-limiting fuses (Class L) are protecting the circuit; they opened the fault current in less than ½ cycle and limited the current. The arcing fault was initiated on the line side of the motor branch circuit device in both Test 4 and Test 3. This means the fault is on the feeder circuit but within the controller enclosure. In Test 1, the arcing fault is initiated on the load side of the branch circuit overcurrent protective devices, which are LPS-RK 30SP, 30A, current-limiting fuses (Class RK1). These fuses limited this fault current to a much lower amount and clear the circuit in approximately ¼ cycle or less.

A couple of conclusions can be drawn from this testing:

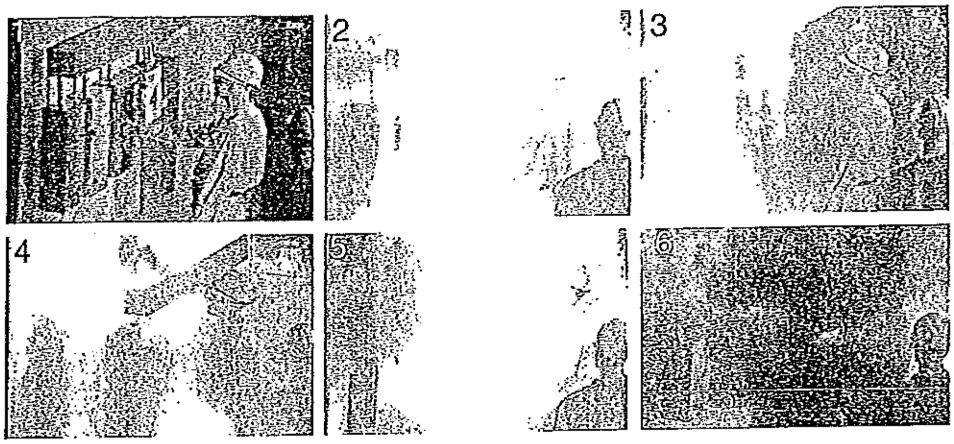
1. Arcing faults can release tremendous amounts of energy in many forms in a very short period of time. All the measured values can be compared to key thresholds of injury for humans given in a previous paragraph. Test 4 was protected by a 640A, non-current-limiting device that opened in 6 cycles or $\frac{1}{10}$ second (0.1 second).
2. The overcurrent protective devices' characteristic can have a significant impact on the outcome. A 601A current-limiting overcurrent protective device, protects the circuit in Test 3. The current that flowed was reduced (limited), and the clearing time was ½ cycle or less. This was a significant reduction compared to Test 4. Compare the Test 3 measured values to the key thresholds of injury for humans and the Test 4 results. The measured results of Test 1 are significantly less than those in Test 4 and even those in Test 3. The reason is that Test 1 utilized a much smaller (30A), current-limiting device. Test 3 and Test 1 both show that there are benefits of using current-limiting overcurrent protective devices. Test 1 just proves the point that the greater the current-limitation, the more the arcing fault energy may be reduced. Both Test 3 and Test 1 utilized very current-limiting fuses, but the lower amps-rated fuses limit the current more than the larger amps rated fuses. It is important to note that the fault current must be in the current-limiting range of the overcurrent protective device to receive the benefit of the lower current let-through. See the diagram that depicts the oscillographs of Test 4, Test 3 and Test 1.

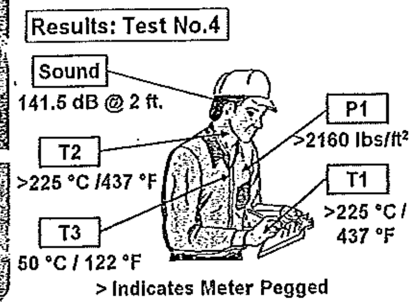
Current-Limitation: Arc-Energy Reduction



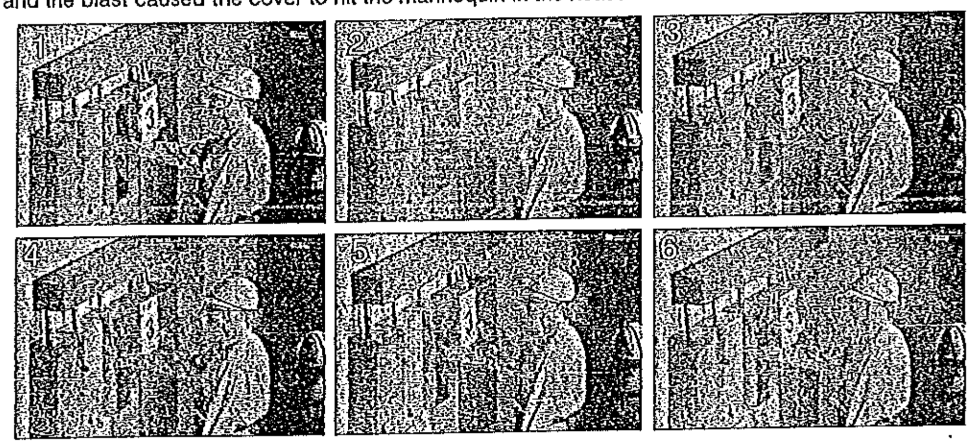
3. The cotton shirt reduced the thermal energy exposure on the chest (T3 measured temperature under the cotton shirt). This illustrates the benefit of workers wearing protective garments.

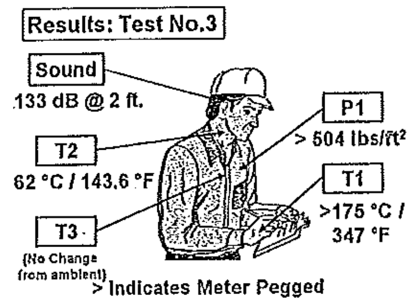
Following are the results recorded from the various sensors on the mannequin closest to the arcing fault. T1 and T2 recorded the temperature on the bare hand and neck respectively. The hand with T1 sensor was very close to the arcing fault. T3 recorded the temperature on the chest under the cotton shirt. P1 recorded the pressure on the chest. And the sound level was measured at the ear. Some results "pegged the meter." That is, the specific measurements were unable to be recorded in some cases because the actual level exceeded the range of the sensor/recorder setting. These values are shown as >, which indicates that the actual value *exceeded* the value given but it is unknown how high of a level the actual value attained.



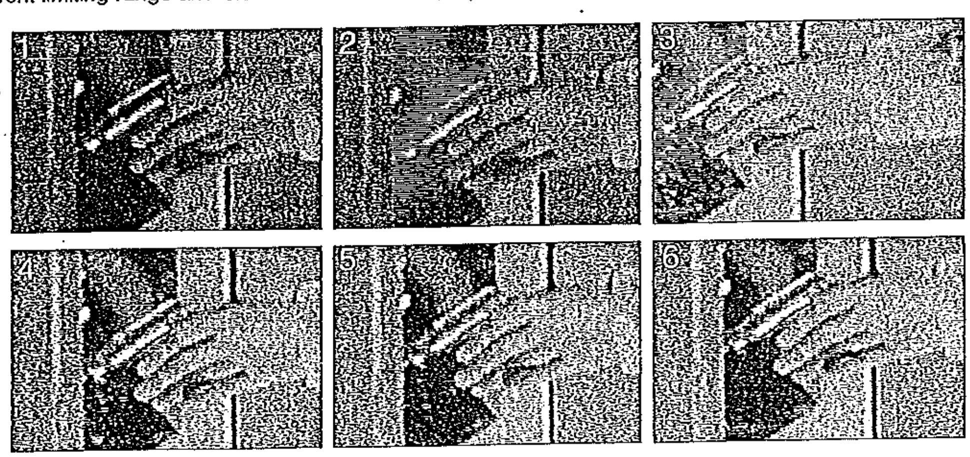


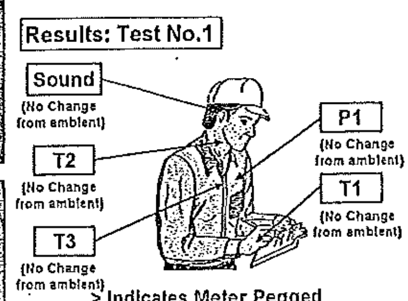
Photos and results Test 4: Staged test protected by circuit breaker with short-time delay (not a current-limiting overcurrent protective device). Short-time delay intentionally delayed opening for six cycles (0.1 second). Note: Unexpectedly, there was an additional fault in the wireway and the blast caused the cover to hit the mannequin in the head.





Photos and results Test 3: Staged test protected by KRP-C-601SP LOW-PEAK® current-limiting fuses (Class L). These fuses were in their current-limiting range and cleared in less than a $\frac{1}{2}$ cycle (0.0083 seconds).





Photos and results Test 1: Staged test protected by LPS-RK-30SP, LOW-PEAK® current-limiting fuses (Class RK1). These fuses were in current-limiting range and cleared in approximately $\frac{1}{4}$ cycle (0.004 seconds).