# UNDERSTANDING ARC RATINGS

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## Overview

In the world of flame-resistant (FR) clothing, the arc-rated garments market is relatively new, yet it has grown (and evolved) at an impressive rate. FR clothing, as we know it today, is also fairly recent, but arc-rated FR clothing has quickly become a distinct category of its own. It gets confusing, because all arc rated (AR) clothing is FR, but not all FR clothing is arc rated. The term "arc rated" means that a garment or fabric has been tested against a staged electrical arc to determine its level of arc protection. How the arc rating process works and how that level of protection is determined can be confusing, but a quick look at the long and varied history behind it is quite revealing.

## A Brief History

Electricity has always been a known hazard, even before people learned to harness and control it. But dedicated research over the past few decades has shed a lot of light on the many dangers associated with electricity, giving rise to an array of ever-evolving and improving safety and industry consensus standards.

In 1897, 15 years after Thomas Edison brought his Pearl Street generating station online and illuminated more than 50 incandescent light bulbs, the first electrical standard emerged in the United States. Although electric shock was the earliest and most obvious hazard that was recognized, people also quickly learned that wires and power equipment that were not correctly installed posed a fire threat. After a few different workers' groups developed and published five different electrical installation codes, a single committee—citing the confusion around the multiple codes—formed to develop a single, and uniform, electrical code. This was the beginning of what is now called the National Electrical Code (NEC).

The NEC, and similar codes produced by industry associations, was basically a collection of lessons learned and best practices based on the practical knowledge workers had gained while working with electricity, and while the fact that electricity could be dangerous was a widely accepted fact, very little was known about exactly how it affects the human body, how much current was too much, and so forth.

Charles Dalziel, a researcher and a professor of electrical engineering and computer sciences at UC Berkeley—as well as the inventor of the Ground-Fault Circuit Interrupter (GFCI)—conducted extensive research in the early 1950's on animals and humans, and in 1956, he published the book, "The Effects of Electric Shock on Man," which is still in use today. Until Dalziel published his work, no one really knew how electrical currents affected the human body. By conducting experiments with low levels of current using volunteers and developing calculations to extrapolate what the results would be at higher levels, he was able to develop charts showing the effects of increasing current levels, from noticeable tingling to painful jolt to ventricular fibrillation—a heart-stopping shock.[1]

Dalziel's electrical shock experiments helped establish longstanding principles for protecting people from electrical hazards, and many of his findings have been used in various tables included in the National Electrical Code, however, the dangers of arc flash remained largely overlooked for a long time to come.

## The Arc Flash Hazard And Arc Rating

An electrical arc, sometimes called an "arc flash" or "arc blast," is an electric current that passes through the air between electrified conductors. The release of energy created by such an electric fault is instantaneous and produces intense heat, blinding light, blast pressure, loud sound, and blast shrapnel in the form of molten debris. In nature, lightening could be considered an open-air electrical arc.

Every day, electrical, utility, and maintenance workers perform tasks—such as voltage testing, removing or inserting circuit breakers, and opening or removing bolted-on panel covers—that expose them to the risk of arc flash. The National Burn Repository Report, in data collected between 2006-2015, shows 6,265 electrical burns, with more than 60% occurring on the job.

[1] King, C. C. (2015). Effects of Current on the Human Body, Section 2. Retrieved June 29, 2016, from www.hubbellpowersystems.com/literature/encyclopedia-grounding/pdfs/07-0801-02.pdf

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While the phenomenon of "arc flash," as we call it today, has certainly existed for as long as people have been using electricity to power lighting and industry, it was not until the early 1980s that the hazard was formally addressed and given a name. When Ralph Lee presented a paper in 1982 called "The Other Electrical Hazard: Electrical Arc Blast Burns," he quantified potential burn hazards, thus raising awareness and spotlighting safety concerns, and his work established a method of estimating how much energy produced by an electrical arc was enough to produce a second-degree burn to human tissue.[2]

Lee's assertion that burns caused by the heat generated in an electrical arc were more deadly than the electricity itself was new information. He wrote:

> *Next to the laser, the electric arc between metals is the hottest thing on earth, or about four times as hot as the sun's surface. Where high arc currents are involved, burns from such arcs can be fatal when the victim is even several feet from the arc, and debilitating burns at distances of 10ft are common. Clothing is ignited at distances of several feet; this itself can cause fatal burns because the clothing cannot be removed or extinguished quickly enough to prevent serious burns over much of the body's skin.*[3]

Many credit Lee with getting the "modern" arc flash conversation started, and his idea to measure a "curable burn level" has remained the basis of most arc testing to date.

Over the next decade, research and experiments in arc testing were gradually improving, and in 1994, the Occupational Safety and Health Administration (OSHA) revised 1910.269, which applies to utility workers who are involved in electric power generation, transmission, and distribution. The revision addressed personal protective equipment (PPE) for utilities workers and brought the regulation in line with updated industry consensus standards, but it would be another 30 years before OSHA would recognize FR clothing as PPE.

Even with this increased awareness, the shock hazard still received a lot more attention than arc flash. That was until several US electric utility companies, using test methods developed by Committee F18 of the American Society of Testing and Materials (ASTM), began to investigate clothing ignition due to arc flash.[4]

This initial set of ignition tests conducted by Alan Privette of Duke Power, Allen Bingham of Georgia Power, and Tom Neal of DuPont confirmed what Dalziel had determined in his research. Their work showed, writes Hugh Hoagland in *Flame resistant textiles for electric arc flash hazards*, that "clothing ignition was a primary cause of serious burn injuries and fatalities for electrical workers exposed to an arc flash." Hoagland continues, "The adoption of FR clothing for electrical workers by many utilities and industrial companies resulted in a significant reduction in arc flash burns and fatalities."[5]

Although the first edition of *NFPA 70E* (then titled *Standard for Electrical Safety Requirements for Employee Workplaces*) was published in 1979, it was not until the 1995 edition that it included any mention of the arc flash hazard and required an arc flash hazard analysis.

Two papers published around that time led to more changes to *NFPA 70E*. In "Testing Update on Protective Clothing and Equipment for Electric Arc Exposure,"[6] Bingham, Doughty and Neal used test data to measure incident energy at various distances from a low voltage arc fault and were the first to express an arc's directional effect in an enclosed space. "Predicting Incident Energy to Better Manage the Electric Arc Hazard on 600V Power Distribution Systems,"[7] by Doughty, Floyd, and Neal, defined incident energy for arcs in air or in an enclosure based on working distance and current level.

[2] Phillips, J. (n.d.). How Did We Get Here? Retrieved June 29, 2016, from http://www.ecmag.com/print/section/safety/how-did-we-get-here
[3] Lee, R. H. (1982). The Other Electrical Hazard: Electric Arc Blast Burns. *IEEE Transactions on Industry Applications IEEE Trans. on Ind. Applicat., IA-18*(3), 246-251. doi:10.1109/tia.1982.4504068
[4] Hoagland, H. (2013). Flame resistant textiles for electric arc flash hazards. In F. S. Kilinc (Ed.), *Handbook of fire resistant textiles* (1st ed., Vol. 140, Series in Textiles, p.553). Philadelphia, PA: Woodhead Publishing.
[5] Ibid, p.553
[6] Doughty, R., Neal, T., Dear, T., & Bingham, A. (1999). Testing update on protective clothing and equipment for electric arc exposure. *IEEE Industry Applications Magazine IEEE Ind. Appl. Mag., 5*(1), 37-49. doi:10.1109/2943.740758
[7] Doughty, R., Neal, T., & Floyd, H. (2000). Predicting incident energy to better manage the electric arc hazard on 600-V power distribution systems. *IEEE Transactions on Industry Applications IEEE Trans. on Ind. Applicat., 36*(1), 257-269. doi:10.1109/28.821823

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The 2000 edition of *NFPA 70E®* marked a turning point in the use of FR clothing and PPE as protection from arc flash hazards. That edition introduced the Hazard/Risk Category (HRC) classification system. The five categories were defined by a range of arc ratings (HRC 0-4), and levels of protection were based on the category number.

Although NFPA 70E® was created specifically for electricians, the electric arc hazard is the same for anyone working with electricity, therefore utilities and others have looked to it for guidance.

| Hazard/ Risk Category | Typical Protective Clothing Systems | Required Minimum Arc Rating of PPE (cal/cm²) |
|---|---|---|
| 0 | Non-melting, flammable materials (natural or treated materials with at least 4.5 z/yd²) | N/A (1.2) |
| 1 | FR pants and FR shirt, or FR coverall | 4 |
| 2 | Cotton Underwear, plus FR shirt and FR pants | 8 |
| 3 | Cotton Underwear, plus FR shirt and FR pants and FR coverall | 25 |
| 4 | Cotton Underwear, plus FR shirt and FR pants and multiple layer flash suit | 40 |

By 2000, test methods and performance standards had been improved and refined; ASTM PS-58, *Test Method for Determining the Arc Thermal Performance (Value) of Textile Materials for Clothing by Electric Arc Exposure Method Using Instrumented Sensor Panels* (the provisional standard that evolved into ASTM F1959) had been introduced in 1997, and ASTM F1506-94, *Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards* was introduced in 1998. Up until that point, no specialty fabrics or garments were being produced specifically for arc protection. Instead, FR fabrics and garments that had been on the market for flash fire and protection from other thermal hazards were being tested and given an arc rating.

In 2014, 29 CFR 1910.269 was revised once again, but this time, OSHA not only explicitly stated that FR clothing should be considered PPE, but also mandated that employers provide and ensure that workers wear protective clothing and equipment if exposed to electric arc hazards. And, for the first time, workers were required to wear clothing and equipment with an arc rating equal to or greater than the estimated incident energy whenever it exceeds 2.0 cal/cm2. Up until then, 1910.269 had only required that "...each employee who is exposed to the hazards of flames or electric arcs does not wear clothing that, when exposed to flames or electric arcs, could increase the extent of the injury that would be sustained by the employee."[8]

When *NFPA 70E®* was updated again in 2014, the Hazard Risk/Category was replaced with PPE Category, and the 0 category was eliminated.

| PPE Category | **Typical Clothing Description** (Typical number of layers is given in parentheses) | Required Minimum Arc Rating of PPE (cal/cm²) |
|---|---|---|
| 1 | FR shirt and FR pants or coveralls, Faceshield/ Hardhat (1 layer) natural fiber underlayer allowed | 4 |
| 2 | FR shirt and FR pants or coverall (1 or 2 layers) Faceshield/ Hardhat with balaclava | 8 |
| 3 | FR shirt and FR pants or coverall plus FR coveralls, or two FR coveralls (2 or 3 layers) with arc flash hood | 25 |
| 4 | FR shirt and FR pants or coverall plus multilayer flash suit (3 or more layers) with arc flash hood | 40 |

## Arc Testing And The Stoll Curve

In the late 1950's and early 1960's a set of researchers, Alice Stoll and Maria Chianta, began working with the U.S. Navy to study burn injury, or the effect of heat energy on human tissue. Their focus was on determining what heat levels and exposure times triggered the onset of a second-degree burn. When a second-degree burn occurs, blisters form separating the inner and outer layers of skin, and that is the point at which the severity of a burn injury will increase quickly and exponentially. Although the research itself had nothing to do with the effects of electricity, it quantified the heat levels and exposure times

[8] Occupational Safety & Health Administration [OSHA]. (2014). Regulations (Standards-29 CFR 1910.269).

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required for a second-degree burn to occur, ranging from high temperatures for a short time to low temperatures for a much longer duration. Their findings led to the development of what is now called the "Stoll Curve," the predictive model used in most test methods to measure heat flux against the probability of burn injury, including arc tests that determine when a second-degree burn is likely to occur.[9]

The arc rating of a fabric is determined by exposing it to a staged electrical explosion in a laboratory setting. Arc behavior can be unpredictable, so testing requires that the samples be exposed to a "controlled" arc multiple times.

In North America, the test method used to determine arc ratings is ASTM F1959, Standard Test Method for Determining the Arc Rating of Materials for Clothing. This procedure requires that a specimen of fabric be mounted on a sensor panel placed 12 inches away from electrodes where the arc is generated. Two copper calorimeters embedded in the panels under the test specimens measure the amount of heat from the arc flash that passes through the fabric. This exposure is repeated on 21 test specimens over a range of incident energies. The data collected by the sensors is compared to the Stoll curve to predict at what incident energy there is a 50% chance a wearer will sustain a 2nd degree burn. That incident energy, expressed in cal/cm$^2$, becomes the fabrics' arc rating.

## Arc Rating

An arc rating is the protection level afforded by an FR fabric when exposed to an electric arc. Fabrics are tested against arc flashes of varying intensity or levels of incident energy. Wearers must determine the incident energy they are likely to be exposed to in their work environment and select clothing that has an arc rating at least as high. Note, there are two types or arc rating: ATPV and $E_{BT}$. Each reports a 50% probability of a specific fabric response

ATPV (Arc Thermal Performance Value) predicts a 50% probability that sufficient heat transfer through the fabric panel will cause the onset of second-degree burn injury based on the Stoll Curve. It is the measure of protection that a garment provides against the heat flux of an arc flash.

$E_{BT}$ (Energy Breakopen Threshold) predicts a 50% probability that the material will break open before the sensor detects probable onset of a second-degree burn. Breakopen is defined as any open area of at least 2.5cm. This means that an ATPV could not be reached, and at the breakopen point, skin could be exposed and a burn could occur.

While there are exceptions, arc ratings of $E_{BT}$ are often generated by knits, not wovens. Woven fabrics, which tend to be stronger than they are insulative, typically receive an ATPV arc rating; FR knits, which are more insulative than strong, receive an $E_{BT}$ arc rating. Both ratings are said to indicate the same level of protection.

For example:
If an incident energy level of 8 cal/cm$^2$ causes the Stoll Curve to show a 50% probability of second-degree burn, the arc rating is ATPV 8 cal/cm$^2$.

If an incident energy level of 8 cal/cm$^2$ causes a 50% probability of breakopen, the arc rating is $E_{BT}$ 8 cal/cm$^2$.

In 2002, the Committee F18 committee determined that the two measures were "functional equivalents" and updated ASTM F1506.[10]

## Building Fabric For The Rating

When the notion of testing an FR fabric or garment to determine its arc rating first arose, manufacturers began testing the products they already had. As manufacturers identified gaps in product lines based on arc rating, comfort level, and price they began research and development of new fabrics that would protect against electric arc—delivering a specific range of arc rating—while fitting into specific price ranges and exhibiting certain comfort characteristics. That led to this new era in the fabric world devoted to the electric arc end user segment.

[9] Stoll, A. M. And Chianta, M. A., "Method and Rating System for Evaluation of Thermal Protection," Aerospace Medicine, Vol. 40, 1969, pp.1232–1238.
[10] ASTM F1506-15, Standard Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards, ASTM International, West Conshohocken, PA, 2015, www.astm.org, p.4 DOI: 10.1520/F1506-15

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Although he points out that there are "very few 'pure fiber' options,"[11] Hoagland breaks the fiber types used in arc flash applications into four basic categories:

- Natural fibers treated with flame retardant chemicals (cotton and wool)
- Natural fibers blended with synthetics and treated with flame retardant chemicals (cotton/nylon, aramid/wool, aramid/Lenzing)
- Natural fibers/synthetics that retard flame (modacrylic/cotton)
- Synthetics with flame resistant properties, mostly blended (Nomex®, Kevlar®, Twaron®, etc.)[12]

When the arc testing of FR fabrics and garments began, there were only two options available, they were Nomex®, 100% FR Cotton and 88/12 Cotton/Nylon. Modacrylic blends were developed and introduced to fill the product gaps, and particularly satisfied the demand for an inherently FR fabric delivering CAT 2 protection. Because modacrylic fiber is a poor conductor of heat, these new fabrics performed well.

When more protection was needed than a single layer garment could deliver, wearers began layering garments to achieve higher arc ratings. It was discovered that adding the arc ratings of the individual fabric layers was not a reliable method of predicting the arc rating of the system. In other words, an 8 cal/cm$^2$ shirt worn over a 4 cal/cm$^2$ base layer does not necessarily deliver a 12 cal/cm$^2$ system rating, sometimes it is lower. This unexpected result requires that composites of fabrics be tested as they would be worn to generate a system arc rating for that combination of garments. As mandated by NFPA 70E, only FR layers can be used to increase a system arc rating.

## Conclusion/What Next?

The quest to invent and produce flame resistant fabrics and clothing began centuries ago. And while the past few decades have seen vast improvement for FR clothing designed for the flash fire hazard, the progress made with arc rated clothing over the last few years has also been impressive. The strong focus on this market segment is due to increasingly stringent industry consensus standards, more demanding government regulations, and rapid technological advances in manufacturing, design, and testing.

However, while so much progress has been made, there are still areas for improvement, and some issues within the industry remain under discussion.

Obviously, improving comfort without sacrificing protection is the ultimate goal in developing a new fabric for electric arc protection. Fabric manufacturers will continue to experiment with fiber blends, weaves, and finishes in an attempt to minimize the weight of the fabric while maintaining its protective properties. Lighter weight fabrics typically are more comfortable to wear, so fabric manufacturers are compelled to try new fiber blends, in the hope of finding the perfect synergistic combination that delivers the most protection at the lightest weight.

Another ongoing topic of interest is the question of how frequently a fabric's arc rating should be confirmed. Currently, there is no requirement that fabric manufacturers re-test their fabrics. ASTM F1506-15 defines the design test for AR and FR fabrics as "one made on a sample treated as representative of an industrial product; these tests will not generally be repeated in quantity production."[13] The only variable condition is that if a fabric changes, it must be re-tested, and although it clearly states "Perform the design test only when a new or modified textile material, that is, fabric, is used to manufacture apparel,"[14] the description of what constitutes "new or modified" is not as clear. The standard goes on to say, "A modification in the fabric could be, but is not limited to, any of the following: the supplier, composition, weave type, weight, or dyeing and finishing process."[15]

[11] Hoagland, H. (2013). Flame resistant textiles for electric arc flash hazards. In F. S. Kilinc (Ed.), *Handbook of fire resistant textiles* (1st ed., Vol. 140, Series in Textiles, p.566). Philadelphia, PA: Woodhead Publishing.
[12] Ibid, pp.566-567
[13] ASTM F1506-15, Standard Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards, ASTM International, West Conshohocken, PA, 2015, www.astm.org, p.2 DOI: 10.1520/F1506-15
[14] Ibid.
[15] Ibid.

Since some FR fabrics have been on the market for years, it possible that the arc rating for a particular fabric might have been generated many years ago. While the standards don't yet require a periodic retest, one could argue the need to occasionally confirm the arc rating knowing that the original data could become obsolete. Even if a manufacturer does not intentionally change or modify a product, routine efforts to improve efficiencies, reduce waste, and upgrade equipment could add up to a change that might affect the arc rating.

And, there are no requirements that manufacturers test every color individually for arc rating, although testing has shown some discrepancy between colors. Navy blue and other dark colors typically generate higher arc ratings than lighter shades (e.g., khaki and light blue) of the same fabric. The differences are not dramatic, and some of the variability is due to the test method itself; work continues on an informal basis to understand the significance of this phenomenon. These discrepancies are noted, yet it has become common in the testing community to evaluate navy blue goods and assign that arc rating to all colors. Hugh Hoagland writes:

> An early ASTM committee study looking at both undyed cloth and navy blue cloth indicated there was little effect from fabric color on arc rating; the study concluded that the effect of these color differences was negligible. Since then, our continuing studies have shown that some colors do make a difference...[16]

The progress that has been made since the arc flash hazard was acknowledged more than 30 years ago has been fast-paced but incremental. As understanding of the electric arc hazard becomes clearer and as capabilities of the textile industry continue to advance, what comes next will build on what's been learned, and the pace of progress will only increase.

[16] Hoagland, H. (2013). Flame resistant textiles for electric arc flash hazards. In F. S. Kilinc (Ed.), *Handbook of fire resistant textiles* (1st ed., Vol. 140, Series in Textiles, p.570). Philadelphia, PA: Woodhead Publishing.

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