Advanced FR/AR Concepts:

A deeper look into FR/AR protection

THIS PRESENTATION IS FOR INFORMATIONAL PURPOSES ONLY

Customers of Bulwark Protection are solely responsible for conducting their own Hazard Risk Assessment to identify safety hazards in their work environment.

Customers of Bulwark Protection are solely responsible for selecting appropriate garments and protective gear for their employees and ensuring wearers use the garments and protective gear properly and in conjunction with appropriate gloves and footwear. Because working conditions and other factors may vary, Bulwark Protection does not make any representation that these garments and protective gear will protect wearers from injury.

Premise – we receive a lot of questions around FR/AR clothing and how does it **NOT** catch fire, how fabrics are tested for arc flash and flash fire protection. What is the future of FR?

What you will take away….

- FR science – how does it self-extinguish
- How FR Properties are engineered into fibers and fabrics
- What is and how we get an arc rating
- How garments are certified to NFPA® 2112 for short-duration thermal exposures
- Where FR technology is heading

A few definitions…

A **fire retardant** is a chemical additive that suppresses fire by interrupting the fire flow (fire tetrahedron).

Flame resistance refers to the property of an article or material (fabric, plastic part, film, etc.) with **reduced propensity to burn.**

Flame resistant – self extinguishes, does not support combustion, does not melt, drip or add to the injury

Arc Rated – tested to the electric arc flash hazard

FR/AR – flame resistant/arc rated garments

Flame-Resistant Fabrics

Flame resistant fabrics have generally been divided into two groups:

- Treated: Applied chemical treatment
- Inherent: Essential characteristic of the fiber

The terms "inherent" and "treated" have become fixtures in the FR world, but what do they mean and are they even accurate anymore?

What are the Advantages/Disadvantages ???

Common understanding of "the terms"…

“Inherent”

- Doesn’t wash out
- Number of launderings doesn’t matter
- FR properties remain for the life of the garment

“Treated”

- Depends on chemicals
- Eventually washes out
- Surface treatment
- Repeated launderings affect FR properties

Actual Meaning of the Terms

"Inherent"

- FR chemistry is built into the polymer of the fiber
- No added FR chemistry at the fabric level
- FR properties remain for the life of the garment

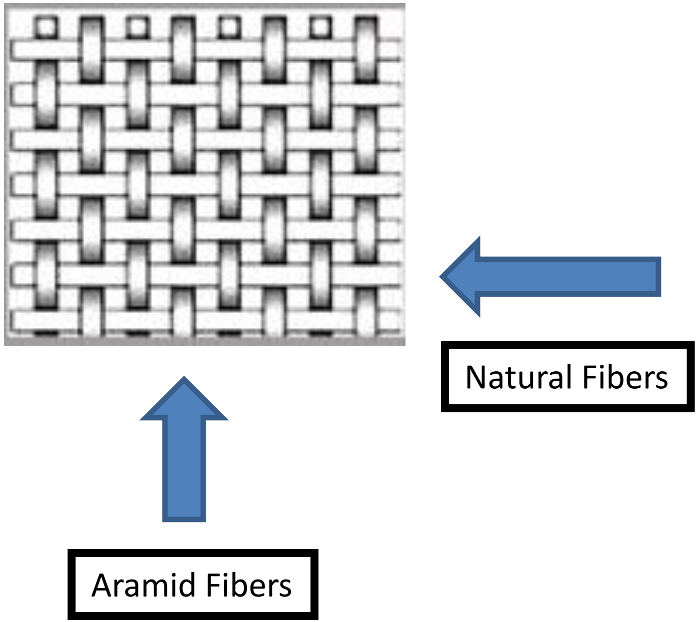
"Treated"

- FR chemistry is applied to the fabric
- FR chemistry is impregnated into the core of the fiber
- FR properties of established brands of fabric remain for the life of the garment

The State of FR Today

The terms refer to single fiber types, so even if they are taken to be accurate in their original context, how can today's many blends that utilize combinations of some or all 3 engineering levels—be called "inherent" or "treated?"

So what do we call this?



FR Engineering

FR fabrics in common use today for arc flash and flash fire protection are **engineered** to have FR properties. (FR properties defined as the fabric will self-extinguish when the ignition source is removed)

There are 3 levels at which those FR properties can be achieved:

- **The Molecular Level –** Synthetic derivatives are engineered at the molecular level to be FR (e.g., Nomex®, Kermel®, Twaron®, Kevlar®, etc.)
- **The Fiber Level –** At this level, flame retardant chemicals are added during fiber extrusion (e.g., FR Modacrylics, FR Rayons)
- **The Fabric Level –** Flammable fabrics are engineered at the fabric level through chemical and mechanical processes to permanently impart FR properties (e.g., FR Cotton, 88/12)

Bulwark FR

Where we are today….

Today, we utilize manufacturers with the right scientific knowledge, state-of-the-art equipment to engineer fabrics made with several types of fibers and flame resistant technologies.

Manufacturers understand what it takes to make cotton rich, aramid or blended flame resistant fabrics.

The important piece is they must be guaranteed to be flame resistant for the life of the garment.

Understanding Industry Terms

Inherent

Fibers are engineered to be flame resistant before being woven into fabric.

Treated

Fabric is engineered to be flame resistant after it is woven.

Engineered

The scientific process of manufacturing flame resistant fabric.

The perfect fiber does not exist!

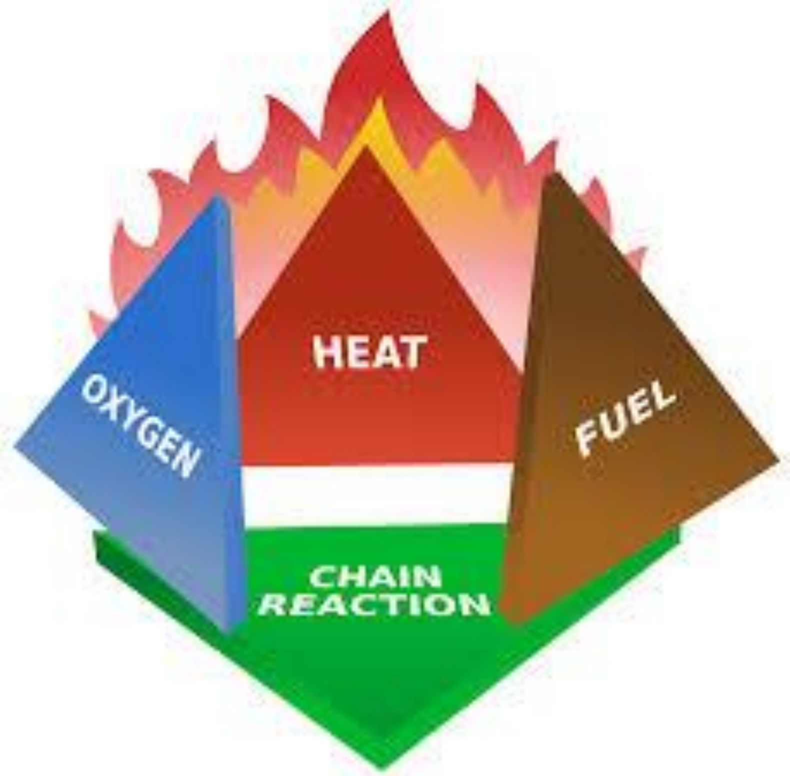
There is no perfect fiber blend thus no perfect fabric – the contributing fibers bring their various contributions of strength, durability, moisture management, light weight etc.

What is important is that the FR engineering is accomplished in such a way that the FR is guaranteed for LIFE

Be assured Manufacturers are:

ALWAYS looking for the next winning fabric
ALWAYS looking to evaluate viable FR fabrics
ALWAYS looking for fabrics to enhance and compliment their line

Interrupting the Fire Tetrahedron



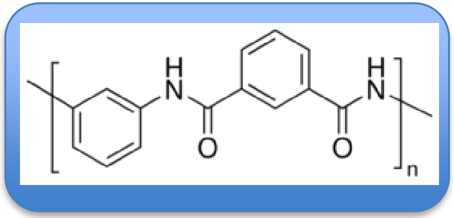
Interrupting the Fire Tetrahedron

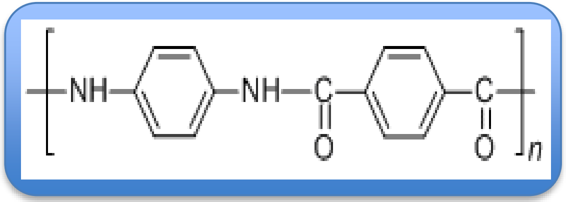
- ✓ Thermally Stable Fibers
- ✓ Radical Scavengers
- ✓ Char Formers

Thermally Stable Fibers

- Thermally Stable Fibers are defined as materials that do not decompose at temperatures less than 400ºC (750ºF).
- These fibers produce flame resistant fabrics by reducing the amount of volatile compounds available as fuel.
- Aramids (aromatic amides) are the most widely used.

*Contain **no fire retardant** chemicals.





Thermally Stable Fibers

Fiber type	Common trade names	Decomposition temperature (ºC)	Primary uses
Meta-Aramid	Nomex® (DuPont) Conex® (Teijin) Kermel® (Kermel)	420 ºC	Protective apparel, fire barrier layers for furniture
Para-aramid	Kevlar® (DuPont) Twaron® (Teijin)	550 ºC	Composites, protective apparel
PBI (polybenzimidazole)	PBI (PBI)	>700 ºC	Fireman's turn-out gear (blends with para-aramid)
PPS (polyphenylene sulfide)	Torelina® (Toray)	>500 ºC	High temperature filters
PBO (polybenzoxazole)	Zylon® (Toyobo)	700-720 ºC	High strength composites
POD (polyoxadiazole)	Pod-Z® (Podrun) Arselon (Svetlogorsk Khimvolokno)	490 ºC	Protective apparel, filtration
OPAN/PPAN (oxidized polyacrylonitrile)	Pyron® (Zoltex) PANOX® (SGL group)	>450 ºC	Brake pads, apparel, aircraft fire barrier layers

Thermally Stable Fibers

Advantages

- Fabrics are highly durable and can last many years.
- Does not rely on fire retardants – permanent regardless of care conditions
- Can provide protection at lighter weights.
- No FR agent to consume, can resist heat for longer times (i.e. firefighter gear).

Drawbacks

- Easily the most expensive option (initially).
- Fibers are relatively stiff, resulting in a firmer, harsher hand. Low water absorption.
- Difficult to dye. Some must be solution-dyed, others need a carrier (which are flammable).
- Since no fire retardant is present, contamination must be avoided. Blends with flammable fibers require additional FR agents.

Radical Scavengers

- Radical scavengers are fire retardant chemicals that release radicals capable of combining with and scavenging reactive radical intermediates.

- Most commonly **Bromine or Chlorine-based**.

- Work in the gas-phase of the fire mechanism. Thermal degradation of the additive produces radicals that are ejected into the gas phase where they scavenge other radicals.

- Modacrylic is the most common use of radical scavengers in protective apparel.

Radial Scavengers

Small Molecule Radical Scavengers: Used in foams, plastics, and other molded materials. Used extensively with binders as back coatings for textile for many years. Most common in plastic parts are the polybrominated compounds.

Polymeric Radical Scavengers: Most common fiber-based Radical scavengers are the modified acrylics (modacrylic). This is a copolymer of acrylonitrile and vinyl chloride, normally including an Antimony synergist.

Modacrylic protective apparel

Radical Scavengers

Advantages

- Fabrics can have good flame resistance at low loading levels of radical generators.
- Modacrylics are generally easy to dye and process.
- Modacrylic has permanent FR properties.
- Modacrylic has a nice hand, at a reasonable cost.

Drawbacks

- Modacrylic fibers are relatively weak, and can be brittle. Normally less than 50% of blend (often reinforced with aramids- increasing cost).
- Modacrylic fabrics have some thermal shrinkage and thermal stability issues (must be dyed at low temperatures).

Char Formers

Phosphorus-based char forming additives act in two ways:

- Phosphorus catalyzes ring forming reactions that consume the volatile organic compounds formed from the fiber decomposition.
- The resulting char serves as a thermally insulating layer that reduces the decomposition rate of the underlying organic material.

- Nitrogen is a synergist that forms a more stable char with phosphorous and carbon.
- Works in the solid phase of the fire mechanism. Thermal degradation of the phosphorous FR agent and the fiber produce a char that reduces the volatile fuel load.

2- ways to achieve the same result

The chemical process must be controlled properly to achieve durable FR properties.

Ammonia Process

Impregnate with THP pre-condensate → Dry to specific moisture level → React with gaseous ammonia → Oxidize → Finishing

Fabric is dipped and squeezed with a solution of the THP pre-condensate compound.

Cross-linking occurs to make the polymer and react it to the fiber surface

Oxidation makes the reaction irreversible, so the polymer does not "unzip" with laundering

Includes softening, and pre-shrinking

Thermal Process

Impregnate with THP pre-condensate and Nitrogen crosslinker → Cure in thermal oven → Oxidize → Finishing

*The key take away is the process is not as simple as applying chemistry to fabric

Char Formers - (THP-based Phosphorus Chemistry)

Advantages

- Cost effective.
- Comfort properties of cotton are largely preserved.
- Dyeing/finishing attributes of cotton based products are retained.
- Char provides thermal insulation to protect the wearer from thermal heat transfer.

Drawbacks

- Lower service life due to natural properties of cotton.
- Must be processed correctly. Incomplete crosslinking or oxidation can lead to non-durable coatings.
- FR properties can be reduced with repeated chlorine bleaching.

Testing to and for the Hazards

- What makes up an **ARC RATING**

- What goes into being **NFPA® 2112 compliant**

What is an Arc Rating?

NFPA® introduced the term in the 2012 edition:

Arc Rating. The value attributed to materials that describes their performance to exposure to an electrical arc discharge. The arc rating is expressed in cal/cm2 and is derived from the determined value of the **arc thermal performance value (ATPV)** or **energy of breakopen threshold (E_{BT})** (should a material system exhibit a breakopen response below the ATPV value). Arc rating is reported as either ATPV or EBT, whichever is the lower value.

Informational Note No. 1: Arc-rated clothing or equipment indicates that it has ***been tested for exposure to an electric arc****. Flame resistant clothing without an arc rating has not been tested for exposure to an electric arc. All arc-rated clothing is also flame-resistant.*

ASTM F1959 Testing

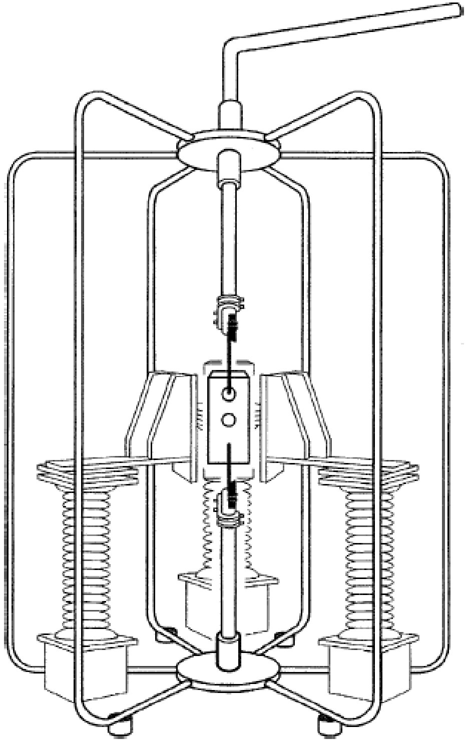


FIG. 7 Supply Bus and Arc Electrodes for Panels

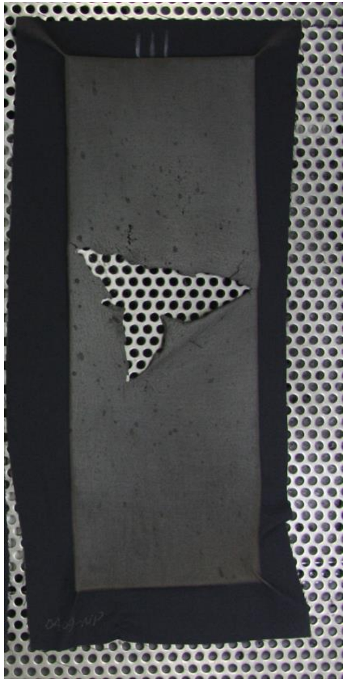
- Fabric panels are subjected to electric arcs
- Calorimeters measure heat transfer through fabric
- Voltage, amperage, gap and distance are held constant
- Duration (cycles) are varied to achieve higher and lower energies

ATPV or E_{BT}....

A “break-open” or “no break-open ” is determined by visual inspection.

One will result in an ATPV and the other an E_{BT} – they are both arc ratings.

You report/record the lower of the two – note all fabrics will eventually break open – one occurs before a 2nd degree burn is reached.



Dynamics of Arc Flashes

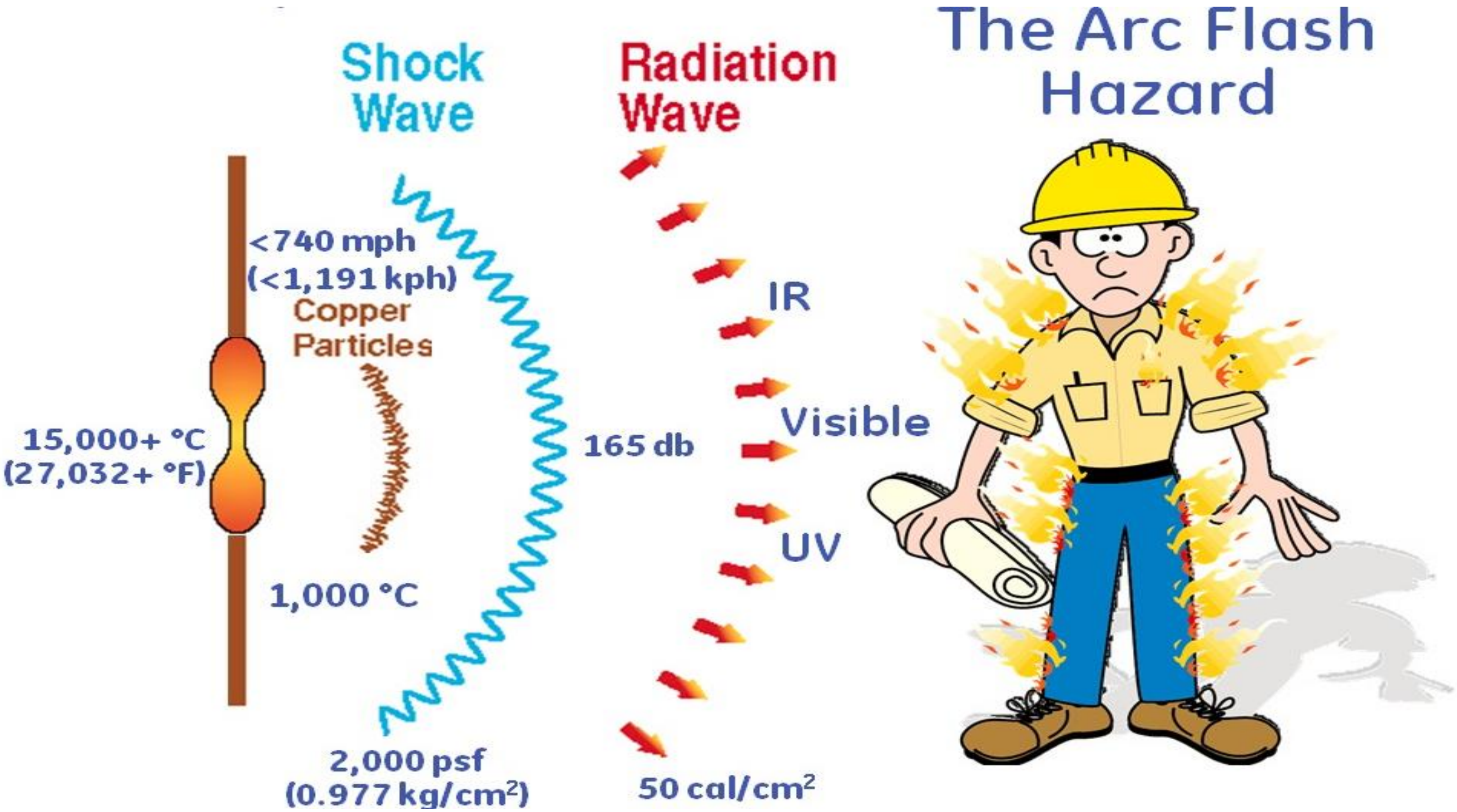
As the arc is first established, the intensity of the light can cause immediate vision damage. **BLINDNESS**

The electric current flowing through the ionized air can reach temperatures up to 35,000 degrees. **BURNS**

The intense heat from the arc causes the air to expand producing a shock wave with sound that can potentially rupture eardrums, collapse lungs, and cause fatal injuries.
DEAFNESS/SOFT TISSUE DAMAGE

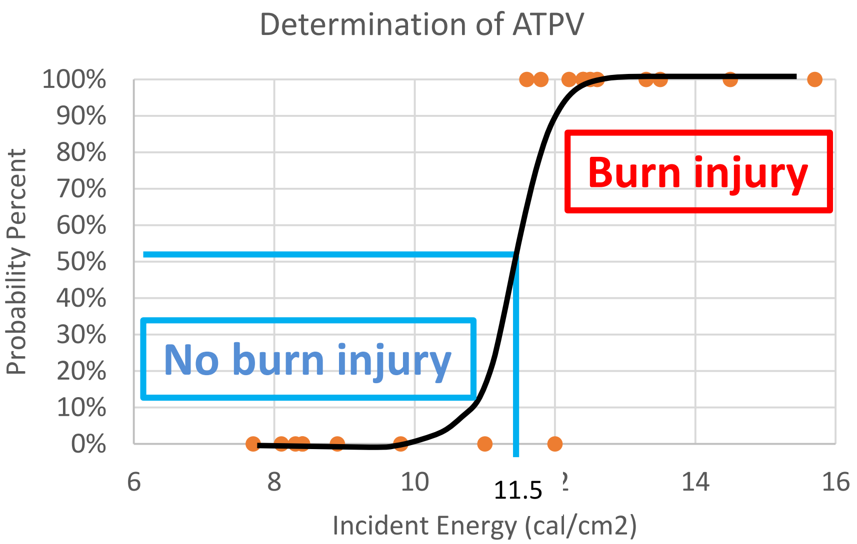
All known materials are vaporized at this temperature, subsequently expanding in volume. The resultant air blast can eject molten metal to great distances with extreme force. The molten metal can ignite conventional clothing and the shrapnel that's ejected can result in physical trauma to the worker.
PHYSICAL TRAUMA and BURNS

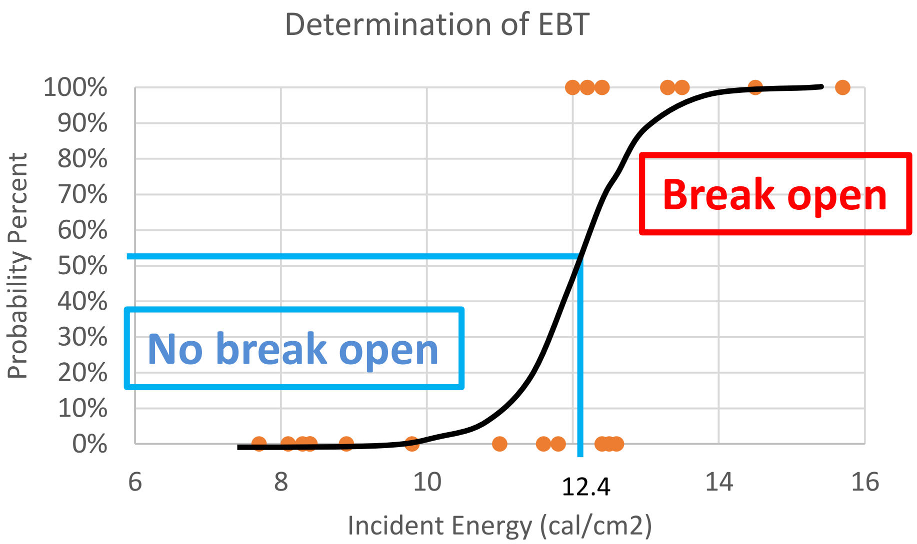
Dynamics of ARC FLASH



Getting to an Arc Rating

A best-fit curve is calculated using a *nominal logistic regression* to determine the APTV or E_{BT} value





https://www.arcwear.com/blog/atpv-vs-ebt-explained-simply/

Flash Fire & NFPA® 2112

Today's Definition

Flash Fire. A type of short-duration fire that spreads by means of a flame front rapidly through a diffuse fuel, such as dust, gas, or the vapors of an ignitable liquid, without the production of damaging pressure.

Short-Duration Thermal Exposure from Fire. ***A period of egress from or accidental exposure to thermal events***, including but not limited to, vapor cloud fires, jet flames, liquid fires (pool fires or running liquid fires), solids fires (fires of solid materials or dust fires), or warehouse fires.

NFPA® 2112 Requirements

What it is….

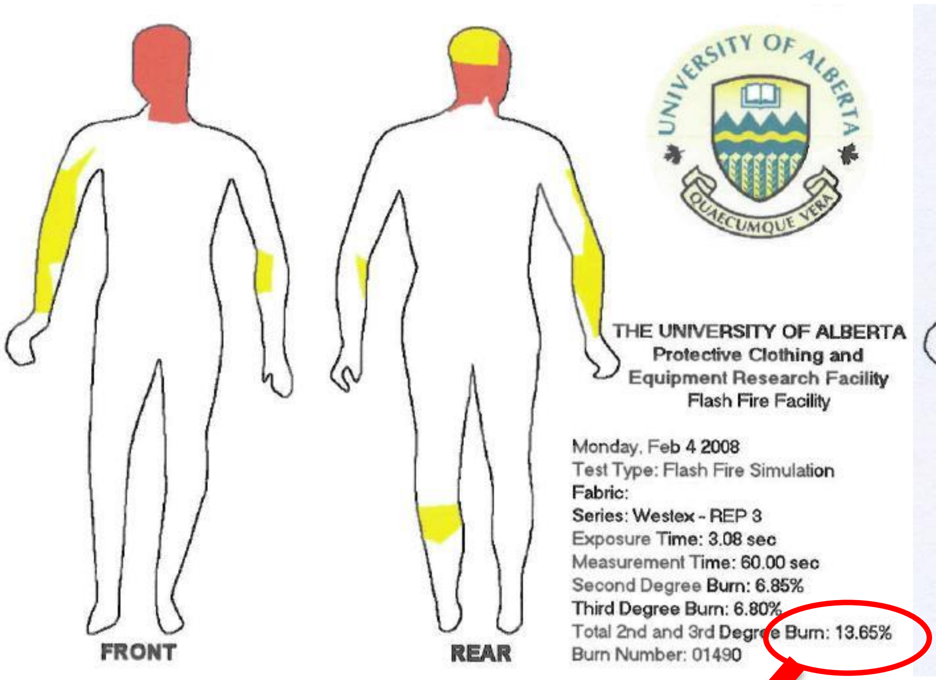
- A means of certifying fabrics & findings suitable for use in FR clothing to be worn as protection against possible flash fire exposure

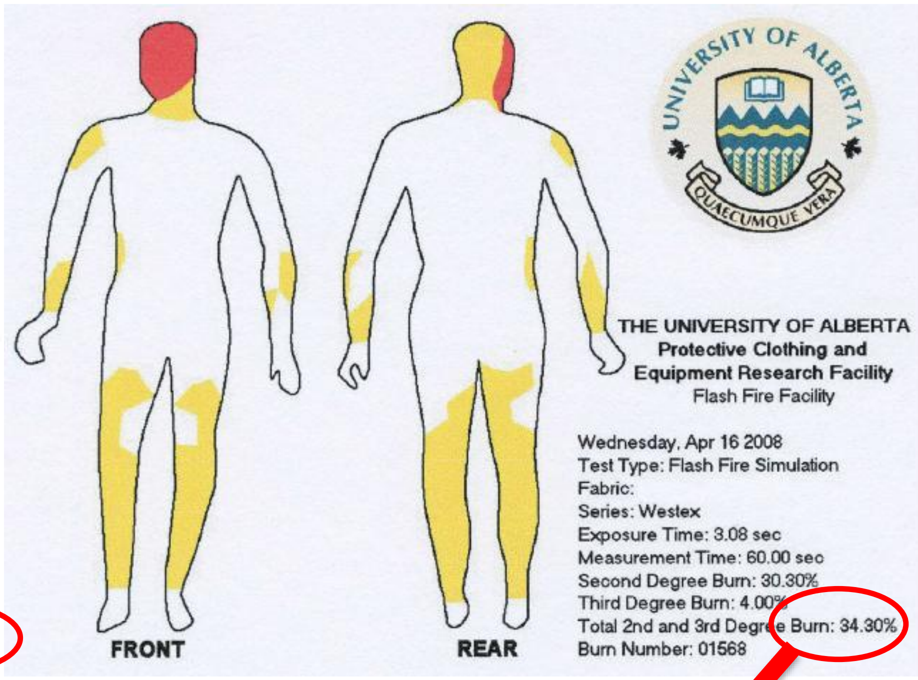
Fabrics must:

- Retain flame resistance through multiple launderings - 100
- Meet standards for heat transfer performance, thermal stability and heat resistance
- Result in less than 50% predicted body burn when tested on a thermal manikin over underwear in a jet fire of 3 seconds at 2 cal/cm2

Based on what we know today – it gives you peace of mind that this garment meets or exceeds all the standards and tests available for the hazard

What are the RESULTS





13.65%

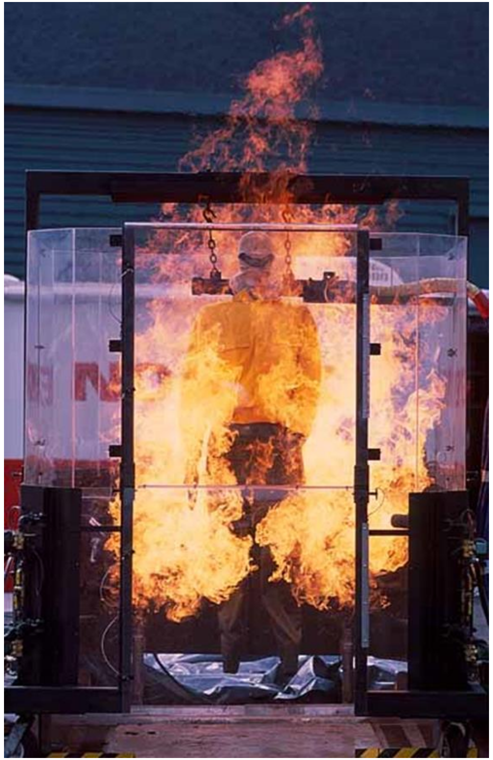
34.30%

Real World Flash Fire vs ASTM 1930

It is important to understand the difference between the ASTM 1930 test method for fabric and real world flash fires

Many decision makers have been influenced to focus on the results of ASTM 1930 testing alone without fully understanding how to view the information

Some manufacturers have attempted to "make up" a category "flash fire rated" that only focuses on ASTM 1930 test results



ASTM 1930 – warrants additional explanation

This test involves placement of a flame-resistant garment on a manikin with exposure to a 3-second duration, 84 kW/m2 (2.0 cal/cm2 · sec) intensity engulfment **"jet" fire**. The test is used as a qualification of garment fabric performance, not the garment design, since a standard garment design is used for evaluating the fabric. The standard garment is a coverall with a front slide fastener (zipper) closure and no pockets. Flame-resistant garments with different designs are not evaluated using this test. Organizations should judge the performance of their garment designs by comparing their design with that of the standard garment design or conduct independent testing.

Garment designs that provide different areas of body coverage, have different closure systems, or have pockets can demonstrate lesser or better performance than the standard garment design

Fire vs Flash Fire

Fires:

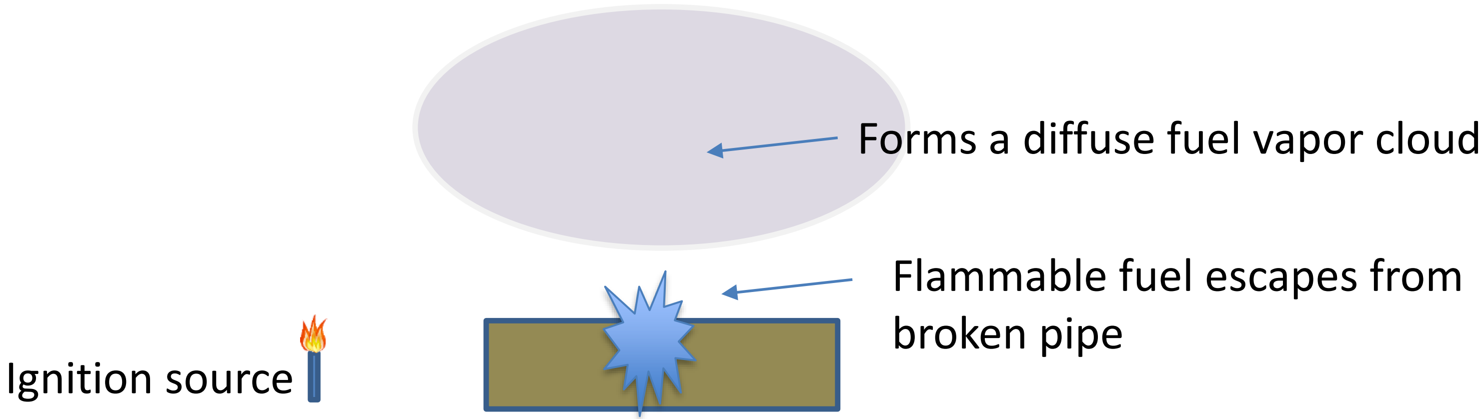
- Fuel-fed
- Relatively static
- Normally planned or known
- Multi-layer protection required (turnout gear) - Primary Protection
- Respiratory protection is required

Flash Fires:

- Fuel-limited
- Rapidly moving flame front
- Normally unplanned
- Single layer of flame resistant fabric can offer protection – Secondary Protection
- Respiratory protection is generally not required

Flash Fire Dynamics – Vapor cloud

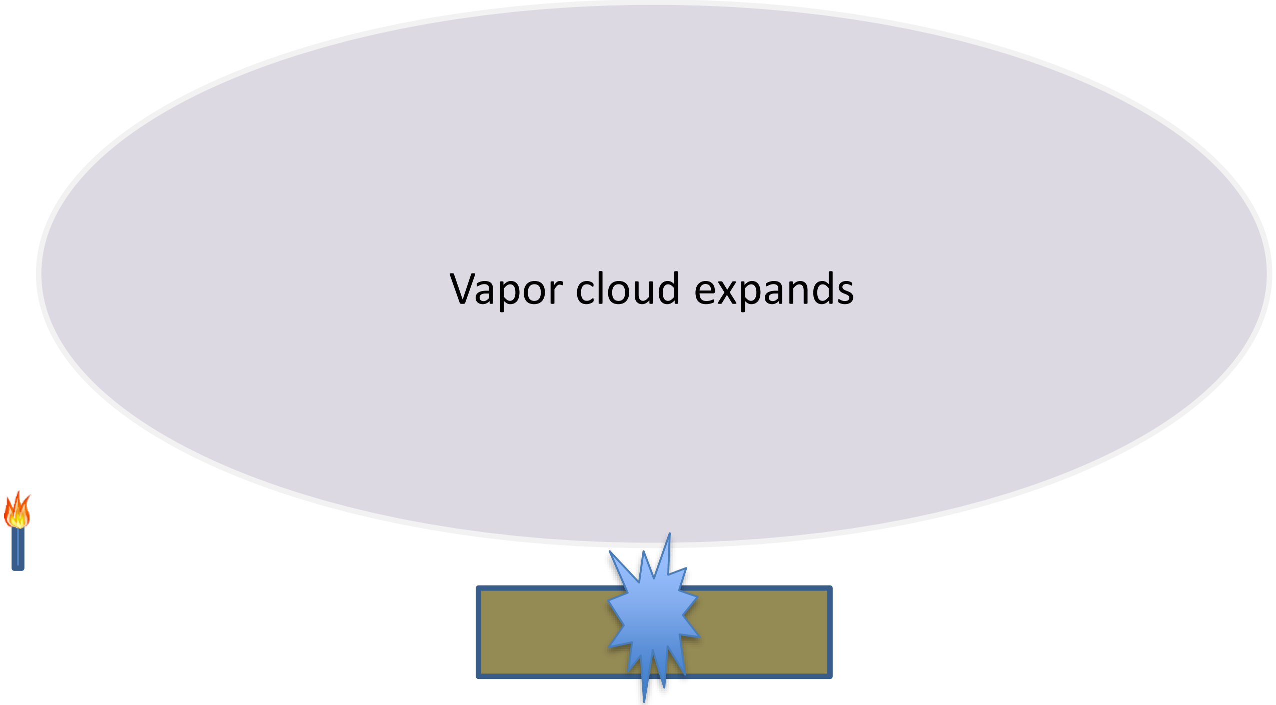
Flash fires consist of a diffuse fuel, such as dust, gas, or the vapors of an ignitable liquid with a separate ignition source.



https://en.m.wikipedia.org/wiki/Flash_fire

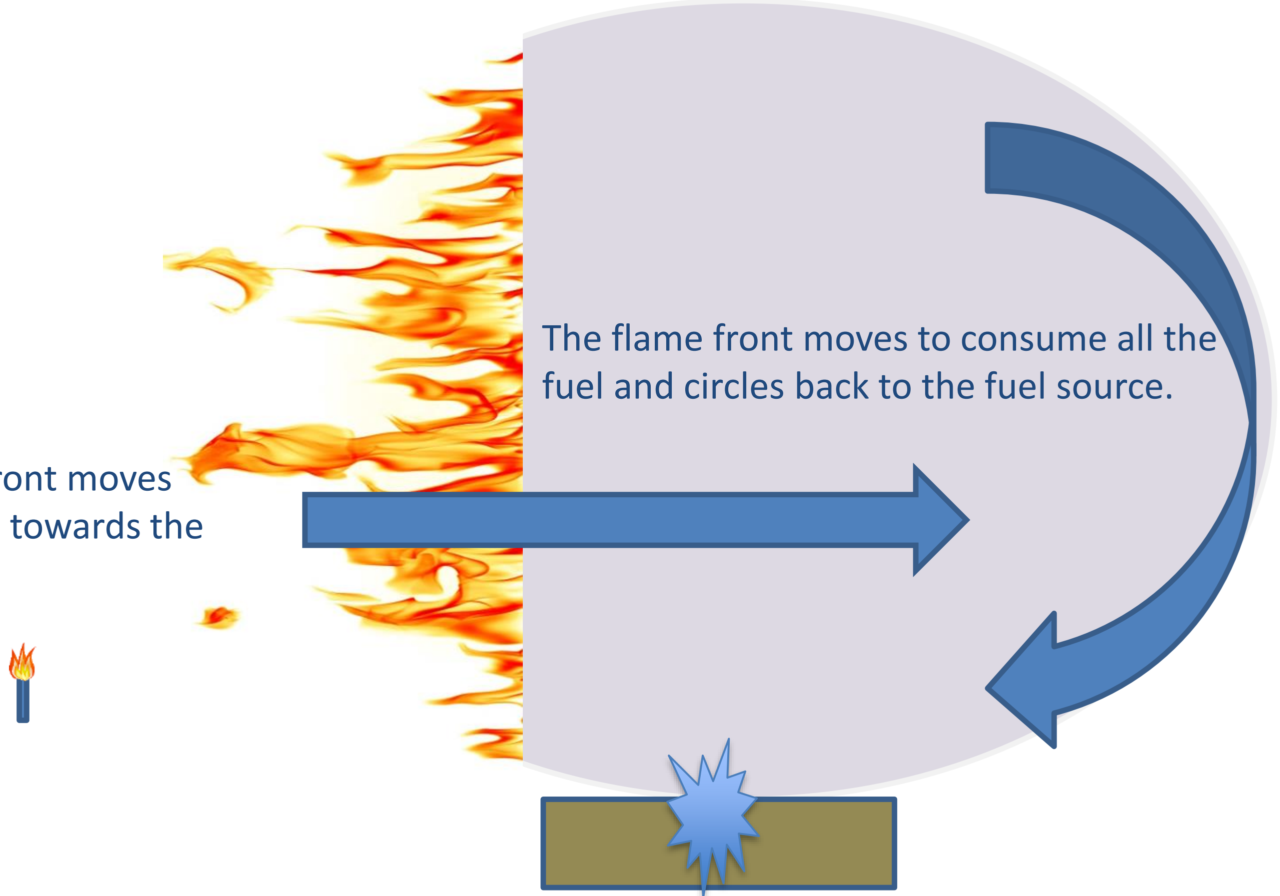
Flash Fire Dynamics

The vapor cloud of flammable gas continues to grow until it nears the ignition source where the activation energy is present.



https://en.m.wikipedia.org/wiki/Flash_fire

Flash Fire Dynamics



The flame front moves to consume all the fuel and circles back to the fuel source.

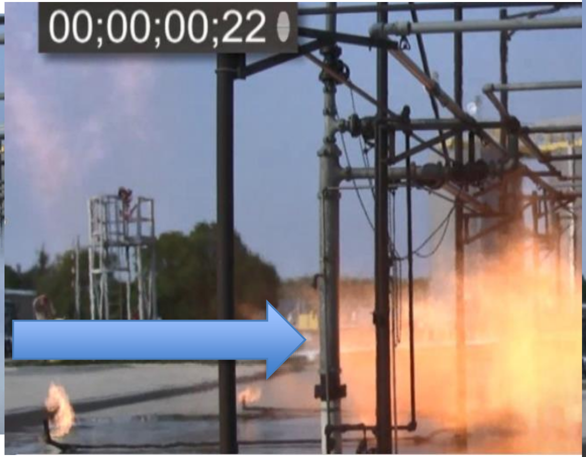
The flame front moves rapidly back towards the fuel source.

Flash Fire Dynamics

After the vapor cloud is consumed, the flash fire becomes a fuel-fed fire unless the fuel source is eliminated/cut off.

https://en.m.wikipedia.org/wiki/Flash_fire

What does it look like ….



https://www.westex.com/blog/how-long-do-flash-fires-last/

Limitations of testing and certifications

- Both ASTM 1959 for Arc Flash and ASTM 1930 for Flash Fire are fabric tests in a laboratory, NOT REAL WORLD
- How the garment is built is extremely important to how it performs in a real event
- Certifications and test results are on that fabric on that day under those conditions
- Market Proven Performance

Know your supply chain

Today's and Tomorrow's SMARTER FR/AR

Comfort

- **New** Chemistry allows for lighter weight fabrics to protect like much heavier fabrics
- Features technology that allows for enhanced moisture management

Durability

- **Improved** fabric to withstand high water and dry temperatures
- Greater rip and tear resistance

Mobility

- **NEW** ergonomically enhanced coveralls
- Features technology to allow less pull on the lower half when the top half is engaged

Goal

- To build performance garments with FR properties for the occupational athlete.

Summary and Conclusions

Fire is a complex chemical reaction. Retarding fire can be accomplished by interrupting any leg of the fire tetrahedron.

In flame resistant fabrics, three common techniques are employed: the use of thermally stable fibers, gas-phase radical scavengers, and solid-phase char formers.

Each of the flame resistant fabric strategies has advantages and drawbacks. Developers of flame resistant fabrics often create blends of fibers and chemistries that attempt to optimize the properties for each application.

Whether the FR technology is a property of the fiber structure, engineered into the fiber, or engineered into the fabric, **flame resistant fabrics can be produced which are durable for the life of the garment**.

Certifications and test results are on that fabric **on that day** under those conditions

***Work with Proven Supply Chain Partners**

Thank You!

Questions & Discussion

Bulwark Protective Apparel

Derek Sang

derek_sang@vfc.com