Fire Behavior Basics

You know the old rhyme; "stick and stones may break my bones, but names will never hurt me." Well, I am not so sure that names are that benign. Failing to call something for what it really is, could lead to underestimating its impact on your world. For example, what do we talk about when we talk about fire in a structure? What words come to mind? How about Flashover? Of course, there is the Fire Triangle. Some might not even agree with that term, preferring the Fire Tetrahedron. Here is one that the fire behaviorists might understand; Thermal Balance. All of these words come from the world of fire suppression don't they. Can we get hurt by not knowing what they mean in the real world? I think so.

However, you are reading this column in a magazine devoted to fire prevention, specifically about fire sprinkler technology. Your job is to prevent an ignition from occurring, or if that cannot be achieved, to keep flashover from occurring - right? Is the concept of fire chemistry as important a concept to you as it is to the fire suppression crews? The answer is not only yes, but a great big capital YES.

There are a lot of other fire behavior terms that should be part of your vocabulary that go beyond the basics. If you are talking about preventing the ignition and spread of fire there is a vocabulary that goes way beyond the simple rookie school definition of what it takes to create a fire. Your task as a fire prevention professional is to elevate these more technical terms to the same level of discussion as the ones that populate the world of fire suppression.

This column is being created as a Primer for discussing these terms. We will be exploring this concept over a period of several separate columns in order to give the subject enough emphasis.

We might start with what you already know. Can you easily recite the definitions of the fire tetrahedron?

The Fire Triangle - it is necessary to have all three sides of the fire triangle present in the proper portions in order to have a fire. Once a fire is burning, the removal of one side of the triangle will cause the fire to go out.

The Fire Tetrahedron - A four-sided figure that incorporates the fire triangle, fuel, heat, oxygen, & the added feature of the chemical chain reaction.

Fires by Type - the primary purpose for which fires have been classified by type is for identifying the type of material required for extinguishment.

Classification of Fires - matter, whether in a solid or liquid state must be converted through pyrolysis or vaporization into a gaseous state before it can burn.

Class A Fires -Ordinary combustibles such as paper, wood, cloth, etc.. Water works well on these types of fires.
Class B Fires -Flammable & combustible liquids & gases. Dry chemical & a water/foam mixture work well on these fires.
Class C Fires - Electrical fires. Eliminate the source of electricity & the fire changes to another class of fire.
Class D Fires - Combustible metals. Extinguished with Dry Powder.
Class K Fires - Flammable cooking oils extinguished with wet chemical agents

Fuel, Heat, Air, Chemical Reaction….Great. Now let's try some other aspects of fire behavior that relate more to your function as a fire inspector.

Let me give you an idea of what I am referring to: What is

- Rate of Flame Spread
- Rate of Heat Release
- Products of Combustion
- Fire Resistance
- Fire Retardant

How well do you know those terms?

Each of these phrases is a Base Line Definition when it comes to creating a specific fire problem in the community. They are the elements of Fire Behavior that are imbedded in the codes and statutes. The materials we put into buildings are evaluated according to these terms and they either contribute to fire safety or they contribute to the problem when not properly considered. Let us take the first one for example; Rate of Flame spread.

The mechanism of flame spread is affected by a variety of factors. These factors fall into the classification of chemical composition of the fuel, physical properties of the fuel and environmental factors. There is an excellent source of information on this topic on the internet at http://fire-dynamics.info/page1/page1.html

Rate of spread is the horizontal distance that a flame zone moves per unit of time (feet per minute) and usually refers to the leading segment of the fire as it moves across a fuel. In short hand terms, it means that in some materials the fire spreads slower and in other materials the fire spreads faster. It is a definition of variability and is a function of the fuel characteristics and the environment.

As fire fighter you probably already know that a fuel that is lying flat on the floor is going to burn faster than one that t is setting upright. A horizontal orientation and a vertical orientation create different flame spread scenarios. Which orientation we allow in the installation of certain materials is a key factor in what kind of fire behavior we might see in a code compliant structure.

Back in the late 1940's and early 1950's combustible acoustical tile used on ceilings was of serious consequence in loss of life in building fires. After several major incidents involving schools, nursing homes, hospitals and similar structures, revision of fire protection standards brought correction of this defect by requiring that the fire spread characteristics of such materials be tested. As result these materials are regulated by code requirements today.

Today there are several methods of evaluating surface burning characteristics of building materials to judge their suitability within any specific occupancy. The most widely recognized laboratory test of such fire characteristics is defined in NFPA Standard No. 255 - Method of Test of Surface Burning Characteristics of Building Materials. This document is also mirrored in Standard E-84 of the American Society for Testing and Materials and No. 723 of Underwriters' Laboratories, Inc.).

These standards define the equipment and test method that can be used to discern the flame spread rating of a material. The rating that comes from this test is a number, calculated from results of the test. The number indicates the relative rate at which flame will spread over the surface of that material, as compared with flame spread on asbestos-cement board (rated zero) and on red oak (rated 100). It should be emphasized that this rating number is not **the** rate at which the flame actually spreads along the surface and is not an indication of the fire resistance of the material. It is a comparison to a base line

The method and equipment used in this evaluation is commonly referred to as the Tunnel Test. In a tunnel test procedure, the sample of material (18 inches wide, 25 feet long) is installed on the underside of the removable top panel. A gas flame is applied at one end and a regulated constant draft is directed through the tunnel from the flame end. The progress of the flame front along the sample is observed through side windows and timed. "From these observations a flame spread rating can be calculated. For example, if the flame travels 19-1/2 feet in less than 5-1/2 minutes (the time required for flame to spread on 19-1/2 feet of red oak), the rating is 100 times 5-1/2 divided by the time (minutes) in which flame spreads 19-1/2 feet on the sample. "[1]

[1] Tseng , Ya-Ting, T'ien, James S. , A Comparison of Flame Spread Characteristics over Solids in Concurrent Flow Using Two Different Pyrolysis Models, Journal of Combustion
Volume 2011 (2011), Article ID 250391, 9 pages

Fire Protection Engineers, who are very familiar with this test, know that pyrolysis occurs only on the surface of a fuel. They also know that the fuel thickness decreases the longer the fuel is burning. But, rate of flame spread is not a test for that factor. It is only a test to determine how fast flame will propagate over a surface. Some fuels support rapid spread. Some do not. Which do you think contribute more to the fire suppression crew's dilemma of getting ahead of a fire?

The burning of a piece of wood that was described in the rookie schools as being the combination of fuel, air and heat is a little more complex than that. The speed of flame over surface interior material can affect the safety of people within a building if flame spread is faster than evacuation can be accomplished, or if fire spreads throughout an entire building before adequate fire protection measures can extinguish the blaze. That includes fire suppression by our firefighters. For purposes of classifying flame spread the codes have adopted a set of baseline points. They are as follows:

- Class A flame spread rating 0-25
- Class B flame spread rating 26-75
- Class C flame spread rating 76-200
- Class D flame spread rating 201-500
- Class E flame spread rating over 500

A is best. E is not so good.
In 1963, G.W. Shorter, noted that "Fire spread is influenced by a number of factors that vary from one case to another, but experience has shown that it can be markedly influenced by the nature of the interior linings. The flammability of the materials used as interior linings often determines both the likelihood (ease of ignition) and rate of development of a fire within a compartment.[2] That was over 50 years ago. How much change have we seen in the nature of the materials being used inside of structures since then?

If you want to become more familiar with the concept of flame spread characteristics of wood products see the following website: http://www.acrodisplay.com/PDFs/DCA1.pdf

But what about the actual Rate of Heat Release from a fuel? Isn't that a different consideration? For that lesson we need to turn to Dr Vytenis Babrauska. He has an excellent discussion of this phenomena on his web site; http://www.doctorfire.com/hrr_prmr.html

What he tells us is that heat is measured in joules. I know when I went through recruit training I heard a lot about BTU's but I never heard of joules. He goes on to explain that measuring how much heat is released is not based on the total amount of heat being released, but how much of it being released in a

[2] Shorter, G.W, Canadian Building Digests, NRC-IRC Publications, 1963

second. He defines rate of heat release as the number joules per second that a fuel gives off, which is termed as **WATTS**. Since most fires put out much more than a few watts, scientists' usually convert the rate of heat release into kilowatts (1000) or megawatts (a million watts.)

According Dr Vytenis Babrauska

> *"HRR is not just 'one of many' variables used to describe a fire. It is, in fact, the single most important variable in describing fire hazard. (The only notable exception is for explosions). There are three main reasons for this.*
>
> ***HRR is the driving force for fire.***
> *The HRR can be viewed as the engine driving the fire. This tends to occur in a positive-feedback way: heat makes more heat. This does not occur, for instance, with carbon monoxide. Carbon monoxide does not make more carbon monoxide.*
>
> ***Most other variables are correlated to HRR***
> *The generation of most other undesirable fire products tends to increase with increasing HRR. Smoke, toxic gases, room temperatures and other fire hazard variables generally march step-in-step with HRR as HRR increases.*
>
> ***High HRR indicates high threat to life.***
> *Some fire hazard variables do not relate directly to threats to life. For instance, if a product shows very easy ignitability or high flame spread rates, this does not necessarily mean that fire conditions are expected to be dangerous. Such behavior may merely suggest a propensity to nuisance fires. High HRR fires, however, are intrinsically dangerous. This is because high HRR causes high temperatures and high heat flux conditions, which may prove lethal to occupants.[3]"*

What I find interesting is that most experimental test fires are described in megawatts, but I seldom here the term used in the fire service as a determinate of the potential size of a real fire. Just how many megawatts are in a full involved single family dwelling fire are there?

Products of Combustion

One cannot pickup a current fire protection publication without noticing that fuels have a serious implication for firefighters when they breathe in the products of their combustion. Again, Dr. Babrauska has provided some insight here also. He states:

- *Coroners tell us that inhalation of toxic fire gases is the main cause of fire deaths, so we should control toxicity, not HRR*

Babrauska, [3] Dr. Vytenis, Fire Science and Technology, copyright 1996

Toxic potency is the toxicologist's term for defining **how toxic is the substance when you inhale 1 gram of it.** But of course the victim will inhale something other than 1 g of it. **How much** of the substance will be inhaled is governed by the fire's **mass loss rate.** The mass loss rate is closely proportional to the HRR of the fire.[4]

Is there anyone out there that still doubts that exposure to smoke and the toxic products of combustion should be avoided at all costs? Is there anyone out there who still believes that being a "smoke-eater is a desirable nickname? If there is have them check out the Fire Smoke Coalition. [5] Well, I hope not, but what does that have to do with your task as a fire prevention officer? My answer is simple, become more educated and informed about what this issue of toxicity is all about. If you agree with the following statements I have a question for you when you finish reading them.

1. Smoke consists of a mixture of gases, liquid droplets, and an solid particle that represent the decomposition and combustion products' from fuels that are allowed to be utilized within structures as components of either the structure itself or the contents of the structure.
2. Toxic products can be considered as one of three different categories: Asphyxiates Irritants or Unusual organic Products.
3. Toxic Products may differ at varying distances from a fire, so the closer you are to the combustion the higher the exposure

Here is the question: How much attention do we pay to the contents of structures from a code enforcement or regulatory point of view? If we recognize that there are basically three types of fires that our firefighters have to fight we should also be sensitive to what we are allowing into the occupancies that we regulate. The three types of fire scenarios are:

- ✓ Smoldering non/flaming fires: In these fires slow decomposition results in oxidation of non-flaming materials, the products are rich in organic compounds and irritants to the respiratory tract.
- ✓ Well ventilated fire: These fires have plenty of air, and combustion is very efficient, but they still develop carbon monoxide and carbon dioxide. They also produce inorganic acids.
- ✓ Ventilation limited Controlled flaming fires: These create high concentrations of all of the most potent of the gases.

Fire Resistance

So what is going to keep a building from burning down and why do we have to risk firefighter's lives to go into them to control a fire from time to time. The answer is that all buildings are designed to have a limit to the amount of damage they can experience before they are consumed by a fire once they occur. In other words, buildings have a design level to fail. It is all based on the fire-resistance rating. Fire-

[4] ibid
[5] http://www.firesmoke.org/

resistance rating typically means the duration for which a passive fire protection system can withstand a standard fire resistance test. The definition includes the idea that an assembly will serve as a barrier to the spread of fire after it is exposed to a standard fire test protocol, such as defined by ASTM E119. It represents the time that a given set of conditions will result in the building remaining intact. The standard rule of thumb in dealing with resistance is measure in hours. That is what 1 hour, 2 hour and 4 hour resistance is all about.

Fire resistance ratings have long been used by code organizations to measure the performance of various combinations for fire containment purposes. Generally they refer to walls, ceilings, and floor assemblies.

Regardless of the complexity of any given test regime that may lead to a rating, the premise is that there is generally a product certification and, most importantly listing and approval use and compliance for an assembly to be so rated. If you don't have the rating, you don't have the protection.

Fire Retardant

The term flame retardant refers to a function, not a specific family of chemicals or substances. A fire retardant, in general, is a substance other than water that reduces flammability of fuels or delays their combustion. Different chemicals, with different properties can act as flame retardants. Often one or more chemical are mixed to achieve the result.

This term, which refers to chemical retardants, is not the same as fire resistance. Let me give you a graphic example. Imagine you have a Christmas tree out in the backyard. Most everyone realizes that as a Christmas tree dries out as flammability increases. The trees have very little fire resistance. We can reduce the probability that the tree will ignite by coating it with a fire retardant. The retardant may delay the ignition, but once it occurs the ability of the plant to resist destruction is short-lived.

According to the North American Flame Retardant Alliance

Flame retardants are added to different materials or applied as a treatment to materials (e.g., textiles, plastics) to prevent fires from starting, limit the spread of fire and minimize fire damage. Some flame retardants work effectively on their own; others act as "synergists" to increase the fire protective benefits of other flame retardants. A variety of flame retardants is necessary because different materials that need to be made fire-resistant are very different in their physical nature and chemical composition.

So, they behave differently during combustion. The elements in flame retardants also react differently with fire with different materials. As a result, flame retardants have to be matched appropriately to each type of material. Flame retardants work to stop or delay fire, but, depending on their chemical makeup, they interact at different stages of the fire cycle. To better understand how flame retardants work, it's helpful to understand the fire cycle:

- Initial ignition source can be any energy source (e.g., heat, incandescent material, a small flame).
- Ignition source causes the material to burn and decompose (pyrolysis), releasing flammable gases.
- If solid materials do not break down into gases, they remain in a condensed phase. During this phase, they will slowly smolder and, often, self-extinguish, especially if they "char," meaning the material creates a carbonated barrier between the flame and the underlying material.
- In the gas phase, flammable gases released from the material are mixed with oxygen from the air. In the combustion zone, or the burning phase, fuel, oxygen and free radicals combine to create chemical reactions that cause visible flames to appear. The fire then becomes self-sustaining because, as it continues to burn the material, more flammable gases are released, feeding the combustion process.

When flame retardants are present in the material, they can act in three key ways to stop the burning process. They may work to:

- Disrupt the combustion stage of a fire cycle, including avoiding or delaying "flashover," or the burst of flames that engulfs a room and makes it much more difficult to escape.
- Limit the process of decomposition by physically insulating the available fuel sources from the material source with a fire-resisting "char" layer.
- Dilute the flammable gases and oxygen concentrations in the flame formation zone by emitting water, nitrogen or other inert gases. [6]

In general, fire retardants reduce the flammability of materials by either blocking the fire physically or by initiating a chemical reaction that limits ignition. The way a retardant works may be from a physical action or a chemical reaction. In all cases the concept of a fire retardant includes the idea that the combustion process is retarded, but not eliminated.

The many in which these products is used is to be applied to a material that is going to be used in some fashion that results in human exposure. For example fire retardants are used in children sleep-ware, mattresses, curtains and drapes, wall coverings, wood products and in furniture. These, for the most part are not structural elements as much as they are contents of structures. Some are applied as sprays, some as paints, other are introduced when the produce is being treated under pressure.

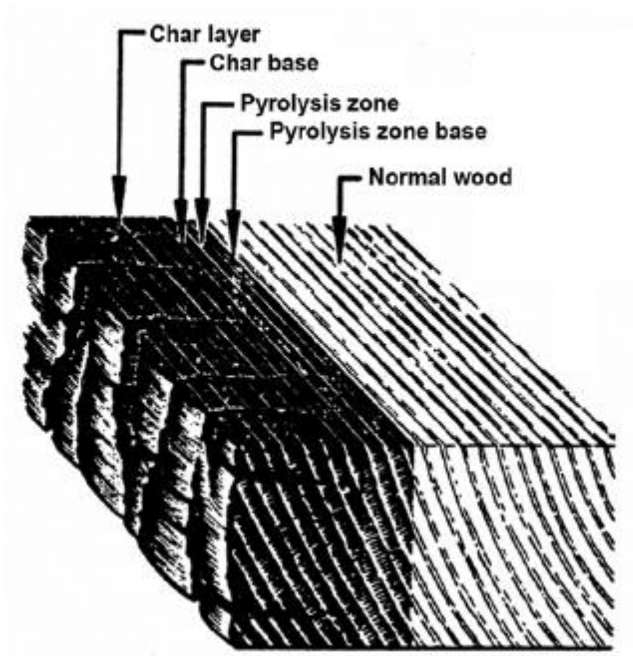
It is true that wooden products can often be treated with fire retardant to make up a component of a building.

[6] See website http://flameretardants.americanchemistry.com/FR-Basics

In the old day people used to use the term fire-proofing, but that term is hardly ever used anymore to describe a product that has been treated. What is important for fire personnel to understand is that Flame retardants are not all the same, and they are not interchangeable when it comes to the fire safety of materials and products. A variety of flame retardants is necessary because the elements in flame retardants react differently with fire. In addition, materials that need to be made fire-resistant are very different in their physical nature and chemical composition, and they behave differently during combustion

Before we finish our primer we ought to look at one very specific fire behavior component and that is the idea that when materials burn they consume the material by converting a solid into a gas. In your studies of the fire chemistry in boot-camp, did they every talk to you about the "Char Layer"
The following illustration is of piece of wood that is undergoing combustion. [7]You will note that there are several "levels" of reaction to the phenomena of being heated. They are called as follows:

- ✓ Char Layer
- ✓ Char Base
- ✓ Pyrolysis Zone
- ✓ Pyrolysis Base
- ✓ Unburned Wood



[7] White, Robert H., Dietenberger, Mark, A., Fire Safety of Wood Construction, Chapter 18

What does this illustration tell us about fire behavior? The first is that wood exposed to high temperatures will decompose. When it does decompose, it provides an insulating layer of char that retards the further degradation of the wood for period of time. This means that the fuel side of the tetrahedron is a variable that is always changing when a fire is in progress.

There are formulas for this rate of deterioration. As firefighters we all know that the load-carrying capacity of a structural wood member depends upon its cross-sectional dimensions. The longer a wooden member is exposed to flame the thinner the dimension gets. In the case of metal members, they do not "burn", but they weaken in accordance with the temperatures being created. What does all of this add up to – the inability to predict with any degree of accuracy how long any structural member will survive under load? There are no real rules of thumb that provide anyone with assurances that a roof or a floor will remain intact.

And, that leads me to the finally conclusion in this article and that is that the best solution to prevent a home, a business or any type of building from burning to the ground is to sprinkler it.

That is what this whole discussion is about anyway, how to keep buildings from burning down. Isn't that why we have fire prevention bureaus; to keep homes, business and industry from being destroyed?

As we apply the terms we have discussed in this series to the fire environment we are going to change the nature of the fire problem. The basic idea can be summarized in this series of statements:

If we can prevent ignition then we should do so.

If we cannot prevent all ignitions we should limit the rate of spread and rate of heat release from endangering occupants and install adequate warning devices to get people out of occupancies.

If we are going to have to deal with a rate of spread and rate of heat release that does endanger occupants then we should apply fire resistance and fire retardant techniques to create the smallest exposure possible.

If we can stop a fires growth before it results in the destruction of a compartment that has been established for fire resistance purposes, we should do so by installing active fire protection devices, such as sprinklers.

Summary

As we bring this series to a close, let me focus on the nature of dealing with modern fire problems for a moment. We live in a complicated world today. The simple explanation that fire has some simple terms and definitions that can be recited after a minimal period of study is way too simple to serve as the vocabulary of coping with the modern fire problem. I would submit that the process of combustion has not changed since the dawn of time, but the use the information regarding each nuance of fire behavior is what distinguishes the amateurs from the professionals. There is a static fire tetrahedron and there is an active fire behavior vocabulary. I would ask you, as a fire inspector, or fire marshal to contemplate the following questions:

- ✓ What things have changed in the world of fire behavior in your town
- ✓ Has the nature of "fuel" in our homes and businesses changed in the last 30 years?
- ✓ Has construction technology changed in the last 30 years?
- ✓ Has our approach to solving the fire problem changed in the last 30 years?

If the answer to any of these questions is yes, then we need to develop a broader and more thorough understanding of the specifics of these changes. It is my belief that fires burn hotter today than they did 20 years ago because the fuels have changed in that same time frame. I believe that fire spread faster than they use to because of those same changes in fuel. I believe that construction technology has introduced the need to be very aware of the impact of this fuel and ventilation phenomena as a part of fire-ground decision making. And, lastly, I really believe that we have to escalate our pursuit of build-in fire protection technology as part of the solution.

Good luck in applying the concepts we have explored in this article.

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