The Flashover Phenomenon

Firefighting is inherently dangerous. However, through increased awareness and understanding of the science of fire, along with realistic fire training, the number of injuries and fatalities may be reduced. This educational whitepaper is designed to help firefighters understand the nature of the deadly phenomenon called flashover and help them recognize its warning signs.

ABSTRACT

Today, flashover – also known as rapid fire progress (RFP) – is one of the leading causes of firefighter deaths in the United States[1]. According to the National Fire Protection Association's NFPA Journal, the second leading cause of fatal injury to firefighters in 2013 was being caught or trapped by rapid fire progress, including flashover, and explosions.[2] Current building materials and furnishings are producing fires that burn faster and hotter and are more deadly than ever before. In fact, the rate of flashover in a modern home is 8 times faster than a home of 50 years ago.[3]

The purpose of this whitepaper is to explain the science behind the phenomenon of flashover and outline the important role that live fire training plays in teaching firefighters to recognize the warning signs of flashover.

INTRODUCTION

In the past, flashover occurred less frequently because construction was primarily wood-based and the contents were made of natural materials, such as wool, cotton and paper. Today, construction materials are much lighter in weight and contents such as carpets and upholstered furniture are often made of highly flammable synthetic materials.

According to studies[3] by Underwriters Laboratories (UL), the rate of flashover for modern homes is 8 times faster than it was 50 years ago, when the average time it took a home fire to transition to flashover was around 29 minutes.Today's homes transition to flashover in less than 5 minutes.[4]

When ventilation is introduced, the time from onset of escalating temperature to firefighter untenability can be less than 10 seconds.[5]

Today's larger homes, open floor spaces, increased fuel loads and new construction materials have resulted in faster fire propagation, shorter time to flashover, rapid changes in fire dynamics, and shorter escape times.[4]

Wood, cotton, and paper – materials more commonly found in houses in the 1950s – give off about 8,000 BTUs per pound when burned. Polyurethane, the plastic often used in today's soft materials such as cushions and carpeting, gives off 12,000 BTUs per pound when burned. Polystyrene, the hard plastic used in TVs, toys, and other plastic items in today's homes, gives off 18,000 BTUs per pound when burned.[6]

Given the increased speed of flashover and higher fire temperatures, it's no surprise that flashover is one of the leading causes of firefighter deaths in the U.S. Between 2003 and 2012, 63 firefighters died in the line of duty as a result of being caught or trapped (including flashover).[1]

The firefighting techniques represented in this whitepaper are for informational purposes only. Training programs, curriculum, methodologies, and terminology may vary by region and department, as do structure entry and escape, nozzeling, and venting techniques. Always exercise your own professional judgment and follow your department's standard operating procedures and guidelines when fighting fires.

Increasing lack of first-hand flashover experience
Due to improvements in fire prevention and lower incidence of house fires, firefighters experience flashover much less frequently today than in the past. The first time a firefighter experiences flashover, instincts aren't enough: real-world training is required to recognize the warning signs and respond appropriately. However, few firefighters receive adequate flashover training. In the U.S., on average, firefighters receive less than 1% of their training[4] on the topic of fire behavior. Essential live fire training could mean the difference between life and death.

So while advancements in fire protection have reduced the frequency of fires, modern materials have made the intensity of those fires far greater. In addition, because of technological improvements in their personal protective equipment (PPE), firefighters can go deeper into structure fires than they did in the past. That extra protection can sometimes give a false sense of security, ultimately allowing firefighters to get closer to danger.

This makes it all the more important for firefighters to protect themselves with the knowledge that comes from studying the characteristics of fire behavior, including flashover.

WHAT IS FLASHOVER?

There are several different definitions of flashover, including:

International Fire Service Training Association (IFSTA)[7]
The stage of a fire at which all surfaces and objects within a space have been heated to their ignition temperature, and flame breaks out almost at once over the surface of all objects in the space. (Fire Service Orientation and Terminology, Third Edition)

National Fire Academy[7]
The ignition of combustibles in an area heated by convection and radiation, or a combination of the two. The combustible substances in a room are heated to their ignition point and almost simultaneous combustion of the material occurs.

National Fire Protection Association (NFPA 921)[7]
As the fire continues to grow, the ceiling layer gas temperatures approach 900°F, increasing the intensity of the radiation on the exposed combustible contents in the room. The surface temperature of these combustible contents rises, and pyrolysis gases are produced and become heated to their ignition temperature. When the upper layer temperature reaches approximately 1,100°F, pyrolysis gases from the combustible contents ignite along with the bottom of the ceiling layer. This is the phenomenon known as flashover.

DANGERS OF FLASHOVER

Flashover is deadly because it can catch firefighters off guard, develops rapidly with warning signs that are difficult to detect, and increases firefighting risk.

If a flashover occurs, those present in the room are unlikely to survive. Many of the firefighters who died in flashover were experienced firefighters.

It is important to understand that no one can accurately predict 100% of the time when a flashover will occur, but knowing the warning signs can help.


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FIRE SCIENCE: THERMAL BALANCE, OFF-GASSING AND FLASHOVER

In nature, everything seeks a thermal balance. For example, if you pick up a cold drink, your hand gets cold and your drink warms up. Likewise, when hot metal is submerged in cold water, the metal cools and water temperature increases. In each case, heat energy is transferred toward a more even balance of temperature.

Likewise, in a structure fire the heat generated by the seat of the fire absorbs into the walls and furnishings as the room temperature and the materials within it seek to find a thermal balance.

As the fire progresses into growth mode, the room and its contents reach a point where they can no longer absorb all the heat. At this point, the material will start radiating heat back into the room in the form of superheated gases or smoke. This process is called off-gassing.

Off-gassing is important to understand, because it is what actually makes fire possible. Solids, in and of themselves, don't combust. Rather, heat can increase a solid's temperature until it off-gases – whereupon a chemical reaction between the vapor, oxygen, and heat ignites a flame.

In a structure fire, the absorption of heat and off-gassing is a continual and cumulative process. As the intensity of the fire increases, heat constantly radiates back and forth between the seat of the fire and all surfaces. If not interrupted, this cycle – known as thermal radiation feedback – drives up the temperature and creates an environment full of superheated smoke and/or fire gases.

It was originally believed that flashover was caused by combustible gases released during the early stages of the fire and that these gases collected at the ceiling level and mixed with air. When they reached their flammable range and suddenly ignited, flashover occurred.

The current thought is that combustible gases mixing with air precede flashover. The cause of flashover is attributed to the excessive buildup of heat from the fire itself. Combustion only occurs within the flammable range of a vapor (gas). Within this range, the concentration of gases is ideal for burning.

Lower Explosive Limit (LEL)

the minimum % of vapor in air
that will burn (lean end)

The lower limit of the flammable range is the minimum concentration at which gases will burn. Below this point, the mixture of gas is too lean to burn – meaning that there is too much oxygen and too little gas.

Upper Explosive Limit (UEL)

the maximum % of vapor in the air
that will burn (rich end)

The upper limit of the flammable range is the maximum concentration at which gases will burn. Above this point, the mixture is too rich to burn because there is too little oxygen and too much gas.

Generally, with the progressive addition of heat to substances, the lower limit of the flammable range decreases.

TYPES OF FLASHOVER

There are several different types of flashover. The NFPA now calls all the different types of flashover "rapid fire progress" (RFP).

Hot rich flashover

Hot rich flashover is the rapid ignition of heated fire gases and smoke that have built up in a burning room. It's caused by thermal-radiation feedback (also known as re-radiation), which is the energy of the fire and hot gases being radiated to the contents of the room from the heated enclosure surfaces (e.g., upper walls and ceiling). Once the upper area of the room is saturated with heat, it radiates downward to all combustibles in the space, causing the room's contents to simultaneously reach the ignition point. At that point, flames break out, resulting in a fully developed and engulfing fire known as hot rich flashover.

Backdraft

Another type of flashover is backdraft, which is the least common type of flashover that firefighters encounter. Backdraft is the explosion or rapid burning of heated gases that occurs when oxygen is introduced into a building that has not been properly ventilated. At the latter stages of the fire, the building will have a depleted supply of oxygen with a high level of heat. The oxygen in the fresh air mixes with the gases and when it ignites, it ignites with an explosive force.

Delayed flashover

Delayed flashover occurs when a fire starts in a back portion of a structure, such as a rear bedroom in a house. The smoke and energy travel throughout the home, filling it with superheated gases. When firefighters enter the building, a hot rich flashover occurs in the rear bedroom. The sudden spike in temperature ignites the gases throughout the entire house. While the seat of the fire is in another part of the structure, firefighters can be faced with gases igniting all around them.

Rollover

Rollover, also called a "lean flashover", is the ignition of the fire gases in the upper ceiling area. The only thing firefighters can see – if anything at all – are sporadic snakes or wisps of flame that are occurring in the smoke. This is the last warning sign before a flashover occurs. If firefighters witness rollover, they have seconds before flashover will occur.

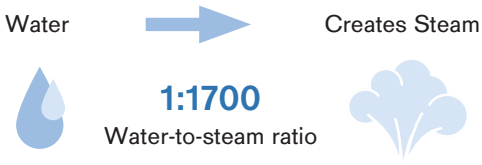
WATER AS AN EXTINGUISHING AGENT

Years ago, the school of thought was to "put the wet stuff on the red stuff." In other words, the goal was put water on the seat of the fire. However, fire science has shown that it's not the fire that kills firefighters, it's the smoke.

Firefighters can create a flashover by using the wrong nozzle pattern. A fog pattern with a swirling motion can mix up the different layers in a superheated environment, creating perfect conditions for flashover. However, if they use a solid stream of water to cut through all the layers of smoke, they are able to project water up to the upper atmosphere and cool the environment. Then they can go in and find the seat of the fire, affect a rescue, or retreat to safety.

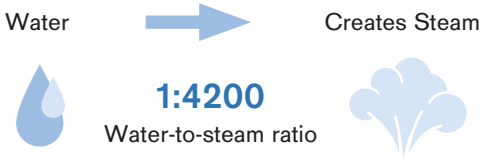
Steam Expansion Ratio at 212°F

At 212°F, the steam expansion ratio is 1700 to 1.



Steam Expansion Ratio at 1,128°F

At 1,128° F, the steam expansion ratio is 4200 to 1.



Flashover temperatures can range from 1,000°F to 1,500°F and can peak at over 2,300°F. At a flashover temperature of 1,128° F, one gallon of water becomes 4,200 gallons of steam. If firefighters in a confined space use the wrong nozzeling techniques, it could drive all those heated gases down into their environment and possibly bring on a flashover.

A more effective way of preventing flashover is to first cool the atmosphere overhead by carefully using nozzle techniques that direct water into the smoke layer that's above their heads.

WARNING SIGNS OF FLASHOVER

While every fire is different, experience has shown that there are warning signs of an impending flashover. These warning signs may include:

High heat: Smoke and gases are so hot that firefighters are forced to crouch down when entering a building. The lower they are forced to crouch, the greater the chance of flashover.

Thick dark smoke: Heavy, rolling clouds that violently twist upward indicate extremely hot smoke from an intense fire deep in the building. This is frequently followed by fire igniting through the openings in the building.

Rollover: Sporadic small flashes of flames (sometimes called "snakes" or "jellyfish") mixed with smoke that can be seen just before flashover occurs. Before entering a room, firefighters should check the smoke exiting the structure for signs of rollover.

FLASHOVER VARIABLES

Several factors can affect the speed at which a flashover occurs. They include:

Room size: A small room will flash more quickly than a larger room. The close proximity of the contents in a small room increases the absorption of thermally-radiated energy. In large rooms with high ceilings, it takes longer to heat the combustibles below. When radiated heat travels longer distances, it loses energy.

Room contents: A room with many combustible furnishings – such as synthetic carpets, drapes and furniture – will produce more heat and radiated energy, and therefore have a greater potential for flashover.

Window construction: Today's thermal-pane windows hold heat in the "dead air" space between the panes of glass and delay spontaneous breaking, which prevents the fire from self-venting, thus increasing the potential for flashover.

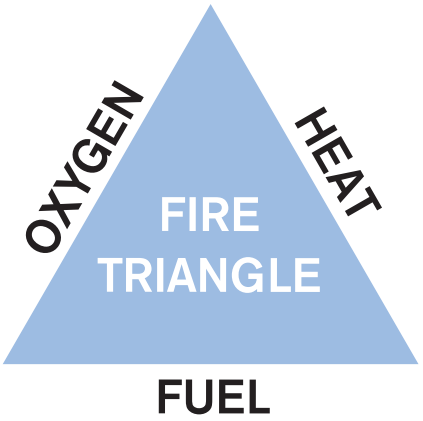
Insulation: Insulation in walls and ceilings traps heat inside the structure. This prevents heat from escaping to other areas of the structure and increases the room's potential for flashover.

PROPER ATTACKS FOR FLASHOVER PREVENTION

Break up the "fire triangle"

Most of the time, flashover occurs in an unvented structure. For example, if firefighters pull up to the scene of a fire and see wispy smoke escaping from the eaves, that is not a vented structure.

The three things a fire needs to survive are heat, fuel and oxygen. This is called the "fire triangle".



Many times, the fire triangle is not complete because it lacks oxygen – until firefighters arrive on scene. When they enter the building, air rushes in and feeds oxygen to the seat of the fire. The fire triangle is completed. Now the job of the firefighters is to break up one leg of that fire triangle, which can be done with ventilation.

Ventilation[5] refers to the tactic of creating a draft with an opening above or opposite the entry point so that heat and smoke will be released, allowing firefighters to locate and attack the fire. If used properly, ventilation improves visibility and reduces the chance of flashover or back draft. If done improperly, ventilation can actually accelerate flashover.

As a result, proper ventilation requires a coordinated effort.

COORDINATED ATTACK

An example of a coordinated attack is when the engine company makes entrance at the same time that the truck company vertically or horizontally ventilates in the correct location. By doing so, gases can vent, the environment clears up, and firefighters can attack the seat of the fire.

If the process is not coordinated – for example, if the hole is cut or the glass is broken too soon – the velocity of the flame can actually be accelerated. Therefore, it is important that firefighters not open doors and windows at random. If they do, they may accelerate the growth of the fire unless they have a hose in place to put water on the seat of the fire.

ENVIRONMENTAL CONDITIONS AND FLASHOVER

Flashover recognition can start before firefighters reach the scene. They should ask themselves: What type of weather is it? Is it windy? From which direction is the wind coming? These factors can all have an effect on the way a structure is going to burn.

Wind-driven fire acceleration

If firefighters open a door and have a strong wind at their backs, the wind will pressurize the structure, creating accelerated growth of the fire. Based on whether the wind is at their back or in their face, they might want to select a different entry portal because opening that door could super-accelerate the growth of that fire.

Uninvolved to involved

Generally in the fire service, the best practice is to go from the uninvolved portion of the structure to the involved portion of the structure. For example, if the fire is in a rear bedroom, firefighters should enter from the front door to keep from pushing or accelerating the fire through the rest of the structure.

Softening the target

Sometimes it is best to “soften the target” from the outside of the structure. For example, if firefighters see heavy smoke coming out of the back window, they should try to cool flammable gases from the outside before entering the structure. In this case, they should direct a straight stream of water through the window to the ceiling level and knock the fire down slightly before making an attack from the inside.

Be aware of the “point of no return”: 5 feet from an exit

Without a hose line, firefighters in full protective gear can travel an average of 2.5 feet per second. That means they have approximately 2 seconds to exit when a flashover occurs. So if the firefighter is 5 feet or less from an exit and sees signs of impending flashover, there is a possibility of escape. Beyond this point, firefighters will be unlikely to escape to safety.

NOZZLE TECHNIQUE TO DETECT ROLLOVER

When firefighters enter a building, they can determine the likelihood of flashover by using the following nozzle technique to recognize rollover, which is a warning sign of flashover:

- Test the atmosphere with the nozzle on full fog.
- Hold the nozzle straight up and above the head.
- Direct short, quick bursts of water into the upper atmosphere.
- Do not use so much water as to upset the thermal balance and force the smoke and steam down.
- If drops of water fall on the firefighter’s face piece, the atmosphere is less than 212°F.
- If no water falls back down, then the water has turned to steam and the possibility of flashover exists.

NOZZLE TECHNIQUES THAT MAY DELAY FLASHOVER

If there is a possibility of flashover, the following nozzle techniques may delay flashover by cooling down the walls and ceiling and slowing re-radiation.

Aggressive cooling

- Set the nozzle on 60° fog pattern and hold as high as possible.
- Give several short intermittent bursts of water into the upper atmosphere to absorb the heat and cool the flammable gases to below their ignition point.
- Do not use so much water that the thermal balance becomes upset, or steam burns may result.
- Move the nozzle in a circular pattern to provide maximum cooling from the water droplets.

Penciling

- Set the nozzle to straight stream.
- Use several, short intermittent bursts of water to cool walls and ceiling and slow re-radiation of heat.
- Move the nozzle to cool different areas of the room.

When used in conjunction with each other, these two techniques – aggressive cooling and penciling – may possibly delay a flashover long enough to allow firefighters to immediately exit the structure.

It is important to remember that this is a ONE TIME ONLY survival technique to buy a few extra seconds.

Firefighters should leave the building immediately if flashover is imminent.

FLASHOVER SURVIVAL TECHNIQUES: BE PREPARED

To give themselves every advantage in a flashover situation, firefighters should follow these guidelines:

Learn to recognize the warning signs

Today's PPE enables firefighters to get deeper into the structure and closer to the fire, where they are more at risk of experiencing flashover. This is why it is critical to understand the signs leading up to a flashover before it happens – giving them time to make changes in the fire attack or withdraw from the danger area.

Always wear full PPE and wear it correctly

Firefighters should never remove their SCBA face pieces and should keep their helmet chinstraps attached at all times.

Maintain situational awareness

Firefighters should always be aware of their location and where other firefighters are operating. In addition, they should:

- Enter and leave through the same door, if possible.
- Have a secondary means of escape.
- Follow a predetermined, coordinated process as outlined by their department.
- Work in teams of at least 2 firefighters.
- Take a rope or hose lines to follow out.
- Take a flashlight and forcible entry tool.

Stay low

This is one firefighting principle that has not changed. The lower firefighters stay to the ground, the cooler it will be and the better the visibility will be.

Remain calm

If firefighters become lost or disoriented, they should make every effort to remain calm and control their breathing.

Always bring a charged, operating handline

Water is the enemy of flashover. Using a small amount of water during the early warning signs of flashover can greatly slow the process, allowing time to evacuate the area.

Remember that the "point of no return" is 5 feet from the exit. If flashover is imminent, get out immediately!

If caught in a flashover, fight
Firefighters should get as low as possible and open the nozzle into the area to provide some cooling:
- Put the nozzle on full fog.
- Open the nozzle fully and leave open.
- Hold the nozzle above the helmet.
- Move the nozzle in a circular pattern to provide maximum cooling.
- Evacuate the areas as quickly as possible.

FLASHOVER TRAINING

Because of advancements in building codes, public education and fire prevention technology, today's firefighters respond to fewer structure fires than they did in the past. While this is a positive evolution, the negative consequence is that today's responders do not get as much field experience with fire as they used to. This means fewer hands-on opportunities to build a skillset to combat the many variables that accompany present-day fires.

To provide this hands-on flashover training, the Swedish National Rescue Services Board developed a container system and training program in 1986. Today, various forms of container training are available in North America and are designed to meet NFPA 1500 and NFPA 1403 standards.

Container design
Container systems have one or more burn areas, referred to as the burn box. A burn box is an 8-foot section of the container that holds the burnable fuel loads and is reinforced to withstand extremely high temperatures. The design of the burn box replicates the conditions of a real structure fire – only on a smaller scale.

Typically, plywood or oriented strand board (OSB) are used as the primary fuel, and the walls and the ceiling are lined with it as well. Though the preferred fuel is OSB on every surface, Class A (or wood-fueled) containerized training systems can use other materials such as wood pallets, hay or paper as the primary fuel source.

Each burn box is equipped with a modified barrel that holds what is called the "crib" fire. The crib acts as the seat of the fire, which means it is both the ignition point and the heat source for the entire fire evolution. In a very real sense, the crib is the engine of any burn session.

Class A containerized training platforms utilize a cumulative, or phased approach to fire training. One of the biggest benefits of Class A fire and smoke is that they behave as they would at a real structure fire, so the training is very realistic.

Container training
The purpose of the flashover training is to:

- Demonstrate various fire stages as they occur in confined area
- Teach students how to recognize the warning signs of flashover by "reading the smoke"
- Give students an opportunity to learn various firefighting techniques that may delay a flashover

It is important to remember that the flashover recognition simulator is a training aid to help firefighters recognize fire conditions that can lead to flashover. In actual fires, the firefighters are on the same level as the fire and not 3 feet below the fire floor, as they are in the simulator.

EXPERIENCING FLASHOVER

During live fire training, instructors will cause the fire to produce several flashovers so that everyone will have an opportunity to observe and participate in the evolution.

While the observation area is a safe and controlled environment, it is an intense experience.

It is imperative for students to understand that during actual emergency fire conditions, the techniques that are demonstrated are to be used ONE TIME to provide firefighters additional time to escape.

Live fire training gives firefighters an opportunity to recognize their own personal limitations – such as their individual response to heat. It also gives them an opportunity to understand the limits of their protective clothing and equipment prior to thermal collapse.

To locate a flashover training session near you, visit **www.draeger.com/roadshow**

SUMMARY

Flashover is one of the leading causes of firefighter fatalities today. The best defense against flashover is knowledge and experience.

Because firefighters respond to fewer structural fires than they did in the past, their field experience with flashover is increasingly limited. To gain this critical experience, live fire training is essential. Container training systems give firefighters firsthand knowledge in recognizing the warning signals of flashover and techniques for delaying its onset.

For more flashover educational resources, visit **www.draeger.com/Flashover**

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