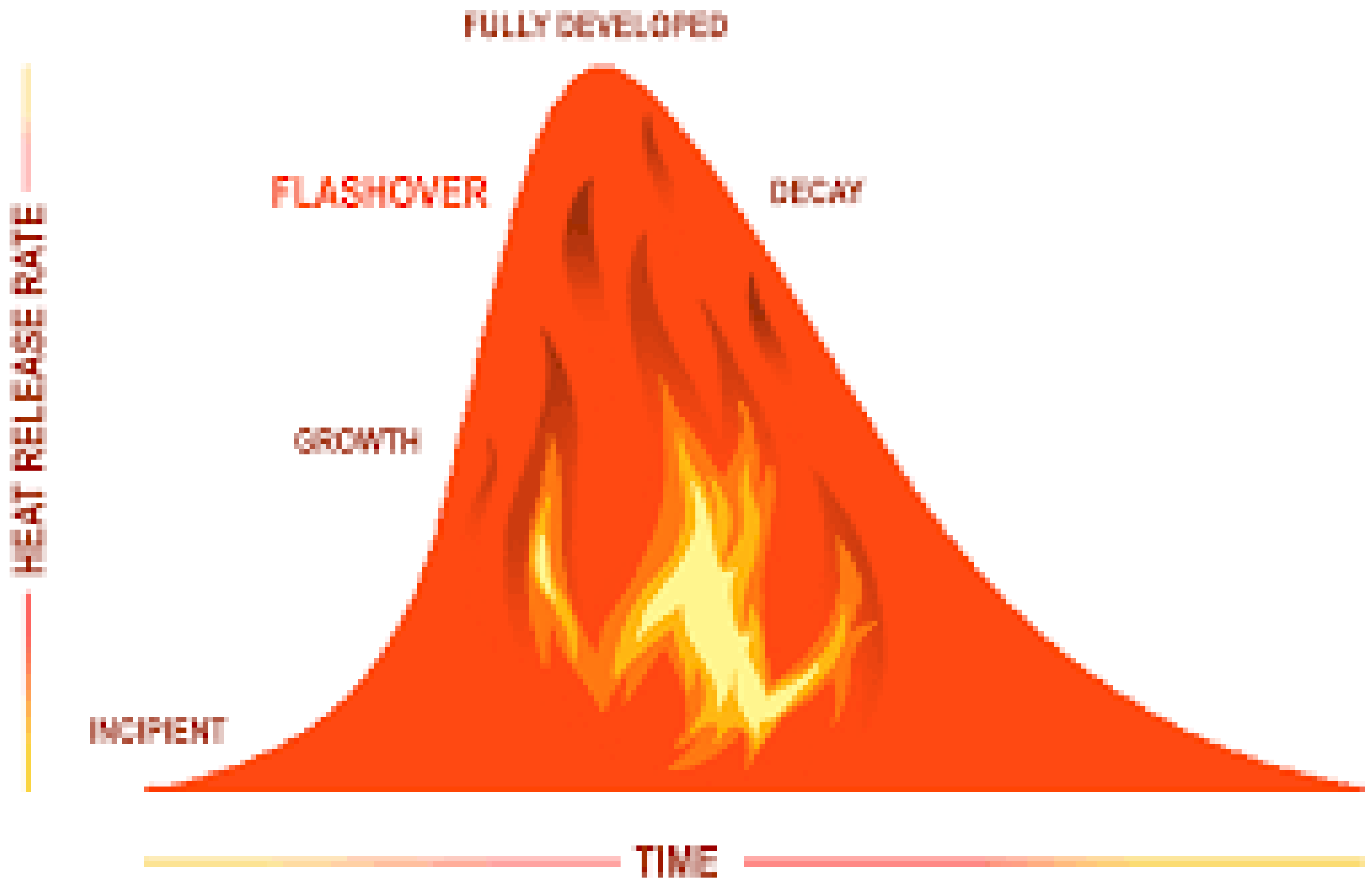
Fire – Stages – Growth - Ventilation

Fire Development
Fire Stages and Growth
Fuel v Ventilation
Heat Transfer
Rapid Fire Development
Flashover
Smoke Ignition
Smoke Explosion
Backdraft
Flash Fires
Classes of Fire



- The content of BSI 8670 is now being mandated to be inserted within all learning and upskilling, with some main areas of development,
- Competence Behavior, and
- Fire Safety.

(BSEFSD – K1/12/21/22)

THIRD PARTY CERTIFICATION

6.2 Fire and life safety

All sector-specific competence frameworks shall stipulate requirements for competence that meet or exceed the threshold set out in Table 2 relevant to role, function, activity or task.

frameworks – Code of practice

April 2021 Version 3

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Table 2 – Ethical Principles, Standards and conduct

Core competence;	Sub-competence
a) Contribute to establishing fire safety strategies, practices and technological systems in higher-risk buildings	1) Understand the foundation principles of fire safety including; principles of fire chemistry including ignition and heat transfer; the impact of structure and materials; human behaviour and escape requirements; methods of suppression, limitation of fire growth and fire spread. 2) Use practices of design concepts, fire strategies, training and safety case functions that assist safe use and occupancy of a building. 3) Recognize and apply the mitigation and control functionalities of fire protection technologies and systems that detect, alert, confine fire growth and effluents, suppress ignition and fire, ventilate and secure escape or reduce fire spread and support firefighting and rescue.
b) Demonstrate awareness and contribute to managing fire safety in higher-risk buildings through legislative controls	Demonstrate knowledge of the purpose and application of regulatory and legal frameworks to protect people and property from fire through fire safety requirements to protect occupants and buildings from fire including; Statutes, Regulations and advisory documentation; relevant building regulations and advisory documents; definitions and approaches to aid warning, escape containment and support extinction; and exchange of fire safety information.
c) Contribute to the maintenance of fire safety in higher-risk buildings	Awareness of functional requirements to be managed by audits, inspections, and risk assessments that ensure buildings escape and fire protection systems (including physical and technological means), remain available and appropriate to occupancy, use, construction and level of fire risk throughout a building's whole life.
d) Contribute to establishing and maintaining structural safety in higher-risk buildings	1) Awareness of the Key principles of structural design and construction including characteristics of typical systems, and typical behaviours under load and in the event of fire. 2) Awareness of the purpose and application of requirements of building regulations, codes and standards in relation to structural stability of primary structure, secondary structure and fixings and contribute to compliance when acting as designer or contractor. 3) Awareness of functional maintenance requirements for structural safety and contribute to commissioning or undertaking of assessment, inspection, or maintenance tasks. 4) Awareness of appropriate techniques to manage structural safety including contributing to use of the safety case; provision of information relating to design, installation or maintenance of structure; how and when to respond to events which can affect structural safety; undertake procurement of competent specialist advice when necessary.

Let us review the stages of fire, growth, development and the effects of ventilation.

The following slides will review some of the tiles here, there's a more detailed document available.

- **Enclosure Fire Development**
- Incipient Stage
- Established Burning
- Fire Growth
- Flashover
- Fully Developed Stage (Full Room Involvement)
- Decay
- **Different Paths of Fire Development**
- Fuel- vs. Ventilation-Controlled Fires
- Under-Ventilated Fires
- **The Fire Plume & Two-Zone Model**
- The Two-Zone Model
- Ventilation in Real Fires
- Neutral Plane in Real Fires
- Heat Transfer in Fire Growth
- Effect of Wind on Fires
- **Rapid Fire Development**
- Flashover
- Smoke Ignition
- Distinguishing between Smoke Ignitions
- RFD - Possible Outcomes

(BSEFSD – K1/12/21/22)

Enclosure Fire Development

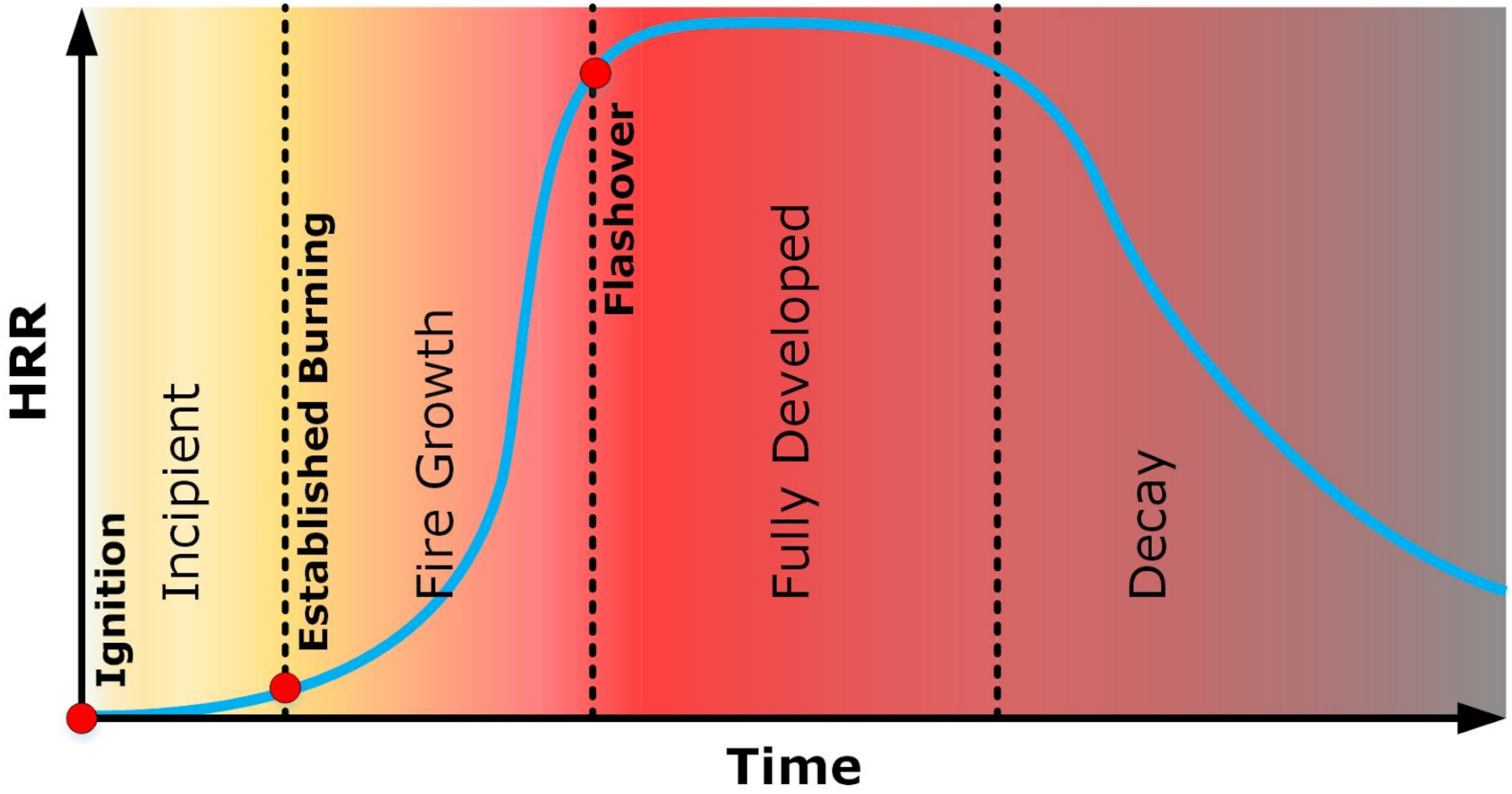
Fire development is composed of 4 key stages:

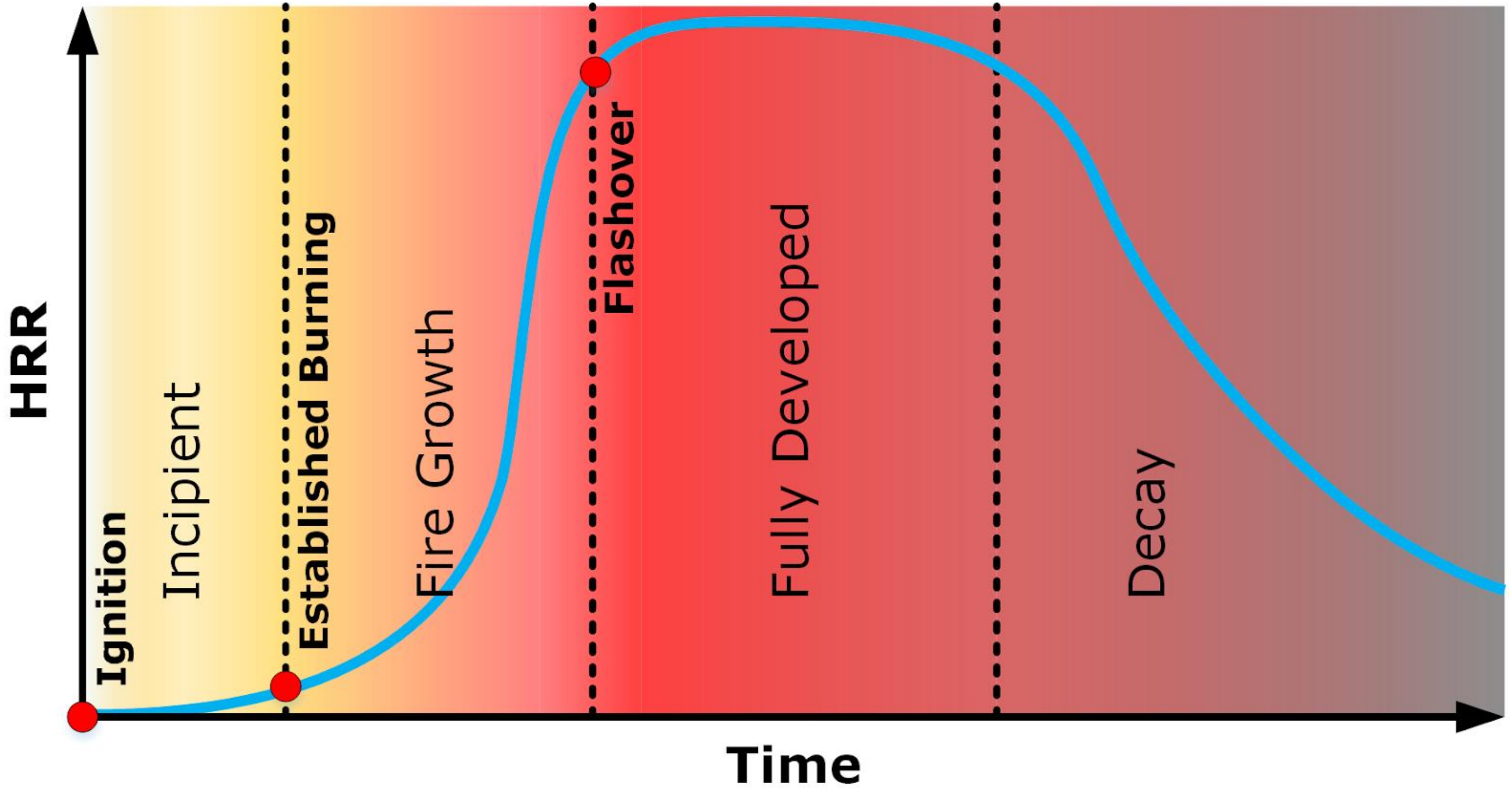
Incipient

Fire Growth

Fully Developed

Decay



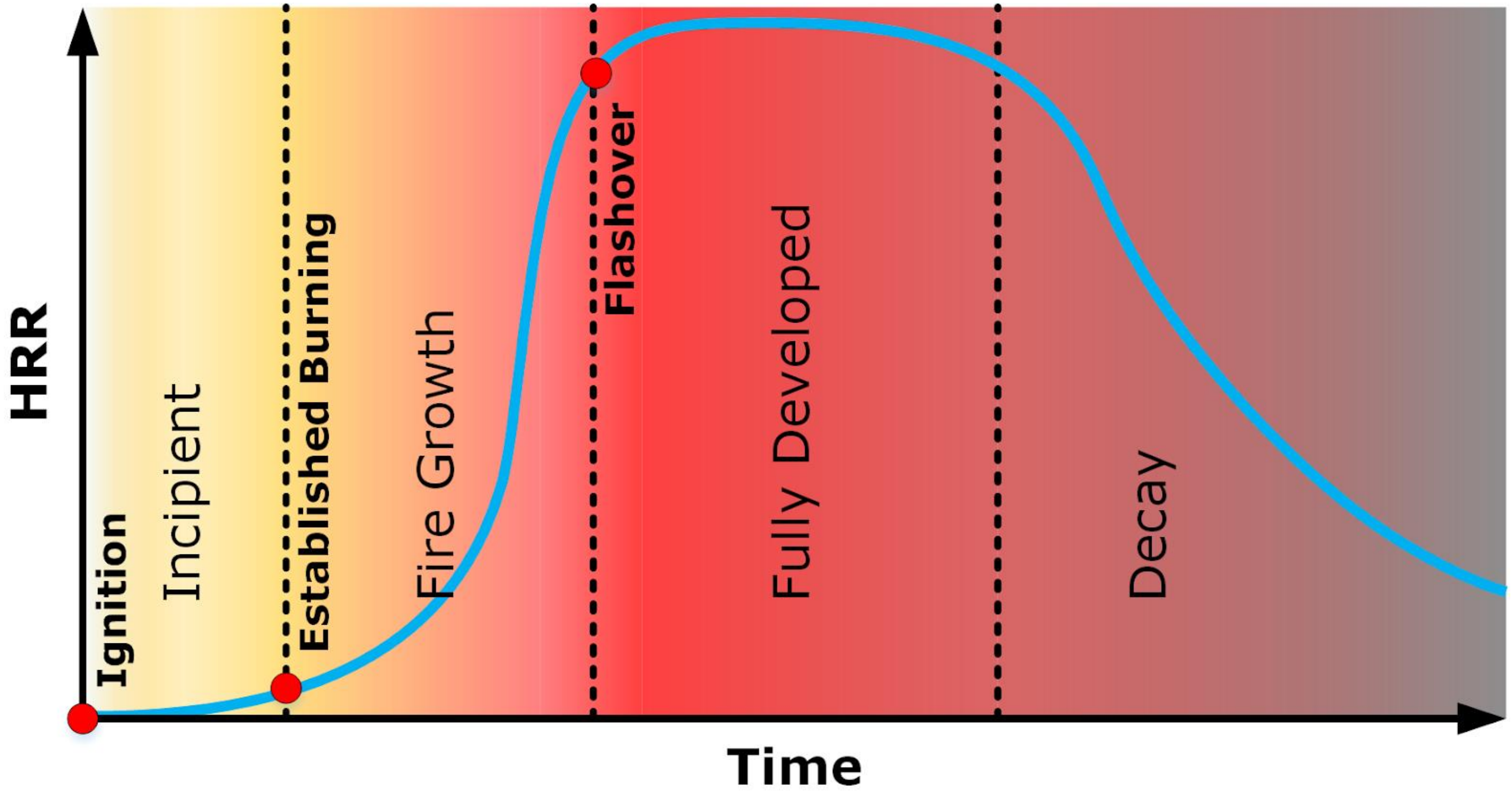


Ignition is the beginning of the incipient stage.

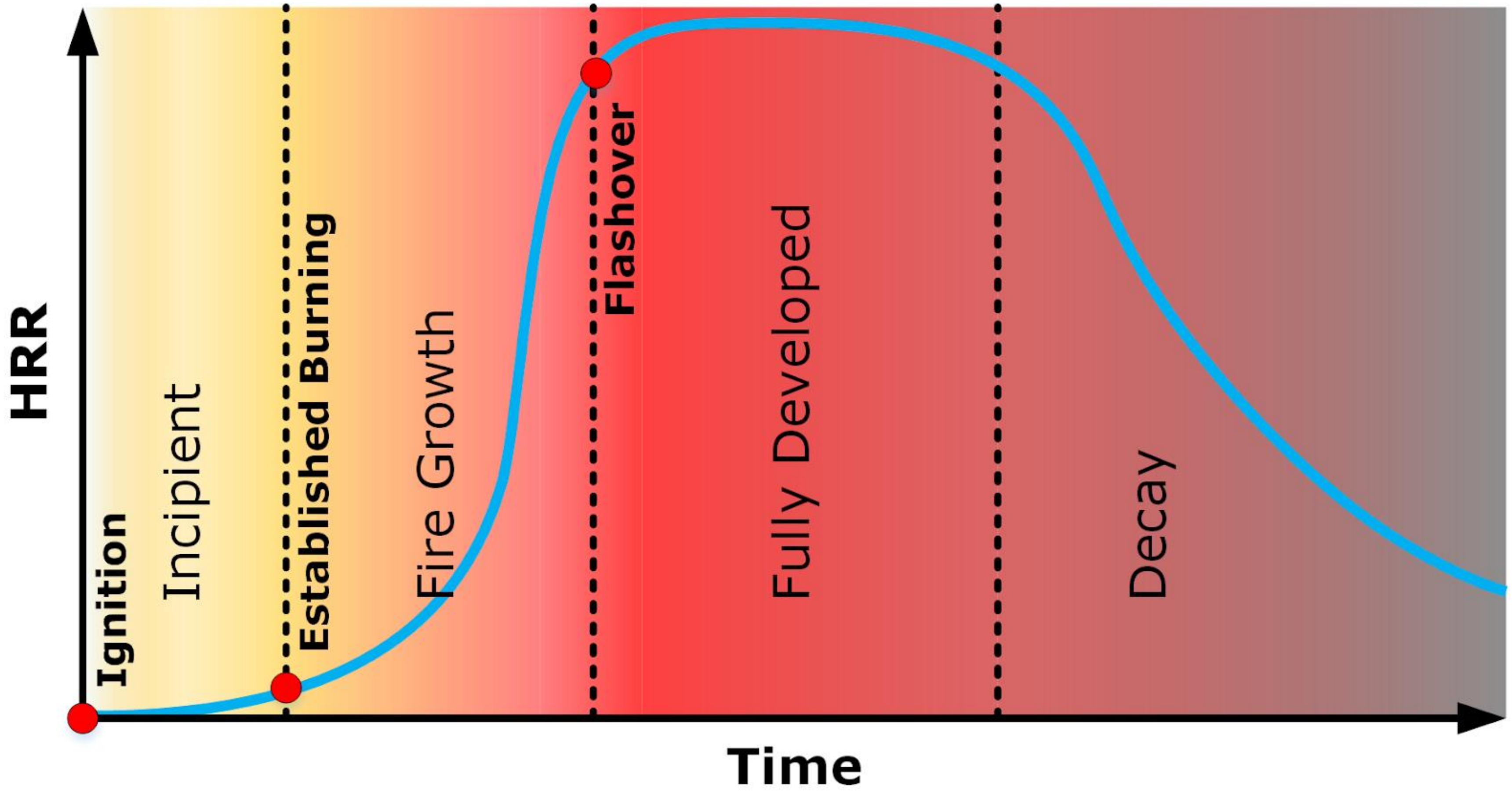
Once the fire has ignited, it must reach the stage where burning is established.

This requires the correct mix of fuel and oxygen with sufficient heat to support combustion, and feed new fuel vapour into the fire (positive thermal feedback loop).

After the incipient stage, the fire enters the ***growth stage*** in which the Heat Release Rate (HRR) grows depending on the fuel mass burning rates; availability of air; heat loss to the compartment walls and outside of the fire enclosure due to heat transfer within the hot smoke layer; and any other compartment conditions.



Once the fire grows large enough that it generates sufficient heat to overcome the heat lost from the compartment, it undergoes a transition-often termed ***flashover***-to the ***fully developed*** stage where HRRs (Heat Release Rate) are relatively constant.



The ***decay stage*** is the final stage a fire enters as it runs out of available fuel.

Incipient Stage

The incipient stage of fire growth begins with ignition, after which the fire can take one of two paths: self-extinguishment or continued growth.

If it consumes the readily available fuel or if it remains small enough that it cannot produce enough fuel vapour to continue burning, then it will self-extinguish.

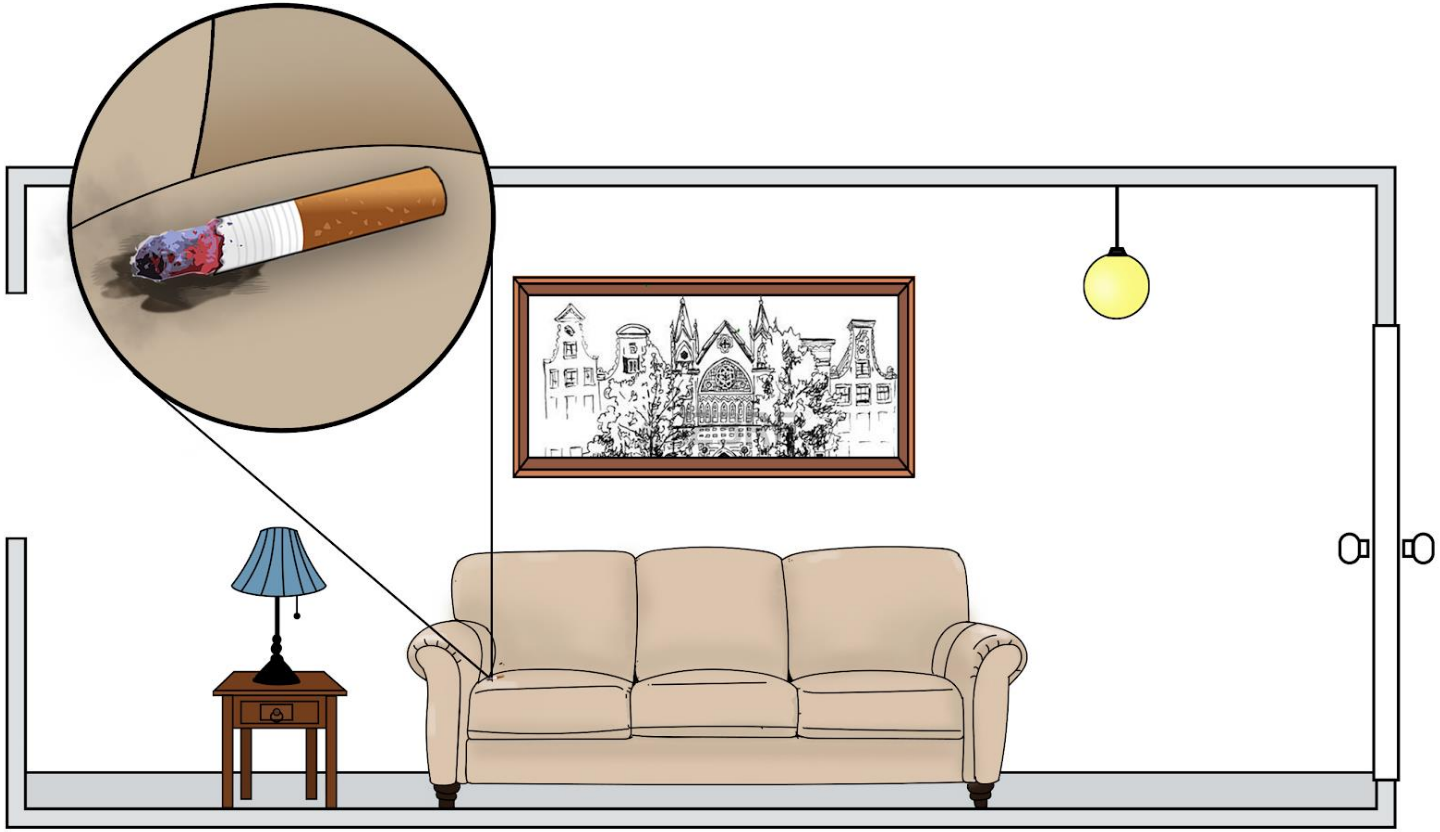


Figure 2: Incipient fire development

This can happen when items contain high levels of fire retardant additives, or when only one item is burning and any other fuel packages are located too far away for radiant ignition to occur and continue to provide the fuel needed to sustain combustion.

Another way a fire may self-extinguish is if it runs out of air while growing

Established Burning

On the other hand, the fire may develop into a steadily growing fire plume. This requires that the correct mix of fuel and oxygen is available to support combustion in the flaming regions.

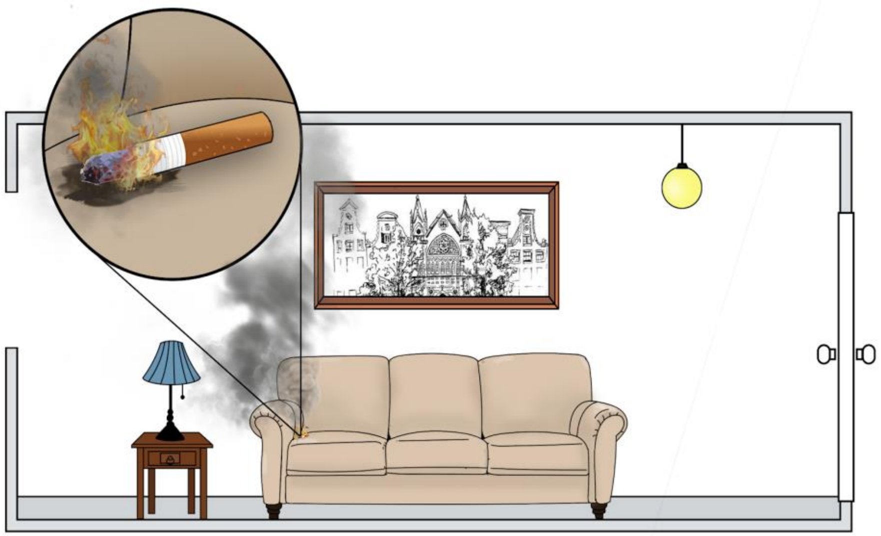


Figure 4: Established burning

In this case, self-sustaining oxidation reactions are established and generate enough heat to feed new fuel vapour to the fire.

The fire can grow as long as sufficient oxygen, fuel, and energy feedback are available so that combustion will continue, unless some outside force, such as a water stream, acts upon it.

This phase in the life of a fire is commonly referred to as "established burning."

For fuels found in many residential and commercial structures, a fire size (HRR) of 20 kW is often accepted as an indication that a fire has entered the established burning stage.

Fire Growth

After a fire has ignited and steady burning is established, the fire enters a stage of growth.

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Figure 6: Fire growth

In Figure 6, the fire has ignited behind the couch. The fire has established itself and is now growing up the wall, fuelled by the fabric and foam in the couch.

In the early stage of the fire, the HRR (Heat Release Rate) and physical size of the fire are essential parameters, as those determine how fires grow and spread.

Figure 7: Fire growth in a residential test burn

Typically, when a fire begins, there is only one fuel item that has ignited and is burning. The driving force for the initial fire growth is primarily flame spread across this item.

The fire size increases as flames spread to nearby fuels, either by direct flame contact, or by radiant ignition.

The combined HRR of the initial fuel(s) are important factors determining the rate of fire growth. Finally, the distance between different fuels is important.

In the fire growth period, rapid flame spread across any fuel item contributes to a larger burning area (area of the fire), which in turn increases the HRR (Heat Release Rate) as more and more fuel becomes involved in the oxidation reactions.

When the growing fire generates sufficient heat to overcome the combination of heat lost to the walls and to heat flowing out of the enclosure in the escaping smoke, an energy feedback loop can lead to a thermal imbalance. The fire HRR grows to a maximum, approximately steady value. The end result of the thermal imbalance is that the fire undergoes a transition, termed "flashover," and enters the fully developed stage.

Flashover

Figure 8: Flashover

Flashover is a situation in which a fire develops rapidly, and is extremely important for fire fighters to recognize and understand.

The actual HRR (Heat Release Rate) values will depend on many factors such as room size, ambient conditions, lining materials, fuel types, geometry and loading, and ventilation.

Fully Developed Stage (Full Room Involvement)

After a fire has flashed over, it is considered fully developed (in a stage of full room involvement) in which the fire can be characterized as having a relatively steady HRR.

Fuel vapour is produced from all of the fuels in the room.

There is so much fuel vapour being formed and heat being released that combustion occurs wherever there is an appropriate mixture of oxygen and fuel.

Since there is most often an excess of fuel vapour in the enclosure, the fire is “ventilation-controlled”.

Figure 10: Fully developed fire in a residential structure

The overflow of hot gases and combustion products from one compartment to another during the fully developed stage may allow for ignition within other compartments and the fire may then spread from one compartment to the next.

At this stage, hot smoke will definitely be flowing out of the enclosure and into any other accessible areas within the full structure.

Decay

When the fuel and/or oxygen are depleted, the fire enters the decay period. HHRs (Heat Release Rate) and temperatures begin to diminish and the fire will die out.

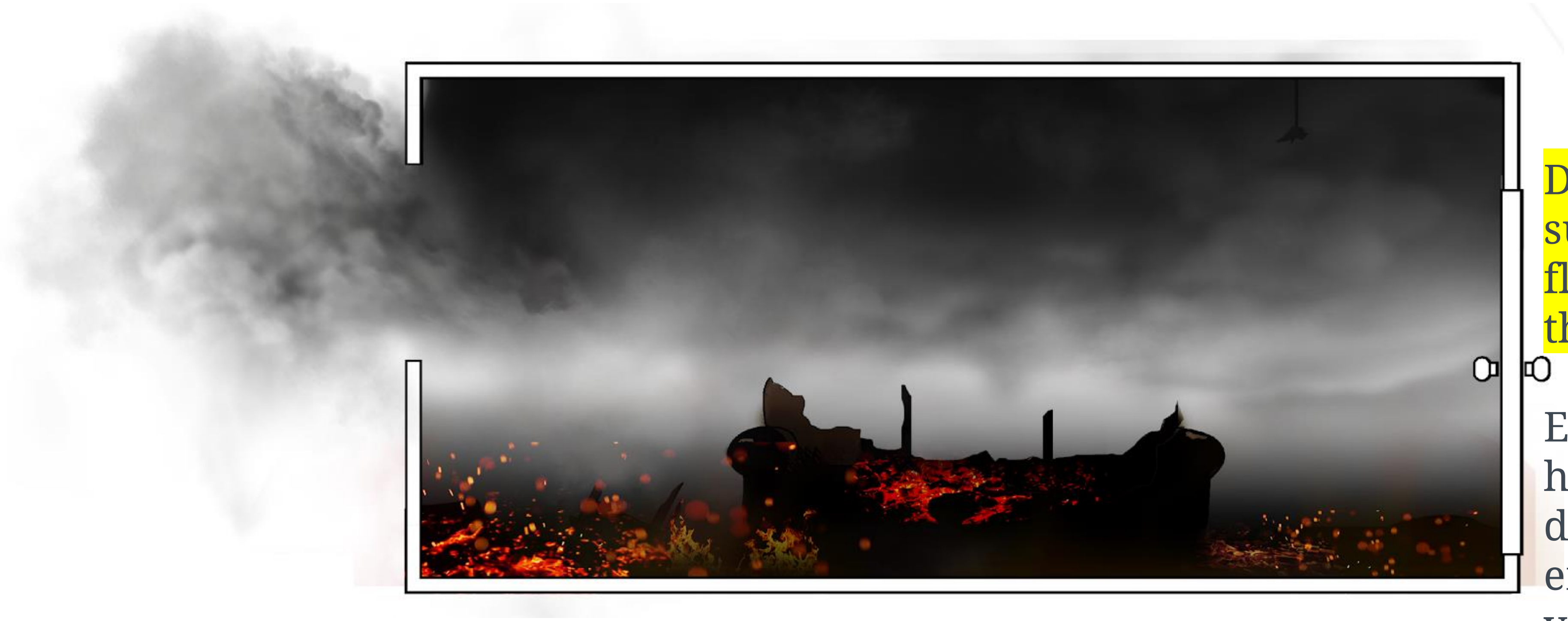


Figure 11: Decay

During decay, or if the fire is suppressed, large volumes of flammable smoke can migrate throughout the structure.

Even when the visible smoke has cleared, heated aerosol deposits on surfaces within an enclosure may contain volatiles that continue to vaporize and mix with air in the fire room and adjacent compartments for a long period of time.

Depending on the ventilation and mixing conditions during the fire, these deposits and volatiles can ignite and may also contain many dangerous (toxic) organic combustion by-products, including some that increase the risk of cancer.

Thus, appropriate safety precautions and use of personal protective equipment must be continued throughout the various stages of overhaul and clean-up after each fire.

Early decay in a test burn

Here, in this test, an under-ventilated furniture fire, ran out of oxygen, before reaching flashover and the fully developed stage.

As a result, some furniture remains; some is damaged, but most was not totally burned in the fire.

Fuel- vs. Ventilation-Controlled Fires

After ignition, a fire grows and develops according to the available fuel and the ventilation characteristics within the enclosure or structure.

The temperature rise within the enclosure depends on the HRR (Heat Release Rate); the area and heights of any openings; the total surface area of walls and ceilings in the room; the geometry of enclosure; the thermal properties of enclosure linings; and whether the construction is combustible or non-combustible.

The fire may be either fuel-controlled or ventilation-controlled, and the transition between these two will depend on the circumstances, as is shown schematically in Figure 13.

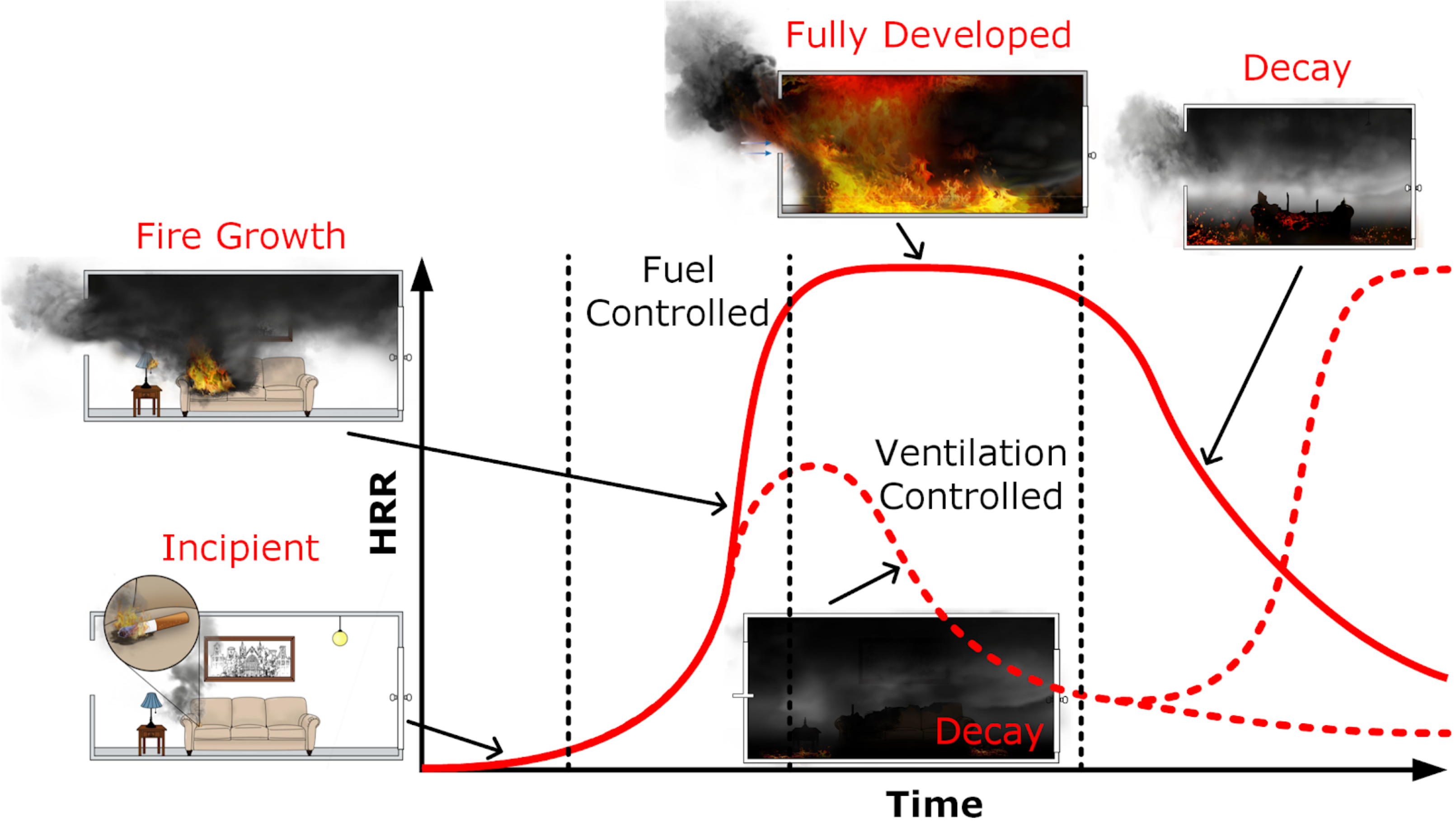
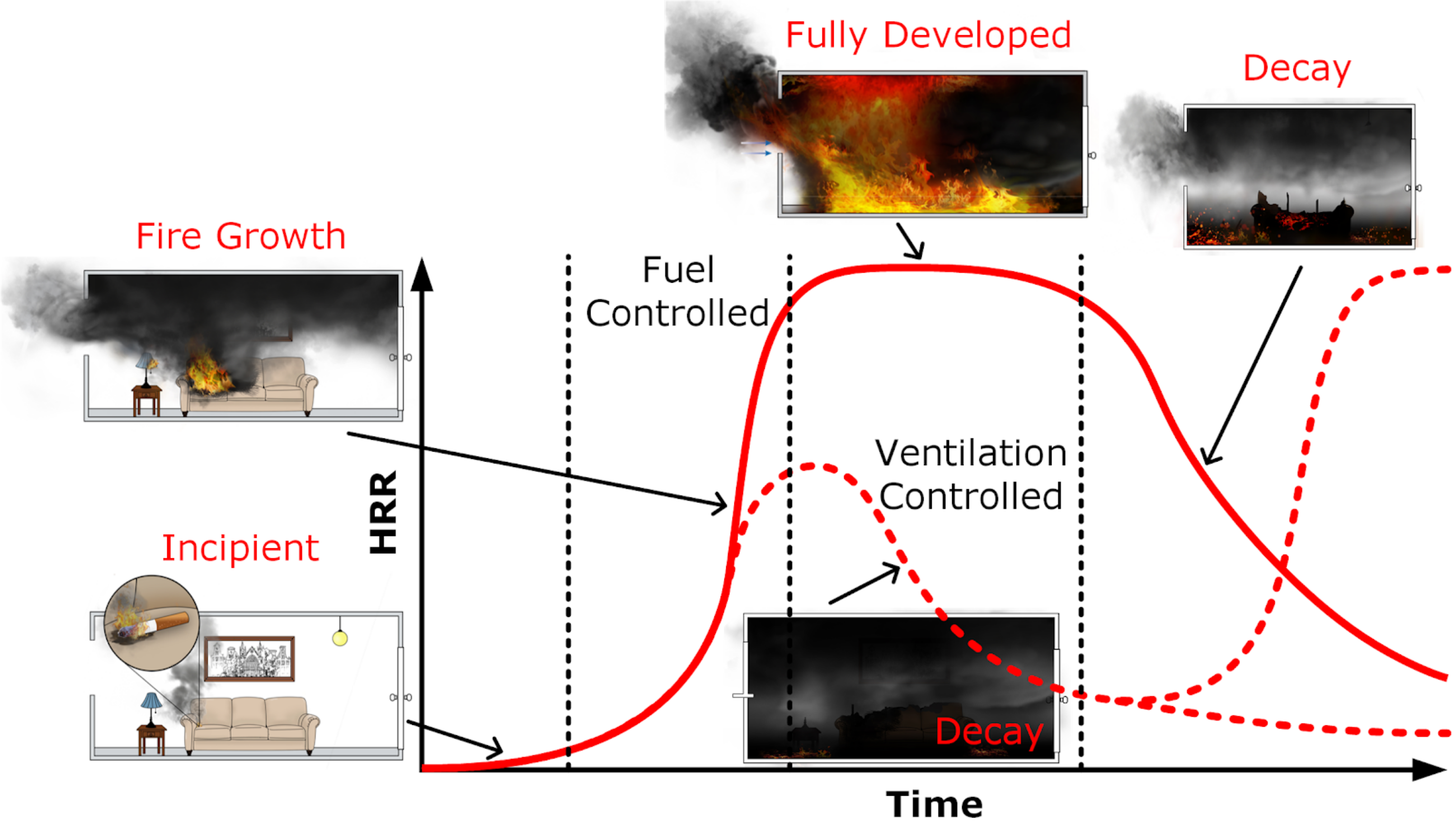


Figure 13:
Fuel-controlled vs. ventilation-controlled fire development

As indicated by the solid line in Figure 13, if there is sufficient air to sustain the growth of the fire, it will steadily increase in size until it undergoes a transition into the fully developed state of full room involvement. In this situation, the early HRR (Heat Release Rate) and fire growth rates are controlled by the availability of vapour from the fuel.

This is referred to as a fuel-controlled fire, since the rate of burning depends on how much fuel vapour can be produced and mixed with the readily available air. Early-stage fires are most often fuel-controlled, and will continue to burn as long as sufficient fuel and oxygen are present.



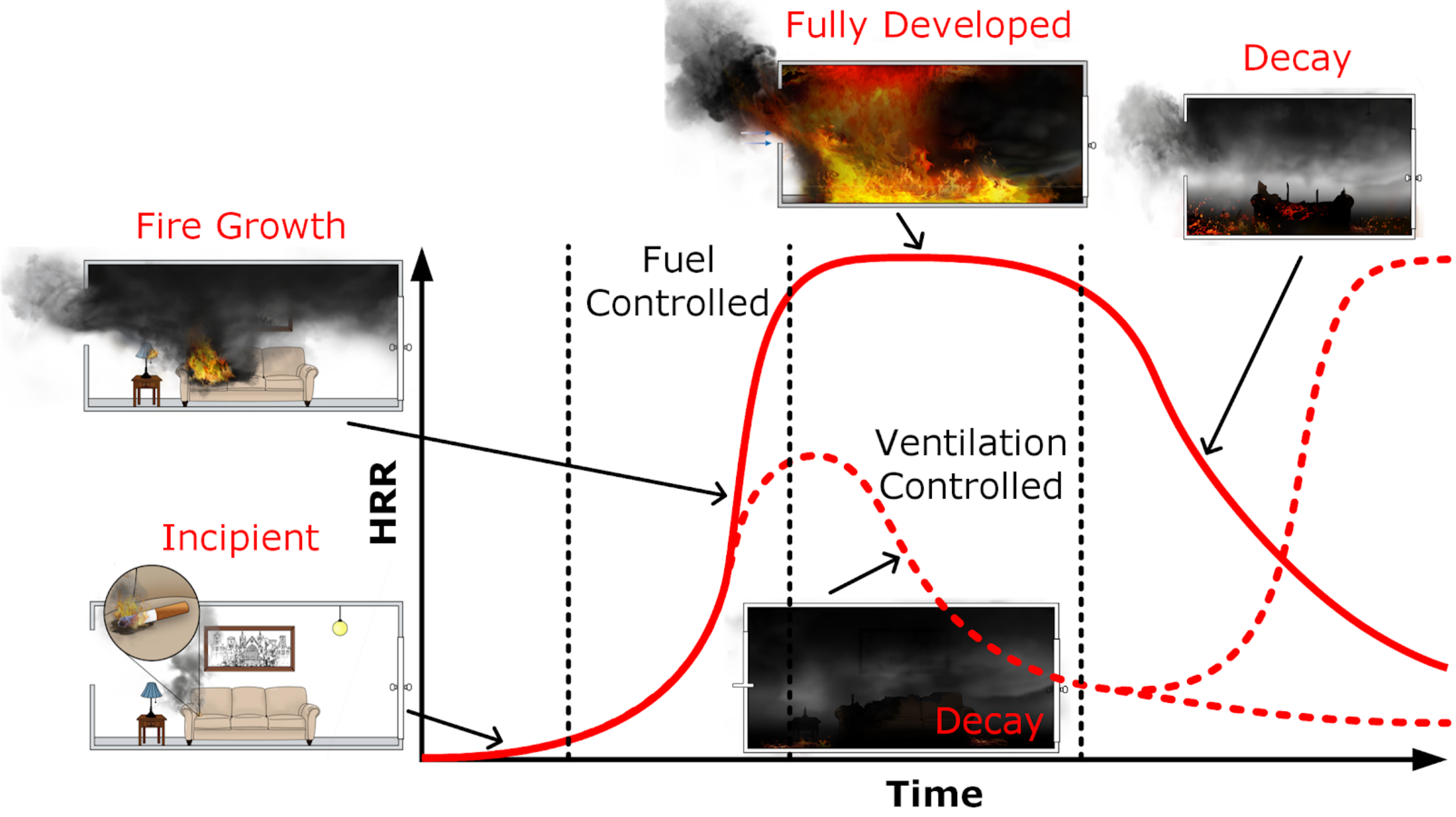
Fires begin as fuel-controlled, and at some point within the fire growth, so much fuel vapour is produced that the HRR (Heat Release Rate) and growth become limited by the availability of oxygen. The fire then becomes a ventilation-controlled fire.

Whether or not a fire will transition into a ventilation-controlled state depends on the fuel load as well as the size of both the compartment and ventilation openings.

As a fire becomes ventilation-controlled, its rate of growth will decrease relative to that of a well-ventilated fire.

As this happens, the HRR will also decrease and the fire may decay and extinguish itself if no additional air is provided.

Extinguishment can occur if oxygen levels in the enclosure fall below the range of 10-15%.



If the fire is not extinguished, subsequent fire development will depend on:

the stage of fire development up to the point at which the fire became ventilation-limited;

the temperatures of the fire gases when any additional air is added to the enclosure;

and the size of openings that are made when any air is subsequently added to the enclosure.

As a fire transitions to a ventilation-controlled state, the overall environment can be hot and very dangerous. Even if the HRR (Heat Release Rate) decreases, there is already hot smoke in the enclosure.

If the ventilation to the enclosure is increased following a period of ventilation-controlled fire development, one of several rapidly occurring events, herein referred to as "rapid fire developments" (for example smoke ignition, flashover or backdraft), can be initiated. These eventualities are extremely dangerous.

Heat Transfer in Fire Growth

In the early stages of the fire when there are still distinct upper and lower layers and a localized fire plume, the rate of fire growth is usually unaffected by the availability of oxygen. Instead, the fire is fuel-controlled, with its rate of growth limited by the availability of fuel. The fire grows as long as fuel can be vaporized in sufficient quantity and locally mixed with air at a temperature high enough to support combustion in the fire plume.

The HRR (Heat Release Rate) of the fire at any given time depends on the mass-burning rates and flaming areas of the different fuels that are involved in the fire. These then dictate the amount of heat energy generated by the fire as well as the temperature distribution in the enclosure.

Figure 23: Heat transfer in fire growth

Convection is the primary mode of heat transfer during these early stages of fire growth, since the fire plume is small and radiation heat transfer is limited. The hot gases exchange heat by convection as they flow upwards and across the ceiling, heating it and any other surfaces with which they come into contact.

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Heat Transfer in Fire Growth

To understand what can happen later in the fire development, however, it is crucially important to recognize that the hot smoke that is collecting near the ceiling is also emitting thermal radiation to its surroundings throughout the life of the fire.

Thermal radiation from the ceiling and walls back into the fire enclosure increases in intensity as the surfaces heat up.

This combines with radiation from the upper layer, leading it to preheat, and produce fuel vapours from any combustible items in the enclosure.

Radiation therefore has a major impact on the fire environment as the fire continues to grow.

THIRD PARTY CERTIFICATION

Fire Growth and Spread

As the fire grows, it may spread by ignition of objects via any combination of radiation, convection and conduction (e.g., from the fire plume, hot objects or hot ceiling gases), as shown in Figure 24. One mechanism is through direct impingement of the flame plume onto any secondary flammable materials or objects, causing them to ignite and become involved in the fire.

Alternately, the first item ignited (e.g., foams, plastic materials) can melt and then pool, drip or fall down to ignite secondary items. Very often, however, ignition of other objects occurs predominantly through the enhanced radiation.

This includes both radiation stemming directly from the flame plume, as well as that from heated smoke in the upper layer.

Figure 24: Fire spread through radiation, convection and conduction

As the fire develops to this state, pockets of flame may begin to form in the hot layer as the first indication that unburned fuel in the hot smoke layer may be coming close to its auto-ignition temperature. If it does ignite, a rollover (travelling flames) occurs in the unburned fuel gases in the hot layer, enhancing the radiation loading down onto the materials below. The flames can also travel along the hot layer and out of the enclosure into any areas in which there is a flammable mixture, sometimes extending into areas well outside the fire enclosure.

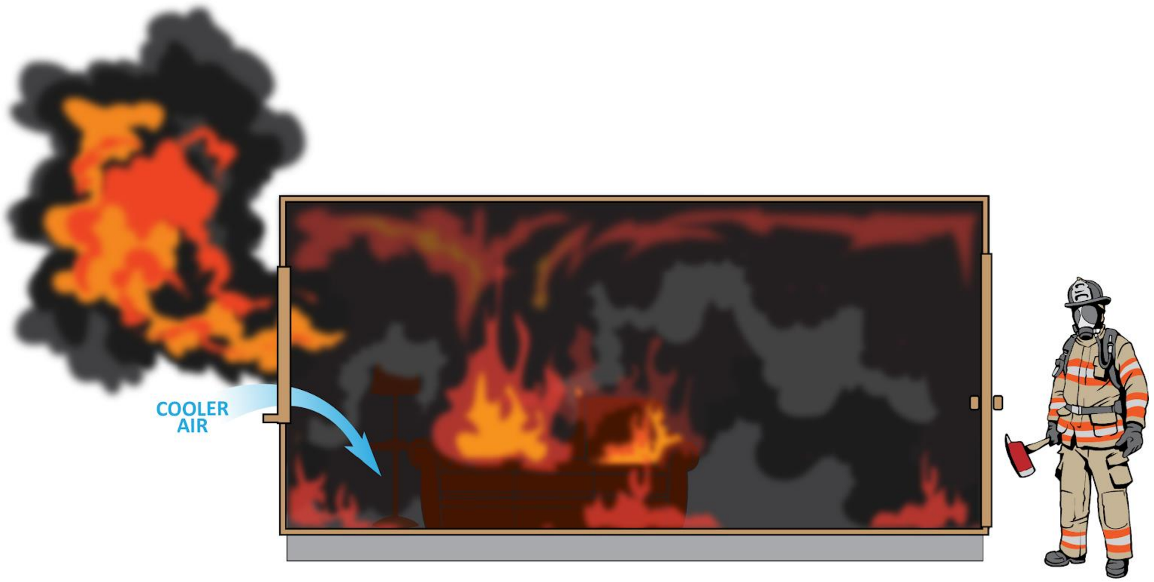
Flashover: Transition of Fuel-Controlled to Ventilation-Controlled Behaviour

As the fire continues to grow, temperatures continue to increase throughout the enclosure due to ongoing heat transfer and flame spread, Figure 25.

This can lead to a phenomenon commonly referred to as "flashover". This is the transition of the fire from a growing, fuel-controlled fire to a fully developed, ventilation-controlled fire.

Flashover is *a transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperatures more or less simultaneously and fire spreads rapidly throughout the space, resulting in full room involvement of the compartment or enclosed space.*

Figure 25: Heat transfer in fire growth



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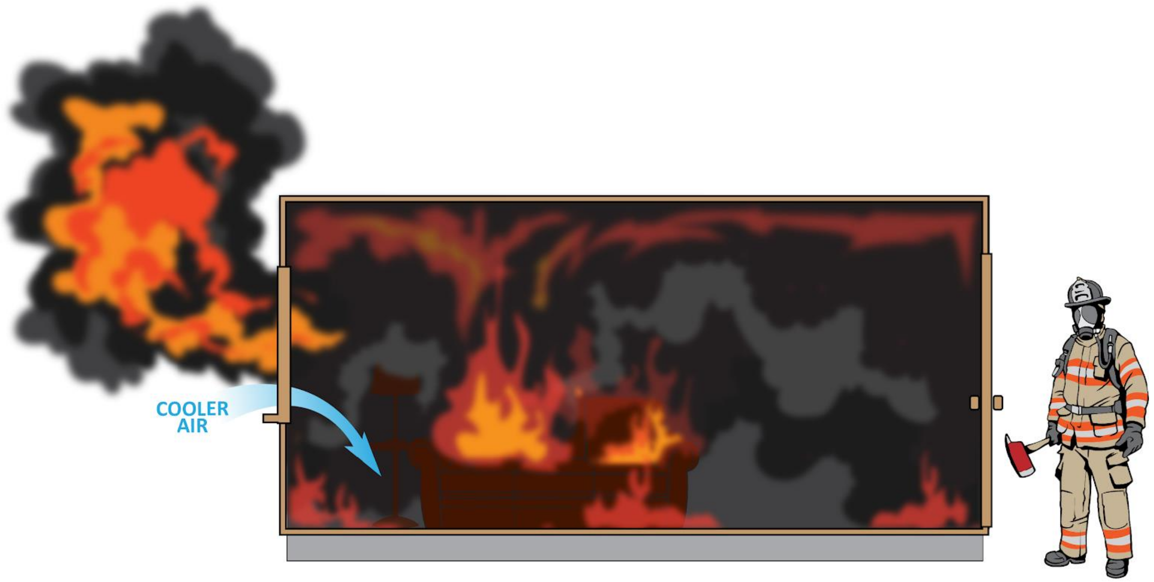
Flashover: Transition of Fuel-Controlled to Ventilation-Controlled Behaviour

Flashover can happen in one of two ways:

either as a relatively slow transition of the fire to a fully developed fire; or

through a very rapid and dangerous change in behaviour of the fire in which the entire enclosure is engulfed in flames virtually instantaneously.

Figure 25: Heat transfer in fire growth



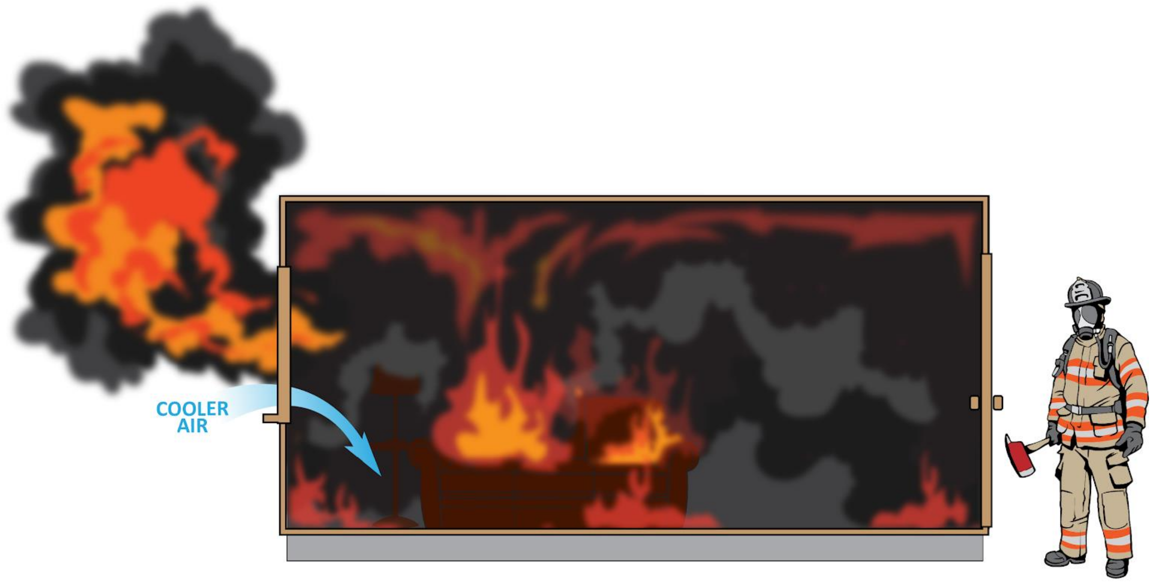
The fully developed fire is normally a stage of ventilation-controlled burning. The HRR (Heat Release Rate) value is therefore determined by the amount of air available to the fire.

There may be flaming if the air-fuel mixture is correct, and there may also be rolling flames in various locations throughout the enclosure and into the surrounding compartments depending on the quantity of unburned fuel.

Flashover: Transition of Fuel-Controlled to Ventilation-Controlled Behaviour

How a given fire develops from ignition to the point of fully developed behaviour will be linked to the quantity of fuel available as well as the fuel height, orientation and location-all of which impact the HRR (Heat Release Rate) of the fire. Fire development is also greatly impacted by the geometry and other characteristics of the enclosure boundaries. The geometry of the enclosure includes the size, shape, area and volume of the fire compartment. The distance to the ceiling of the enclosure, the volume in which hot gases collect in the upper layer, and the geometric relationship between the upper layer and any combustibles will all influence heat transfer and therefore govern how the fire will grow and spread.

Figure 25: Heat transfer in fire growth



The lining materials in an enclosure also have a significant impact on the growth of the fire. The thermal inertia, surface area and thickness of the lining (wall and ceiling) materials affect the retention and/or loss of energy within the enclosure. If the thermal inertia is lower, surface temperatures of compartment walls and ceiling will increase faster, providing accelerating thermal feedback to items within the enclosure. This will lead to higher mass fuel burning rates-and thus heat release rates-of the fire. In this way, lining materials may be a determining factor in whether an enclosure fire will transition through flashover.

Other Factors Affecting Fire Growth

AMBIENT TEMPERATURE

The ambient temperature, including the outside temperature and that of various fuels at their time of ignition, affects how quickly the fire can spread, as well as how heat is transferred in an enclosure fire. Buoyancy forces and movement of the flame and fire plumes are greatly dependent on ambient conditions.

AVAILABLE FUEL

The fuel sources in the room have a great impact on flashover. Fuel material and height of fuel impact the HRR, temperature of gases in the hot fire plume and hot layer, as well as fire growth rate. Often, fuel sources positioned higher in an enclosure will result in higher temperatures in the ceiling jet when they burn. Alternately, secondary sources of fuel located high in a compartment may absorb more radiant heat from the upper layer and therefore ignite faster than sources that lie closer to the ground.

GEOMETRY

The size, shape, area and volume of a room affect the formation of the upper layer and thus heat transfer within a given fire enclosure. A flashover may occur more slowly in enclosures that have peaked or cathedral ceilings, since these features make it difficult for ceiling jets to form, slowing down the collection of gases in the upper layer and limiting the amount of radiant heat produced and fed back towards the fire and other fuels in the enclosure.

Other Factors Affecting Fire Growth

VENTILATION

Access to a fresh source of oxygen is essential for continued combustion. As such, limiting the ventilation to an enclosure can slow or stop the growth of the fire, even leading to early decay.

However, when this occurs at a time when there has been a large accumulation of hot smoke in the upper layer, extreme care must be taken.
This is because if additional ventilation is introduced into the compartment after the fire has entered an under-ventilated state, various rapid fire developments can occur.

When the layer of hot smoke within an enclosure grows deep enough to reach an opening, such as a door or window, the smoke flows out through the top of the opening into the adjacent space.

The increased volume of the hot gases in the smoke and their accumulation in the upper layer result in a small but noticeable pressure increase inside the compartment. Since gases follow the path of least resistance, the pressure difference between the inside and outside of the compartment drives the flow of smoke through each opening. Ambient air will therefore flow back in through the bottom of the opening to replace the gases that have exited the compartment. The demarcation between flows is often visible in a doorframe or window.

Other Factors Affecting Fire Growth

VENTILATION

During a fire, flow occurs through openings because of vertical pressure differences in the opening as the upper layer builds.

For any position(s) in the opening where the pressure is higher inside than outside the compartment, smoke will flow out of the enclosure (outlet). Conversely, cooler air will flow into the compartment (inlet) for places where the opposite is true; the pressure is higher on the outside than the inside of the compartment.

Across a doorway, ambient air will flow back into the fire compartment through the bottom of the opening to replace the gases that have exited it. In this way, the flow of hot smoke in a fire compartment will be affected by natural ventilation (windows, the opening and closing of doors).

Moreover, it will be affected by the forced ventilation of any mechanical inlet or exhaust systems in an enclosure.

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Rapid Fire Development

A wide variety of terms to define transition situations in which the fire environment rapidly deteriorates.

In this section, the fire behaviour related to these transient situations is grouped into a category called "Rapid Fire Developments" (RFDs).

Rapid Fire Development: A transient phase in fire behaviour accompanied by a rapid increase in the heat release rate of the fire and temperature in the environment, sometimes accompanied by the generation of over-pressure.

Rapid Fire Development

RFDs are subdivided into two main categories: flashover and smoke ignition. Smoke ignition is then further subdivided into three separate developments: smoke explosion, backdraft and flash fire (propagating flame fronts including rollovers), as shown in Figure 27.

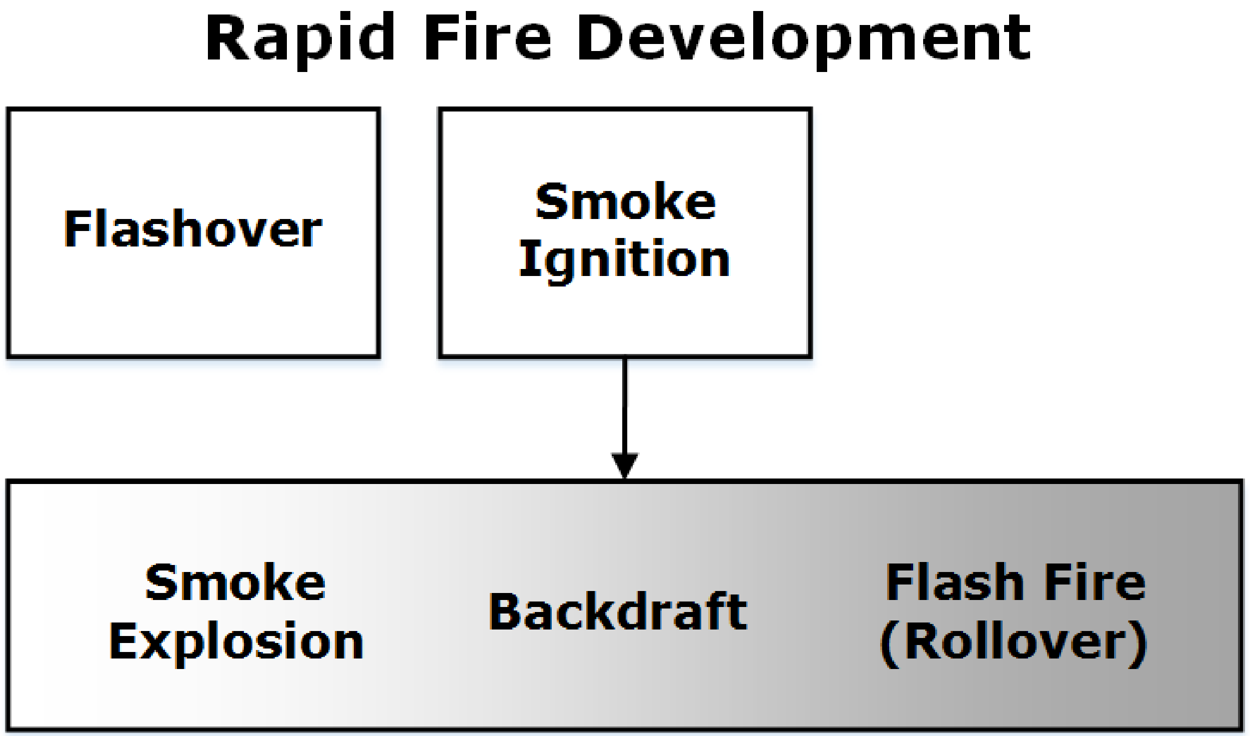

Figure 27: Rapid Fire Development

Flashover is considered separately as it involves a thermal feedback, which leads to the transition to a fully developed fire, whereas smoke ignitions involve the (auto- or piloted-) ignition of smoke.

Smoke ignitions are distinguished by the temperature of the mixture prior to ignition as well as the amount of pressure generated following ignition. These developments will be described according to their potential development, how they may be recognized, and their hazards to firefighters.

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Flashover

The most common of the RFDs (Rapid Fire Development) is flashover, which is identified as a transition stage of fire growth.

Flashover is a thermally-driven event stemming from the situation in which a fire generates sufficient heat to overcome the heat lost to the ceiling, walls and any openings.

This creates an imbalance and an energy feedback loop that results in the HRR increasing to its maximum value for that situation.

The actual temperature and HRR (Heat Release Rate) values will depend on many factors, including room size; lining materials; fuel types and loading; and ventilation. The enhanced HRR is accompanied by one or a combination of:

- A sharp (often termed "exponential") temperature increase in the smoke;
- Preheating of adjacent fuel surfaces to the point of piloted ignition;
- Remote (non-piloted) ignition of other surrounding fuels.

Flashover

The end effect is the transition to a fully developed fire. Flaming combustion may also occur external to the enclosure where there is sufficient oxygen available.
A flashover may also occur following another RFD (Rapid Fire Development) or as the end result of a change in ventilation conditions in the fire enclosure, such as the breaking of a window or the opening of a door. It is extremely important that firefighters understand that flashovers can occur following a change in the ventilation profile.

The other RFDs (Rapid Fire Development) discussed are distinct from flashover as they are not driven by a thermal imbalance in the enclosure. They involve the accumulation of smoke, which mixes with additional air and ignites, and therefore are considered together under the category of smoke ignition.

Figure 28: Flashover

Observations made during flashover describe the phenomena as fire "exploding" in an enclosure with rapid flame extension across the room and out compartment doors or windows. Exterior windows may break and general burning may also take place at floor level. The rapid change in conditions culminates in full-room involvement.

Smoke Ignition

The smoke ignition category includes developments and outcomes related to the accumulation, movement and mixing of smoke with additional air to create a flammable mixture that subsequently ignites and burns.

Smoke: *The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with a quantity of air that is entrained or otherwise mixed into the mass.*

Smoke is produced during the heating, smouldering, or flaming combustion of solid, liquid or gaseous fuels. The composition of smoke varies widely, depending on the type of fuel.

Due to the tremendous variability in conditions encountered during a fire, it is important to consider all of the products of combustion, pyrolysis and vaporization to be smoke.

Of critical importance to the firefighter is the understanding that smoke is fuel.

Smoke ignition present potential risks due to further fire extension or deterioration of existing fire conditions.

Smoke Ignition

Another concept related to the risk posed by smoke ignition is a fuel's flammable range. For flaming combustion to occur, the mixture of fuel and air must be within the flammability limits for that fuel.

As smoke is composed of many different constituents, when we consider it as fuel, its flammability limits are poorly defined. An auto-ignition will occur across a range of temperatures due to the different auto-ignition temperatures of the mixture's components.

Nonetheless, as with any gaseous mixture of fuel and air, there will be a range of concentrations of smoke in air that can sustain propagation of flames (the flammability range). The energy released during combustion will also vary according to how well-mixed the mixture is, and the proximity of the concentration of fuel in the mixture to its ideal concentration in air.

The better mixed and the closer the mixture is to ideal, the greater the potential HRRs and temperatures. If ignition occurs in a confined space, when the mixture is close to ideal and well mixed, higher over-pressures may be generated.

These concepts related to smoke and flammability ranges explain why certain RFDs (Rapid Fire Development) are grouped together under the category of smoke ignition.

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Smoke Ignition

Smoke ignition: *The ignition of the products of pyrolysis and incomplete combustion interior or exterior to the fire compartment due to the accumulated smoke layer falling within its flammability range and either auto-igniting or igniting due to an ignition source.*

Events related to smoke ignition usually occur after an enclosure fire has become under-ventilated and a volume of smoke has accumulated. For smoke ignition to occur, the fuel/air mixture in this volume must be within its flammability range, or sufficient mixing must occur between air and a fuel-rich mixture that is initially above the upper flammability limit.

If the mixture is within its flammable range and the volume encounters an ignition source of sufficient energy, or is above its auto-ignition temperature, it will ignite. If the initial mixture is above its flammable range, it must first mix with a sufficient quantity of additional air to be within the flammable range. Following this, it too can ignite.

RFDs (Rapid Fire Development) under the category of smoke ignition are further sub-classified as smoke explosions, backdrafts and flash fires, depending on the sequence of events that culminate in ignition; how the flame propagates through the mixture; and the potential consequences of that event. In general, there are no consistent quantitative definitions for these events. Instead, they relate to a spectrum of different phenomena that are described in the following sections.

Smoke Explosion

A smoke explosion can occur either inside or outside the fire compartment when an accumulation of fuel-rich smoke mixes with additional air and falls within its flammable range.

Smoke Explosion: *A rapid fire development that occurs when a smoke-air mixture falls within its flammable range, either external or internal to the room of origin, and is ignited, resulting in a significant pressure front.*

Figure 29: Smoke explosion

One common example occurs when smoke migrates and accumulates in hidden areas such as other rooms or void spaces (including lofts, attics or voids within walls). This smoke then mixes with air to fall within its flammable range and encounters an ignition source, resulting in a flame front propagating through the mixture, as shown graphically in Figure 29.

If the ignition occurs in a relatively confined volume, or if obstacles promote turbulence, the flame front may accelerate, leading to an over-pressure situation that may result in structural damage. If the explosion occurs away from the seat of the fire, it poses an additional hazard since firefighters in the vicinity of the explosion may not be wearing full protective equipment.

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Smoke Explosion

A smoke explosion can also occur within an enclosure without any change in ventilation, catching firefighters unaware. In Figure 30, the smoke explosion occurs following the decay of a fire in a closed compartment, as a result of under-ventilation.

Despite a reduction in HRR (Heat Release Rate) and temperature, smouldering combustion and/or pyrolysis will continue to generate smoke that accumulates in the enclosure. Small amounts of leakage that naturally occur will introduce fresh air into the compartment, and as this air mixes with the smoke, the mixture may fall within the flammable range. If and when a mixture that is local to an ignition source (such as remaining flames, embers, smouldering combustion or heated surfaces) falls in the flammable range, it will ignite and a flame front will propagate.

As this process can take significant time, the resultant mixture may be well mixed when it eventually ignites, and the flame front may propagate quickly. When confined in the compartment, this series of events can lead to the build-up of a significant over-pressure. The resulting smoke explosion can cause significant damage to the structure and/or result in the injury or death of nearby fire fighters.

Figure 30: Smoke explosion in a closed compartment

Backdraft

Backdrafts are widely studied and referenced events, caused when the ventilation profile of an under-ventilated fire enclosure is suddenly changed and fresh air enters the enclosure. Similar to a smoke explosion, backdrafts are accompanied by significant over-pressure.

Backdraft: *A deflagration resulting from the sudden introduction of air into a confined space containing oxygen-*

Figure 31: Gravity current

Backdrafts begin with the fire entering an under-ventilated state, resulting in the accumulation of flammable smoke in the enclosure. During this phase of fire development, a change in ventilation occurs (e.g., a window breaking or a firefighter opening the door to the enclosure). As hot smoke exits above, fresh, cooler air enters below. This air is fed by a gravity current and mixes with the compartment gases, as shown in Figure 31. Ignition can occur along the smoke-air interface through auto-ignition or when a pocket of flammable mixture reaches an ignition source within the enclosure.

Backdraft

The resulting flame front will propagate through any regions of flammable mixture, promoting turbulence and additional mixing of smoke and air. The flammability of the mixture that is ignited will depend on many variables. If the ignition source is more remote-allowing more time for the smoke and air to mix-or if more turbulent mixing occurs due to obstructions in the air track, the smoke and air are more likely to be closer to an ideal mixture. This will result in faster flame propagation and higher flame temperatures.

Regardless of the mixture ratio, the ignition pushes unburned fuel-rich gases ahead of the burning smoke-air mixture as it expands. As shown in Figure 32, a large fireball results as the burning flammable smoke-air mixture is forced, under pressure, from the enclosure.

Figure 32: Progression to backdraft

The over-pressures and dramatic fireballs produced during backdraft can result in damage to the structure and extension of the fire beyond the enclosure, and can pose severe risks to firefighters who are in its path. The risk of a backdraft is highest shortly after a change in ventilation conditions.

Backdraft

Despite developing in ways to similar a smoke explosion, there are key characteristics that differentiate backdrafts from smoke explosions:

- A backdraft occurs as a result of a change in the ventilation profile, which produces a gravity current.
- Backdrafts emanate as smoke is pushed ahead of the flame front, resulting in the characteristic fireball emanating from the opening.

Figure 32: Progression to backdraft

BACKDRAFT INDICATORS

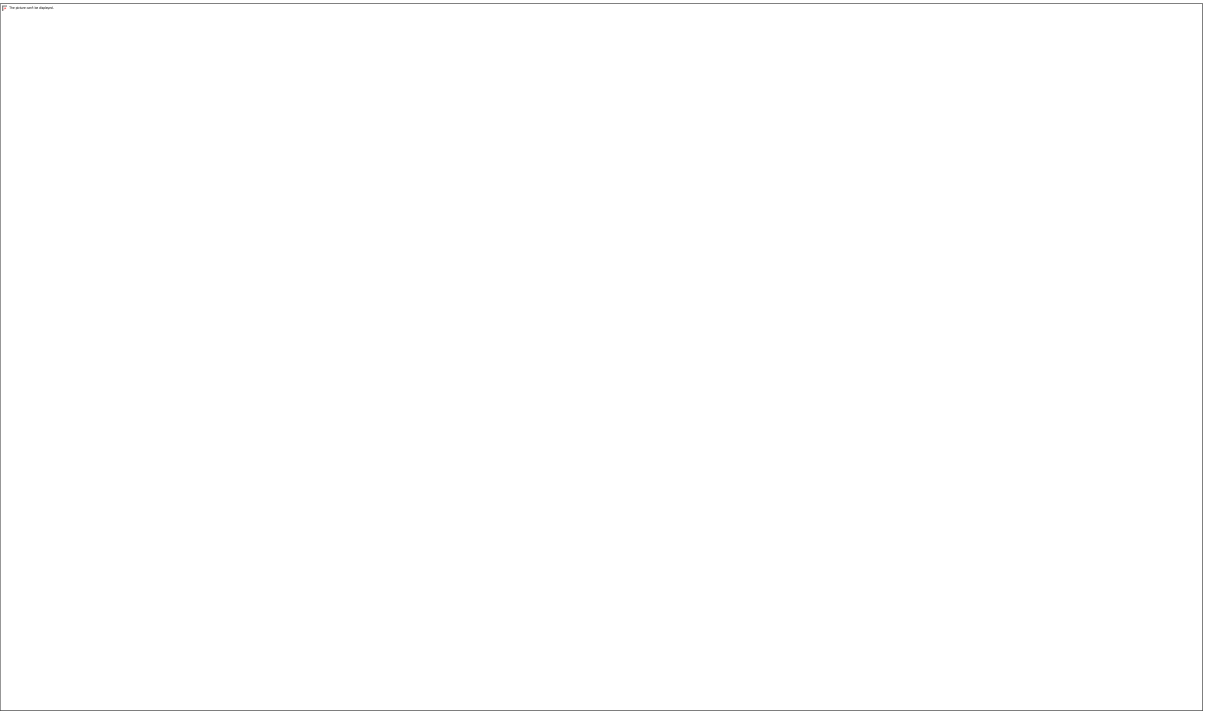
A key indicator witnessed previously in backdraft situations is described as an in-and-out movement of the smoke, giving the impression that the "building is breathing." In addition, the fire may appear to be pulsating. As shown in Figure 33, windows and doors may be closed, yet yellowish-grey smoke will seep out around them under pressure, and then subsequently be drawn back into the building. There may not be visible flames in the room, but doors and windows will be very hot, and the window glass may be discoloured and cracked from the heat. There may also be whistling sounds around doors and windows.

Backdraft

If a fire has been burning for a long time in a concealed space, a lot of unburned gases may have accumulated. In a number of past incidents, a pulsating rising and sinking of the hot gas layer has been observed.

Limited ventilation leads to the production of large amounts of unburnt gases. An opening is suddenly introduced and a current of inflowing air mixes with the gases, creating a combustible mixture.

Figure 32: Progression to backdraft



The mixture ignites and moves very quickly in the form of a turbulent deflagration; this will be accompanied by a powerful expansion of gases as combustion takes place. The location of ignition source determines the delay in time until a fire ball will "explode" outside an opening. A backdraft may lead to a fully developed fire, or may expel all of the fire gases, leaving only localised combustion in its path.

Flash Fires

This category of smoke ignition comprises a series of RFDs (Rapid Fire Development) that are characterized by several modes of flame propagation through smoke-air mixtures. In contrast to backdrafts and smoke explosions, the flame propagation in these situations does not result in the generation of any significant over-pressure. Two manifestations of flame propagation that fall into this category are flash fires and rollover.

Flash Fire: *A fire that spreads by means of a flame front rapidly through a diffuse fuel, such as a dust, gas, or the vapours of an ignitable liquid, without the production of damaging pressure.*

Figure 34: Flash fire

Flash fires involve a flame moving through a flammable mixture with considerable speed, without developing a significant over-pressure (Figure 34).

Note that the following definition of flash fire does not specify heat flux or duration, as is specified for the flame-resistant garments.

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Flash Fires

Another process that involves flame propagation through a smoke layer is referred to as rollover. This is where a flame front or pockets of smoke-air mixture ignite and move slowly through a mixture. Rollovers are also considered an early and important indication of impending flashover.

Rollover: *The condition in which unburned fuel (pyrolysate) from the originating fire has accumulated in the ceiling layer to a sufficient concentration (i.e., at or above the lower flammable limit) that it ignites and burns. Rollover can occur without ignition of or prior to the ignition of other fuels separate from the origin.*

Figure 34: Flash fire

In either case, an under-ventilated or smouldering fire produces fuel-rich smoke, which mixes with air to fall within the flammable range and then is ignited, either by auto-ignition or when exposed to an ignition source. These RFD events can happen within an enclosure (such as during overhaul, when embers or sparks may act as an ignition source) or external to the room of origin in any remote location where a combustible mixture has collected.

Depending on the details of the situation, combustion may occur rapidly throughout a volume of diffuse smoke-air mixture (flash fire), along the boundary between the smoke and air layers (rollover) or within the smoke volume in pockets where smoke and air have mixed to within the flammable range.

Rapid Fire Development - Possible Outcomes

Figure 36 shows the HRR curves of several RFDs that could occur following a ventilation-controlled period. The rate of HRR can vary. An HRR peak may occur prior to the initiation of a flashover. At the other extreme, the fire may continue to die out, with its HRR decreasing steadily.

Traditionally, fires were represented as shown by the fuel-controlled line as there was usually enough ventilation to allow a compartment to reach flashover. As modern building techniques resulted in tighter building envelopes, the ventilation-controlled curve was popularized as "Modern Fire Behaviour".

Figure 36: Possible outcomes following an RFD

The reality is more complicated, as no two fires will be the same, and it is practically impossible to predict whether an RFD will occur, which RFD may occur, or whether the fire will simply decay.

Rapid Fire Development - Possible Outcomes

It is important to appreciate that any of the curves in Figure 36-or in fact any outcome bound by the extreme cases-may occur. It is also important that firefighters understand that a given curve is not necessarily representative of any given smoke ignition.

A useful tool to remind firefighters of the range of possible outcomes is the ***GRAB*** mnemonic. A ventilation-controlled fire can:

- **G**o out;
- **R**esume growth;
- **A**uto- or piloted-ignite; or,
- **B**ackdraft.

A range of RFDs are possible, and firefighters should be aware of their environment to watch for signs of RFD, and to be aware of changes in fire conditions in general.

Firefighters should also remember that their actions can have significant impacts on fire development. Modifying the ventilation profile of a compartment might initiate an RFD, or reduce its potential by dissipating accumulated smoke.

Application of water-either directly to the fire, or to a heated volume of smoke-will lower the temperature, and inert the mixture, delaying or mitigating an RFD.

Different Classes of Fire in the UK from A to F

Class A fires - Combustible materials:

Caused by flammable solids, such as plastics, wood, paper, straw, coal, textiles, furniture, etc.

Class A fires are probably the most common type of fire and they can spread quickly if there are enough combustible materials, oxygen, and heat to sustain the fire. Most commercial and industrial premises are likely to contain a large number of common combustibles

The appropriate extinguishers used to tackle a Class A fire include water, foam, dry powder, and wet chemical extinguishers.

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Class B fires - Flammable liquids:

Such as petrol, diesel, oils, turpentine, paraffin, paint, ethanol, methanol, etc.

Class B fires are incredibly dangerous and can occur in any area where flammable liquids are stored or used such as garages, construction sites, warehouses, hospitals, and laboratories.

Flammable liquids have a low flash point so they burn easily when an open flame or other ignition point is introduced. A match, lighter or spark can ignite the vapours of a flammable liquid, so proper storage is required to minimise the chances of a Class B fire occurring.

The appropriate extinguishers used to tackle a Class B fire include CO_2, foam, and dry powder extinguishers.

Class C fires - Flammable gases:

Such as propane, butane, methane, natural gas, hydrogen, etc.

Flammable gases are highly volatile and pose a major fire and explosion risk, therefore in any industrial or commercial area where flammable gases are used, they should be kept stored in a secure location that is strictly monitored and kept clear of open flames.

The concentration of flammable gases in the air will dictate the potential fire hazard, and even small or isolated leaks of these gases can lead to quick ignition if an open flame or igniter is introduced.

The appropriate extinguisher used to tackle a Class C fire is a dry powder extinguisher.

Class D fires - Combustible metals:

Fuelled by ignited metals such as magnesium, aluminium, lithium, titanium, potassium, etc.

Metal-based fires are not common as not all metals are flammable. Due to the excessive temperatures needed to ignite flammable metals these types of fires are often extreme,

Class D fires must be tackled with a specific dry powder extinguisher (L2 or M28) that includes graphite, copper, and sodium chloride-based powders. The main risks for Class D fires are the smaller deposits of metal, such as shavings or powders.

The appropriate extinguishers used to tackle a Class D fire include L2 or M28 (specialist) dry powder extinguishers.

Electrical fires (Class E is not used, instead the symbol of an electric spark is displayed)

Caused by electrical equipment such as TVs, computers, faulty wiring, frayed cables, broken electrical appliances/tools, short circuits, overloading multi-adaptor plug sockets, hairdryers, extension leads, etc. Once the electrical item is removed, the fire changes class.

Electrical fires are not given their own full class, as they can fall into any of the other classifications. After all, it is not the electricity that is burning but the surrounding material that has been set alight by the electric current.

Electrical fires can be very common, with potential hazards present in virtually every commercial or industrial setting. If an electrical item or appliance is showing signs of a fault or deterioration, the power to the item should be cut immediately and the appliance should be kept out of use until it is repaired or disposed of.

The first step when fighting a fire caused by electricity is to switch the equipment off. As water conducts electricity, spraying an electrical fire with water can cause the current to travel back up the stream and potentially electrocute the operator.

The appropriate extinguishers used to tackle a Class E fire include CO2 or a dry powder extinguisher.

Class F fires - Cooking oils:

Such as fats, cooking oils, grease, etc.

Class F fires consist of cooking oils and fats that have been ignited. With the high flash point of cooking oils and fats and the extremely high temperatures necessary to cause a blaze with these materials, it has been designated its own fire class.

These kinds of fires are most common in restaurants and commercial kitchens.

A common cause of Class F fires relates to deep fat frying; oil can be left to cook for too long, or in too great a quantity. Deep fat frying is the leading cause of accidental fires in kitchens, so great care is required at all times. Most often, they occur when pans containing oils are left unattended or are not carefully monitored.

A fire blanket is often the best solution for smaller cooking oil/fat fires, eradicating the need to clean up any debris from the use of chemical suppressants.

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Different Classes of Fire in the UK from A to F

Fire Extinguisher Types and Classes

(BSEFSD – K1/12/21/22)

The reaction to fire classification determines how much (if any) a material contributes to the spread of flame:

- A1, A2 = Non-Combustible Materials.
- B, C, D = Ranges from very limited to medium contribution to fire.
- E, F = High contribution to fire.
- The ‘**s**’ part relates to total **smoke propagation**, during the first ten minutes of exposure. **These determine a ‘smoke’ index:**
- S1 = a little or no smoke
- S2 = quite a lot of smoke
- S3 = substantial smoke
- The ‘**d**’ part relates to ‘**flaming droplets and particles**’
- during the first 10 minutes of exposure. **The index is:**
- D0 = none
- D1 = some
- D2 = quite a lot

Classification	Fire Risk
Class A	Solid Combustible Materials i.e. Paper, Wood, Textiles.
Class B	Flammable Liquids i.e. Petrol, Diesel, Oil.
Class C	Flammable Gases i.e. Natual Gas, Propane.
Class D	Combustible Metals i.e. Sodium, Potassium, Lithium.
Class F	Cooking Oils/Fats i.e. Deep Fat Fryers
Class E*	Electrical Fires i.e. Short Circuiting Equipment

Fire Resistance Classes

Definition	Grade	Smoke Propagation	Flaming Droplets
Non-Combustible Materials	A1	-	
	A2	s1	d0
		and all variations	
Combustible materials: Very limited contribution to fire	B	s1	d0
		and all variations	
Combustible materials: Limited contribution to fire	C	s1	d0
		and all variations	
Combustible materials: Medium contribution to fire	D	s1	d0
		and all variations	
Combustible materials: High contribution to fire	E	E-d2	
Combustible materials: Easily flammable	F		

Question Paper