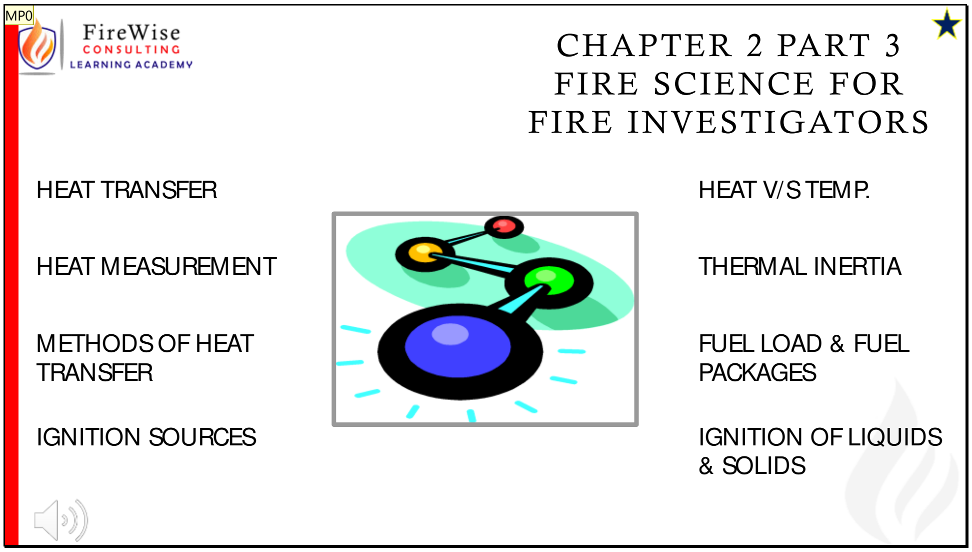
Slide 1



Welcome to Chapter **2** Part 3 of Fire Science **for Fire Investigators**.

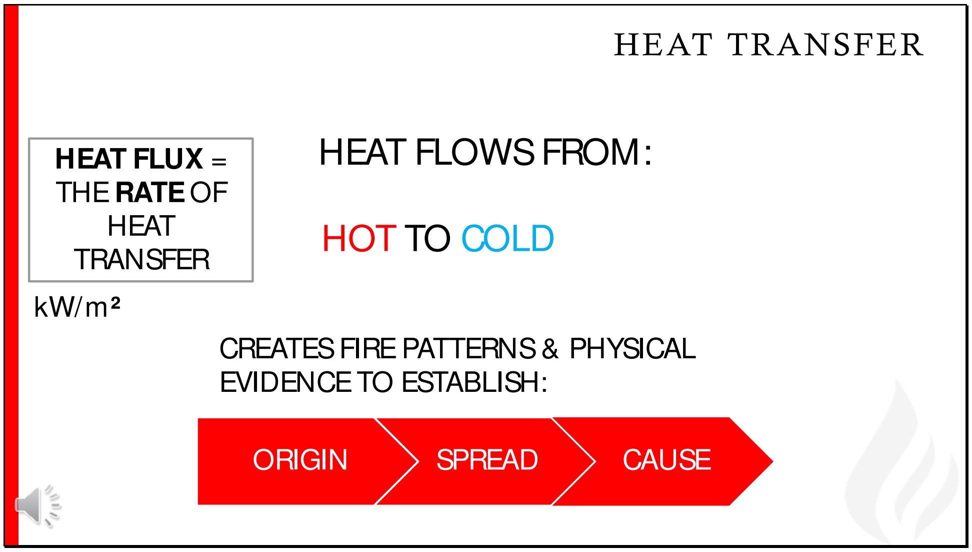
In this part we will discuss:

- Heat Transfer
- Heat versus temperature
- Heat Measurement
- Thermal Inertia
- Methods of heat transfer
- Fuel load and fuel packages
- Ignition sources

And

- Ignition of liquids and solids

Slide 2

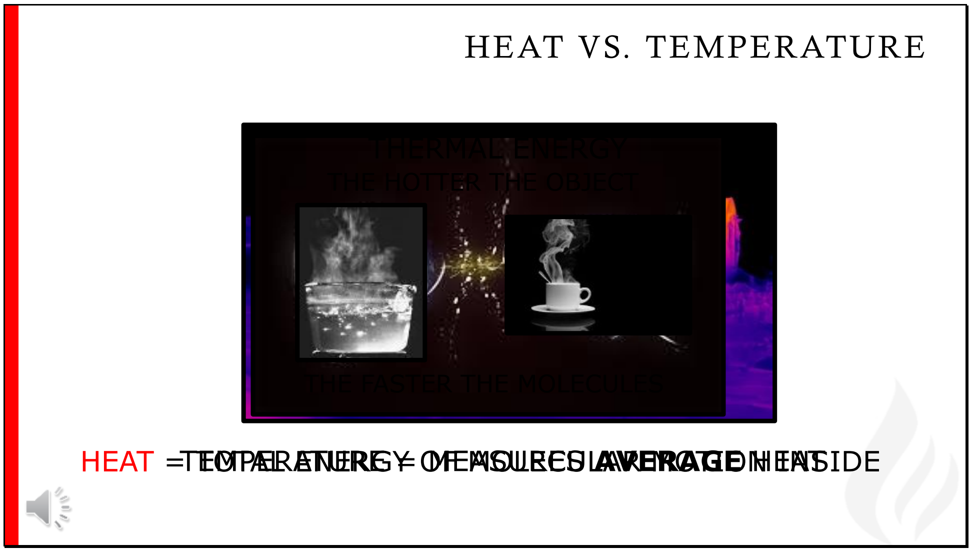


Heat energy moves from hotter objects to cooler objects through a process known as heat transfer.

Heat flux is the rate at which the heat energy is transferred. The rate of transfer increases when the temperature differences between objects are greater and is commonly expressed in kilowatts per square meter.

As the fire progresses through the various stages, the effects of heat transfer create fire patterns and physical evidence that the investigator will rely on to establish the origin, spread and cause of the fire.

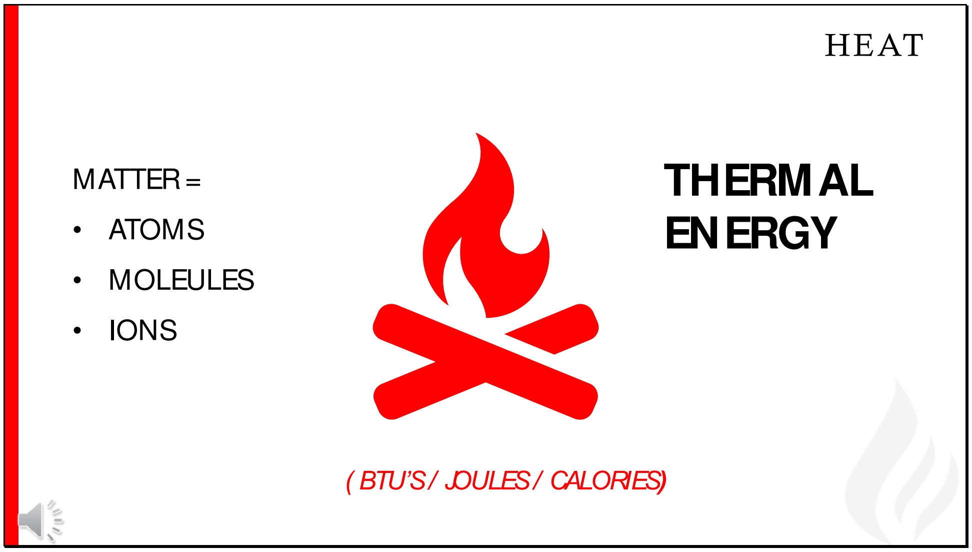
Slide 3



Often people use the terms heat and temperature interchangeably; however, they have different meanings. The hotter an object is, the faster the motion of the molecules inside it. Thus, the heat of an object is the total energy of all the molecular motion inside that object.

Temperature, on the other hand, is a measure of the average heat or thermal energy of the molecules in a substance. Since it is an average measurement it does not depend on the size of the material. For example, the temperature of a small cup of boiling water is the same as the temperature of a large pot of boiling water - even if the large pot is much bigger than the cup and has millions more water molecules.

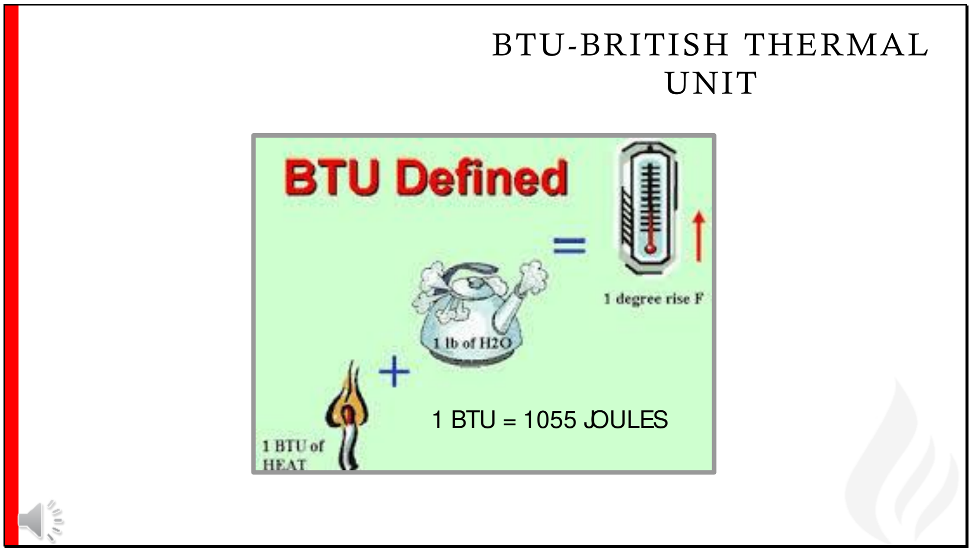
Slide 4



Heat is the amount of energy needed to change an object's temperature. All matter is made of tiny particles called atoms, molecules and ions. These tiny particles are always in motion – either bumping into each other or vibrating back and forth. It is the motion of these particles that creates heat or thermal energy. The faster those particles are moving the more heat is created.

Heat is measured in BTU's, Joules or Calories.

Slide 5

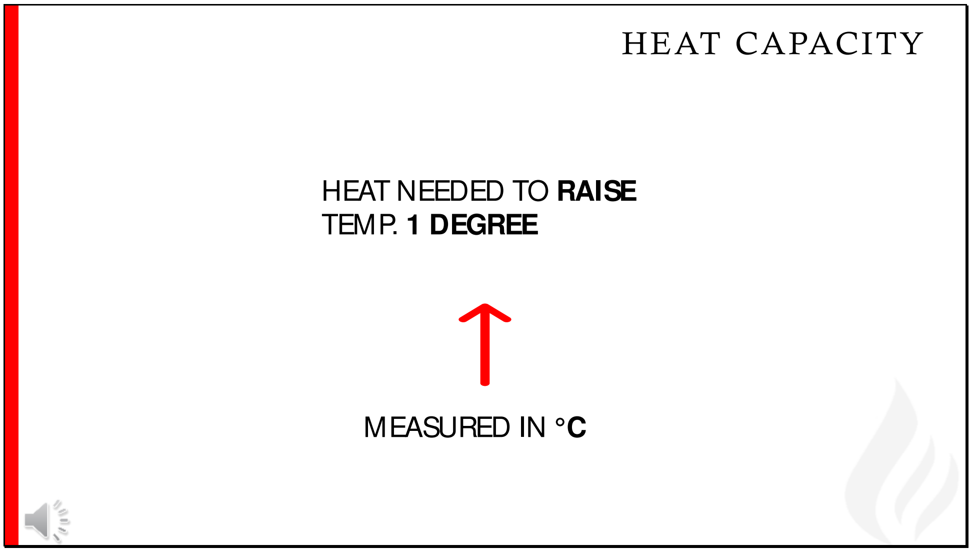


A British thermal unit (Btu) is a standard unit of energy that represents the amount of thermal energy necessary to raise the temperature of one pound of water one degree Fahrenheit. The Btu is a measurement in the Imperial system of units like inches, feet, pounds and gallons.

Btu's can also be measured in joules. A Btu is equivalent to approximately 1055 joules (or 1055 watt-seconds).

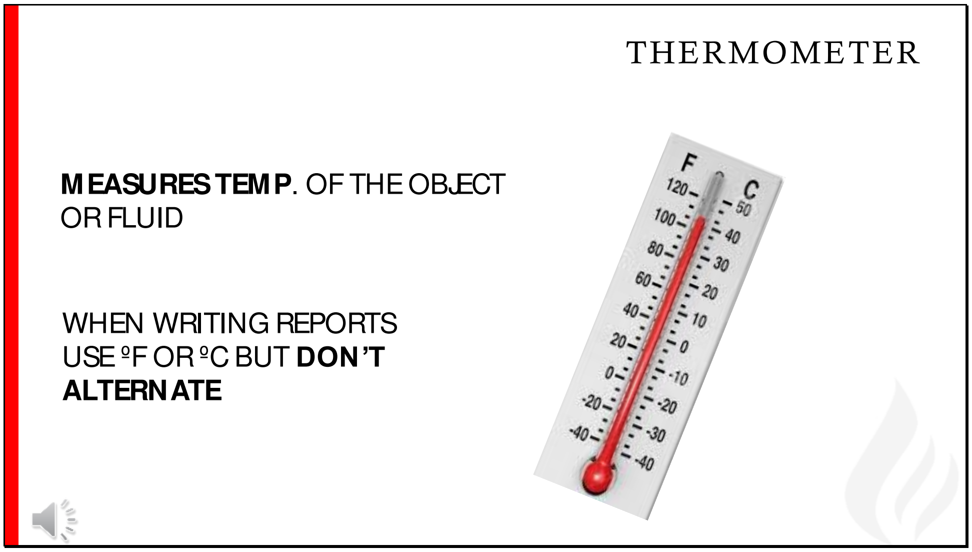
The Btu is often used as a quantitative specification for the energy-producing or energy-transferring capability of heating and cooling systems such as bar-b-ques, furnaces etc.

Slide 6



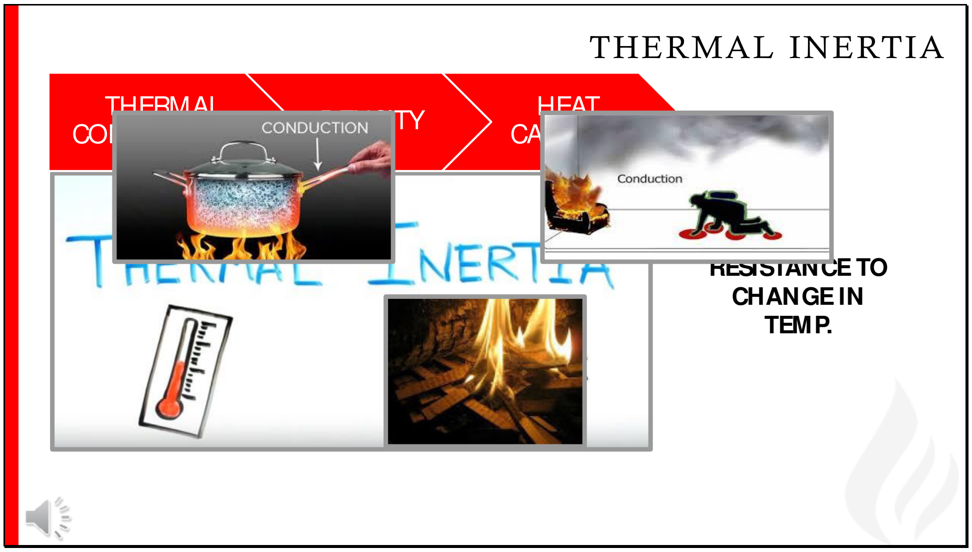
Heat capacity is the amount of heat needed to raise the temperature of a substance by one degree and is usually expressed in degrees Celsius.

Slide 7



A thermometer measures the temperature of the object or fluid and is recorded in Celsius or Fahrenheit. It is very important to use the correct terminology when you are writing reports that will be reviewed by others. Although the terms Fahrenheit and Celsius are both correct you should use consistent terminology throughout the report. In other words use one or the other but don’t alternate between both in the report. Using the correct terminology shows your expertise in the field and your understanding of the subject matter.

Slide 8



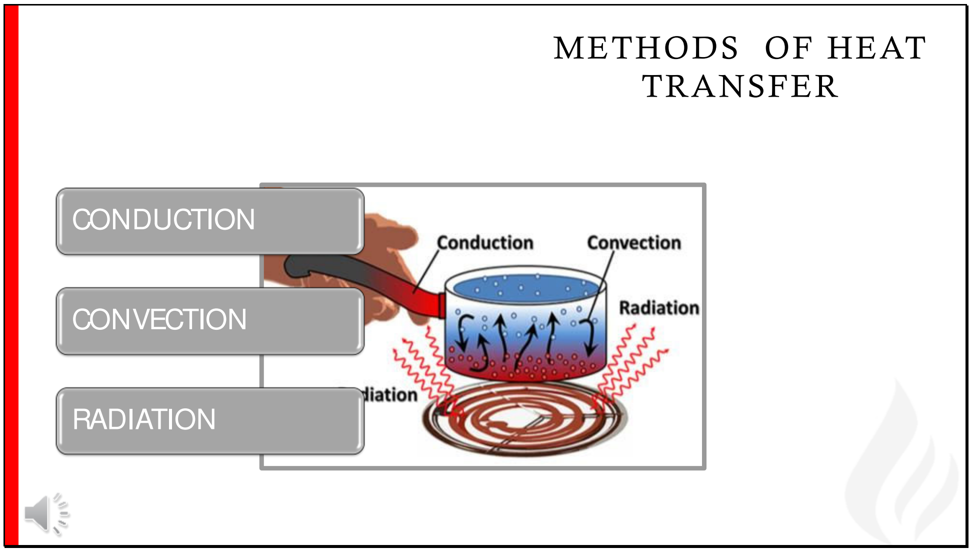
Thermal inertia is the resistance of something to changes in temperature. It is the properties of a material that characterize its rate of surface temperature rise when exposed to heat. It is the product of thermal conductivity, density, and heat capacity.

As materials are heated, the surfaces of the object begin to absorb heat that is then transferred through the remainder of the object by conduction. The speed at which the object's surface absorbs heat is determined by its thermal inertia. For instance, objects that are thin tend to heat and ignite faster than objects of like materials that are thicker. This effect has a direct impact on ignitability and flame spread. For example, campfire kindling burns much more readily than larger pieces of wood.

Slide 9

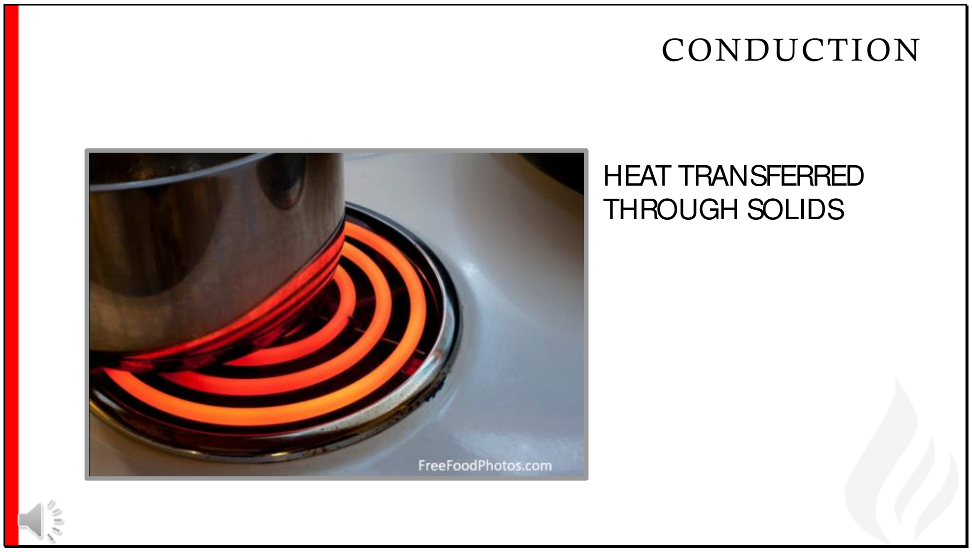
THERMAL INERTIA

Slide 10



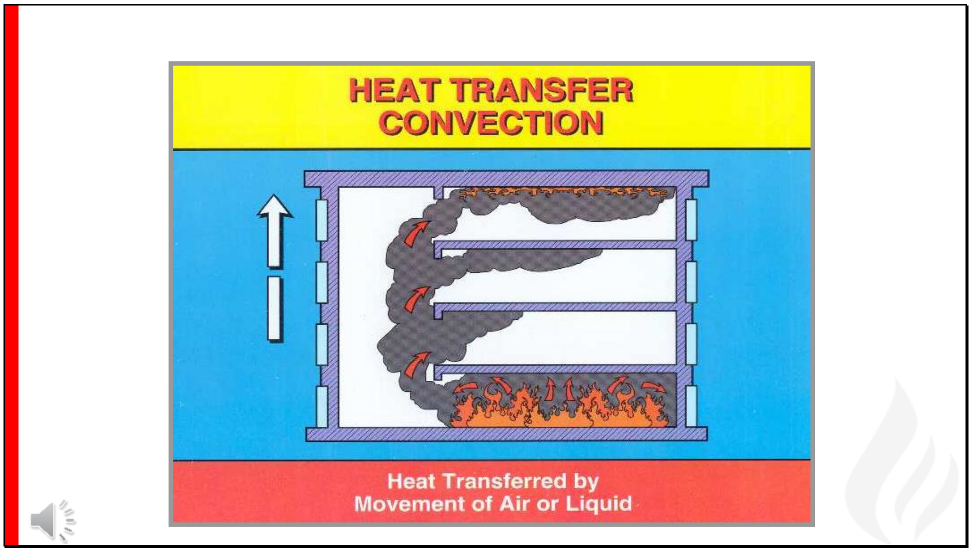
Heat can be transferred from one object to another by three methods; conduction, convection, or radiation. Fire investigators must be aware of how each method of heat transfer can influence the development and spread of fire.

Slide 11



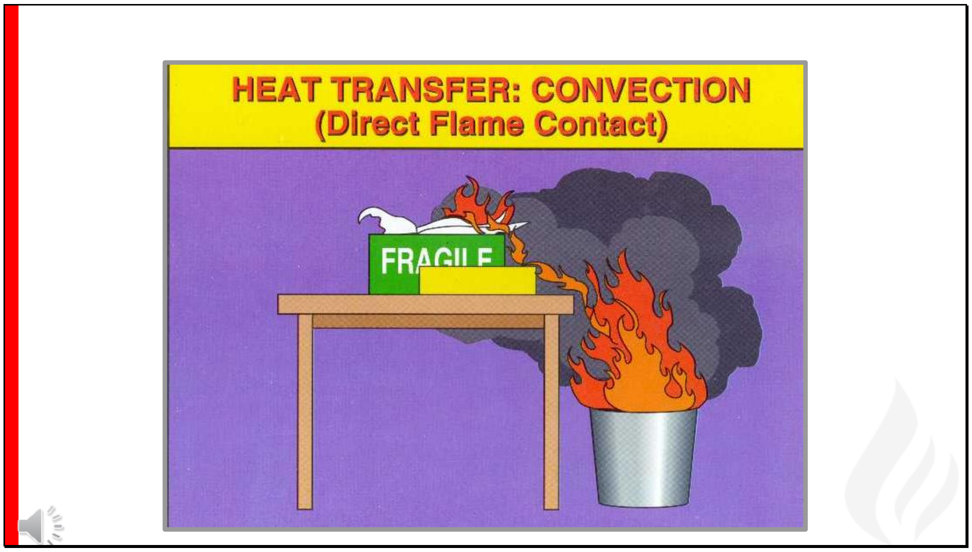
Heat transferred from one body to another through a solid is known as conduction. The rate of heat transfer is influenced by the difference in temperature and thermal conductivity of the object. A good example of this is a metal pot on the stove. Heat conducts from the hot element to the bottom of the pot and through the pot to the handle. As materials are heated, the heat absorbed at the surface of the object is transferred through the rest of the object via conduction.

Slide 12



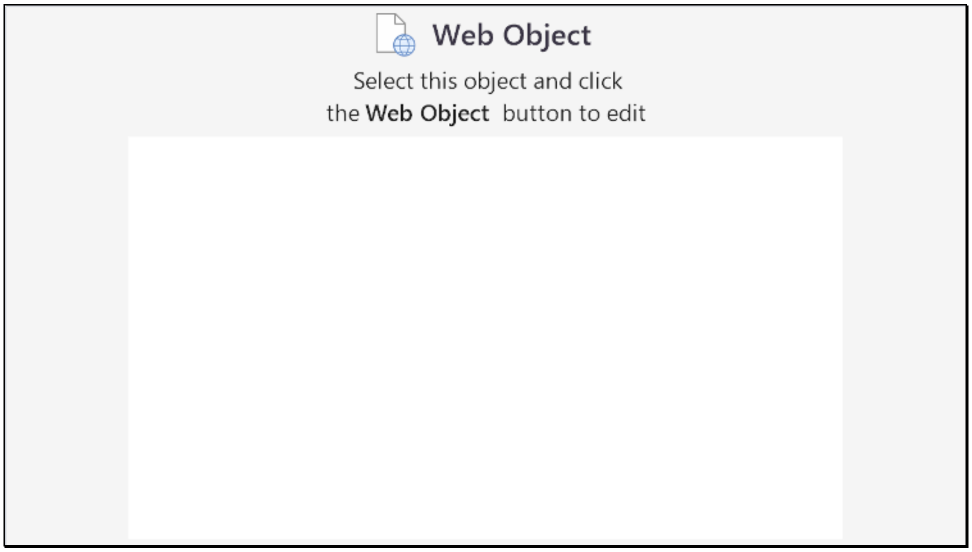
Convection is heat transferred from or to a surface through contact with moving air or a liquid. The air above a hot surface expands and becomes less dense so it rises spreading vertically and laterally through the space. As the hot air rises it pushes cooler air downward and convective currents are formed. This is one reason why fire separation between floor levels in buildings is critical to prevent the upward spread of fire.

Slide 13



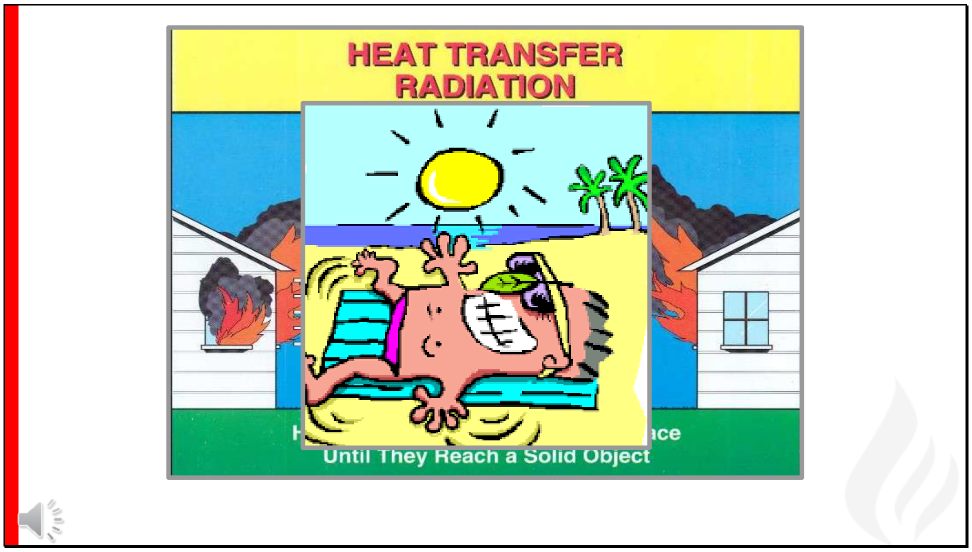
Direct flame contact on an object is also considered heat transfer through convection **and radiation**.

Slide 14



Dehaan Video #4 Dr. DeHaan Convective Heat Transfer

Slide 15



Radiation is heat transferred via electromagnetic waves through the vacuum of space or the air. Heat from the sun is radiated to earth.

The rate the heat is transferred between two objects is affected mainly by the size and temperature of the fire and the distance between the fire and the target, but other factors come into play as well. The relative temperatures of the two objects and the angle between the radiator and the target, also affects the transfer rate.

Radiated heat from a fire is transferred in a direct line away from the heat source and absorbed by cooler materials including liquids and gases.

Most exposure fires are the result of radiated heat transfer. The next five pictures are a graphic representation of fire spread through radiation.

Slide 16


The next four photographs are a graphic example
of heat transfer by radiation.

Slide 17

The next four photographs are a graphic example of heat transfer by radiation.

Slide 18

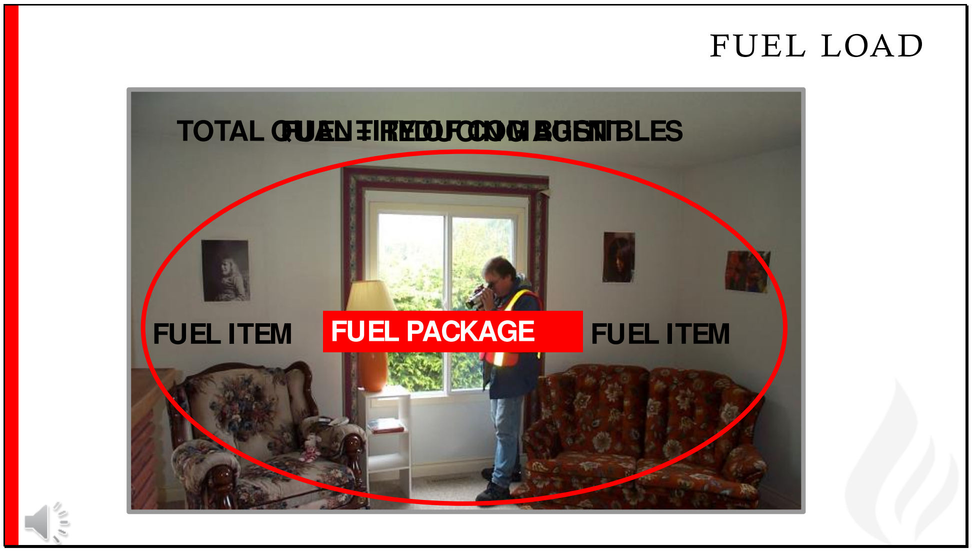
Slide 19

Slide 20

Slide 21

Here is another example of radiated heat. In this case, a forest fire went through the community. Sprinkler protection was set up on the roof of this house. Prior to the fire a large pile of firewood was located where you see the downed tree. The firewood pile was similar to that seen in this photo. The sprinkler protected the home but the firewood ignited because the sprinkler did not reach it. As the firewood burned radiated heat melted the siding on the house. There was no damage to the interior of the home.

Slide 22

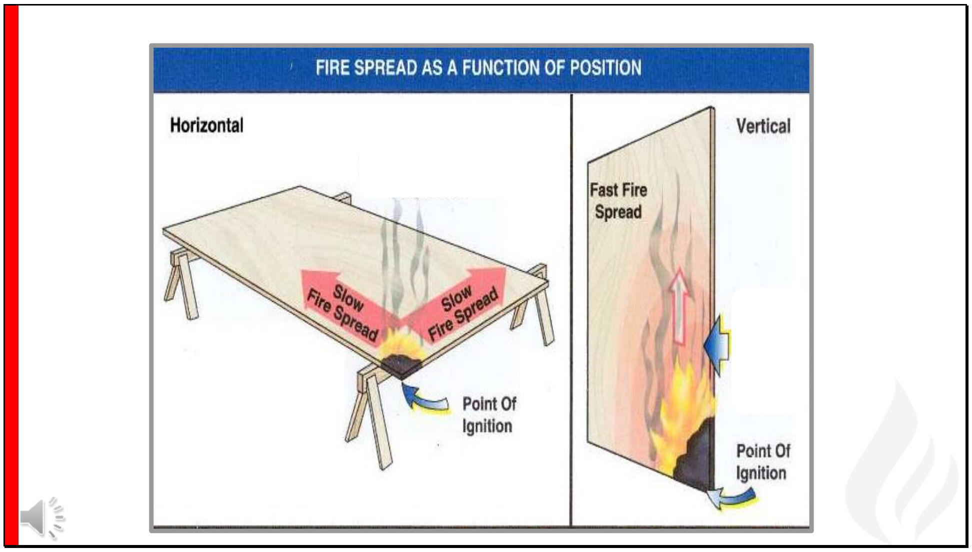


Fuel load refers to the total quantity of combustible contents of the building, space, or fire area, including interior finish and trim. Fuel is the material or substance being oxidized or consumed in the combustion process. In scientific terms the fuel, in a combustion reaction, is known as the reducing agent.

A fuel item is any substance that can undergo combustion. So in this photograph the chair is a fuel item as is the love seat.

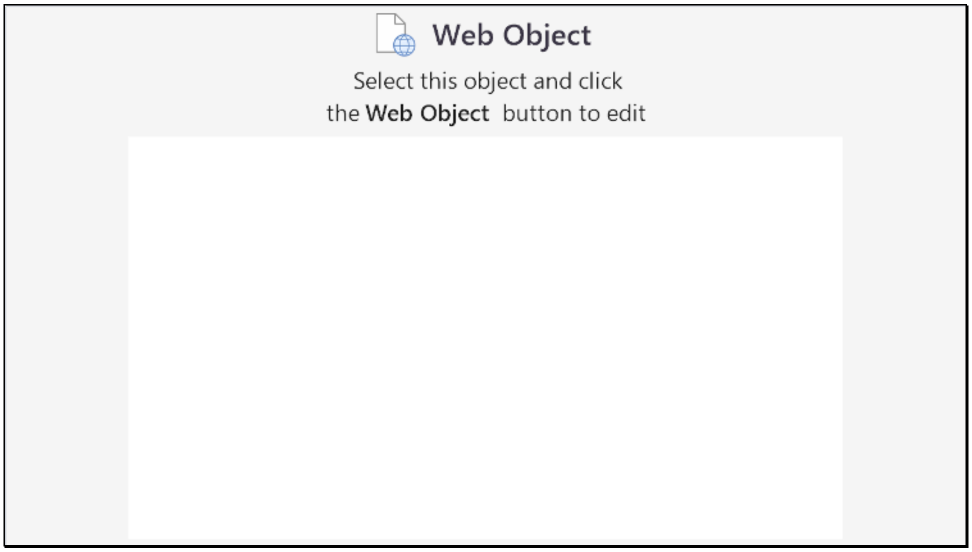
A fuel package is a collection or array of fuel items in close proximity to each other such that heat can transfer from one item to other items in the fuel package. In this case the chair, love seat, end table, lamp, photos on the wall, the wall covering and the floor coverings are all part of the fuel package. If only one specific fuel item exists, it may also be considered a fuel package.

Slide 23



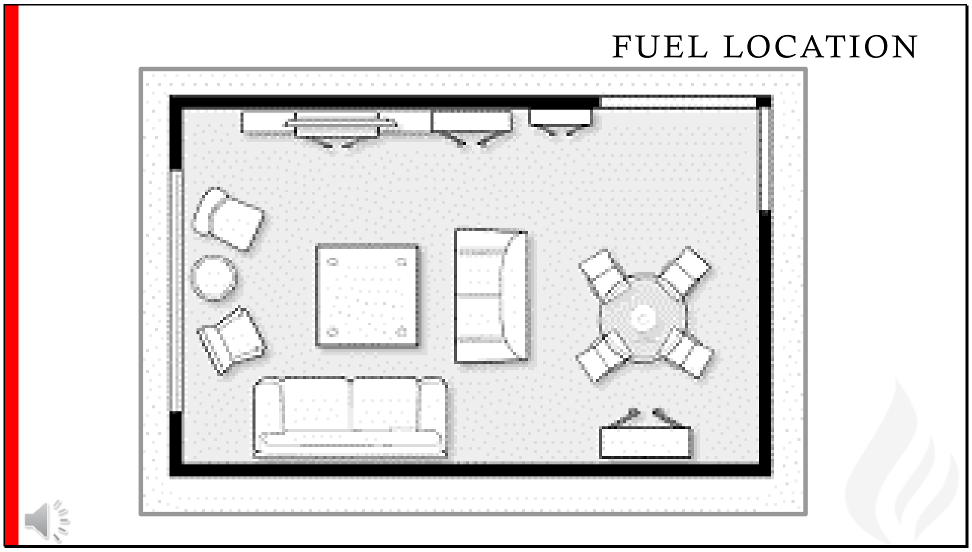
Two key factors that influence the combustion process are the physical state of the fuel and its distribution or orientation; horizontal or vertical. As a fire grows, flames begin to move across the surface of the fuel at varying rates. Obviously, fire spread across the vertical surface of a solid is more rapid than across a horizontal surface because heat rises.

Slide 24



Dehaan Video #5 Dr. Dehaan: Material Dynamics

Slide 25



The location and position of the fuel package are also important factors for the fire investigator to consider. For example, fuel packages that are located next to or near a wall or corner will restrict air entering the plume which creates an imbalance. Restricting air entrainment will cause an increase in plume and upper layer temperatures as well as increase the flame height. Plume and upper layer temperatures are increased because of the reduction of cooler air entrained into the fire. Additionally, a reduction in air entrainment will also cause an increase in the flame height.

The position of the fire in relation to fuel packages and walls and corners must be considered by the fire investigator when interpreting damage patterns.

For example, if the fire starts in this corner of the room it will take time to develop and spread to other fuel items because of the separation distance even though the amount of air entrained is limited by the walls. But, if the fire starts in this corner it will develop much more rapidly due to the proximity of the fuel package. Heat from the fire will quickly reach the available fuel, through radiation or convection and even less air will be entrained.

The ceiling height is also a factor. The higher the ceiling the longer it will take for flames to reach it.

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This photograph shows a fire set in the corner of the room which dramatically reduced the amount of air entrained into the plume. In addition there was a curtain hanging on the wall which acted to spread the fire rapidly towards the ceiling increasing the rate of fire spread.

During a compartment fire, heated gases and smoke rise and are confined by the ceiling. As the temperature at the ceiling level rises, the radiant heat created begins to accelerate the rate of fire spread as well as the rate of heat release.

As the flames begin to impinge on the ceiling, the plume begins to spread across the ceiling in all directions as a ceiling jet. The ceiling jet continues to spread latterly until it is blocked by a wall or partition. The heated layer of gas and smoke begins to descend into the room. Heat then radiates back on the burning fuel package as well as other target fuels located within the compartment. The gas layer stops descending when an opening such as a door or window allows for the flow of gases out of the compartment.

The following video is a graphic example of fire development in a compartment.

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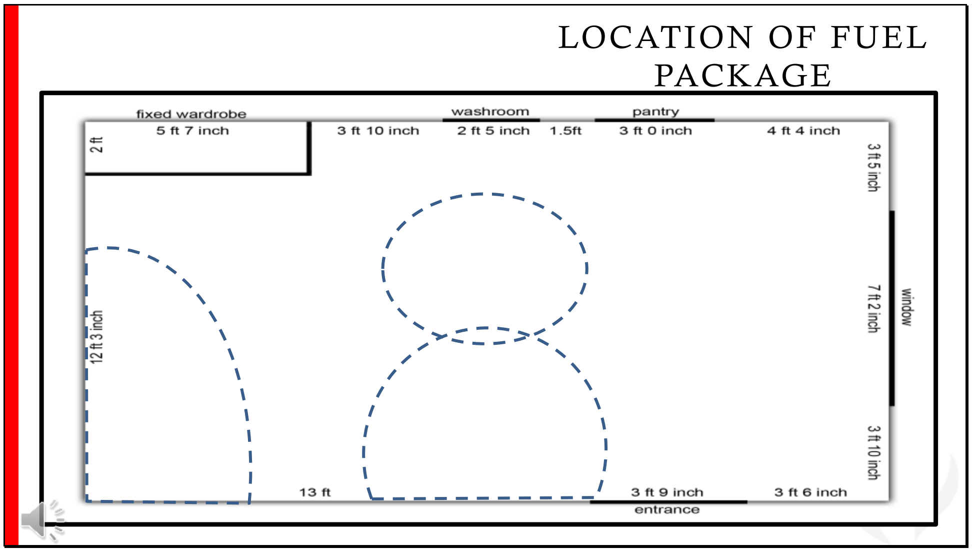
FIRE DEVELOPMENT

Slide 28



Equally important to the fire investigator is the location of the fuel package within the room. A fuel package burning in the center of the room will have a plume that is able to entrain air from all sides. This entrained air not only fuels the fire but cools the rising flame plume. This central perimeter will result in a cooler plume and lower flame height. If that package is moved against the wall only half of the air is available for entrainment and the flame height will increase.

If the fuel package is located in the corner of the room, only a quarter of the air is available resulting in much taller flames. This effect is known as the wall or corner effect and can lead to misinterpretation of the origin of the fire because heavier fire damage will be located above fuel packages located against the walls or in corners.

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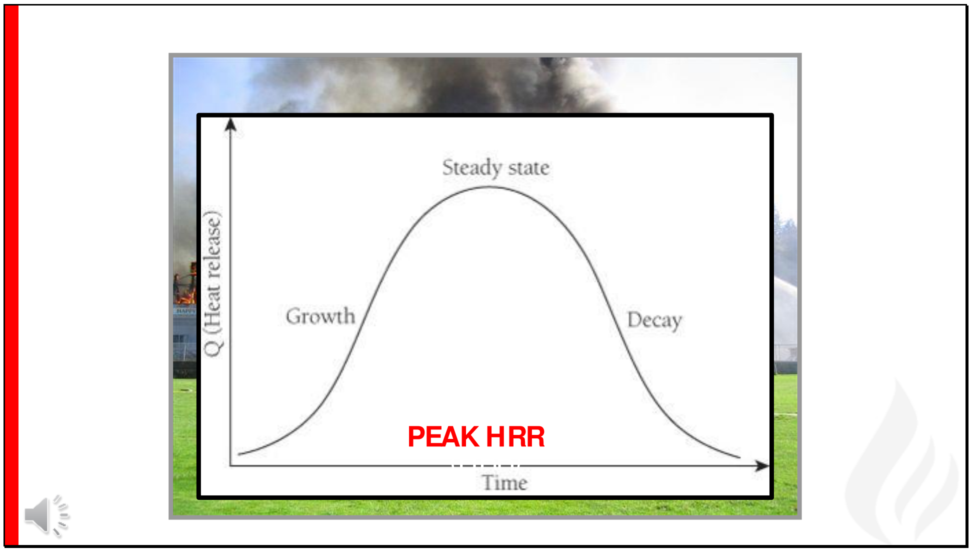

The power of the fire is determined by calculating the energy being released by the individual fuel packages as they are consumed. This is called the heat release rate or HRR and is measured in either watts or kilowatts. The heat release rate of the fuel is often illustrated on a curve to indicate the energy being released during the incipient, growth, fully developed and decay stages of the fire. When a fuel is burned, the highest value measured is termed the peak Heat Release Rate.

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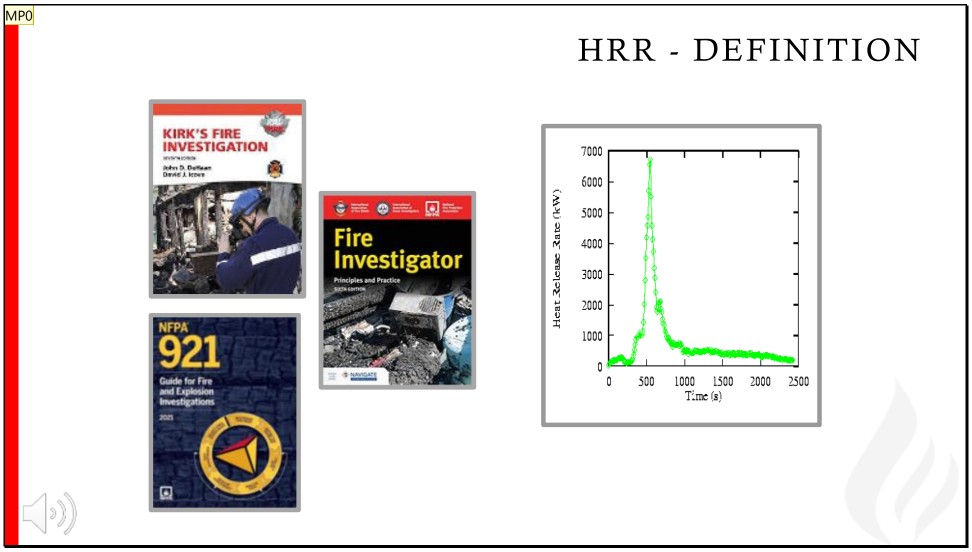

Knowing peak HRR values for various fuel packages may assist the investigator in explaining both fire development and spread issues.

The potential heat release rate of products can be found in a number of technical publications including Kirks Fire Investigation table 3 – 4, **figure 2 – 4** in Jones and Bartlett's Fire Investigator manual and in NFPA 921.

It is important to remember that any estimate of HRR is just that—an estimate.

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Fuel	Weight kg	Weight lb	Peal HRR (kW)
Wastebasket, small	0.7–6.1	1.5–3	4–50
Trash bags, 42 L (11 gal) with mixed plastic and paper trash	1.1–3.4	2 1/2–7 1/2	140–350
Cotton mattress	11.8–13.2	26–29	40–970
TV sets	31.3–32.7	69–72	120 to over 1500
Plastic trash bags/paper trash	1.2–14.1	2.6–31	120–350
PVC waiting room chair, metal frame	15.4	34	270
Cotton easy chair	17.7–31.8	39–70	290–370
Gasoline/kerosene in 0.185 m^2 (2 ft^2) pool	19	—	400
Christmas trees, dry	6–20	13–44	3000–5000
Polyurethane mattress	3.2–14.1	7–31	810–2630
Polyurethane easy chair	12.2–27.7	27–61	1350–1990
Polyurethane sofa	51.3	113	3120
Wardrobe, wood construction	70–121	154–267	1900–6400

Some common peak heat release rates include those shown in this table. A copy of the table can be found in NFPA 921 and in the resource section of this chapter.

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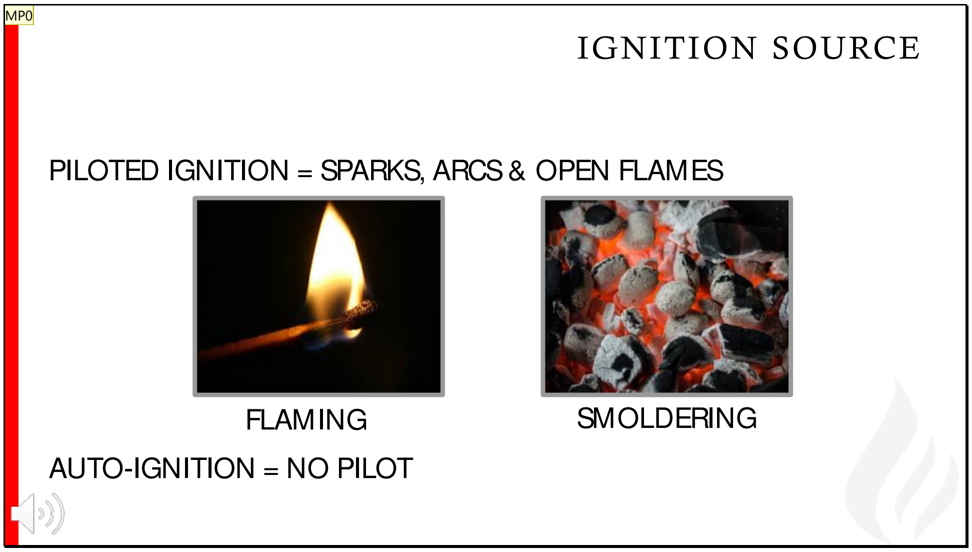
The chemical composition and density of the material is another factor that must be considered. The cotton fiber construction of the mattress at the top of the photo is high density and the composition of the material limits the energy release and speed of the fire. The cotton mattress can be expected to produce a peak heat release rate of under 1 Mega Watt.

The mattress freely burning is low-density and the material is polyurethane foam with a cotton cover. This produces a much higher heat release rate and more rapid fire spread. The peak heat released from this mattress can be expected to be 800 to 2,600 kilowatts.

This is a good example of the difference between heritage fuels and the fuels of today.

Slide 33



With any fire investigation, the source of ignition is critical in determining the cause of the fire. An ignition source can be defined as either smoldering, as in the case with hot coals and glowing embers, or flaming ignition when a match, lighter or open flame is the source. The source of ignition may also be characterized as piloted or autoignition.

Sparks, arcs, and open flames are examples of piloted ignition.

Autoignition occurs when the fuel item is heated to a temperature at which fuel gases being released from the object ignite without a piloted ignition source.

Hot Surface ignition will be talked about in more detail in unit **17, Automobile, Marine, and Equipment Fires**.

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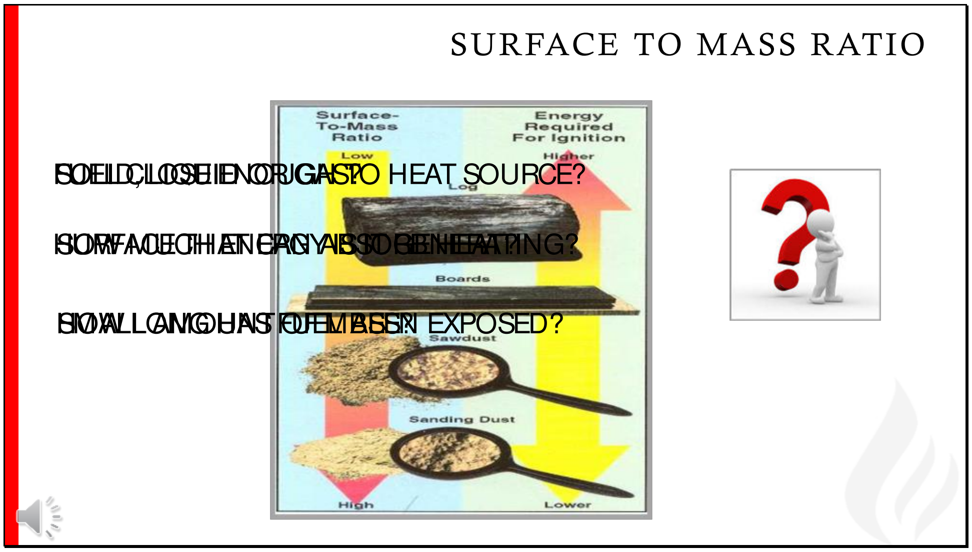

To heat fuel sufficiently to generate ignitable vapors, there are a number of interrelated factors that should be considered.

Is the fuel a solid, liquid or gas?
Does it have a lot of surface that can absorb heat and a relatively small amount of mass? The greater the mass, the more heat is needed.
Is the fuel close enough to the heat source?
How much energy is the heat source generating?
How long has the fuel been exposed to the heat source? Some fuels do not require a long exposure to reach their ignition temperature while others do.

In this drawing the log has a low surface to mass ratio so it would be difficult to ignite the log with a match. On the other hand, the sanding dust has a very high surface to mass ratio and would ignite easily with a match. The log would require significant sustained heat to cause ignition while the sanding dust would require very little. In this example both products are cellulose fiber but we would not expect to see an explosion of logs but we certainly have experienced explosions of fine dust.

The thickness of the material also plays a role in the ignition of the fuel. Items that are thicker are generally more difficult to ignite than thinner ones. Thinner fuels such as paper, and thin wood pieces or shavings allow for heating of more than one side, reducing the time required to ignite the fuel item.

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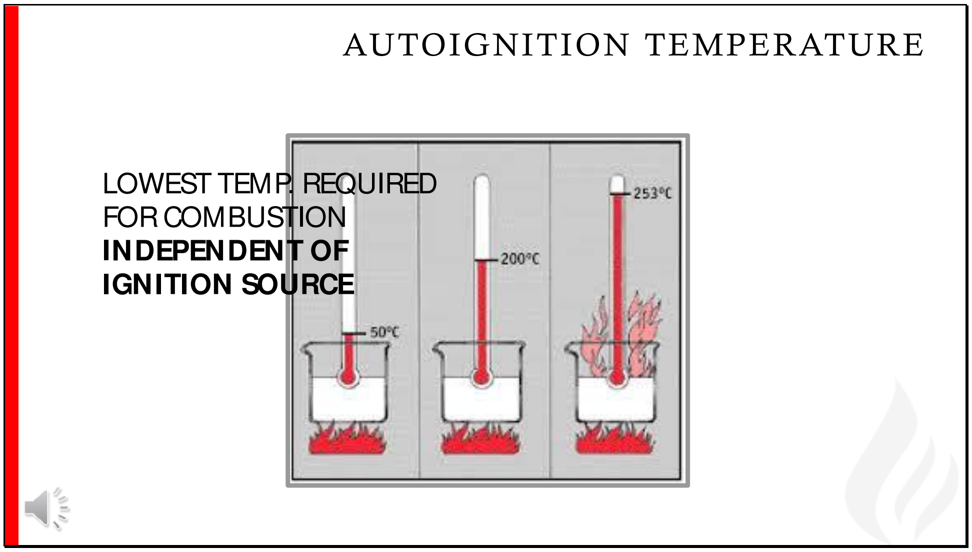

Flammable materials may also ignite if heated to a specific temperature. This temperature is referred to as the autoignition temperature. The autoignition temperature of a substance is the lowest temperature at which it spontaneously ignites in normal atmosphere without an external source of ignition, such as a flame or spark.

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IGNITION OF LIQUIDS

FLAMMABLE LIQUID
DOESN'T EXCEED 100°F /37.8ºC

COMBUSTIBLE LIQUID
ABOVE 100° F/37.8ºC

IGNITABLE LIQUID:
Any liquid capable of fueling the fire

REMAINS OF A GAS CAN
FOUND IN THE FIRE DEBRIS

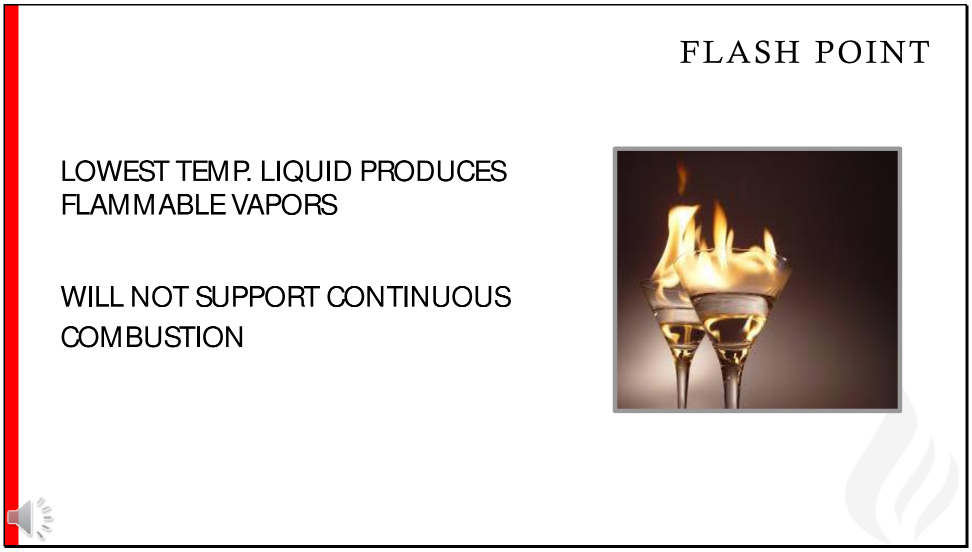
Flammable and combustible liquids are frequently found as the fuel source in many fires. Fire investigators need to understand the characteristics of these types of fuels.

A flammable liquid is a liquid whose flash point does not exceed 100 degrees F.

A combustible liquid has a flash point above 100 degrees F.

Combustible liquids are often considered less of a fire hazard than flammable liquids but the fire hazard should actually be determined by the physical properties of the liquid and external factors, such as the amount of liquid and the container it is stored in. Many fire investigators now use the term ignitable liquid to avoid confusion regarding the severity of the hazard. An ignitable liquid is any liquid capable of fueling the fire.

Slide 37



Flashpoint is the lowest temperature at which liquid produces flammable vapors. It is the lowest temperature at which liquid will produce enough vapor to support a small flame for a short period of time but will not continuously combust. The flame will flash across the surface of the liquid and go out. The flashpoint is usually a few degrees lower than the fire point.

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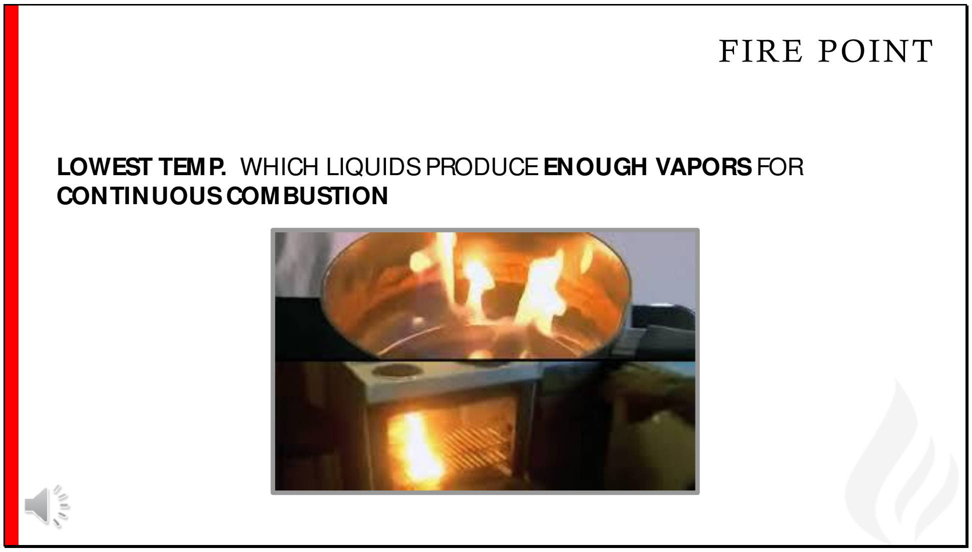
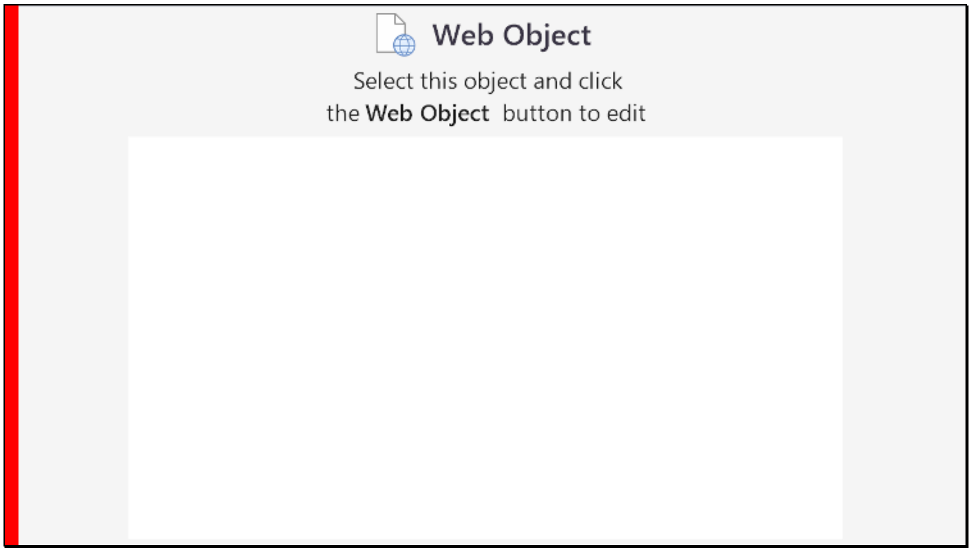


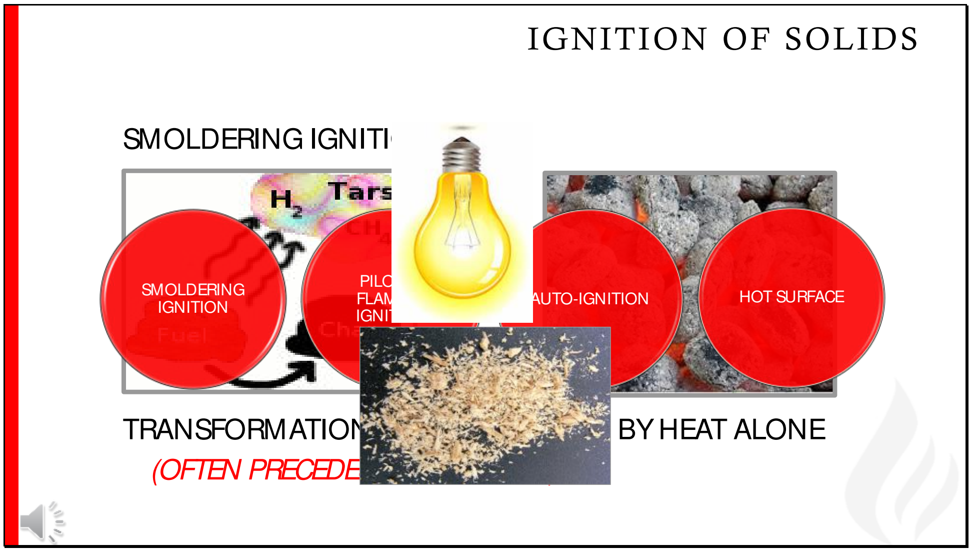
To sustain burning after the removal of an ignition source, the liquid must be heated to what is known as its fire point. The fire point is usually only a few degrees higher than the flash point. The fire point is the lowest temperature at which a liquid fuel produces enough vapors for continuous combustion.

Slide 39



Dehaan Video #26

Slide 40



Solids may be ignited by either a smoldering ignition, piloted flaming ignition, autoignition or hot surface ignition.

Most cellulose products, including wood and paper must undergo pyrolysis to produce vapors before they will support combustion. The char produced by pyrolysis may allow smoldering or solid phase burning to consume the remaining material without actual flaming combustion. Charcoal briquettes are a good example of a smoldering fire that will often consume the rest of the briquettes without an open flame.

Hot surface ignition is direct contact between a heated solid and a susceptible fuel. A good example would be a hot light bulb in contact with sawdust.

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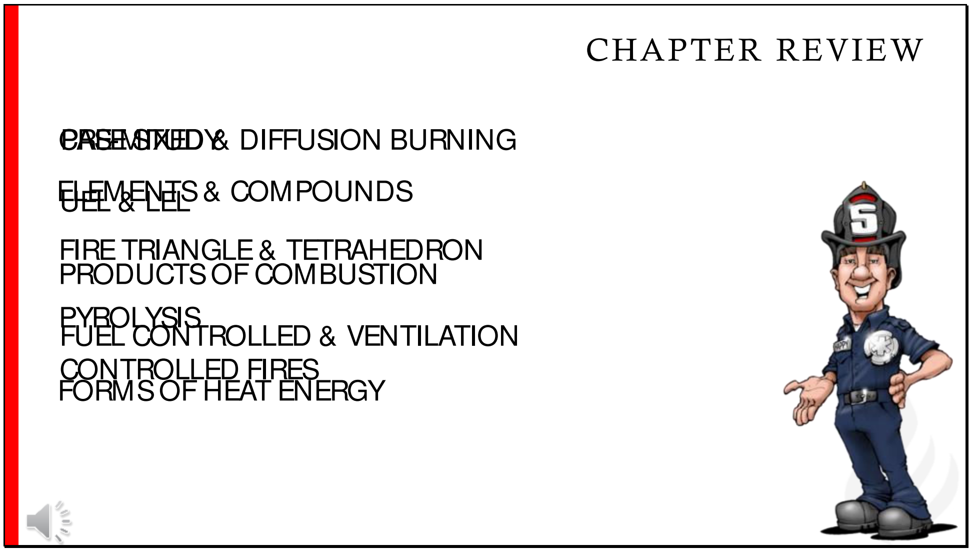
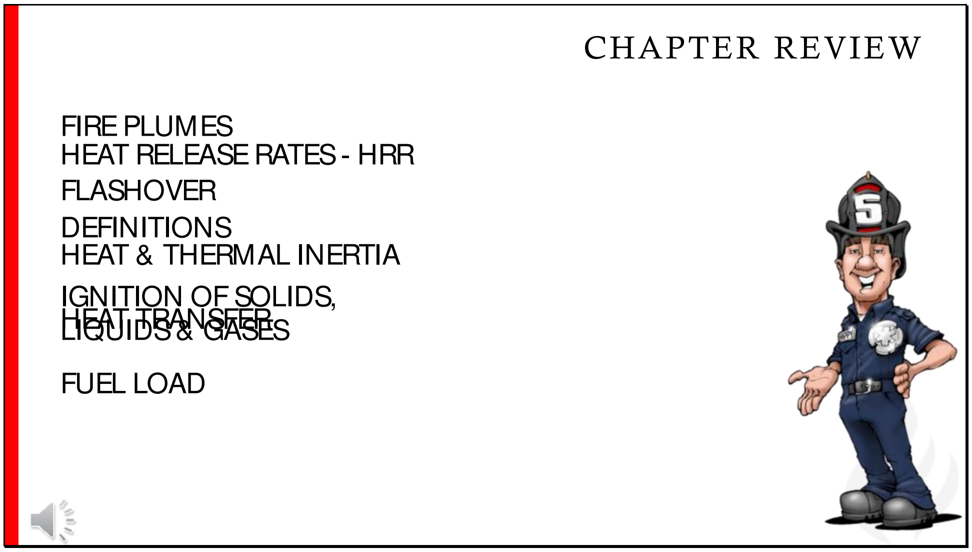


In this chapter we discussed:

- A case study based on chemistry of fire and the fire triangle
- Elements and compounds
- The components of the fire tetrahedron including; fuel, heat, oxygen and the chemical chain reaction that sustains or increases the fire
- The process of pyrolysis which causes materials to decay and produce fire gases
- The forms of heat energy chemical, electrical, mechanical and nuclear
- Premixed and Diffusion burning - Premixed is where the fuel and oxidizer are mixed prior to combustion - Diffusion flames are flames in which fuel and air mix or diffuse together at the region of combustion.
- Upper and lower explosive limits or upper and lower flammability limits which are described as UEL and LEL or UFL and LFL
- The products of combustion
- Fuel controlled and ventilation controlled fires

Slide 42



- Fire plumes and fire development
- That flashover is not a stage of fire development but the transition between a fire in a room and a room on fire
- Heat and thermal inertia
- Heat transfer by conduction, convection and radiation
- Fuel loads and fire spread
- Heat release rates or HRR

And

- definitions of autoignition, flashpoint and fire point and the ignition of solids, liquids and gasses

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That’s the end of Chapter 2 **Fire Science for Fire Investigators**. You are now ready to move on to Chapter 3 which deals with **Building Construction and Systems for Fire Investigators** but please complete the quiz for Chapter 2 first.

If you have any questions now is a good time to contact your teacher.