NEBOSH International Certificate in Fire Safety and Risk Management
Unit IFC1

INTERNATIONAL FIRE SAFETY AND RISK MANAGEMENT

ELEMENT 2: PRINCIPLES OF FIRE AND EXPLOSION

SAMPLE MATERIAL

(Material correct Autumn 2013)

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Classification of Fires

Key Information

A useful classification system for fires is based on the type of fuel source and is therefore valuable in specifying the extinguishing method to be used.

Fires Classified According to Fuel Source

Fires must be extinguished

So that an appropriate method to extinguish a fire can be identified, it is useful to classify fires into different types relating to the nature of the fuel source.

(Note that electrical fires are excluded from this classification system because of the problem of energised equipment. Once the equipment is isolated from the electrical supply it can be treated as appropriate to the burning material (typically Class A).)

Topic Focus

Classification of fire according to its fuel source:

Class A - involving **solids**, usually of an organic nature such as wood, paper or plastics.

Class B - involving **liquids** or liquefiable solids, such as petrol, oil, paint or wax.

Class C - involving **gases** such as LPG, natural gas and acetylene.

Class D - involving finely divided **metals**, such as zinc and magnesium.

Class F - involving cooking **fats and oils**.

Metal fires pose particular problems due to their reactivity with typical extinguishing agents at high temperatures and therefore require special arrangements:

- Metals are likely to ignite in the form of powders and/or swarf.
- These are classed as Class D fires.
- Appropriate extinguishing agents include:
  - Special powders (m28 or l2).
  - Dry sand or earth.
  - Graphite powder.
  - Sodium carbonate and salt and/or talc.
- Combustible metals include:
  - Lithium, sodium, potassium.
  - Magnesium, aluminium, titanium.
  - Uranium, plutonium.

Revision Questions

7. Outline, with examples, the five different classes of fire.

(Suggested Answers are at the end of Unit IFC1.)

Principles of Fire Growth and Fire Spread

Key Information

- General factors affect the rate at which a fire advances, such as the nature of the fuel and the containment in which the fire occurs.
- Specific factors such as building design, the use of insulated core panels, construction materials, internal linings, ventilation levels and contents of the premises influence fire growth rates and smoke movement.
- Fire spread depends on the principal methods of heat transfer: conduction, convection, radiation and direct burning.
- There are important differences between the development of a fire under free burning conditions and a fire in enclosed conditions; two important phenomena related to enclosed fires are flashover and backdraft.

Fire Growth

The rate at which a fire advances by consuming available fuel depends on general factors such as:

- **Fuel characteristics:**
  - Ease of ignition, depending on the material and its physical form.
  - Heat of combustion (the amount of heat generated by the exothermic combustion process of that particular fuel) which determines how quickly the temperature will rise (particularly in enclosed spaces where heat can quickly build up).
  - Fluidity of liquids (uncontained burning liquids can spread very quickly) and easily melted solids (plastics can become pools and drips of burning liquid which can spread the fire to other areas).
- **Fuel separation**, e.g. where isolation of pockets of combustible furnishings from each other by non-combustible building components will hinder or prevent fire spread.
- **Containment**:
  - Open fires (those with minimal or no containment) will have a plentiful supply of oxygen to sustain combustion.
  - Contained fires (such as in a building) will be restrained by oxygen depletion and if insufficient oxygen is available (through poor ventilation), the rate of growth will slow and may eventually stop.
- **Room dimensions**, such as ceiling heights and location of walls in relation to the seat of the fire, will affect the course of the fire and its growth.

Fire Growth Rates and Smoke Movement

There are also specific factors that influence fire growth rates and smoke movement related to the structure and contents of the particular building:

- **Building design** - where smoke generated from a fire may:
  - Escape through gaps in doorways, ceilings and walls.
  - Spread:
    - Through vents, lift shafts, staircases, ducts and ceiling voids.
    - Horizontally by convective currents under the ceiling.
    - Vertically between storeys by convective transfer of hot gases and smoke.
- **Insulated core panels** (containing fire rated rigid urethane insulation) - which provide effective fire resistance and slow the rate of fire growth.
- **Internal linings** - materials on the surfaces of walls and ceilings significantly affect the spread of fire and its rate of growth:
  - Particularly the potential for fire spread on internal linings in escape routes (rapid fire spread could prevent occupants from escaping).
  - Materials used should inhibit development of fire and smoke from the surfaces of walls and ceilings.

Topic Focus

Spread of fire and its rate of growth on the surface of walls and ceilings:

- Properties of lining materials that might **increase** the risk of fire spread and its growth:
  - Ignitability.
  - Rate of surface flame spread and heat release.
  - Amount of smoke produced when ignited.
  - Tendency to produce flaming droplets.
- Properties that lining materials **should have to limit** the spread of fire and maximise the time available for escape:
  - Resistance to ignition.
  - Low rate of surface flame spread and heat release limiting:
    - Spread of fire.
    - Production of smoke.
    - Rate of fire growth.

  Examples of such materials include:
  - Exposed brickwork.
  - Exposed blockwork.
  - Mineral fibre board.
  - Woodwool slabs.
  - Plasterboard and skim.
  - Intumescent linings.
  - Concrete, stone or ceramic tiles.

Jargon Buster

Intumescent lining

A material that expands when heated to form an insulating fire-retardant barrier that protects the underlying surface.

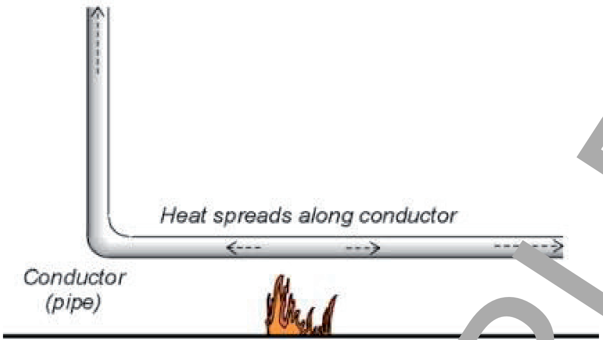
- A building's **construction materials** have an impact on the potential for, and rate of, fire spread:
  - **Concrete:**
    - Dehydrates, crumbles and collapses.
    - Surface spalls at >300°C; this is increased by steel reinforcement.
    - Loses structural integrity on cooling.
  - **Steel:**
    - Expands.
    - Conducts heat.
    - Loses strength and deforms as temperature increases.
    - Changes properties on cooling.
  - **Brickwork:**
    - Fired clay bricks exhibit better fire resistance.
  - **Timber:**
    - Combustible and will be consumed and generate smoke in fire.
    - Burns in a predictable way and its fire resistance can be improved by increasing thickness, selection of fire resistant varieties (dense wood is better) and surface treatment.
  - **Plastics:**
    - Thermo-setting plastics **do not melt** but decompose, generating smoke and fumes.
    - Thermoplastics **melt**, drip and flow in a fire and generate smoke and fumes.
  - **Glass:**
    - Generally offers little resistance to fire (but some specific fire-resisting laminated glasses can provide fire resistance of up to 90 minutes).
  - **Thermal insulating materials** in concealed areas:
    - Most modern varieties are non-combustible.
    - Some older buildings used combustible materials (e.g. sawdust).
  - **Lime-based plaster** on internal walls:
    - If supported by lathing or expanded metal, has good fire resistance.
  - **Paints:**
    - Most are combustible and will aid surface spread of fire (but there are also flame-retardant paints and paints which bubble up to protect the timber beneath).
- **Ventilation levels** determine the oxygen supply to a fire in an enclosed space and if air is not replenished the fire will decay. The level may be a combination of:
  - Natural ventilation (through doors, windows and other openings).
  - Forced ventilation (mechanical air handling systems).

- **Contents of the premises** might typically include:
  - **Paper** (wallpaper, books, magazines) - will burn in a fire and aid fire spread.
  - **Plastics** (wall and ceiling linings (expanded foam types), window frames) - some types are self-extinguishing (e.g. unplasticised PVC) and others smoulder, drip and burn.
  - **Fabrics and furnishings** (seating, curtains and other textiles) - natural fabrics tend to smoulder while synthetic fabrics (mainly thermoplastics) shrink, melt and ignite.

Methods of Heat Transfer

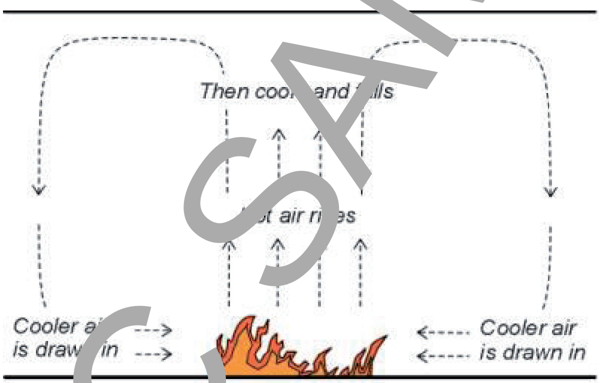
A fire will initially spread by **direct burning**, where there is direct contact between the burning material and the new fuel source.

Once established, **conduction** may allow heat transfer through conducting materials to ignite fuel that is remote from the original fire.



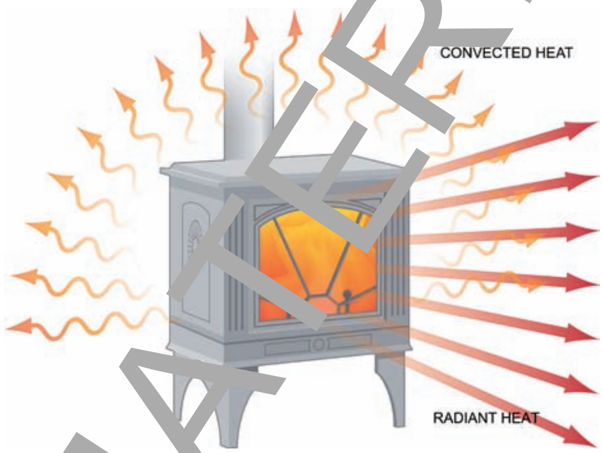
Conduction

Convection currents, generated by heated gases expanding, becoming less dense and rising will transfer heat to surfaces above the fire, such as ceilings and ductwork.



Convection Currents

The heated materials in a fire will radiate heat (thermal **radiation** or infra red) which can be absorbed by surfaces near the seat of the fire and cause ignition of nearby fuel.



Radiant Heat

Topic Focus

The FOUR methods by which heat may be transferred during a fire are:

Conduction

- Molecule to molecule transfer of heat through conducting solids such as metal beams or pipes.
- Heat is transferred to other parts of the building and can ignite combustible or flammable materials.

Convection

- Hot gases rise and become trapped beneath a ceiling or travel through voids and ducts to other parts of a building.
- The hot gases ignite combustible or flammable materials.

Radiation

- Heat is emitted in the form of infra red radiation.
- Radiant heat can raise the temperature of adjacent materials to above their ignition temperatures or flash points.

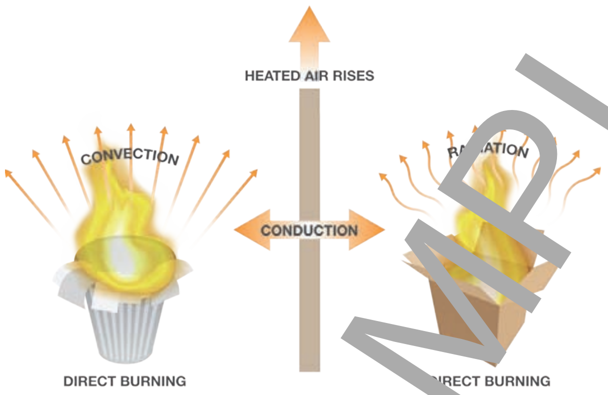
Direct burning

- Heat comes in direct contact with combustible materials.
- Direct contact causes ignition.

Development of a Fire

Under Free Burning Conditions

- Smoke and toxic gases:
  - Initially rise and are trapped by the ceiling in the room in which the fire starts.
  - Accumulate and spread outwards in all directions at ceiling level, forming an increasingly deep layer throughout the room.
  - Eventually escape through gaps in doorways, ceilings and walls and use vents, lift shafts, staircases, ducts and ceiling voids to spread rapidly to other parts of the building.
- Fire in a room can spread to other parts of the building by:
  - Convective currents allowing horizontal spread of fire under ceilings, and vertical spread of fire between storeys.
  - Radiative heat transmitting to other parts of the room, to other rooms and to other buildings.
  - Conduction through steel structural members and services.
  - Flames (deflected by the ceiling) to the floor below and general direct burning.



Development of a Fire

In Enclosed Conditions

- The heat, hot gases/vapours, flames and smoke become trapped, are retained and concentrated by the enclosure, and so accelerate the fire.
- Within a short time the temperature may exceed the auto-ignition temperature of the remaining fuel in the room and, if there is enough air, cause sudden ignition (sometimes referred to as "flashover").

People are at a greater risk from inhalation of toxic gases and smoke from a fire in enclosed spaces.

Flashover and Backdraft

These two important phenomena increase the risk in a fire situation.

- A **flashover** occurs when all the combustible material in an enclosed area simultaneously ignites due to heat build up to above its auto-ignition temperature (typically around 500°C).
- A **backdraft** occurs when air is introduced into a fire which is decaying through oxygen starvation, causing a rapid and explosive re-combustion.

Topic Focus

A flashover may occur:

- When a fire is free burning in a room.
- Where there is a good supply of oxygen from the large size of the room or from a ventilation source.
- When the fire generates a high level of radiated heat which is absorbed by other materials in the room, including unburnt gases.
- When materials and gases reach their spontaneous ignition temperatures and ignite even though they are not in direct contact with the flame.

The effect is that the fire has "flashed" from one side of the room to the other.

Revision Questions

8. Outline the main factors that influence the rate of fire growth.
9. Describe, with the aid of suitable sketches where appropriate, the following methods of fire spread:
   (a) Direct burning.
   (b) Conduction.
   (c) Convection.
   (d) Radiation.
10. Outline the ways in which fire can spread within buildings.
11. Outline the main differences between fires under free burning conditions and fires in enclosed conditions.

(Suggested Answers are at the end of Unit IFC1.)

Explosion and Explosive Combustion

Key Information

- There are two basic categories of explosion (based on reaction velocity): deflagration and detonation.
- Explosions arise from flammable vapours, gases, and dusts, in the form of confined vapour cloud explosions, unconfined vapour cloud explosions, boiling liquid expanding vapour explosions (BLEVE) and dust explosions.
- Good housekeeping procedures, sufficient ventilation, safe storage and handling of explosive materials, control of detonation sources, cooling, and inerting are methods used to prevent explosions occurring.
- Explosions may be controlled by means of: suppression; venting (using pressure relief valves, bursting discs and explosion venting panels); and containment.

Mechanism of Explosion

An explosion is a sudden, rapid, violent release of energy accompanied by a pressure blast wave. Explosions may be caused by chemical reactions or by physical changes (such as in a pressure vessel explosion). In the context of fire and explosion we are concerned with explosions of chemical origin and combustion-type reactions.

Beware Explosions!

Topic Focus

There are two basic categories of explosion (based on reaction velocity):

- **Detonation**
  - The combustion zone travels at supersonic velocity (i.e. greater than the speed of sound).
  - The reaction initiates and rapidly increases to the point where a shock wave develops (like the sonic boom from an aircraft as it exceeds the speed of sound).
  - The shock wave compresses the unburned gas/air mixture as it passes through it, increasing its temperature to the auto ignition point.
  - Detonations produce very high temperatures and pressures and high rates of pressure rise.
  - Equipment and building structures have no time to move to relieve pressure, so there can be a great deal of localised damage, with fragments thrown out at high speeds.
- **Deflagration**
  - The combustion zone travels at subsonic velocity (i.e. slower than the speed of sound).
  - The pressure rises more slowly and maximum pressures reached are lower than for detonation.
  - Damage from a deflagration tends to be more generalised, and more severe at further distance from the ignition point.
  - A more common form of explosion than detonation.

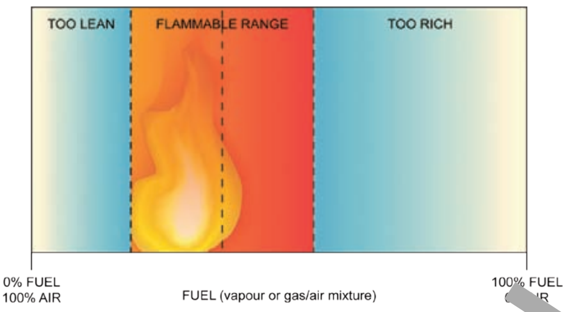
Materials Commonly Involved in Explosions

Combustion explosions principally involve the following types of flammable materials:

- **Vapours** - from flammable solvents used for cleaning, in paints and adhesives, such as toluene, acetone, ether, hexane.
- **Liquid petroleum gas** (LPG).
- **Gases** - such as acetylene, propane, butane, hydrogen.
- **Dusts** - in the form of finely divided wood, flour, coal.

Types of Explosions

For combustion to take place a material must first generate sufficient vapour/gas/dust so that, when mixed with air, its concentration lies within the **explosive range** (between the lower and upper explosive limits).



The Explosive Range

There are four important types of explosion:

Confined Vapour Cloud Explosion (CVCE)

This involves:

- Ignition of a flammable gas/vapour in a confined space, such as a process vessel or building.
- The pressure rise may rupture the containment.
- Only small amounts of flammable gas/vapour are needed, such as a small gas leak in a building or the flammable residue left in a drum.
- There is limited blast damage.

Unconfined Vapour Cloud Explosion (UVCE)

Here:

- Ignition of a flammable gas/vapour is in an unconfined external space.
- The rapid release of large quantities of material with some mixing with air is required to produce a flammable gas/air mixture.
- Ignition must occur before the cloud has sufficient time to dilute below the lower explosive limit.
- The resultant pressure waves and heat generation from the large quantity of material involved cause extensive damage.

Boiling Liquid Expanding Vapour Explosion (BLEVE)

There are several types of BLEVE, but probably the most widely described and known is that of LPG vessels under fire conditions. In this case the typical sequence of events is:

- Exposure of a pressure vessel containing LPG to direct heating from open flames.
- Liquid inside vessel begins to boil/vaporise and the internal pressure increases. (**Note** Although the vessel may be fitted with a pressure relief valve, these are often inadequate under sustained, intense fire conditions.)
- Vessel over-heats and its walls begin to lose their strength, thin and eventually rupture against the increasing internal pressure (this is commonly, but not always, in the vapour space above the liquid because the vapour is less effective at removing heat).
- After rupture, the sudden release of pressure causes the remaining liquid to suddenly vaporise and escape.
- Vapour ignites from heated surfaces and generates flames, explosion, fireball, missiles, etc.

Dust Explosions

Dust explosions involve the generation of fine dust particles:

- From a combustible substance.
- In dry conditions.
- Dispersed in air within the lower and upper explosive limits.

A dust cloud of this concentration would resemble a dense fog and would not normally be produced outside a process vessel.

It is also necessary to have an ignition source of sufficient energy (e.g. electrical arcing or electrostatic discharge).

A dust explosion initiated inside a process vessel under conditions of confinement is called a **primary explosion** and, unless the plant is designed to withstand the pressure, it will rupture the vessel ejecting a fire ball of burning dust.

The force of the primary explosion may disturb surrounding dust, forming another dust cloud, which is then ignited by burning particles from the primary explosion. This is called a **secondary explosion** and such explosions are generally more destructive than the primary explosion.

Explosions can cause severe damage

Topic Focus

Upper and lower explosive limits:

- A flammable mixture will only explode in air if the mixture lies between certain limits.
- The upper explosive limit is the highest amount of flammable vapour in air that will just support an explosion.
- The lower explosive limit is the lowest amount of flammable vapour in air that will just support an explosion.

Conditions required for a gas explosion to occur:

- The presence of a combustible gas which is capable of becoming airborne and mixing with air.
- The concentration of gas lies between the flammable limits.
- The atmosphere contains sufficient oxygen to support combustion.
- There is an ignition source present of sufficient heat energy to ignite the gas.

This:

- Causes an increase in temperature.
- Can occur spontaneously.
- May produce heat quickly and can cause explosions.

Preventing Explosions

The main concern is to prevent explosions by considering such issues as:

- **Housekeeping** - dust explosions can occur from the accumulation of finely divided combustible material in the workplace, and secondary explosions when dust collecting on surfaces becomes airborne from the primary explosion and also ignites. Good housekeeping is also important when it comes to the correct storage of combustible and flammable materials which reduces the risk of ignition.
- **Ventilation** - ensures that any concentrations of dust or vapour in the workplace are kept well below the lower explosive limit.
- **Safe storage and handling of explosive materials** - strict procedures are necessary for explosive solids. Flammable liquids which can generate explosive vapour clouds should be securely stored with bunding used to contain any leakages or spillages.
- **Cooling** - can be used to control the potential for an explosion from an uncontrolled exothermic reaction that generates excessive heat and over-pressurisation.
- **Inerting** - involves substitution of the air in an enclosed space by an inert gas where the possibility of flammable atmospheres exists. Inerting prevents the formation of a fuel/oxygen mixture above the lower explosive limit but inert gases, if not controlled, can present a risk of reduced oxygen content in the atmosphere that operators are required to breathe.

Topic Focus

Typical rules for the storage and handling of explosive materials:

- Identification of all explosive and potentially explosive chemicals.
- Correct labelling.
- Maintaining records of opening and discard dates to prevent chemicals degrading and becoming potentially explosive.
- Keeping explosive chemicals away from all ignition sources such as open flames, hot surfaces, spark sources, and direct sunlight.
- Designating a special area for explosive chemical use.
- Periodically checking containers of chemicals that could become over-pressurised.
- Making sure that staff using explosive or potentially explosive chemicals are thoroughly trained in safe storage methods, the hazards of the chemical, and disposal procedures.

The possible result of unsuccessful explosion prevention techniques

Controlling Explosions

In situations where explosions may occur the consequences can be reduced by controlling the explosion.

Suppression

This is an active system, whereby the pressure rise from a developing explosion is detected by an appropriate sensor and triggers the discharge of an extinguishing agent to suppress the combustion process.

Venting

The following systems can be used to release any pressure developing from an explosion:

- **Pressure relief valves** - designed to allow sufficient outflow of combustion products to relieve the pressure generated by the explosion, venting to a safe or sealed area.
- **Bursting discs** - commonly used for overpressure protection as the weakest point in the system, and designed to fail and so avoid mechanical damage to the rest of the system.
- **Explosion panels** - similar to bursting discs, but designed for higher rates of pressure rise (such as happen during an explosion) and for larger capacities of gas to vent.

Containment

Containment allows the explosion to occur but confines it to a specific area and prevents propagation to the surrounding atmosphere. Explosion-proof enclosures are based on this method and are designed to withstand the maximum explosion pressure likely to occur in the particular facility.

Topic Focus

Cause and control of dust explosions where powders are handled:

Cause

The **primary explosion** occurs when:

- The concentration of dust falls within the explosive range.
- The moisture content of the dust is low.
- The particle size is such to propagate a flame.
- A source of sufficient heat energy is available to ignite the dust.

A **secondary explosion** may occur if:

- Air turbulence from the initial explosion discharges dust from horizontal surfaces, causing an airborne suspension of combustible dust.
- Ignition occurs from the initial source or from combustion by-products of the primary explosion.

Controls

- Sealing joints on powder handling systems to prevent the escape of dust.
- Providing exhaust ventilation on dust filters and open bag dust collecting filter units.
- Regular maintenance of plant and a high standard of housekeeping minimising the accumulation of dust on floors and high ledges.
- Insulating hot surfaces, e.g. lagging pipes.
- Ensuring that the surface temperature of electrical equipment is kept below that required to cause ignition.
- Using intrinsically safe electrical equipment.
- Bonding all metal work to earth.

Hints And Tips

Highlight sections of the text to make key ideas stand out. This will be very useful when you start your revision.

Revision Questions

12. Explain the main difference between a confined vapour cloud explosion (CVCE) and an unconfined vapour cloud explosion (UVCE).

13. (a) Outline the main factors and conditions that determine the likelihood of a dust explosion occurring.

    (b) Describe the sequence which may trigger a secondary dust explosion.

14. Outline, with examples, three different means of controlling the effects of an explosion.

(Suggested Answers are at the end of Unit IFC1.)